Mehmet Tuncay Duruöz
Editor

Hand Function

A Practical Guide to Assessment

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To my excellent mother Servet and wonderful father Talat; my heartfelt thanks infinitely for your never-ending love, support and selfless help.

Preface

The hand is extremely involved in our daily lives because of its vital and sophisticated functional role. With the growing expectation in society of a life without disability and handicap, hand function has become increasingly important over the past decades. The accurate assessment of hand function is very important for establishing strategies to maximize functional potential and evaluating treatment and the progress of disease.

The evaluation of hand function is of critical importance in determining the extent of functional loss in patients with many rheumatic and neurologic diseases and traumatic injuries and in assessing the outcome of some surgical and rehabilitative procedures. Thus, the clinical assessment of hand function remains complex and controversial. This book of practical information will be very useful in physicians' and in healthcare professionals' daily practice.

There are four main sections in this book: Basic principles of hand function, hand function assessment in clinical assessment, hand function and imaging outcomes, and appendices. The authors approach their subjects in an especially practical dimension. Because hand assessment is performed in the daily practice of many areas, such as rheumatology, physical and rehabilitation medicine, orthopaedic surgery, plastic and reconstructive surgery and neurology, this book is written by a multidisciplinary team with adult and pediatric rheumatologists, physiatrists, physiotherapists, occupational therapists, hand therapists, neuroscientists and neurologists.

Many clinicians and healthcare practitioners insist on the evaluation of outcomes based on questionnaires for the functional status of patients. Questionnaires provide us with better information on what our patients truly experience in their daily lives. The appendices of this book include seven famous and practical scales for hand assessment, all of which were validated in many different kinds of hand disorders, such as rheumatoid arthritis, osteoarthritis, systemic sclerosis, psoriatic arthritis, geriatric and pediatric hand disorders, hand tendon injuries, stroke, tetraplegia, diabetes mellitus, carpal tunnel syndrome and haemodialysis patients.

The goal of this book is to present recent practical information to assess hand function in daily practice and scientific research. I hope it will help in accurate and practical evaluation of hand function and the interpretation of functional outcomes in clinical practice.

I wish to thank the chapter authors assembled in this book for graciously giving their time and sharing their experiences.

Istanbul, Turkey Mehmet Tuncay Duruöz, MD

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Section I

Basic Principles of Hand Function

Functional Anatomy and Biomechanics of the Hand

1

Ton A.R. Schreuders, J. Wim Brandsma, and Henk J. Stam

The Hand: A Beautiful but Complex Instrument

> The human hand is so beautifully formed; it has so fine a sensibility, that sensibility governs its motions so correctly, every effort of the will is answered so instantly, as if the hand itself were the seat of the will; its action are so powerful, so free, and yet so delicate, as if it possessed quality of instinct in itself, that there is no thought of its complexity as an instrument, or of the relations which make it subservient to the mind [1].

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Introduction

The complexity of the hand is evident, its anatomy efficiently organized to carry out a variety of complex tasks. These tasks require a combination of intricate movements and finely controlled force production. The close relationship between different soft tissue structures contributes to the complex kinesiology of the hand. Injury to any of these even very small structures can alter the overall function of the hand and thereby complicate the therapeutic management [2].

Rehabilitation of the hand is different from other parts of the body not only because of the hand's complexity but also the delicate surgery that is involved in repairing the different tissues and consequently also the rehabilitation.

All the joints, together with the tendons, ligaments, nerves, and skin, move smoothly, minimally resisting the gliding movements between the various structures. Following trauma the delicate structures between the tissues might lose their length or free motion in the healing process of the body repairing the tissues. Therefore, the tissues that need to glide should start moving as soon as possible to prevent adhesions. Adhesions are the number one enemy of the hand, resulting in a stiff joint resulting in reduced range of motion(s) effecting overall hand function.

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We describe the different structures with relevant pathokinetics in this chapter:

1. Skin and connective tissue
2. Joints and ligaments
3. Muscle and tendons
4. Nerves and innervations

Skin and Connective Tissue

The skin provides a protective and sensitive covering, which is highly innervated volarly for efficient tactile sensibility. The volar surface is endowed with fixed fat pads in addition to numerous sweat glands. The various lines or creases of the skin follow the normal stresses imposed by the movements of the hand (Fig. 1.1). Important ones are distal, palmar, and thenar crease. These lines need to be observed, e.g., when making splints.

There are important differences in the structure of the volar and dorsal skin of the hand. The dorsal skin is loose and has little connection with the subcutaneous tissues like the tendons or bones. The skin of the palm is much thicker and has many connections through fascicular tissue with the bones and palmar fascia, thus making

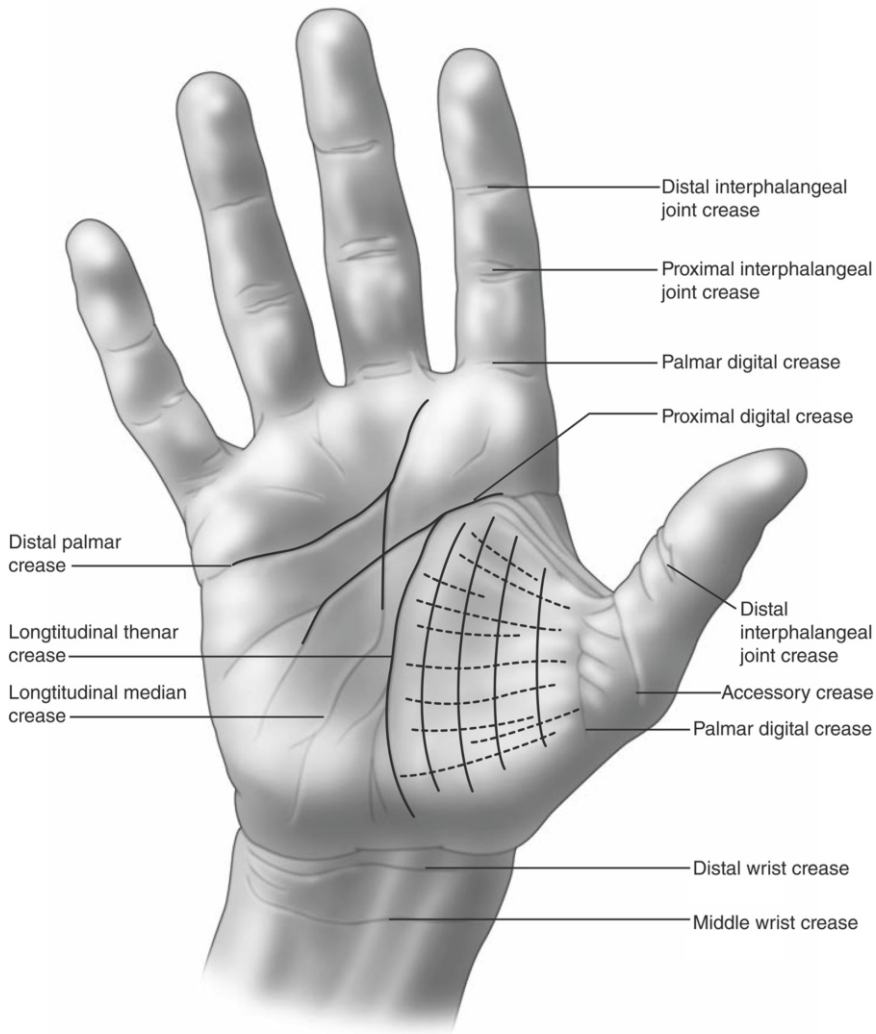

Fig. 1.1 Palmar creases of the hand and wrist

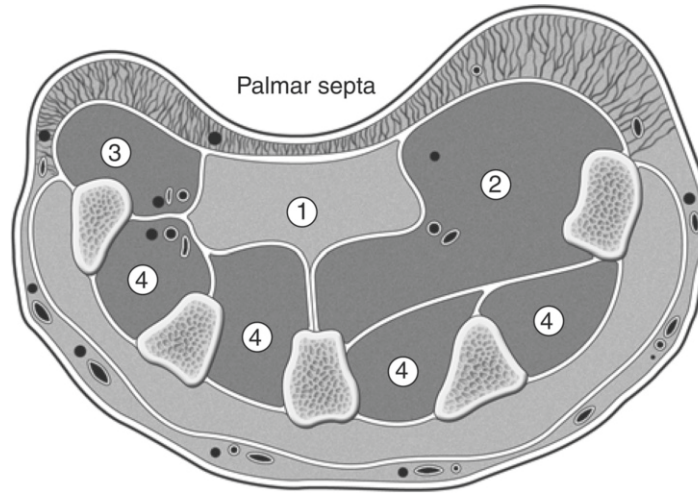

Fig. 1.2 Transverse view of the hand with the fibrous skeleton-forming compartments

the skin of the palm is tough and able to transfer forces to the bones and fascia. In extensive traumas to the palm of the hand, a full thickness graft to the palm which is done for skin closure of the palm of the hand results in the inability to open a tight jar because the skin is too loose.

The transverse structures within the hand create a fibrous skeleton for the nerves, blood vessels, tendons, and muscles (Fig. 1.2). The walls of the compartments are tough and not very elastic.

Clinical Relevance: Example
Trauma could result in compartment syndromes similar to Volkmann's contracture [3]. Swelling in the hand and lower arm therefore are a threat of developing such pathology and must be treated immediately and if possible prevented.

Extensibility and innervation of the skin are important for the ultimate function of the hand. The hand is innervated volarly by the median and ulnar nerves; dorsally, it receives innervation from all three nerves. On the volar surface, the thumb and the index and long fingers are innervated by the median nerve. The ulnar nerve supplies sensation to the ring and little fingers. The sensory division between ulnar and median nerves is usually given as going across the ring finger, but this dividing line can be very variable.

Clinical Relevance: Example
In the palm of the skin, Dupuytren's disease can be the cause of flexion contractures of the MCP and IP joints and is especially common in the fourth and fifth fingers and the thumb.

Joints and Ligaments

There are three arches of the hand which are known as the distal transverse, longitudinal, and proximal transverse arch. The proximal transverse arch is more rigid, while the distal transverse and longitudinal arches are mobile (Fig. 1.3). The intrinsic muscles are important in the creation of the arch of the hand. In grasping, the arches provide a postural base to the hand and have a role in the production of finger joint movements and the assurance of a stable grasp. The arches form a hollow cavity that changes its shape during hand pre-shaping and grasping according to the object to be grasped. The contraction of

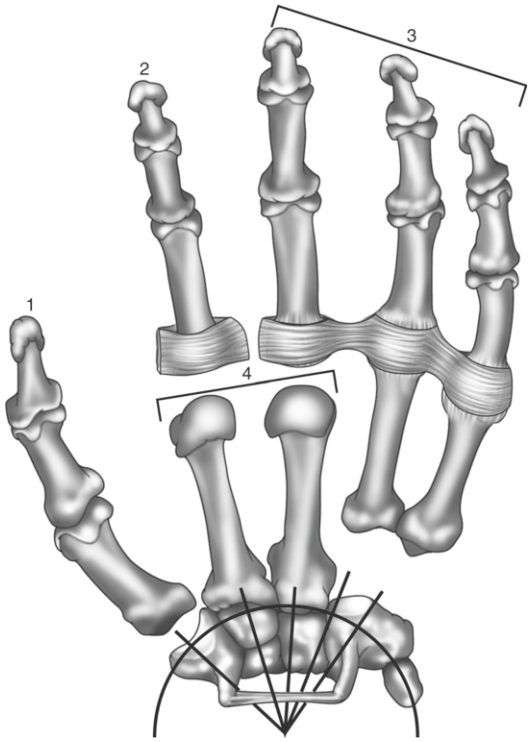

Fig. 1.3 The architectural components of the hand are divided into four separate elements: the central rigid unit (*4*) and the three mobile units (*1*, *2,* and *3*)

thenar and hypothenar muscles play a role during hand shape modulation [4].

The distal transverse arch is formed by the transverse intermetacarpal ligament (TIML) and the metacarpal heads. The TIML is attached to and courses between volar plates at the level of the metacarpal heads along the entire width of the hand.

Carpometacarpal (CMC) Joints

The CMC of the thumb will be discussed later.

The CMC joints of the fingers are incongruous joints and have only one degree of freedom. However, the fifth CMC joint is often classified as a semi-saddle joint with conjunctional rotation [5], allowing more movement in the fourth and fifth ray compared to the index and middle finger CMC joints. The forward/backward movement of the fourth and fifth ray makes cupping of the hand possible which can be observed when holding an object like a hammer in a diagonal position.

The hand has a good grip and maximum contact area because of the ability to "fold" the hand around the object. In addition, abduction and rotation of the proximal phalanges are regulated in an approach to an object and adjusted by the phalangeal-inserting interossei muscles. This permits spatial adjustment to a large spherical object by wide abduction and rotation of the fingers from the central ray or to a cylindrical grip with variable flexion and rotation from the ulnar to the radial fingers [6].

Clinical Relevance: Example
Loss of mobility after fracture or loss of muscle power after ulnar nerve lesion results in loss of the ability of cupping the hand and consequently in less powerful grip.

Metacarpophalangeal (MCP) Joints

The MCP joints are ellipsoidal or condylar joints with two degrees of freedom. The place of the collateral ligament of the MCP joint and the prominent condylar shoulders that the collateral ligaments must cross causes the ligaments to be tight in the flexed position, making it almost impossible to abduct and adduct in MCP-flexed position and adducts the fingers when in flexion.

In the extended position, the ligaments are at its maximum relaxed position (Fig. 1.4) which can be observed in a swollen hand where the hand tends to adapt the position of injury: MCP extension and IP flexion.

Clinical Relevance: Example
There is a danger of (adaptive) shortening of the MCP collateral ligaments when left in extension. If the MCP joint is immobilized, it is preferred to have the MPs splinted in flexion to prevent shortening. For the IP joint, this is extension.

The collateral ligaments are obliquely orientated and resist palmar translator forces induced by the flexors and intrinsics [6]. The enfolded

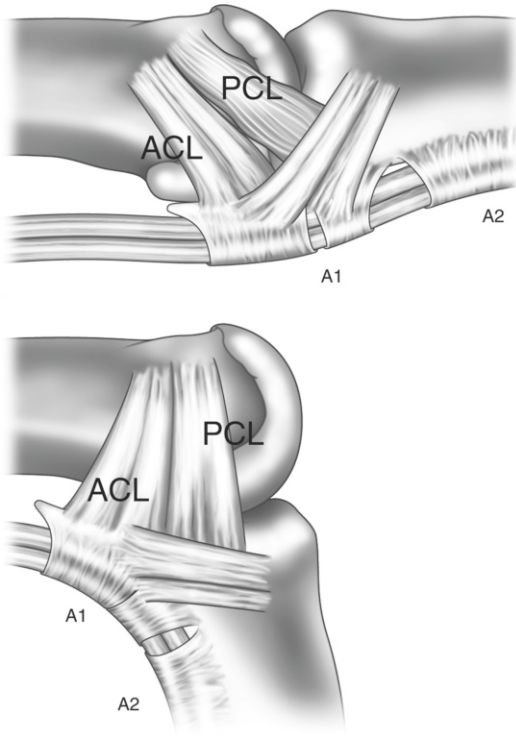

Fig. 1.4 The metacarpophalangeal (MCP) joint with its collateral ligaments. In MCP joint extension (*top*), the proper collateral ligament (PCL) is somewhat relaxed allowing for abduction and adduction. In flexion (*bottom*), both the PCL and the accessory collateral ligaments (ACL) are tight. Both A1 and A2 pulleys are noted in figure

distal component of the collateral ligament, which becomes increasingly taut during full flexion, helps resist proximal subluxation.

Clinical Relevance: Example
In rheumatoid arthritis (RA), the volar luxation of the proximal phalanges is seen as one of the first signs of the progressive deformation of the fingers. Sometimes it is the first symptom in a cascade of superimposed deformities: volar luxation, tendency to move in intrinsic plus position, shortening of intrinsic muscles, more volar luxation, etc.

The metacarpal condylar surface is somewhat asymmetrical. As a result this articular configuration plays a role in ligamentous orientation and subsequent kinesiology of the joint. This is a variable when studying pathological conditions such as ulnar drift [7]. The volar plate attachments at the MCP joint are capsular rather than bony as in the PIP joints, which permits hyperextension.

Proximal Interphalangeal (PIP) Joint

The PIP joint differs from the MCP in that an intact volar plate and its check rein ligaments effectively restrict hyperextension. The volar plate is attached to the accessory collateral ligament (ACL) which is tight in extension, thus pulling the volar plate against the phalanges and together with the proper collateral ligaments (PCL) completely stabilizes the PIP joint. No ulnar or radial deviation is passively possible. In some flexion the PCL is still tight and helps in stability of the PIP joint.

The volar plate is a fibrocartilaginous structure attached to the checkrein ligament, a swallowtail-like structure (Fig. 1.5). The volar plate serves as a volar articulating surface and is an additional confining structure for synovial fluid. Lesion or laxity can result in swan neck deformity. Bowers et al. identified a bony attachment of the PIP

Clinical Relevance: Example
Combining the tendency after a trauma of the MCP and PIP joint to adopt an extended and flexed position, respectively, the splint with MCP in flexion and IPs extended is a protective splint counteracting the tendency of the ligaments to cause undesirable contractures. This is also a position in which minimal muscle and joint function is needed to regain a pinch and some hand function, another reason to choose for such a position when immobilizing the hand. Given the anatomy of the MCP and PIP joints with the inherent tendency to move in extension and flexion, respectively, the hand should, when needed, be immobilized in MCP flexion and just short of full extension in the PIP joints.

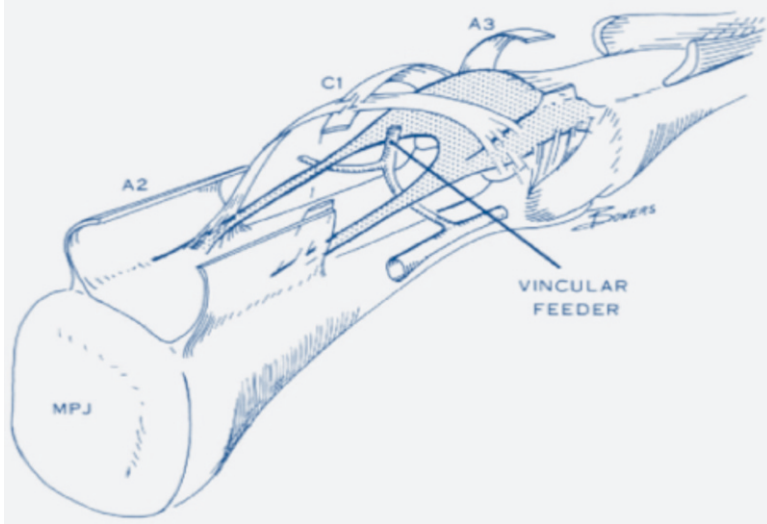

Fig. 1.5 The volar plate (*gray*) of the proximal interphalangeal (PIP) joint with checkreins and the vinculum between the two checkreins and the pulleys cut open for better view

joint's volar plate that provides greater joint stability. In their analysis of joint ruptures, they observed that the static resistance to hyperextension is offered by the lateral insertion of the volar plate-collateral ligament at the margin of the phalangeal condyle.

PIP and DIP Move Interdependently

In the extended finger it is impossible to flex the DIP without also flexing the PIP joint unless the PIP joint is blocked in extension. The main reason is the oblique retinacular ligament (ORL) or Landsmeers' ligament [8] which passes volar to the axis of the PIP joint and attachment at the distal joint on the dorsal side [9] and allows transfer of tension between the dorsal aspect of the DIP joint and the palmar aspect of the PIP joint. This couples the movement of the two joints because increased tension in the terminal tendon simultaneously increases tension in the ORL, thereby adding a flexion moment at the PIP joint. The ORL acts as a passive tenodesis assisting in DIP extension as the PIP joint is extended and relaxing with PIP flexion to allow full DIP flexion [10]. It has been calculated that on average every 1° of PIP joint flexion results in 0.76° of DIP joint flexion [11].

Clinical Relevance: Example
Under pathological conditions, like a central slip lesion (Boutonniere deformity), but also in Dupuytren's contracture chronic claw hand, the ORL may become contracted which may show in a hyperextended DIP joint.

Thumb

The CMC joint of the thumb is a saddle joint exhibiting with reciprocally convex–concave surfaces which permits the motions of flexion and extension (concave–convex), abduction and adduction (convex–concave), and conjunctional rotation. The joint capsule is a fibrous structure composed of irregular, dense connective tissue that accepts stress and permits stretch in all directions of that joint's motion. Within the joint capsule is contained the synovial membrane from which synovial fluid is produced for these joints. The deep anterior oblique ligament (Fig. 1.6; DAOL) or beak ligament has been seen as important in preventing subluxation of the metacarpal bone of the trapezium. However, controversy exists as to the primary thumb

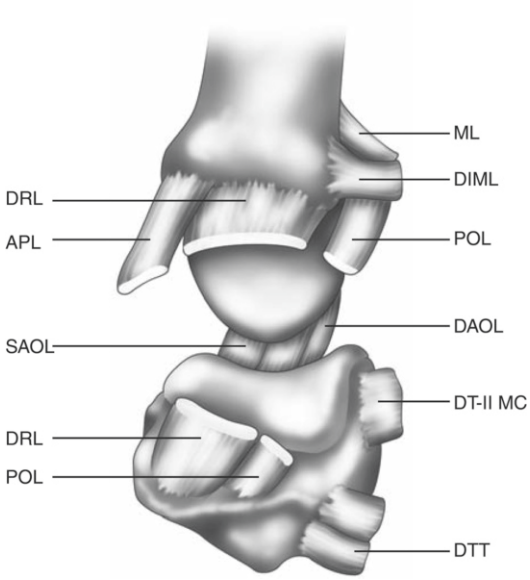

Fig. 1.6 Dorsal to palmar view of the interior of CMC joint of the thumb showing the position of the ligaments. *DAOL*, deep anterior oblique ligament (beak ligament); *DIML*, dorsal intermetacarpal ligament; *DT-IIMC*, dorsal trapezio-second metacarpal ligament; *DTT*, dorsal trapeziotrapezoid ligament; *SAOL*, superficial anterior oblique ligament (Adapted from Fig. 1. Mayo Foundation for Medical Education and Research)

carpometacarpal joint stabilizers. The beak ligament in a more recent study was found to be more structurally consistent with a capsular structure than a proper ligament [12].

The three dorsal ligaments of the deltoid ligament complex compared with the anterior oblique ligament were found to be uniformly stout and robust, the thickest morphometrically and the greatest degree of sensory nerve endings. The anterior oblique ligament (beak) was thin and variable in its location [13].

The configuration of the joint surfaces makes full rotation only possible in the maximum palmar abducted position.

An acute injury to the ulnar collateral ligament of the metacarpophalangeal joint of the thumb is called a Skiers thumb. Not only seen in skiers falling but also in all situations, people fall on their thumb especially when holding as object like a stick. If the ligament lesion is complete, the adductor aponeurosis can get in between the two ends of the ligament and prevent repair. This is called a Stener's lesion and needs surgical repair. If the lesion is partial a number of weeks, immobilization will be sufficient. A Gamekeeper's thumb is a similar impairment but is due to chronic laxity of the collateral ligament caused by breaking the necks of game. In modern times musician playing the saxophone can suffer from this problem.

Clinical Relevance: Example
When the hand is immobilized for surgical or traumatic reasons, the finger joint capsule will adaptively shorten in the immobilized position, preventing normal motion of the articular surfaces later; therefore, the maximum palmar abducted position is preferred.

Loss of MCP mobility (artrodesis) often results in no loss of function.

The thumb MCP joint is similar to the finger MCP joints arthrokinematically. The thumb IP joint's articulating condyles also display an unevenness, resulting in an obliquity of the axis of motion of 5–10°.

Wrist Carpal Bones

The carpal bones can be divided into a proximal and distal carpal row, based on their kinematic behavior during global wrist motion. The distal carpal row (trapezium, trapezoid, capitate, and hamate) is tightly bound to one another via stout intercarpal ligaments, and motion between them can be considered negligible. Similarly, the nearly rigid ligamentous connection of the trapezium capitate to the index and middle metacarpals and lack of motion between these bones allow us to consider the distal row functionally as part of a fixed hand unit that moves in response to the musculotendinous forces of the forearm. The scaphoid, lunate, and triquetrum can be described as an intercalated segment because no tendons insert upon them and their motion is entirely dependent on mechanical

signals from their surrounding articulations. The motions of these bones are checked by an intricate system of intrinsic, or interosseous, and extrinsic carpal ligaments [14].

The distal is more arched than the proximal row with a deep concave volar surface which makes the trapezium lie more palmar compared to the capitate. The ulnar side is deepened by the hook of hamate which produces a deep carpal groove, which accommodates the flexor tendons and the median nerve as they pass into the hand through the carpal tunnel [15].

Distal Radioulnar Joint (DRU)

The DRU joint is most lax in the midrange of pronation and supination. Rotating the wrist into full pronation and supination results in tightening either of the volar or dorsal components of the TFCC, respectively. This stabilizes the DRU. Laxity on ballottement in full rotation is abnormal and indicates loss of the stabilizers of the distal ulna.

Triangular Fibrocartilage Complex (TFCC)

This is a homogenous structure composed of an articular disc, dorsal and volar radioulnar ligaments, a meniscus homologue, the ulnar collateral ligament, and the sheath of the ECU. The best place to palpate the TFCC is between the ECU and the FCU, distal to the styloid and proximal to the pisiform. In this soft spot of the wrist, there are no other structures than the TFCC. Pressure at this point causes pain in cases of TFCC pathology (ulnar fovea sign test) [16].

The TFCC acts as a cushion for the ulnar carpus and carries 18–20 % of the axial load across the wrist in the neutral position. The TFCC also extends the gliding surface of the radius ulnarly for carpal motion and stabilizes the ulnar carpus. The most important function, however, is as a stabilizer of the distal radioulnar (DRU) joint [17].

Another provocative test, the ulnar grind test, involves some dorsiflexion of the wrist, axial load, and ulnar deviation or rotation. If this maneuver reproduces the patient's pain, a TFCC tear should be suspected.

Scapholunate (Interosseous) Ligament (SL)

The scaphoid and lunate are bound together by a strong interosseous SL ligament. This is C shaped and attaches along the dorsal, proximal, and volar margins of the articulating surfaces. The three parts of the SL ligament have different properties, of which the dorsal component is regarded as the thickest, strongest, and most critical of the scapholunate stabilizers.

Normal kinematics of the scapholunate joint are tightly governed by the SL ligament and by an envelope of surrounding extrinsic ligaments, oriented obliquely to the primary axis of wrist motion (flexion–extension).

The scaphoid, lunate, and triquetrum rotate collectively in flexion or extension depending on the direction of hand motion. As the hand flexes or turns into radial deviation, mechanical forces from the distal carpal row drive the distal scaphoid into flexion, and the lunate follows passively into flexion through the strong SL ligament [18].

This ligaments are the most frequently injured of the wrist ligaments [14].

To test for SL ligament injury, Watson's test or the scaphoid shift maneuver is used. The examiner's thumb is placed firmly on the tubercle of the scaphoid, and the wrist is moved into radial deviation. If the SL ligament is disrupted, the proximal pole of the scaphoid remains on the dorsal rim of the radius until it suddenly pops back into place. If this elicits pain, Watson's test is positive.

The Dart-Throwing Motion (DTM)

The plane of the DTM can be defined as a plane in which wrist functional oblique motion occurs, specifically from radial extension to ulnar flexion. During a DTM, there is less scaphoid and lunate motion than during pure flexion–extension

or radioulnar deviation. Clinically, a DTM at the plane approximately 30–45° from the sagittal plane allows continued functional wrist motion while minimizing radiocarpal motion when needed for rehabilitation [19].

Clinical Relevance: Example
Most activities of daily living are performed using a DTM. Scaphotrapeziotrapezoidal anatomy and kinematics may be important factors that cause a DTM to be a more stable and controlled motion.

Muscle and Tendons

To study the anatomy and kinetic chains of the hand and the interplay of more than 40 muscles that control its movements requires an appreciation of the biomechanics of the hand and its dexterity [6]. The muscles of the lower arm and hand can be conveniently arranged according to innervation and localization (Table 1.1). Usually the muscles are divided into extrinsic, where muscles have their origin proximal to the hand, and intrinsic muscles, which have their origin and insertion within the hand (Fig. 1.7). In general, each finger has six muscles controlling its movements: three extrinsic muscles (two long flexors and one long extensor) and three intrinsic muscles (dorsal and palmar interosseous and lumbrical muscles). The index and small fingers have an additional extrinsic extensor.

Intrinsics of the Finger and Thumb

Sterling Bunnell [3] wrote that "the intrinsic muscles of the hand, though tiny, are important because, with the long extensors and long flexors, they complete the muscle balance in the hand." Referring to the intrinsic muscles as tiny or small muscles of the hand is true for some muscles like the lumbricals or third palmar interosseous muscle but not for the first dorsal interosseous (1DI) and the adductor pollicis muscle where they have a cross-sectional area similar to extrinsic muscles [20].

Many valuable studies have been published about the anatomy [9], mechanics [6, 20, 21], and architectural design [22] of the intrinsic muscles of the hand.

Clinical Relevance: Example
There is a considerable decrease in functional efficiency in hands with loss of intrinsic muscle function, often referred to as the claw hand or intrinsic minus hand [23]. Besides the inability to manipulate smaller objects, the loss of holding and gripping large objects is sometimes more evident. Key pinch can be very weak in case the 1DI and/or adductor pollicis is paralyzed.

Table 1.1 Innervation of all the extrinsic and intrinsic muscles of the forearm and hand arranged by nerve and main joints involved

	extrinsic				intrinsic	
	Fore arm	wrist	fingers	thumb	fingers	thumb
ulnar		FCU	FDP (dig 4,5)		Interosseous dorsal (4)	AdP
					Interosseous palmer (3)	FPB (part)
					Lumbricals dig 4, 5	
					Hypothenar muscles	
median	PT	FCR	FDP (dig 2,3)	FPL	Lumbricals dig 2,3	APB
		PL	FDS (dig 2-5)			OpP
		PQ				FPB (part)
radial	BR	ECRL	EDC	APL		
	Supinator	ECRB	EDQ	EPB		
		ECU	EIP	EPL		

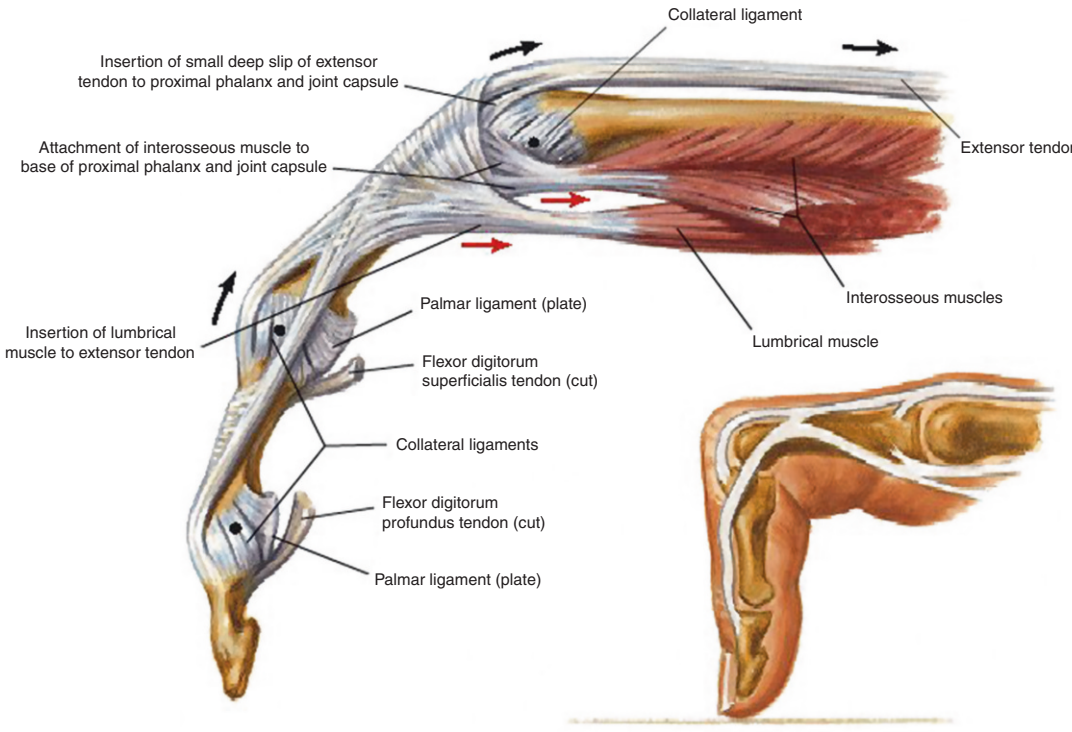

Fig. 1.7 Intrinsic muscles of a finger shape the extensor apparatus of the finger

Clinical Relevance: Example

Strength testing for the interosseous muscles is often done by testing abduction and adduction; however, the more important function to test is the test in intrinsic plus position: pushing against the volar proximal phalanx or PIP joint in attempt to extent this joint (Fig. 1.8). A weak 1DI and adductor pollicis muscle also result in a weak pinch because the MCP joint of the thumb cannot be stabilized; the FPL creates a flexion force for this which results in IP flexion of the thumb, called a Froment sign [20].

The strongest activity of the 1DI is in key pinch when the thumb is pressed against the midphalanx of the index finger. The 1DI is also active in tip pinch, when the tip of the thumb is pressed against the tip of the index finger. In that case, the main action is as a flexor at the metacarpophalangeal (MCP) joint. The first palmar interosseous (1PI) muscle is also active in tip pinch activities and produces some supination of the index finger to get good approximation with the pulp of the thumb. Without interosseous muscles the finger is unstable and will collapse into the intrinsic minus position of (hyper) extension of the MCP joint and flexion of the IP joints when loaded. The primary function of the interosseous is MCP flexion/stabilization allowing extension of the (IP) joints (Fig. 1.9).

Intrinsic Tightness

Shortening of the interosseous muscles is called intrinsic tightness (IT) and is often caused by trauma of the hand. The interossei are situated in rather tight compartments (Fig. 1.2). Therefore, swelling will cause an increase in pressure in these compartments, resulting in anoxia and muscle fiber death, with subsequent fibrosis of the muscle and shortening. This process is identical to the cause of Volkmann's ischemic contracture in the forearm [24]. The IT test consists of two

parts. First, the range of passive PIP flexion is tested with the MCP joint extended. Next, passive PIP flexion is tested with the MCP joint flexed. Intrinsic tightness is present if there is a large difference in PIP flexion between the two MCP positions (Fig. 1.9).

This test is sometimes called the Bunnell intrinsic tightness test [3]. Intrinsic muscle tightness may also play an important role in the pathogenesis of MCP joint subluxation in rheumatoid arthritis.

Fig. 1.8 The manual muscle strength test for the intrinsic muscles of the fingers combined in its action to flex the MCP joint and extend the IP joints. Pressure is applied upward at the volar side of the PIP joint

Clinical Relevance: Example

The long-term complications of IT can result in decreased MCP extension and a swan neck finger, i.e., hyperextension of the PIP joint with secondary DIP joint flexion. A long-standing swan neck deformity might result in a painful snapping of the lateral bands at the PIP level when the finger moves into flexion.

The lumbrical muscles are unique muscles in several aspects. They connect two extrinsic antagonistic muscles. Proximally the lumbricals are attached to the FDP, and distally they are inserted into the lateral band of the extensor tendon. The third and fourth lumbricals also connect, by their bi-penal origin, two adjacent FDP tendons. The effect of the lumbrical muscles upon MCP joint flexion is somewhat controversial. Brand suggested that the lumbrical muscles are not important for MCP flexion [20]. Nonetheless, independent MCP joint flexion is possible when the lumbricals are functioning and the interosseous muscles are paralyzed [21]. There is no controversy, however, regarding the effect of the lumbrical muscle on proximal and distal interphalangeal joint extension. The lumbricals are more efficient for IP extension than the interosseous.

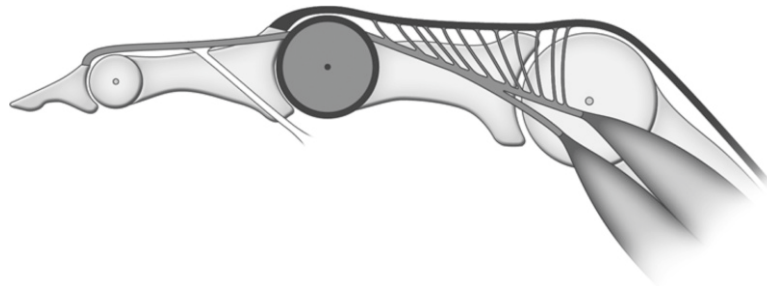

Fig. 1.9 Schematic drawing of extensor apparatus showing the action of the interosseous and lumbrical muscles in producing flexion of the MCP and extension of the PIP joint

Leijnse and Kalker [25] concluded that the lumbricals are in an optimal position for proprioceptive feedback regarding PIP–DIP joint movements. The unique properties of the lumbricals indicate that they are probably important in fast, alternating movements, e.g., in typing and playing musical instruments [26].

Clinical Relevance: Example
In low median nerve injuries, the lumbrical muscles of the index and middle finger are paralyzed. In these hands, it is difficult to discover any problems in the motion of these fingers. A mildly diminished extension of the DIP joint has been noticed in a few patients, which might be explained by the decreased extension force on the extensor apparatus.

Lumbrical Plus

The "lumbrical plus" sign is a situation in which there is an FDP tendon rupture distal of the lumbrical origin. It is also present in the situation where a graft in tendon reconstruction has been used that was too long. The FDP now pulls through the lumbrical muscle rather than through its tendon, causing PIP extension [27].

Fingers Flexing: The Flexors and Pulleys

Often anatomical textbooks present the flexor tendons as simple homogenous cords with all the same diameter, well ordered in one position. Looking in more detail the FDP tendon has certain curvatures according to the contact areas with the FDS [28]. Recent studies found that the flexor tendons change position and shape when moving [29].

Pulleys

Flexor tendon sheaths, with four annular and three cruciate pulleys, not only serve as a protective housing for the tendons but also provide a smooth, gliding surface by virtue of their synovial lining and an efficient restraint system that holds the tendons close to the digital bones and joints [30] (Fig. 1.10).

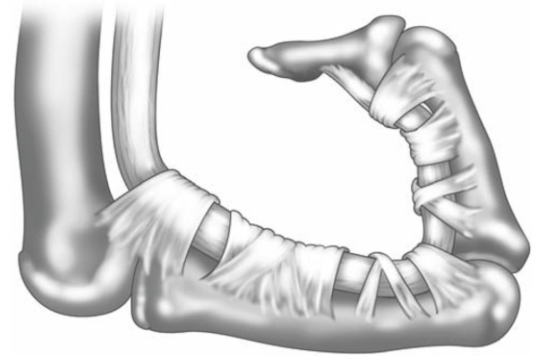

Fig. 1.10 A finger pulled in flexion; the pulleys maintain the close arrangement of the flexor tendon to the bone and prevent bowstringing

Clinical Relevance: Example
Loss of pulley especially the A4 and A2 results in bowstringing and as a result loss of a certain degree of flexion of the involved finger.

Flexor Digitorum Profundus (FDP) Quadriga: Linkage of Tendons

In the carpal tunnel anatomical interconnections between the tendons of the FDP are consistently present. These interconnections limit the mutual tendon displacements, which decrease finger independence; this is sometimes called the Quadriga phenomena [26] or Verdan's quadriga syndrome [31]. Another reason why the FDP cannot move independently is the common muscle belly [32].

Clinical Relevance: Example
The clinical relevance of this phenomenon can be observed in FDS test, dystonia, grip strength, PIP artrodesis, flexor tendon injury exercises, tip finger amputation tip [33].

The index finger can sometimes be flexed independently from the other fingers, but sometimes the FDP of the index finger has an anomalous tendon connection with the FPL first described by Linburg–Comstock [34]. An incidence as high as 60–70 % has been reported [35]. In case of intertendinous connection between index FDP and FPL, thumb IP flexion may also result in DIP index finger flexion.

Flexor Digitorum Superficialis (FDS)

The FDS is not normally activated until firm grasp is required or the wrist is in flexion [6]. FDS of the little finger is absent bilaterally in 4.5 %, absent unilaterally 3 %, and dependant function with ring finger is present in 38 % [36].

If in isolated little finger flexion the PIP joint is flexing, then an independent FDS is present. If there is only flexion of that joint with simultaneous flexion of the ring finger, then the two FDS tendons are most likely connected. If no flexion occurs and the ring finger is allowed to flex, the little finger will flex which shows that the FDS 5 is present but connected to FDS 4.

Congenital absence of flexor digitorum superficialis has implications for assessment of little finger lacerations [37]. For above reasons FDS of the little finger is also not a suitable "donor" in tendon transfer surgery.

FDS Chinese Finger Trap: Tendon Locking Mechanism

The "finger trap" can be observed when making a hook fist: flex IPs and extend MCP. When holding your middle finger in that position actively and extending the other fingers, the DIP can maintain the flexed DIP position. This is due to the FDS squeezing the FDP at Camper's chiasm. Now passively extend DIP (you might feel a little resistance) and see that it keeps an extended position, and you cannot actively flex it (Quadriga) or extend it. The changes in tendon shape and the lateral and anteroposterior forces produce a "compression" mechanism on the FDP tendon by the FDS slips, resulting in a smaller diameter of the FDS loop and altering frictional resistance. This tendon locking mechanism is more apparent in animals like bats [28]. They can hang on the branch of a tree without active muscle contraction.

Clinical Relevance: Example
Tendon lesion at this level is difficult to repair and has a great risk of adhesions and needs special care to regain gliding of the two tendons.

Finger Extension: The Extensors

Extensor Tendons

The extensor tendons do not have a synovial sheath system, but at the wrist level (Zone 7), the extensors are restricted by the extensor retinaculum that forms six fibro-osseous compartments within which 12 extensor tendons pass. Adhesion formation after extensor tendon injuries are not uncommon, but because the requirement of tendon gliding excursion is low and adhesions form under largely moveable skin, adhesions often do not pose an important problem for function of the extensor tendons. Metacarpal fractures, however, including surgical repair, may often result in adhesions.

The extensor retinaculum at the dorsum of the wrist functions as a pulley, keeping the wrist and finger extensor tendons near the axis of the wrist during motion.

Clinical Relevance: Example
Extensor tendon lesions at the extensor retinaculum location (Zone 7) often result in dense adhesions between retinaculum and the tendons and often hinder glding/excursion of the extensor tendons.

The principle function of the sagittal bands of the MCP joints is to extend the proximal phalanx. They lift the phalanx through their attachments to the volar plate and the periosteum of the

proximal phalanx. In addition, the sagittal bands help to stabilize the extensor tendons at the midline of the dorsum of the joint. They prevent bowstringing of the extensor tendons dorsally. When the MCP joint is fully extended, they may also contribute to its lateral stability.

The manner in which the sagittal bands extend the proximal phalanx is worthy of particular attention. Since the extensor tendon is not tethered to the proximal phalanx (except for occasional articular slips), its excursion may be transmitted to more distal joints if MCP hyperextension is prevented. If hyperextension is not prevented, the excursion and force of the extensor tendons are directed principally through its sagittal bands to the volar plate, and little or none of its excursion or force will be transmitted more distally. The interphalangeal joints will then fall into flexion unless they are extended by other muscle–tendon units, i.e., intrinsic extensors, lumbricals, and interossei.

Clinical Relevance: Example

Loss of sagittal bands may occur with rheumatoid synovitis of the metacarpophalangeal joints. Swelling within these joints may gradually stretch and thin the sagittal bands. The extensor tendon will no longer be kept at the dorsal midline of the joint and will be free to dislocate. With finger flexion, the fourth and fifth metacarpals descend volarly, and the extensor tendons have a tendency to be pulled ulnarly through the intertendineal fascia and the juncturae tendinae. Dislocation of the extensor tendons may then occur. Furthermore, with stretching of the sagittal bands, the link between the extensor tendon and the volar plate is weakened. The dislocated extensor tendon will only poorly be able to extend the proximal phalanx. If the tendon had dislocated ulnarly, it may cause the finger to deviate ulnarly.

The dorsal apparatus of the fingers (Fig. 1.11) consists of the two conjoined lateral bands at the dorsolateral aspect of the proximal interphalangeal joints, converging more distally at the dorsum of the middle phalanx to form the *terminal tendon* which is inserted at the dorsal lip of the base of the distal phalanx. The conjoined lateral band is dorsal to the axis of motion of the proximal interphalangeal joint. It is held dorsally by the *triangular ligament*. This "ligament," actually a sheet of transversely oriented fascia, is bounded proximally by the insertion of the central slip and of the medial interosseous bands at the base of the middle phalanx, laterally by the conjoined lateral bands, and its apex, distally, is at the terminal tendon.

The conjoined lateral bands are prevented from dislocating too far dorsally by the *transverse retinacular ligaments*. These structures extend volarly and proximally from the lateral edges of the conjoined lateral bands to the pulley of the flexor tendons on either side of the proximal interphalangeal joint.

In the normal finger, the lateral bands of the dorsal apparatus (or extensor mechanism) at the PIP level shift dorsally and towards the central

Clinical Relevance: Example

When this dorsal expansion is elongated, the lateral bands are too much volarly, resulting in a loss of PIP joint extension; consequently, the ORL is slack most of the time and will adjust to this new situation by shortening, and this may result in hyperextension of the DIP joint. In Boutonniere deformity, the ORL is shortened [20].

The characteristic Boutonniere deformity is not usually present at the time of injury because extension of the PIP joint is still possible via the lateral slips of the extensor tendon. Consequently, a rupture of the central slip of the extensor tendon can easily be missed. Early diagnosis is essential to start treatment as soon as possible to prevent deformity [38, 39].

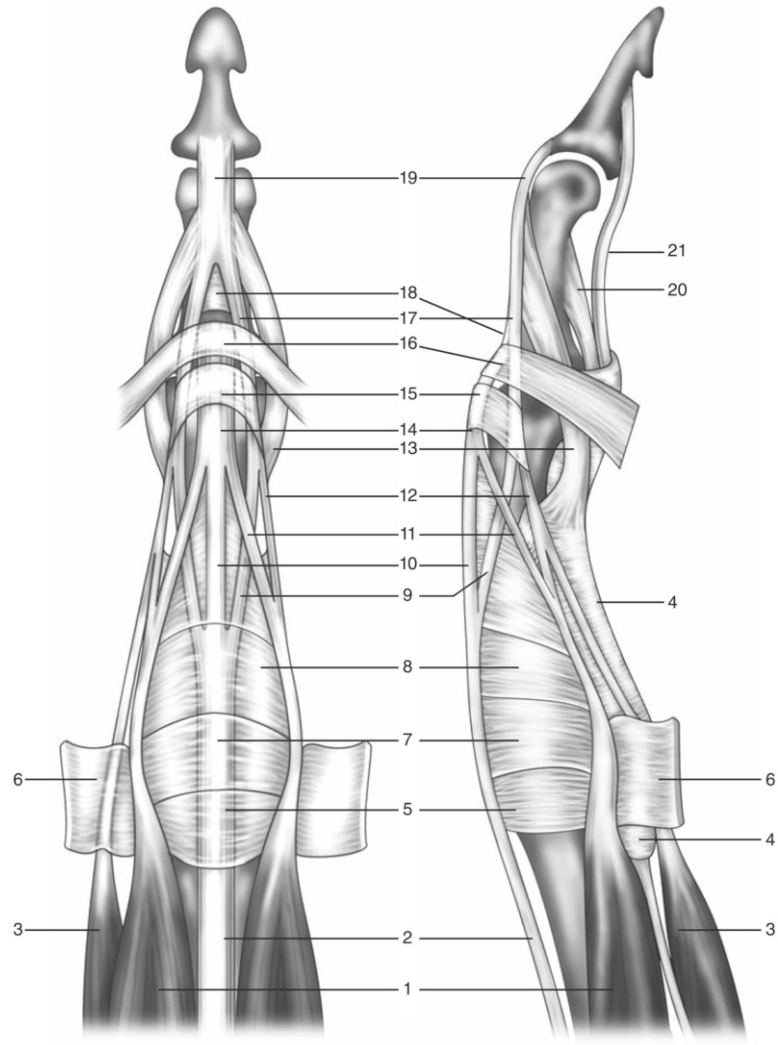

Fig. 1.11 The extensor apparatus of the finger. (*1*) Interosseous muscle. (*2*) Extensor communis tendon. (*3*) Lumbrical muscle. (*4*) Flexor tendon fibrous sheath. (*5*) Sagittal bands. (*6*) Intermetacarpal ligament. (*7*) Transverse fibers of extensor apparatus. (*8*) Oblique fibers of the extensor apparatus. (*9*) Lateral band of extensor tendon. (*10*) Central or middle band/slip. (*11*) Central or middle band of interosseous tendon. (*12*) Lateral band of interosseous tendon. (*13*) Oblique retinacular ligament (Landsmeers' ligament). (*14*) Middle extensor tendon. (*15*) Spiral fibers. (*16*) Transverse retinacular ligament. (*17*) Lateral extensor tendons. (*18*) Triangular ligament. (*19*) Terminal extensor tendon. (*20*) Flexor superficialis tendon. (*21*) Flexor profundus tendon

position of the finger when the PIP joint is extended, whereas when flexing the PIP joint, the dorsal apparatus needs to allow the lateral bands to move volarly towards the flexion–extension axis of movement at the PIP joint.

If the extensor tendon to the middle or ring finger is lacerated proximal to the juncturae tendinae, the finger may still fully extend as was noted above. If the central slip itself is lacerated, there may still be full extension of the middle phalanx through the medial interosseous bands. If these, too, are lacerated and if the triangular ligament is torn, the lateral bands subluxate laterally and a Boutonniere deformity results. If the terminal tendon is divided, the distal joint falls into flexion; a Mallet finger.

EIP and EDC of Index Finger

The EDC strength test is for testing the MCP extension without PIP extension of the fingers. Without the intrinsic you cannot extend all the joints of the fingers simultaneously because the EDC has too little excursion, that is, insufficient proximal movement of the EDC when contracting. When you block the MCP (e.g., with a knuckle bender splint), all the excursion is now used at the IP joints of the fingers, and you can extend the IPs without intrinsic muscle action.

Clinical Relevance: Example
When there is a subluxation of the EDC at the MCP level possible due to rheumatoid arthritis or sagittal band lesion, the EDC tendon can become a flexor and ulnar deviator.

It has been shown that extension of the index finger is possible without the EIP apparently because the loose connection between EDC index and middle finger allows this [40].

Thumb Muscles

Extensor Pollicis Longus (EPL)

The EPL together with the FPL are strong adductors of the thumb. Even in ulnar palsy, the adduction can be quite strong. Because EPL and FPL contribute to adduction, an isolated strength of this muscle cannot be done and should be tested in pinch grip, e.g., with a dynamometer.

The best way to test the function of the EPL is by putting the hand flat on the table and asking for elevation of the thumb [40]. The EPL is a positioning muscle and does only need strength to lift the weight of the thumb. IP extension of the thumb is in radial palsy possible through the intrinsics (FPB and adductor) similar to lumbricals–interossei in the fingers

Clinical Relevance: Example
Froment sign is a sign of adductor weakness, e.g., seen in ulnar nerve paralyses.

Extensor Pollicis Brevis (EPB)

Weakness of the EPB will result in weaker MCP extension of the thumb, which is rarely seen after injury but is more often seen in a congenital deformity called the clasped thumb.

Clinical Relevance: Example
The EPB and the APL are the tendons involved in Quervain tendinitis in the first extensor compartment at the wrist.

Abductor Pollicis Longus (APL)

It is a strong muscle close to the abduction–adduction axis of the CMC. The main function is to stabilize the CMC joint where the metacarpal bone is pulled onto the trapezium.

Clinical Relevance: Example
In CMC arthritis the trapezium is tilted, and pulling on the APL will cause a deforming force by pulling the metacarpal of the trapezium.

When the APB is weak, patient will move the wrist in flexion, allowing the APL to have a better moment arm at the CMC joint and assist in palmar abduction of the thumb.

Similarly, when testing for abduction strength of the thenar muscles, e.g., in carpal tunnel syndrome, keep the wrist in extension. This will prevent the APL from moving volarly, thus assisting in abduction [41]. Brand called this the bowstringing of the APL [42].

Nerves and Innervations

Sensibility tests include different modalities, e.g., touch and temperature. Although a number of tests are useful in diagnosis or describing the location of nerve injury, quantitative tests are more appropriate as outcome measures. Sensibility testing with Semmes-Weinstein monofilaments (SWMF) has become one of the most commonly used quantitative measures in hand rehabilitation. Advantages of SWMF include the ability to assign numbers to sensory touch thresholds, regulation of force variations, and translation of forces obtained into functional levels. The Weinstein Enhanced Sensory Test (WEST) instrument has five filaments with consistent head sizes across filaments.

Tactile discrimination is frequently measured using two-point discrimination (2PD). This test is said to reflect the quantity or innervation density of innervated sensory receptors. The smallest distance that the patient can correctly discriminate one from two probes is recorded. Normal values within the range of 4–7 mm for the fingertips have been reported.

With low ulnar nerve palsy, all interossei and the ulnar two lumbricals are paralyzed. Flexor profundus and flexor superficialis work normally. Abduction and adduction of all the fingers are lost. Grip is weakened because of interosseous paralysis. The ring and little fingers may claw, particularly if the volar plates of the MCP joints are lax since the proximal phalanx will become an "intercalated bone." Overt clawing of the index and little fingers is usually not present as the lumbrical will continue to extend the interphalangeal joints and may achieve flexion of the metacarpophalangeal joints (Fig. 1.12).

Latent-hidden or functional clawing is usually present in functional activities because the two primary flexors of each finger are paralyzed.

The main deformity to prevent is PIP flexion contractures by splinting and exercises.

With high ulnar nerve palsy, if the ulnar nerve is lacerated above the site of innervations of the flexor digitorum profundus to the ring and little fingers, these muscles will be paralyzed along with all the interossei and the ulnar two lumbricals. Abduction and adduction of all the fingers will be lost. The power of finger flexion will be decreased by as much as 50 % as the contribution towards MCP joint flexion by the interossei will be lost. Flexion of the ring and little fingers will be weakened as both the profundus and interossei are paralyzed.

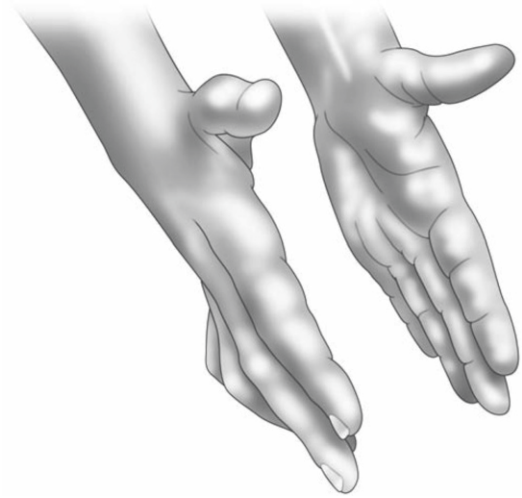

Fig. 1.12 Typical claw hand in an early stage after ulnar nerve lesion. The ring and little finger cannot be fully extended at the PIP joint and often show hyperextension at the MCP joint

There will be only mild clawing of the ring and little fingers since the loss of their profundus tendons will somewhat balance the weakness of extension which follows lumbrical and interosseous paralysis of these digits. Ring and little finger flexion will occur at the proximal interphalangeal joints.

When the nerve recovers from proximal to distal, the long flexors first regenerate which causes a more pronounced flexion of the fingers and clawing; more attention towards preventing PIP flexion contractures must be initiated.

With low median nerve palsy, the main problem is the loss of sensation in the radial side of the hand and the loss of median innervated thenar muscle action. It must be noted that in median nerve palsy, especially when the FPB is entirely

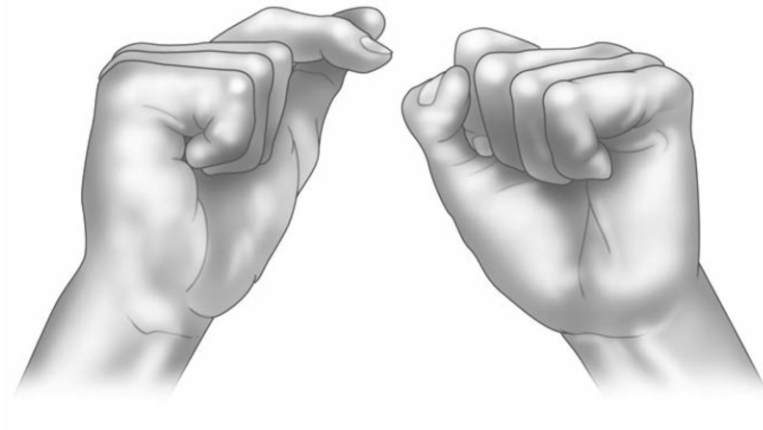

Fig. 1.13 A "pointing finger" as a result of a median nerve lesion at elbow level (high median nerve) in an attempt to make a full fist. The index finger cannot flex at the IP joint due to paralyses of the FDP and FDS while the interosseous muscles flex the MCP joint. The middle finger is flexed due to attachments between FDP tendons of the middle and ring finger (Quadriga phenomenon)

ulnar innervated, there is still a good palmar abduction possible [41].

In some patients with weak thenar muscles, a trick movement of flexing the wrist to activate the APL is adopted [20]. The loss of lumbricals on the index and middle finger does have little effect. Sometimes a slight diminished extension of the DIP can be observed. The main deformity to prevent is adduction contracture of the thumb.

With a low median and ulnar nerve palsy, all interossei and lumbricals are paralyzed. All abduction and adduction of the fingers are lost. Flexion power is weak because of the loss of interosseous muscles as MCP joint flexors. Secondary flexion of the metacarpophalangeal joints occurs through the flexor profundus and superficialis.

With high median nerve palsy, often the so-called Preachers Hand is shown, but this does not describe what is seen in clinical practice. The MCP can still flex because of the ulnar innervated interosseous muscles, and the middle finger will often flex because of the connections between the FDP tendons of the ring and middle finger and the common muscle belly. This represents a *pointing finger* (Fig. 1.13), which is a much better name. Sometimes this is called the orator's hand posture in which the patient has been asked to make a fist. The hand is held in an "orator's hand" posture [43].

With high median and ulnar nerve palsy, all the profundi and the superficialis tendons and all the interossei and the lumbricals will be paralyzed. The only motors still functioning within the fingers will be the (extensor digitorum communis, extensor indicis proprius, and the extensor digiti quinti proprius) finger extensors. Full extension will probably be possible at all three joints since the weakened extension at the interphalangeal joints will not be antagonized by the normal viscoelastic forces of the long flexors. Flexion of the fingers will be impossible, however.

With radial nerve palsy, extension at the metacarpophalangeal joints will be lost. There will still be full flexion at all three joints and good extension at the proximal and distal interphalangeal joints through the intrinsics.

Summary

The anatomy and biomechanics of the different structures of the hand are described in this chapter. All of these structures can be injured, and because of the close relation of these tissues, they

influence each other and can work against restoration of normal movement but can also be used in the benefit of the rehabilitation of the hand.

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Physical Examination of the Hand

2

Fitnat Dincer and Gulbuz Samut

Introduction

The hand is one of the most complex anatomical structures in the human body. It is said that the hand is the mirror of the brain. Especially evolutionary specialization of the thumb as an opposing digit makes it the most important digit in a way providing exceptional motor abilities. Because of these complex functions, injuries to the hand severely compromise a patient's well-being, although they are rarely life-threatening. So immediate evaluation and accurate diagnosis of hand injuries carry great importance. With a thorough history, systematic examination, and knowledge of disease process of the hand, it is possible to make the clinical diagnosis with a considerable accuracy. Radiographs, electrodiagnostics [1, 2], and specialized laboratory test will only be ancillary tools to confirm the diagnosis. However, recording the clinical findings is also important in order to demand the necessary diagnostic tools and in the patient follow-up.

In this chapter an approach to clinical examination of the hand will be outlined as in order: patient history, inspection, palpation, assessing range of motion, neurologic examination, and specific tests.

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Patient History [3]

Patient history is the key point in the examination and provides sufficient information for tentative diagnosis. The diagnosis with 60 % accuracy can be made with only taking a good patient history. As always patient history begins in noting down the demographic information such as the patient's age, occupation, avocation, and hand dominance. The patient's general condition, systemic diseases such as diabetes mellitus, and cardiovascular problems are also important and influence the main pathology. Any previous illness and trauma should also be noted. Especially in acute trauma, site and description of the accident (cuts, crush injuries, saw accidents, chemical or burn injuries, bite wounds, closed trauma) are important in the means of making the diagnosis and deciding the subsequent treatment strategy.

Inquiring pain symptoms is also important. The pattern of pain and whether the pain fluctuates over time should be asked. Location of the pain, characteristics of the pain, and amplitude of the pain should be noted. Asking any aggravating or relieving factors and if the pain is constant or work related is also important. How does the pain affect the patient's daily living activities? What was the patient capable of doing in the past and what is he/she is capable of doing now? Accompanying symptoms beside the pain should be inquired. For example, accompanying numbness and weakness in the index and middle finger are often characteristics of carpal tunnel syndrome.

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Pain aggravating with heat and often worse in the morning and with rest in the metacarpophalangeal and proximal interphalangeal joints is usually a sign of inflammatory condition, especially rheumatoid arthritis [4].

While obtaining the patient history, clinical suspicion usually develops, and other diagnostic studies and physical examination are required only for confirmation. This is why, as mentioned before, taking a careful, detailed, and comprehensive history is very important and necessary in order to make a thorough diagnosis.

General Inspection

Evaluation of the patient always begins with general inspection in all kinds of physical examination, just as in hand examination. Once the patient enters the room, the examination begins, and the patient is observed as a whole, the patient's general being, posture, walking pattern, etc. After a general look, the whole upper extremity is observed. Any asymmetry of shoulders, shape of posture of the hand, and difference between both upper extremities are documented. Any swelling, deformities, and congenital abnormalities are reported. While generalized swelling may be the sign of circulatory problem, localized swelling can indicate inflammation, fracture, tumors, and ganglia originating from tendons or joints. Axial deformities may indicate a fracture. Muscle atrophy may be due to prolonged inactivity or chronic peripheral nerve compression [5] (i.e., carpal tunnel syndrome). Skin color changes can give information about the current state of vascular supply of the hand and should always be observed. Hyperemia may be a result of bacterial infection, dry and shiny skin may occur with systemic diseases such as scleroderma, and hyperpigmentation of palmar furrows is seen in hyperaldosteronism. Hypo/hyperpigmentation plus hypertrichosis and dry skin may be signs of loss of nerve function of the hand.

Inspection of the fingernails can also provide information about systemic disorders. Hollow nails suggest iron deficiency anemia. Clubbing is usually a sign of lung disorders but can also be seen in inflammatory bowel diseases, cirrhosis, etc. Posterolateral swelling of distal interphalangeal fingers due to arthritis in postmenopausal women is observed and called as Heberden's nodes; the same pathology at proximal interphalangeal joints is called as Bouchard's nodes [6, 7] (Figs. 2.1 and 2.2).

In addition to individual swelling of finger joints, bilateral symmetrical swelling of especially metacarpophalangeal and proximal interphalangeal joints is an early sign of chronic inflammatory disorders especially rheumatoid arthritis [4]. Swelling can be accompanied by tenosynovitis, by effusions, and, in chronic conditions, by characteristic finger deformities which are:

- Swan neck deformity: flexion of metacarpophalangeal and distal interphalangeal joints and hyperextension of proximal interphalangeal joints
- Boutonniere deformity: flexion of proximal interphalangeal joint, extension of distal interphalangeal joint of fingers and flexion of mcp, extension of interphalangeal joint of thumb (Fig. 2.3)

Other deformities such as congenital ones should also be noted. Most frequently seen congenital anomaly is polydactyly and the second one is syndactyly. These congenital deformities may be hereditary or exogenous in origin.

Palpation

Palpation is a complementary component of examination after inspection. What is seen with inspection is evaluated in more detail with palpation. Palpation includes not only soft tissue, bone, and joints of the hand but also the whole upper extremity for a thorough examination. Skin surface texture evaluation is important. The hand must be checked whether it is hot or cold, dry or moist, and smooth or rough and if there is any swelling; it should also be checked for its properties – fluctuant or fixed and soft or hard – for its dimensions and accompanying skin color changes, and for any tender points with palpation. Distal pulses are also important as they give idea about current blood supply of the hand. Palpation of major landmarks of the hand is important to make the differentiation between normal and pathological conditions.

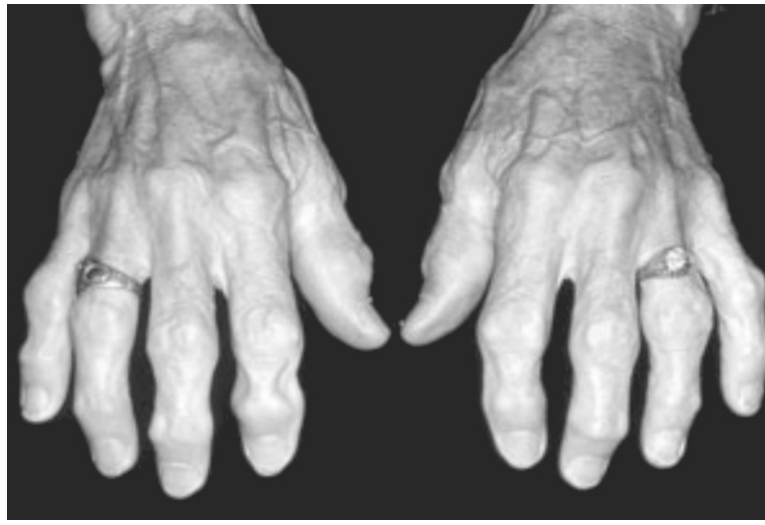

Fig. 2.1 Posterolateral swelling of distal and proximal interphalangeal joints due to osteoarthritis, Heberden and Bouchard nodes, respectively (Received from the www.healthinplainenglish.com web site in 12.10.2010)

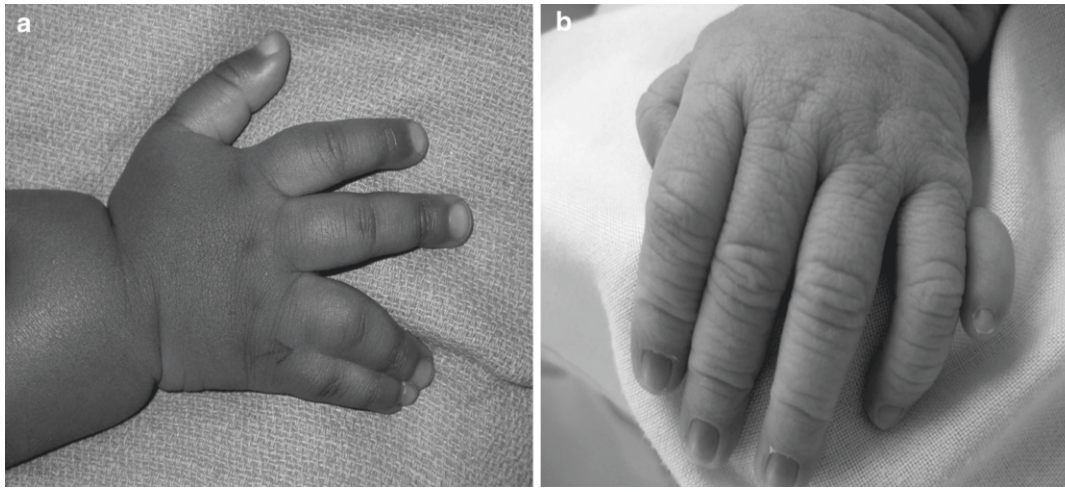

Fig. 2.2 Congenital deformities of the hand. (**a**) Syndactyly on the *left* and (**b**) polydactyly on the *right* (Received from the img.medscape.com/farm3.static.flickr.com web site in 12.10.2010)

Radial Styloid

This is an easily palpable and important landmark for palpation of the wrist. Tenderness at this point in postmenopausal women may indicate fracture which is usually called Colles fracture or rarely tendinitis of brachioradialis muscle which occasionally occurs in athletes performing backhand motions [3].

Anatomical Snuffbox and Scaphoid

Anatomical snuffbox is located distal to the radial styloid process and between abductor pollicis longus and extensor pollicis longus. It is an important landmark in two ways: First of all, radial artery passes through this hollow and can be injured in traumas to this anatomical place. Secondly, scaphoid is palpable on the floor of the hollow.

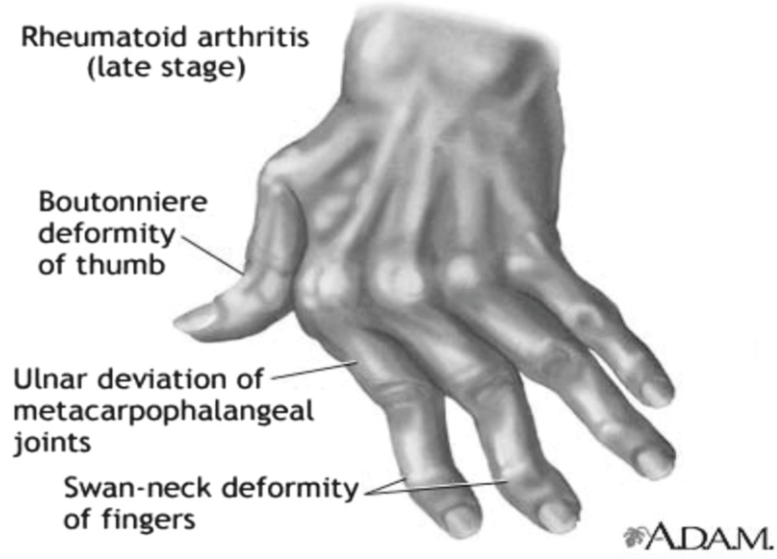

Fig. 2.3 Characteristic finger deformities of chronic inflammatory disease of the hand (Received from the www.clarian.org web site in 12.10.2010)

Tenderness in this area usually indicates a scaphoid fracture which is the most frequently fractured carpal bone (Fig. 2.4).

Trapezium and the Base of the First Metacarpal

Trapezium is palpable just distal to scaphoid. Palpation of this area will be painful especially in degenerative osteoarthritis of the hand.

Capitate

Capitate is palpable proximal to the largest and most prominent of all metacarpal bases, the third metacarpal.

Lunate and Lister's Tubercle

Lister's tubercle lies on the dorsal aspect of the distal radius directly in line with the third metacarpal. Lunate is located distally to Lister's tubercle and prone to dislocation, fracture, and avascular necrosis. Tenderness in this area especially with the wrist motion is an important indicator of lunate damage.

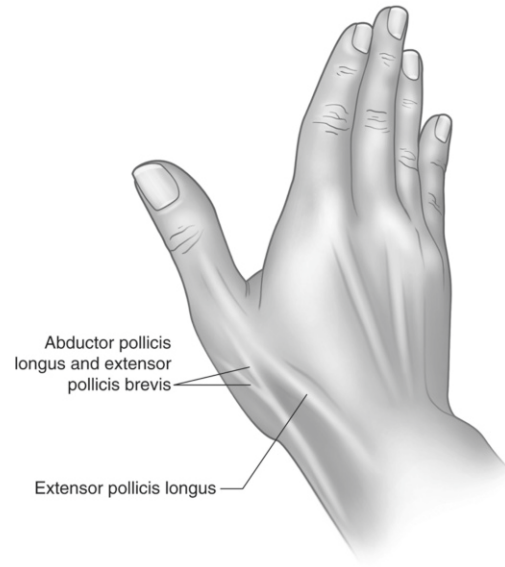

Fig. 2.4 Anatomical snuffbox of the hand. It is located distal to radial styloid between abductor pollicis longus and extensor pollicis longus tendons

Ulnar Styloid

Ulnar styloid is another important and easily palpated anatomical landmark. The pain of flexor carpi ulnaris tendinitis is usually located in this area. This styloid process is also vulnerable to the traumatic injuries especially falls.

Triquetrum and Pisiform

Triquetrum is distal to ulnar styloid, and pisiform is distal to triquetrum. Flexor retinaculum, extensor retinaculum, abductor digiti minimi, and fibrous complex of ulnocarpal compartment insert to pisiform.

Hamate and Guyon's Canal

Hamate is located distally to pisiform, but it is difficult to palpate, because it lies deep in the hand and is covered by soft tissues. Guyon's canal is between the hook of hamate and pisiform, and it is an important anatomical structure because ulnar artery and nerve pass through, and it is prone to compression with acute or chronic trauma.

Assessment of Range of Motion

Range of motion assessment is an essential component of hand function evaluation. Limitation of the motions severely impairs hand function. This is why thorough evaluation of range of motion of each joint carries great importance. Range of motion evaluation can be elicited with or without goniometry. However, using goniometry improves reliability of measurements although there is not much literature supporting this statement [8]. It was found that intra-observer reliability is high [8, 9]. Intra-observer reliability is higher than interobserver reliability, but several measurements should be taken by the same examiner. Placing the goniometer dorsally or laterally has equal reliability [10], and each technique can be used in order to measure range of motion (Fig. 2.5).

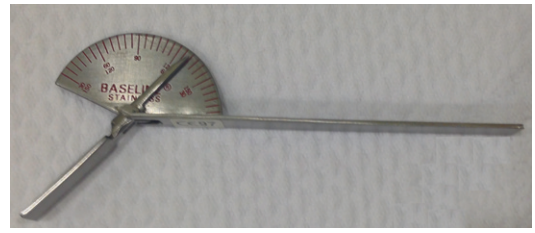

Fig. 2.5 Hand goniometer (Received from the http://www.bpp2.com/physical_therapy_products/1310.html web site in 12.10.2010)

Range of motion evaluation involves active and passive motion measurements. Initially active range of motion and then passive range of motion are evaluated. Active motion refers to the motion achieved by patient's own muscle power. Passive motion refers to the freedom of motion of a joint when an external force is applied. If the patient is capable of doing full range of active motion, passive range of motion evaluation will not be necessary. Flexion is evaluated with the hand in "fisted" position (maximal metacarpophalangeal, proximal interphalangeal, distal interphalangeal flexion), and extension is evaluated with all these three joints in full extension [11].

Total motion values allow one number to represent the total motion capacity of a finger. In order to estimate this number, total extension deficits, including hyperextension, are added together, and the sum is subtracted from total flexion capacity. Passive range of motion tells us if the joint is stiff or not, whereas total passive motion indicates as a functional unit finger lacks motion. Another technique that evaluates lack of overall finger flexion is measuring the distance between the finger pulp and distal palmar crease while the hand is in fisted position. This is an easier way to evaluate finger flexion deficit and more comprehensible in the clinic [11] (Fig. 2.6).

Range of Motion of the Wrist

Measuring rotational movements of radioulnar joint is difficult because of long axis of the movement and lack of anatomical lever arms. In order

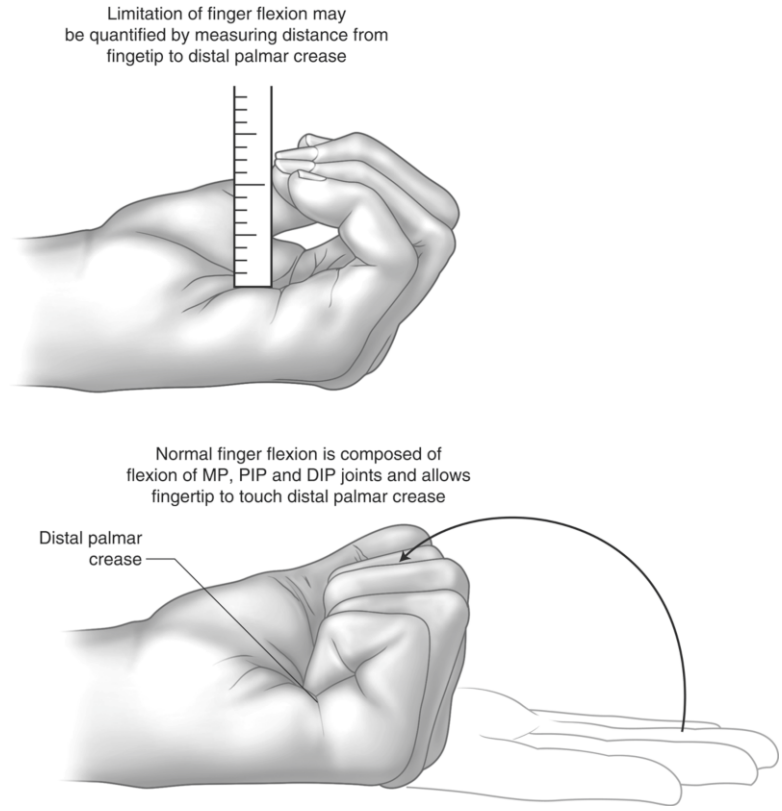

Fig. 2.6 Overall finger flexion measurement. To evaluate overall finger flexion, the distance between finger pulp and distal palmar crease is measured with the hand in fisted position

to make the correct measurement, the patient may be sitting or standing, but the elbow must be flexed 90° with the arm and must be close to the side of the body. The forearm should be in mid-position defined as "0°" [11].

Supination

For supination the patient rotates the forearm to its maximum palm-up position. Stationary arm of the goniometer is placed along the humeral shaft and movable arm across the volar aspect of the wrist at the level of ulnar styloid. Normal range of motion of supination is 0°–80°/90° [11].

Pronation

Starting position for pronation is the same as for supination, but this time the patient rotates the forearm into maximum palm-down position. The goniometer is placed similarly as for the supination measurement. The only difference is the change of position of the hand. Normal range of pronation of the wrist is 0°–80°/90° [11] (Fig. 2.7).

Flexion

For assessing flexion range of motion of the wrist, the goniometer can be placed laterally or dorsally. For lateral placement the goniometer is placed along the radial border of the forearm and the second metacarpal bone. The elbow must be in flexed position, and the forearm and wrist must be in neutral position. When the wrist is flexed, the stationary arm of goniometer is placed along the radius, and the movable arm

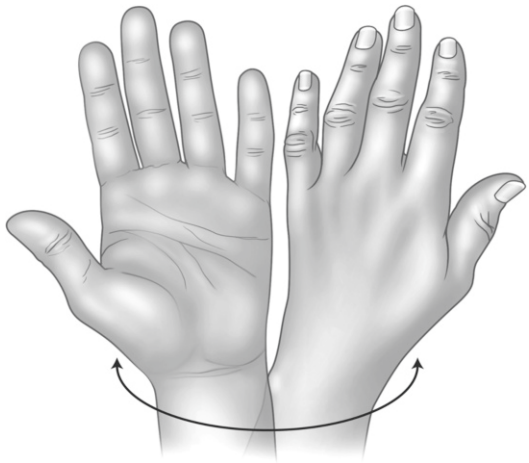

Fig. 2.7 Pronation and supination of the wrist. Normal range of pronation and supination of the wrist is 0°–80°/90°

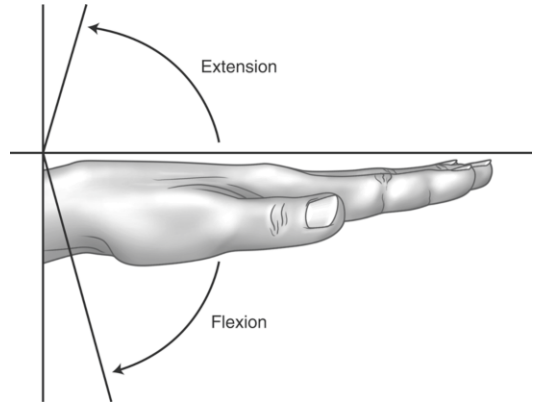

Fig. 2.8 Flexion and extension range of the wrist. Normal range of flexion wrist is 0°–80°. And normal range of extension of the wrist is 0°–70°

is placed along the second metacarpal bone. Axis of goniometer is placed approximately at the level of radius. Wrist flexion with the goniometer placed dorsally requires elbow flexion, forearm pronation, and the wrist in neutral position. The stationary arm is placed along the forearm and the movable arm along the third metacarpal. Normal range of flexion of wrist is 0°–80° [11].

Extension

Starting position for wrist extension measurement is the same as for wrist flexion. After proper positioning, the wrist is extended maximally; fingers can be allowed to flex passively. The stationary arm of goniometer is placed along the long axis of the forearm, and the movable arm is placed along the long axis of the third metacarpal on the volar surface. Normal range of motion for extension of wrist is 0°–70° [11] (Fig. 2.8).

Radial/Ulnar Deviation

Assessment of radial and ulnar deviation of the wrist is elicited by the wrist in neutral position and the forearm in pronation. The goniometer is placed in mid-position dorsally. The movable arm of goniometer is placed along the long axis of third metacarpal bone. Then the wrist is angled towards the thumb and little finger for radial and ulnar deviation, respectively. Normal range of radial deviation is 0°–20°, and ulnar deviation is 0°–30° [11] (Fig. 2.9).

Range of Motion of Fingers

In order to assess range of motion of fingers thoroughly, the wrist must be in neutral position to allow tendon excursion of long flexors and extensors of the fingers. Flexion of one finger is measured by maximally flexing the other three fingers, and extension of one finger is measured by maximally extending the other three fingers actively.

Metacarpophalangeal (MCP) Joint

Lateral or dorsal placement of the goniometer is possible for assessing MCP joint motion. Usually dorsal placement is preferred because it is easier to apply. In dorsal placement, the stationary arm of goniometer is placed over the dorsum of metacarpal bone (MC), and the movable arm is placed along the long axis of proximal phalanx. In lateral placement, the stationary arm of goniometry is placed on the longitudinal axis of MC, and the movable arm is placed on the longitudinal axis of the proximal phalanx. For the second and third fingers, the goniometer is placed on the radial side of the fingers, and for the fourth and fifth fingers, the goniometer is

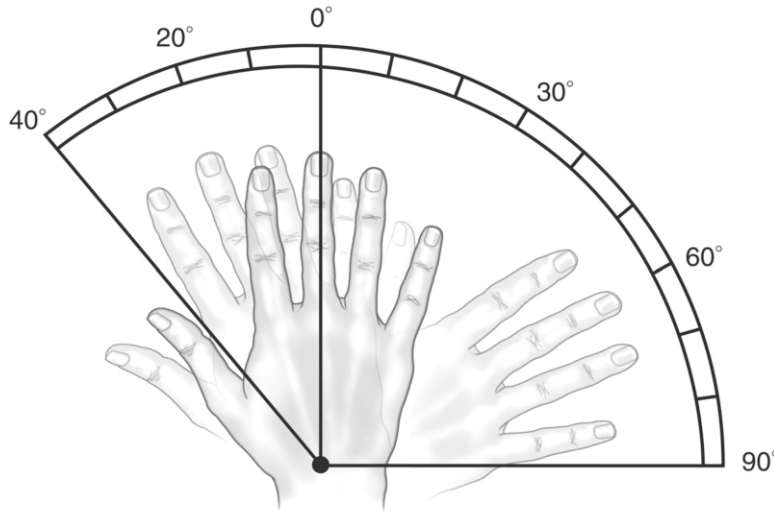

Fig. 2.9 Radial and ulnar deviation of the wrist. Normal range of radial deviation is 0°–20° and ulnar deviation is 0°–30°

placed on the ulnar side of the fingers. Normal range of motion of MCP is 0°–90°, but hyperextension up to 45° is possible and considered to be in normal ranges [11].

Flexion and Extension of Proximal and Distal Interphalangeal (DIP) Joints

Dorsal and lateral placement of the goniometer is possible. Measurement technique of PIP and DIP is quite similar, so they will be discussed together. For lateral placement, the stationary arm is placed along the long axis of proximal phalanx, and the movable arm is placed along the long axis of adjacent distal phalanx. The positioning of the goniometer is the same for both flexion and extension. Dorsal placement of the goniometer is the same as for lateral placement except that it is placed dorsally. Normal range of motion of PIP is 0°–110° and DIP is 0°–60°/70° [11].

Abduction and Adduction of MCP Joint

There is not a standardized technique to measure finger abduction and adduction in exact means. Finger abduction is assessed by measuring the distance between two adjacent abducted fingers. It gives only an estimated and not a standard value, and it is only used to follow up the treatment [11].

Thumb Motions

The thumb has the most complex movement pattern along all other digits. This is why its movement patterns are described separately.

Flexion of the thumb is the movement of the thumb against the base of the fifth finger across the plane of the palm, and it involves the flexion of carpometacarpal (CMC), metacarpal (MC), and interphalangeal (IP) joints. Extension of the thumb is the movement of the thumb away from the second finger across the plane of the palm. Flexion and extension of the thumb can be measured by placing the stationary arm of goniometer along the long axis of the radius and movable arm along the long axis of the first MC. Flexion of CMC joint is 15°. Extension of CMC joint is measured by placing the stationary arm of goniometer on the second MC and the movable arm on the first MC. MCP and IP joint flexion and extension assessment technique is the same as for the other fingers [11].

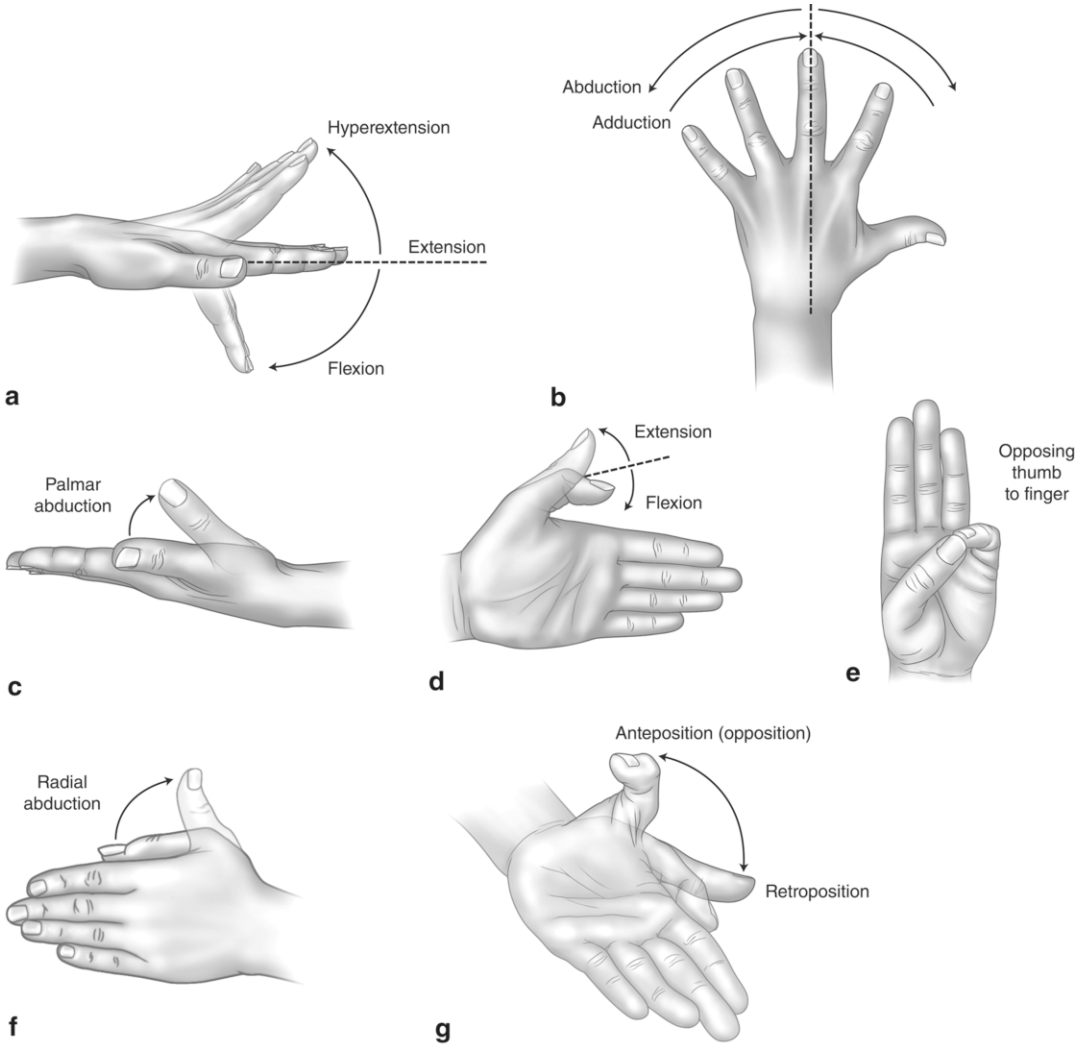

Fig. 2.10 In (**a**) and (**b**) MCP joint motions are illustrated. Figures from (**c**)–(**g**) thumb motions are illustrated

Abduction of the thumb is the movement of the thumb perpendicular to the palm and only involves CMC joint motion and so as adduction. Abduction of the thumb is measured by placing the stationary arm of goniometer on the second MC and the movable arm on the first MC. However, according to de Kraker et al. [12] pollexograph-thumb, pollexograph-metacarpal, and the Inter Metacarpal Distance measurements are the most reliable measurement methods for palmar abduction of the thumb in adults; these measurements are also found to be reliable in children [13]. In adduction, the thumb lies adjacent to the long axis of radius and beside the second MC.

Opposition of the thumb involves multiple thumb movements which are flexion, rotation, and abduction. In order to elicit exact opposition, the thumb should move to abduction first; otherwise, it would be just flexion. Measurement is done by measuring the distance between the tip of the fifth finger and the tip of thumb in opposed position [11] (Fig. 2.10).

Neurologic Examination

Muscle Strength Evaluation

Motor function evaluation of the hand is important and necessary especially in muscle/tendon injury and peripheral or central nerve lesions. In order to make a thorough motor examination of the muscle or muscle group, compensatory movements which can compromise the functions of the muscles being examined should be avoided. For example, failure of dorsal interossei muscle function can be masked by function of finger extensors if the test is done with MCP joints in hyperextension. Muscle strength is evaluated according to muscle strength scale of Medical Research Council [14] (Table 2.1).

Table 2.1 Medical research council (MRC) scale for muscle strength

The patient's effort is graded on a scale of 0–5:
• Grade 5: Muscle contracts normally against full resistance
• Grade 4: Muscle strength is reduced, but muscle contraction can still move joint against resistance
• Grade 3: Muscle strength is further reduced such that the joint can be moved only against gravity with the examiner's resistance completely removed. As an example, the elbow can be moved from full extension to full flexion starting with the arm hanging down at the side
• Grade 2: Muscle can move only if the resistance of gravity is removed. As an example, the elbow can be fully flexed only if the arm is maintained in a horizontal plane
• Grade 1: Only a trace or flicker of movement is seen or felt in the muscle, or fasciculations are observed in the muscle
• Grade 0: No movement is observed

Wrist Extension

Wrist extensors consist of extensor carpi radialis longus (radial nerve, C6–C7), extensor carpi radialis brevis, and extensor carpi ulnaris (radial nerve, C7). These are the primary extensors of the wrist. However, extensor digitorum superficialis, extensor digiti minimi, and extensor indicis proprius also contribute to wrist extension. In order to rule out the contribution of secondary extensors of the wrist, the forearm is stabilized with the other hand, and the patient is instructed to make a fist. Then force is applied and the patient is instructed to extend the wrist against resistance.

Wrist Flexion

Primary flexors of the wrist are flexor carpi radialis (median nerve, C6–C8) and flexor carpi ulnaris (ulnar nerve, C8–T1). Flexor carpi ulnaris is the strongest wrist flexor. Flexor pollicis longus, palmaris longus, and deep and superficial finger flexors also contribute to wrist flexion as secondary flexors. In order to rule out the effect of secondary flexors, hand is clenched in fisted position again. After stabilizing the forearm the patient is instructed to flex the wrist against resistance.

Ulnar Deviation of the Wrist

Ulnar deviation of the wrist is accomplished by flexor carpi ulnaris (ulnar nerve, C8–T1). In order to evaluate ulnar deviation of the wrist, again the forearm is stabilized, and the patient is instructed to move his/her wrist to ulnar deviation against resistance.

Radial Deviation of the Wrist

Flexor carpi radialis (median nerve, C6–C8) is the primary muscle for radial deviation. Radial deviation examination technique is similar with that of ulnar deviation except that the wrist is moved towards the radius.

Finger Extension

Extensors of the fingers are extensor digitorum communis (radial nerve, C7–C8), extensor indicis proprius (radial nerve, C7–C8), and extensor digiti minimi (radial nerve, C7). In order to evaluate the function of primary finger extensors in isolation, the wrist and MCP joint should be in neutral position; proximal and distal interphalangeal joints should be in flexed position. If PIP and DIP joints are kept in extension, intrinsic muscles of the hand also contribute to finger extension. Extension of PIP and DIP joints can be tested by a flicking movement of the fingers.

Finger Flexion

Finger flexors are flexor digitorum superficialis (median nerve, C7–C8), flexor digitorum pro-

fundus (ulnar part of ulnar nerve, C8–T1; radial part of median nerve, C7–C8), and lumbricalis. Flexor digitorum superficialis muscle primarily flexes the PIP joint; flexor digitorum profundus primarily flexes the DIP joint, and lumbricalis primarily flexes the MCP joint. Total flexor strength of the fingers is tested by interlocking the fingers with the fingers of the patient in flexed position. Strength of each finger flexor should be tested separately in order to make the differential diagnosis. Tendon of the flexor digitorum superficialis inserts to the base of the middle phalanx. This is why in order to test the strength and function of this muscle in isolation, all of the fingers of the patient are held in extension except the finger to be tested. Then the patient is instructed to flex the PIP joint against resistance, while MCP is in neutral position and DIP is in extension. Tendon of the flexor digitorum profundus inserts to the base of the distal phalanx. In order to test its function, the patient is instructed to flex the DIP joint against resistance after stabilizing the PIP joint of the same finger in extension.

Finger Abduction

Primary abductors of the fingers are dorsal interossei muscles (ulnar nerve, C8–T1) and abductor digiti minimi muscle (ulnar nerve, C8–T1). Extensor digitorum communis also contributes to abduction when the fingers are in extension. Strength of abduction of the fingers can be evaluated in two different ways. First, after the patient is instructed to abduct all the fingers simultaneously, force is applied to the second and fifth finger, and the patient is asked to resist the force applied. Secondly, the third finger can be tested in isolation by applying force against abduction (Fig. 2.11).

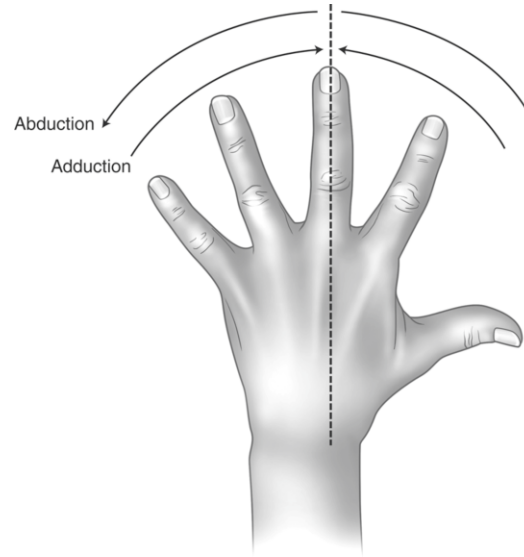

Fig. 2.11 Finger abduction strength can be tested by isolating the third finger and applying force against abduction

Finger Adduction

Primary finger adductors are palmar interossei muscles (ulnar nerve C8–T1). Finger flexors contribute to adduction when fingers are flexed. In order to evaluate the function of finger adductors, you can try to separate extended and adducted fingers of the patient, testing two adjacent fingers simultaneously or you can apply the "paper test." The patient is instructed to hold a paper tightly between the extended and adducted fingers, then try to pull the paper. If there is weakness of interossei muscles, the patient will not be able to resist or even not be able to hold the paper between the fingers. Always check the strength of the other hand for comparison.

Motor Functions of the Thumb

Thumb Extension

Extensors of the thumb are extensor pollicis longus (radial nerve, C7) and extensor pollicis brevis (radial nerve, C7). Extensor pollicis brevis inserts to the base of the proximal phalanx and extends the proximal phalanx; extensor pollicis longus inserts to the base of the distal phalanx, and its contraction extends the distal phalanx. Thumb extension is the movement of the thumb away from second MC across the plane of the palm. Extensor muscle strength of the thumb is evaluated by extending the thumb of the patient against resistance.

Thumb Flexion

Flexors of the thumb are flexor pollicis longus (median nerve, C8–T1) and flexor pollicis brevis

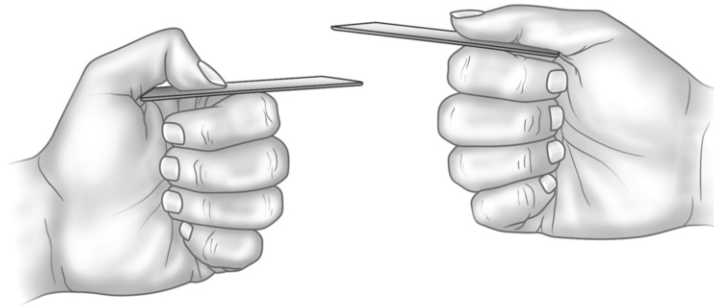

Fig. 2.12 Froment's sign. If there is weakness in adductor pollicis, flexors of the thumb will aid holding the paper, and flexion of distal phalanx will be observed

(deep part of ulnar nerve, C8; superficial part of median nerve, C6–C7). Flexor pollicis longus inserts to the base of the distal phalanx and flexes the distal phalanx; flexor pollicis brevis inserts to the base of the proximal phalanx and flexes the proximal phalanx. Flexion of the thumb is the movement of the thumb towards the fifth finger in the plane of the palm. Flexion function is evaluated by applying force to the thumb in flexed position.

Thumb Abduction

Abduction of the thumb is achieved by abductor pollicis longus (radial nerve, C7) and abductor pollicis brevis (median nerve, C6–C7). Abduction of the thumb is the movement of the thumb perpendicular to the palm and evaluated by abducting the patient's thumb against resistance. If there is a weakness of abductor muscles, especially of abductor pollicis brevis, the patient will not be able to bring the web space between the first and second fingers in contact with when holding a bottle, and there will be a gap between the web space and the bottle. This sign is called as "Lüthy bottle sign" [3].

Thumb Adduction

There is a single adductor of the thumb which is adductor pollicis (ulnar nerve, C8). Adductor pollicis consists of two heads which are oblique and transverse heads. In order to evaluate adduction of the thumb, the patient is instructed to hold a paper between the ulnar side of the thumb and radial side of the second finger in extended position against resistance. If there is weakness in adductor pollicis, flexors of the thumb will aid holding the paper, and flexion of distal phalanx will be observed. This sign is called as "Froment's sign" (Fig. 2.12).

Opposition of the Thumb and Little Finger

Opposition is the function of both the thumb (opponens pollicis: median nerve, C6–C7) and the little finger (opponens digiti minimi: ulnar nerve, C8). Opposition involves abduction, flexion, and rotation of the thumb [15]. Force is applied to each of the opposing fingers using both hands in order to evaluate the function. If there is weakness of opponens pollicis, the thumb will be easily separated from the pulp of the little finger.

Pinch Function of the Thumb

Pulp to pulp pinch is achieved by the contraction of flexor pollicis longus and second flexor digitorum profundus. If these muscles have normal function, the patient will be able to form an "O" shape with the thumb and second finger. If there is weakness of these muscles (anterior interosseous nerve syndrome), distal phalanx of the thumb and second finger will not be able to flex and remain in extension, and the patient will not be able to form an "O" (Fig. 2.13).

Pinch and Grip Strength

There are actually three different types of pinch:

- Lateral or key pinch
- Tip-to-tip pinch
- Three-fingered pinch or three-point chuck

Lateral pinch is the strongest type of pinch followed by three-point pinch. Tip-to-tip pinch is used for more sophisticated processes requiring fine coordination. Pinch function of the hand is tested with a pinchmeter. Average of three trials is recorded (Figs. 2.14 and 2.15).

There are several devices to measure gross grip strength.

Jamar dynamometer developed by Bechtol [16] has been shown to be a reliable test providing that the calibration is maintained [17, 18]. The dynamometer has five adjustable spacings which are 1, $1^{1/2}$, 2, $2^{1/2}$, and 3 in.. Measurement is taken from all of these spacings after the patient is instructed to grasp the dynamometer with maximum strength. Three measurements are taken, and the mean value of these three trials is recorded. Usual grip strength makes a bell-shaped curve, being the middle spacings the stronger and weakest at each ends. Both right and left hands are evaluated. There is usually 5–10 % difference between the dominant and nondominant hand, usually the dominant hand being the stronger (Fig. 2.16).

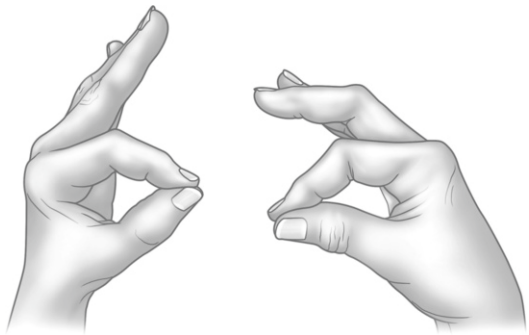

Fig. 2.13 Pinch function of the thumb. If there is weakness of flexor pollicis longus or second flexor digitorum profundus, the patient will not be able to form an "O"

Sensory Function Evaluation

Sensory innervation of the upper extremity follows spinal nerve roots, plexus, and peripheral nerves. If the lesion is not central in origin, sensory deficits also follow the innervation pattern of the peripheral nerves. Evaluation of sensory function of the upper extremity is usually limited to light touch and pain sensation. Evaluation of the other sensory functions is usually unnecessary and useless. There are several instruments available to test two-point discrimination, but sensitivity and reliability of these instruments are low when applied in the hand. Light touch sensation is examined with a cotton swab or with the tip of the finger. Variations of sensorial nerve supply on the overlapping dermatomal areas should also be taken into consideration.

Sensory innervation of the hand is mainly supplied by three peripheral nerves which are radial nerve, median nerve, and ulnar nerve (Fig. 2.17).

Radial nerve innervates only the dorsal part of the hand and fingers. Its innervation area involves two and a half finger of the dorsum of the hand (thumb, index, and radial half of the

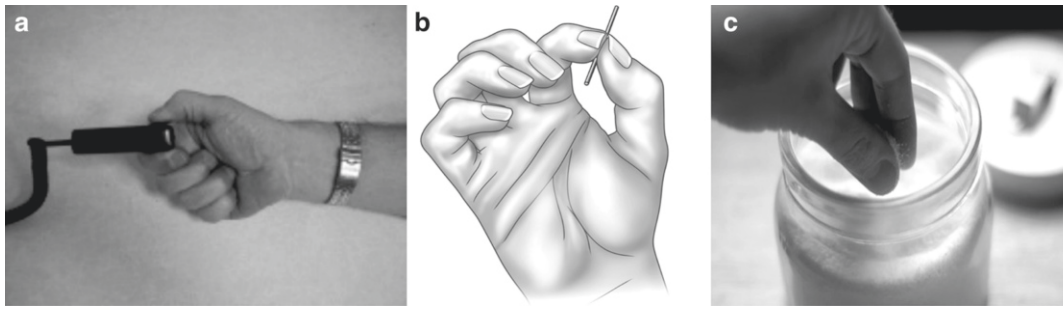

Fig. 2.14 (**a**) Lateral pinch, (**b**) tip-to-tip pinch, and (**c**) three-point pinch (Received from the http://www.simwork.com/products/sapphire/images/LateralPinch200x150.jpg, http://web.student.tuwien.ac.at/~e0227312/images_grasps/i_24_1, http://www.apartmenttherapy.com/uimages/kitchen/2009-07-16-ThreeFingerPinch.jpg, web sites in 15.10.2010)

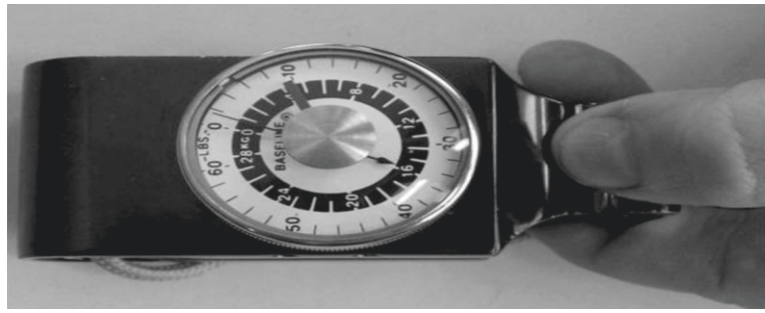

Fig. 2.15 Pinchmeter (Received from the http://www.griprepair.com/images/baseline_pinchmeter.jpg web site in 15.10.2010)

Fig. 2.16 Jamar dynamometer (Received from the http://www.bpp2.com/Merchant2/graphics/00000001/2006CAT/2006CATP50/ JAMAR_HAND_DYNA_L.jpg web site in 15.10.2010)

middle finger) up to distal phalanges and radial side of the dorsum of the hand.

The ulnar nerve innervates the palmar side of one and a half finger (little finger and ulnar half of the ring finger) and dorsal side of two and a half finger (little finger, ring finger, and ulnar half of the middle finger) and adjacent skin area of the hand.

The median nerve innervates the palmar side of three and a half finger (thumb, index finger, middle finger, and radial half of the ring finger) and adjacent skin area and dorsal side of the distal phalanges of the index and middle finger.

There are several tests available to assess sensibility and dexterity of the hand:

- Semmes-Weinstein filament test
- Moberg's pick-up test [19],
- Seddon's coin test, the moving two-point discrimination test described by Dellon, and Weber's two-point discrimination test.

But reliability of all these tests still remains controversial because volitional participation of the patient is required. As a result these are rather subjective tests than being objective.

Semmes-Weinstein monofilaments are shown to produce consistently repeatable forces from set to set and from examiner to examiner, and it is possible to control the amount of force applied [15, 20]. Thus, these monofilaments prove the most sensitive and reliable data among all other clinical sensibility assessment instruments [8, 20, 21]. Originally, there are 20 monofilaments, but now there is also a 5-filament mini set available for practical use. Using Semmes-Weinstein monofilaments, the normal touch threshold is approximately 4.86 g/mm^2.

Evaluation of Vascular Supply of the Hand

Ulnar and radial arteries are vascular supply of the hand. *Allen's test* is a simple test to evaluate vascular supply of the hand and it is easy to apply. Allen first described this test in 1929, but did not mention a time period that the test will be considered

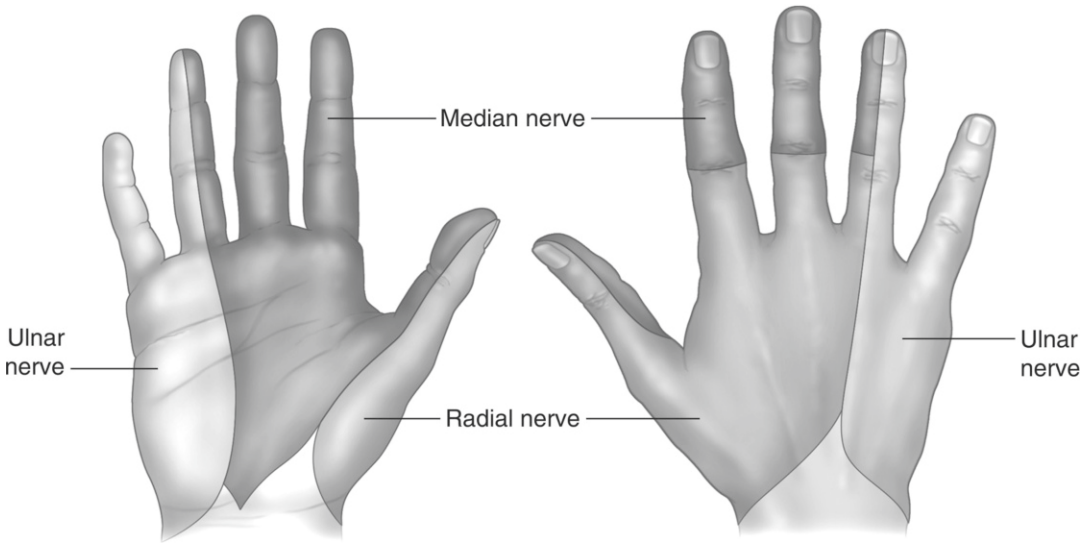

Fig. 2.17 Sensory innervation of the hand

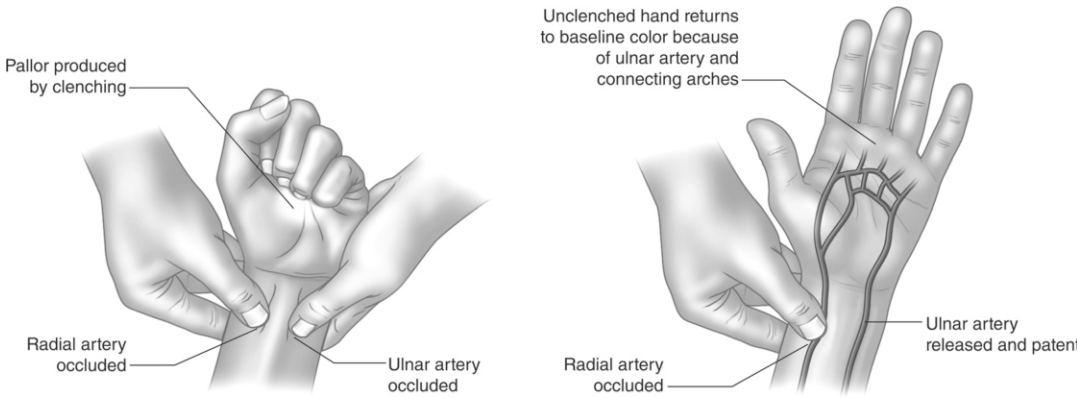

Fig. 2.18 Classical Allen's test

as positive. In time, various time periods are mentioned from 5 to 15 s. Classic Allen's test is applied by compressing the patient's ulnar and radial arteries using the thumb, index, and middle finger of each hand. Then the patient is instructed to open and close his fist in order to drain venous blood of the hand. After repeating it several times, the patient is instructed to open his fist, and it will be observed that the hand becomes pale. Then the compression on one of the arteries is removed, and the hand is observed if it becomes pink again. The same process is repeated for the other artery. If one of the arterial supplies is occluded or somehow disrupted partially or totally, the hand will remain pale or will gain its color slower than expected after removing the compression. Allen's test should be applied to both of the hands in order to make comparison. If the hand does not become pale, the presence of a variant artery should be considered. In 2007 a new version of Allen's test is described [22]. This test is applied by compressing radial and ulnar arteries with three digits using both hands. Then the patient is instructed to clench and unclench the hand ten times and then to open the palm. After that the ulnar or radial artery is released, and flushing is observed. If flushing delays more than 6 s, the test is considered to be positive (Figs. 2.18 and 2.19).

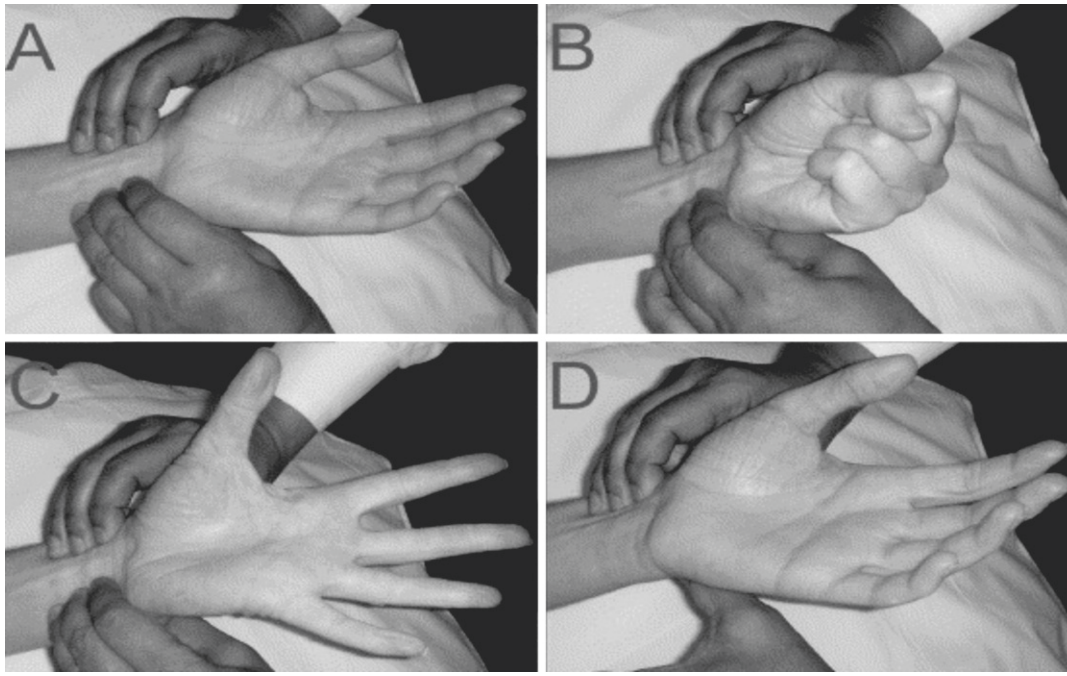

Fig. 2.19 Modified Allen's test. Reprinted from The Annals of Thoracic Surgery, 84, Mohammed Asif, Pradip K. Sarkar, Three-Digit Allen's Test, 686–7, Copyright (2007), with permission from Elsevier

Specific Tests

Carpal Tunnel Syndrome: Tinel's Sign

This is one of the tests applied if the patient is suspected to have carpal tunnel syndrome which is characterized by compression of the median nerve in the carpal tunnel. The test is considered to be positive if the patient feels paresthesia with tapping on the median nerve where it is suspected to be compressed. However, this test can be false negative in the presence of chronic nerve compression or severe reduction in nerve conduction.

Carpal Tunnel Syndrome: Phalen's Test

This is another test used to evaluate carpal tunnel syndrome. Here, the patient is instructed to maximally flex or extend his wrist and wait for a few minutes in that position. The test is considered to be positive if the patient feels paresthesia after several minutes of sustained position. Both Tinel's sign and Phalen's test with the history are 80 % diagnostic for carpal tunnel syndrome. Electrodiagnostics are ancillary tools for confirming the diagnosis [2] (Fig. 2.20).

Wartenberg's Syndrome: Tinel's Sign

Wartenberg's syndrome is the compression of the superficial branch of the radial nerve in the distal portion of the brachioradialis tendon. Test is considered to be positive if the patient feels paresthesia with tapping the nerve in the distal portion of the brachioradialis muscle (Fig. 2.21).

Proximal and Distal Ulnar Nerve Compression Syndrome: Tinel's Sign

Ulnar nerve can be compressed either proximally at the level of medial epicondyle or distally in the Guyon's canal. Tinel's test can be applied for both of these locations. Also, scratch collapse test is a sensitive test that localizes Osborne's Band in cubital tunnel syndrome [23].

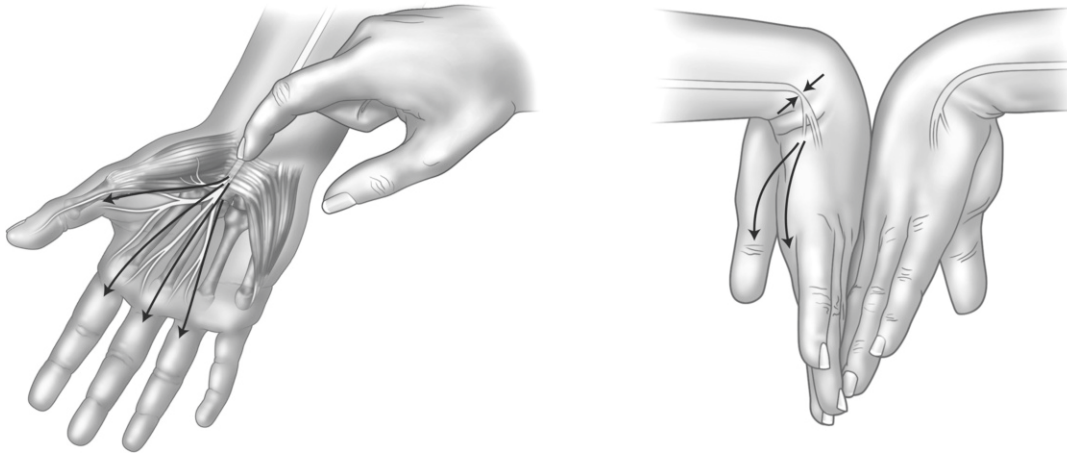

Fig. 2.20 Tests applied in carpal tunnel syndrome. Tinel's test is illustrated on the *left*, and Phalen's test is illustrated on the *right* (Received from the http://www.healthtopicsbysusan.com/?p=48 web site in 15.10.2010)

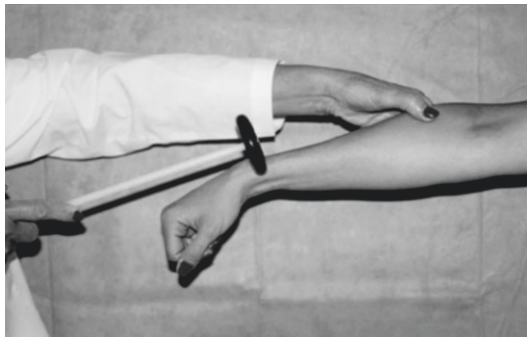

Fig. 2.21 Tinel's test in the Wartenberg's syndrome (Received from the http://img.medscape.com/fullsize/migrated/408/540/mos5854.01.fig6.jpg web site in 15.10.2010)

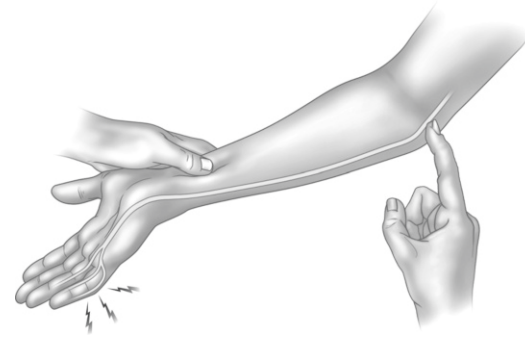

Fig. 2.22 Ulnar nerve compression test: Tinel's test

Distal branch of the ulnar nerve can be compressed in the Guyon's canal. Because the ulnar nerve has only motor fibers in this region, clinical outcome will be only motor paresis without loss of sensation (Fig. 2.22).

Finkelstein Test

This test is used to demonstrate De Quervain's tendinitis which is the stenosing tenosynovitis of the first dorsal compartment of the hand. The patient is instructed to adduct his thumb towards the little finger. Then, the other fingers are flexed covering the adducted thumb. Next, the patient's hand is moved towards ulnar deviation. The test is considered to be positive if the patient feels pain when the wrist is moved to ulnar deviation (Fig. 2.23).

Summary

Thorough physical examination of the hand is crucial in the assessment of hand functions. In this chapter, physical examination of the hand including general inspection, palpation, range of motion assessment of each joint, neurologic

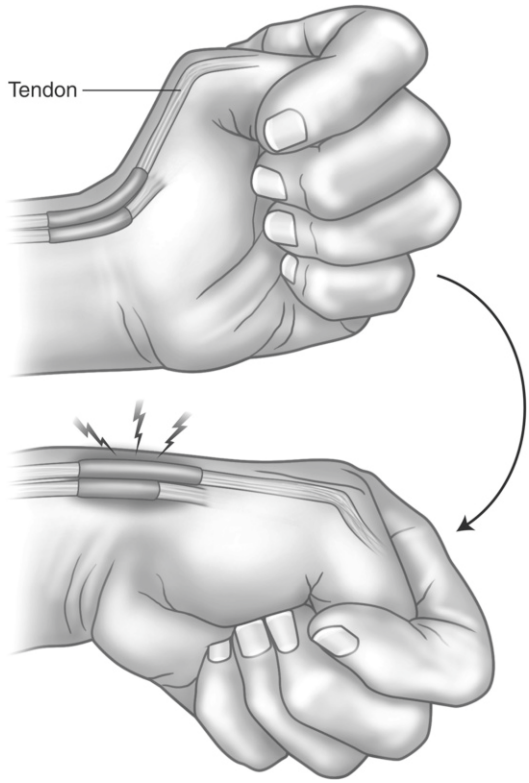

Fig. 2.23 Finkelstein's test applied in the stenosing tenosynovitis of the first dorsal compartment of the hand

examination, specific tests for the common hand pathologies, and evaluation of the hand's vascular supply are reviewed in details.

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Assessment of Hand Functions

3

Mehmet Tuncay Duruöz

The hand is one of the most fascinating and sophisticated biological instrument which plays a very important role in our lives. We use our hands alone or in combination in a wide variety of ways: touching, grasping, feeling, holding, manipulating, and caressing, and sometimes we use it even for communication. Hands can perform extremely gentle, skillful, and precise activities such as painting a picture, making an embroidery, or playing a violin, and our hands also enable to perform heavy labor, such as carrying heavy objects or digging with a shovel. For centuries, outcome evaluation in medicine was limited to the evaluation of the only physiological consequences of the disease. In last decades, the societies growing expectations are mostly have a life without disability and handicap. Because the hand involve very deeply our lives in daily activities, its functional status have become increasingly important to determine the quality of life [1–3].

The hand function may be defined basically as the capacity to use the hand in everyday activities depending on the anatomical integrity, sensation, coordination, strength, and dexterity. We may consider wrist as a functional part of the hand because they are the complementary structures and the most of their functions affect each other.

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The evaluation of hand function is of critical importance in determining the extent of functional loss in patients with many rheumatic and neurologic diseases and traumatic injuries and in assessing the outcome of some surgical and rehabilitative procedures. Thus the clinical assessment of hand function remains complex and controversial. The physicians are mostly interested in reducing pain (impairment), maintaining or improving the ability to perform activities of daily living (disability), and maintaining or improving independence (handicap) [2, 4].

In the last century, an important scientific debate took place on diseases and their consequences, and it generated various conceptual models. The aim of these models was the description of the relationship between pathology and functional consequences. Two models are accepted internationally and have been used commonly which are the International Classification of Impairments, Disabilities, and Handicaps (ICIDH) and International Classification of Functioning, Disability, and Health (ICF).

The ICIDH was the first internationally shared conceptual formulation, and it was the first internationally known system to classify the consequences of diseases [5]. This model was aimed at analyzing, describing, and classifying three different consequences of diseases: impairments (any loss or abnormality of psychological, physiological, or anatomical structure or function), disabilities (any restriction or lack, resulting from an impairment, of ability to perform an activity in the manner or within the range considered normal

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for a human being), and handicaps (a disadvantage for a given individual, resulting from an impairment or a disability). These three different levels in the consequences of pathology are related to different levels of experience and of individual awareness.

Impairment in arthritis is reflected by pain and restriction in the range of movement of joints, whereas disability is expressed by difficulty or inability in performance of daily living activities [6].

ICF offers a useful model of functioning and disability [7]. ICF represents a revision of the ICIDH. The ICF model provides a multiperspective approach to the classification of functioning and disability as an interactive and evolutionary process. A person's functioning and disability are conceived as a dynamic interaction between health conditions (disease, disorders, injuries, traumas, etc.) and contextual factors (environmental and personal). The relationship between the three domains is influenced by contextual factors representing the complete background of an individual's life, including environmental and personal factors.

The ICF model of functioning and disability underscores the importance of interactions between all components of health (physiological, psychological, anatomical, activity or participation related, personal, and/or environmental). Understanding the influence of health components in totality, rather than in isolation, is particularly important when evaluating function. The ICF categories of Duruöz Hand Index (DHI) are as below [8]:

d170 Writing (two questions)
d4300 Lifting (one question)
d4308 Lifting and carrying, other specified (two questions)
d4400 Picking up (one question)
d4402 Manipulating (two questions)
d4453 Turning or twisting the hands or the arms (four questions)
d4458 Hand and arm use, other specified (one question)
d50201 Caring for teeth (one question)
d550 Eating (two questions)
d560 Drinking (one question)
d6300 Preparing simple meals (one question)

Functional Components of the Hand

Hand has some main motor functions, and it uses the harmonization of these functions to realize daily activities. Many factors support these motor functions such as sensory processes for coordination; visual properties that can affect hand function include decreased acuity, accommodation, eye–hand coordination, depth perception, etc. [9, 10]. Because hand is the extension of the upper extremity, their disorders affect directly the hand function. Age, gender, and motivation of the individual to complete specific tasks also influence the hand function level.

The full hand grip and pinch are the main functions of the hand. The hand has already nonprehension and bilateral prehension functions. They are basic functions, but they could be performed if the fingers were amputated. Patients with various hand problems, such as wrist limitations, ruptured extensor tendons, and MCP subluxation, frequently report difficulty or inability in performing nonprehension tasks.

Grip (Prehension)

The grip function of the hand is of great importance in professional and daily life activities. There are four main items to classify and assess the grip. Daily activities are generally the combinations of these different types of grips.

1. *Pinch grip*. It is the holding of objects between the thumb and fingers of a single hand. The tip pinch between thumb and finger tip is used for fine manipulation (Fig. 3.1). Tri-digit pinch (Chuck pinch) increases the stability by utilizing two fingertips instead of one (Figs. 3.2 and 3.3). Lateral (key) pinch is stronger because the pressure of the thumb is resisted by fingers (Fig. 3.4).

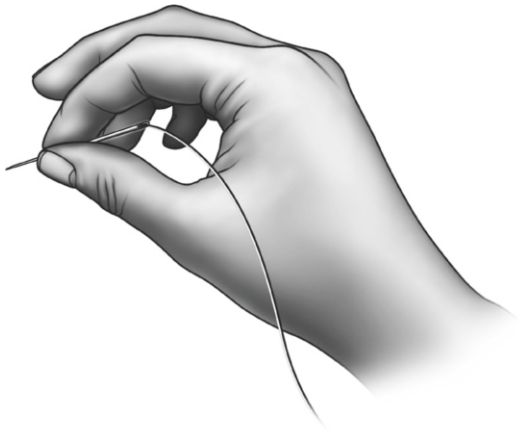

Fig. 3.1 Tip pinch: Holding object (*needle*) between the thumb and second finger's tips

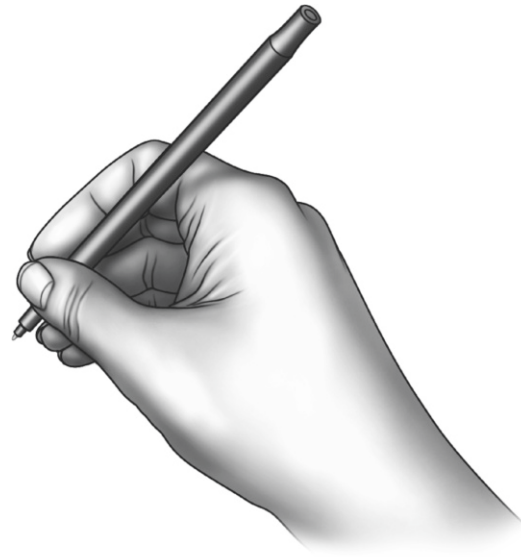

Fig. 3.3 Chuck pinch: Holding pencil with first three finger tips of dominant hand. Precision and dexterity are needed

Fig. 3.4 Lateral pinch: Holding key between lateral edge of second finger and tip of thumb

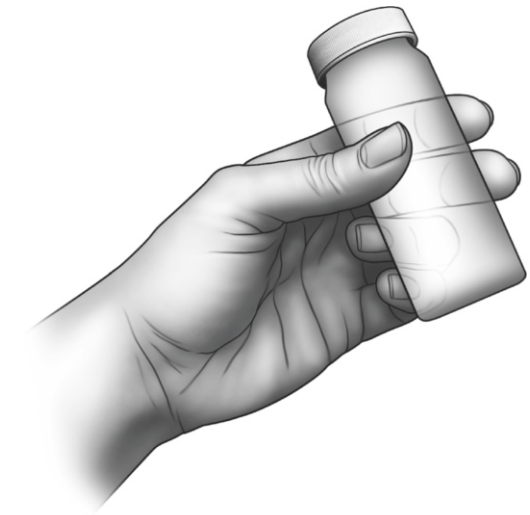

Fig. 3.2 Chuck pinch: Holding object between the thumb and second and third fingers' tips

Fig. 3.5 Full hand grip: Cylindrical grip of thick stick needs gross grasp with power

2. *Full hand grip* (*grasp*). The holding of an object with palm forms of four fingers and the thumb. This includes all of the typical grasps: palmar, power, cylinder, and spheric (Figs. 3.5, 3.6, 3.7, 3.8, and 3.9).
3. *Nonprehension*. Use of the hand as a base for the application of upper extremity strength such as hook grip and use of the extended hand to push objects (Fig. 3.10). Use of the fingers to apply pressure such as in patting soil around a plant (Fig. 3.11). Activities for precision

Fig. 3.6 Full hand grip: Holding glass with thumb and the other four fingers' distal part

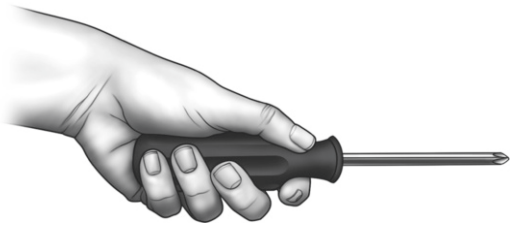

Fig. 3.7 Full hand grip: Oblique grip of screwdriver. It is a variant of cylindrical grip and grip across rectangular surface

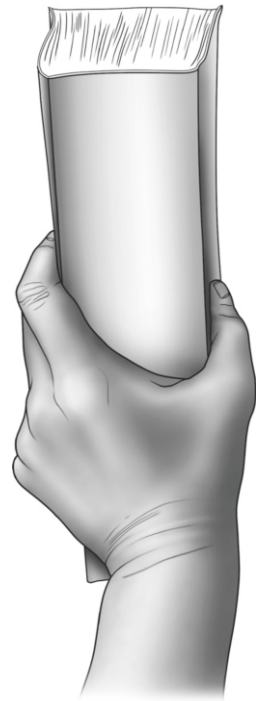

Fig. 3.8 Full hand grip: Grip of book with all palmar surfaces of fingers and the thumb at plain finger position

Fig. 3.9 Full hand grip: A spherical grip has thumb and all fingers abducted around an object (*small ball*) and the fingers are more spread apart than in a cylindrical grip

sorting motions such as sorting coins and dialing a telephone using fingertips (Fig. 3.12). Other nonprehension activities are using of the heel of the hand or the ulnar edge of the palm to apply pressure.

4. *Bilateral prehension*. This is the holding of objects between the palmar surfaces of both hands as in unilateral nonprehension (Fig. 3.13).

A loss in grip strength is associated with a number of different neurological and musculoskeletal conditions, and so an assessment of hand grip strength is generally included in hand evaluations as a test of gross motor power [11–13]. Several large-scale studies have provided comprehensive normative data on the grip strength of healthy children [14] and adults [15]. The peak forces generated with the three-digit and lateral pinch grips are about 40 % greater than that produced with the tip pinch [15].

Many factors may affect the force of grip strength. Some studies have indicated the importance of considering the sex, age, and hand

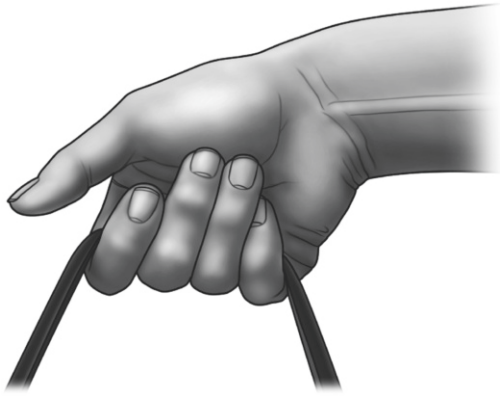

Fig. 3.10 Hook prehension is a kind of nonprehensive function of the hand. The hand is flat with curled fingers that support load and thumb as stabilizer

Fig. 3.11 Nonprehensive function: Patting soil around plant with palmar surface of first four fingers at straight position

Fig. 3.12 Nonprehensive function: Dialing telephone with the tip of the finger of a single hand

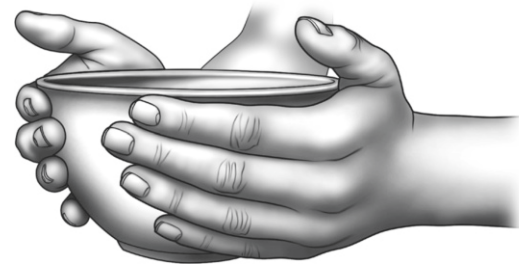

Fig. 3.13 Bimanual prehension is the holding of objects between the palmar surfaces of both hands. It is especially used to hold objects too heavy or too large to hold with a single hand

preference of the individual when interpreting grip strength data in clinical populations. They have also shown that although height and weight are positively correlated with grip strength [16, 17], the influence of these variables is considerably smaller than that of either sex or age. The average grip strength of women is approximately 60 % that of men, and for both sexes grip strength reaches a maximum during the fourth decade of life and declines thereafter with increasing age [15, 18, 19]. Cold has been shown to reduce the force of muscle contraction and reduce the grip function of the hand [20].

The 10 % rule states that the dominant hand possesses a 10 % greater grip strength than the nondominant hand for right-handed persons only; for left-handed persons, grip strength should be considered equivalent in both hands [21]. Differences between the hands in strength must therefore be interpreted with caution if disability or loss of function is defined in terms of such a discrepancy.

Although grip strength is one aspect of hand function which can be objectively and accurately measured, it may bear little relationship to the patient's actual hand function. Clinical experience suggests that some patients with deformed hands and poor grip strength (or high levels of impairment) are able to perform a wide range of hand functions (have low levels of disability). Although the link between grip strength and subjective measures of hand function based on assessment questionnaires has been established,

the relationship between objective measures of disability and impairment is not clear [2, 22].

Grip strength assessment is frequently used in clinical trials and has been shown to be a sensitive indicator of disease activity. Grip strength is a composite measure and may be influenced by dysfunction in muscles, tendons, and any of the small joints of the hand and wrist [23].

McPhee pointed out that most description of hand grip functions categorized static patterns and they have limited value, because they fail to consider the dynamic aspects of hand use [4].

The daily activities of the hand may be classified in three main functional groups according to the factor analysis of a study of Duruöz et al. [2]. The first group activities require force and rotation (e.g., unscrewing the jar lid). The second group activities require dexterity and precision (e.g., peeling fruits). The third factor was dynamic activities, primarily based on pinching and performed with the first two or three fingers of the dominant hand (e.g., writing with a pencil).

Dexterity

Dexterity must be evaluated because of its bearing on upper limb performance and on individual functional independence [24]. Dexterity has been defined by Poirier [25] as "a manual skill requiring rapid coordination of fine and gross movements based on a certain number of capacities developed through learning, training and experience." Speed and precision are the criteria used to measure this skill, and the tests require high-level hand–eye coordination as well as fine motor control of the hand. There are two main dexterities: finger dexterity and manual dexterity.

Finger dexterity is defined as the ability to make rapid, skillful, controlled, manipulative movements of small objects in which the fingers are primarily involved. Purdue Pegboard Tests [26] assess especially finger dexterity (Fig. 3.14).

Manual dexterity is defined as the ability to make skillful, controlled, arm–hand manipulations of larger objects under speed conditions. The Box and Block Test [15] measures are an example for unilateral gross manual dexterity.

Fig. 3.14 Assessment of dexterity and coordination of hands with Purdue Pegboard

There are several accepted methods for testing dexterity. The Purdue Pegboard is one of the most widely used test in which subjects must grasp and lift small pegs and insert them into small holes in a board [26]. The Grooved Pegboard is one of the practical and valid tests where the pegs are key shaped and finer manipulation is required to match the peg with its hole [27].

The Nine-Hole Pegboard Test measures the time that is required for a subject to place and remove nine pegs in a hole on pegboard. Each hand is tested separately [15, 28].

The Box and Block Test has two-compartment box and 150 cubes. The subject grasped one block with a dominant hand firstly and transported the cube into opposite compartment. The subject is stopped after 1 min, and the expert counts the transported cubes. The test is then repeated with the nondominant hand [15].

Assessment Methods

A functional hand assessment determines functional ability, that is, how does a patient use his or her hand in spite of limitation and functional disability. Accurate assessment of hand function is important for evaluating treatment and progress of disease and also for establishing strategies to maximize functional potential and promote well-being. The clinical assessment of "function" has generally focused on range of motion (ROM),

grip or pinch strength (impairment), and subjective assessment of activities of daily living (disability). The dexterity and coordination performance of the hand may be evaluated either with some pegboards or with some daily activities which need dexterity [22]. Although we may assess handicap with a valid scale and Visual Analog Scale (VAS-handicap) [2] we do not assess it in clinical practice routinely.

The ROM and strength assessment provide some information, but they do not demonstrate how the patient can use muscular substitutions and adaptive methods to perform a functional task (Fig. 3.15). In fact, there is often very little direct correlation between hand ROM and the patient's ability to perform functional activities. *Impairment*, *disability*, and *handicap* are complementary aspects of function, and we have to assess all three domains separately to have a complete information about hand function in patients with hand involvement. The functional disability of the patient when we assess it without using assistive device is called as "absolute functional disability" by Duruöz [2].

To measure the joint ROM with the goniometer is placed in clinical practice at the first decades of 20th century. The instrumentation has become very sophisticated, including computerized goniometers, three-dimensional electrogoniometers, and video-based motion analysis systems [29]. There are already observational ROM evaluation tests such as SOFI [30]. It consists of four items: grip a plastic tube (larger tube for men), bend fingers around a pencil, make a round pincer grip, and oppose the tip of the thumb to the base of the fifth finger.

Grip and pinch strengths can be measured with a dynamometer (JAMAR) or a sphygmomanometer [31]. To assess the grip strength, the arm should be unsupported and the elbow held at 90° to eliminate extraneous influence on the recording (Figs. 3.16 and 3.17).

In last decades, there has been a shift toward an evaluation of hand-related function in daily living activities, and several tools for the assessment of disability have been introduced. DHI; Michigan

Fig. 3.15 Assessment of range of motion of finger joints with hand goniometer

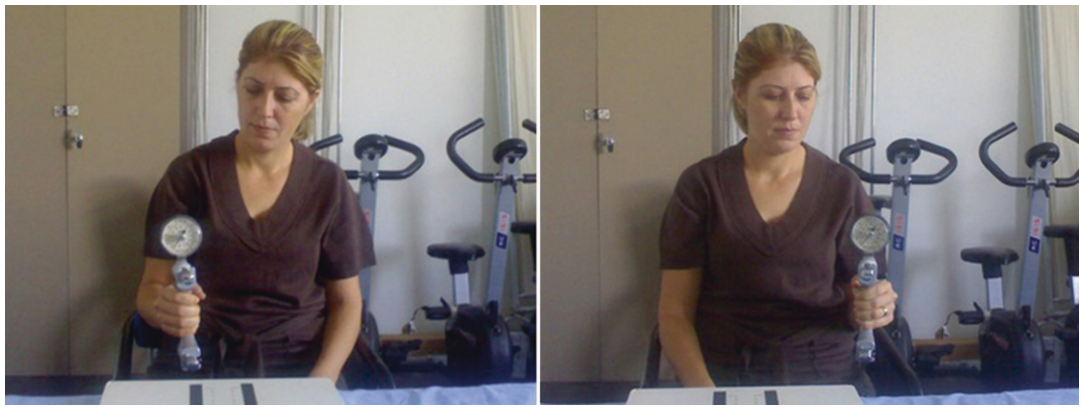

Fig. 3.16 Assessment of grip strength with Jamar dynamometer

Fig. 3.17 Assessment of pinch strengths with Jamar pinchmeter

Hand Outcome Questionnaire (MHQ); Disability of the Arm, Shoulder, and Hand Index (DASH); Arthritis Hand Function Test (AHFT); Australian/Canadian (AUSCAN) Osteoarthritis Hand Index; and ABILHAND manual ability measure (ABILHAND) are some of the most widely used scales in clinical practices [2, 32–36].

The DHI [2] is a questionnaire that was developed to assess functional disability and functional handicap caused by rheumatoid hand. It was validated in other arthropathies of hand such as osteoarthritis, scleroderma, stroke, diabetes mellitus, hemodialysis, psoriasis, and flexor tendon ruptures and was translated into 11 languages. The scale is based on 18 questions concerning activities commonly performed by the hand in a person's daily environment. Each question's scores are summed for the total score, and higher scores indicate the most disability (Appendix of the Book).

The MHQ has a total 37 kinds of questions to assess right and left hands. The pain and the work performance subgroup questions are for both hands; other subgroup questions are asked for each hand separately. The subgroups are (a) overall hand functioning, (b) physical function with activity of daily living tasks, (c) work performance, (d) pain, (e) aesthetics, and (f) patient satisfaction. The six subgroup scores are summed to obtain total score. Higher scores indicate better status (Appendix of the Book) [32].

The QuickDASH has 11 questions which concern symptoms and physical function in persons with disorders involving the upper extremity. The maximum total score is 100 points which indicates the most disability (Appendix of the Book) [33].

These instruments for the assessment of disability usually are self-administered questionnaires that are more or less complex and focus on the evaluation of the hand function by the patients themselves. These questionnaires give us very important information to understand better our patients' experience and difficulties in their daily life.

The primary concern of hand functional disability questionnaires is the concept that they are subjective reflecting the subject's perception of ability rather than their actual ability [37]. Therefore, measures of functional disability are not exactly representative of physiological hand function. This is exemplified by rheumatoid patients who make coping in the way they perform ADLs despite high levels of impaired physiological joint function [38].

The handicap may be assessed by VAS-handicap (0–100 mm), and handicap may be explained as the disadvantage induced by their arthritis (or other hand involvements) in activities of everyday life.

Example: Considering your needs for everyday life, please indicate your handicap level due to the rheumatoid arthritis (*or other hand involvements*) in your hands on the line (10 cm) of the scale with putting (x) mark?

No Maximum
Handicap I_____I Handicap.

Many new techniques are ready to use the assessment of hand function such as video recording, electrogoniometers, optoelectronic and electromagnetic trackers, instrumented gloves for kinematic evaluation, dynamometers including isokinetic and isometric devices, work

simulators, and refined techniques of evaluation of dexterity and finger coordination of measurement of tactile and thermal discrimination. These systems can be enhanced by way of visual feedback [39, 40]. A haptic interface methodology is developed recently which provides objective, quantitative, and repeatable method for the assessment of the upper limb functional state especially for movement capabilities. The tests include tracking tasks to assess the accuracy of movement, to assess the patient's control abilities, to assess both speed and accuracy, and to assess the maximal force capacity of the upper extremity [41].

Which Assessment Method Is the Best?

There is no single assessment method that can be recommended for all clinics and there is no gold standard to assess the hand function because there are many variables that affect the hand function.

There are many types of functional hand assessment currently in use, ranging from simple to complex, quantitative to non-quantitative, and standardized to nonstandardized. The simple tests are better than complex ones, and it is better to use hand function test concerning the purpose of the research and the clinical assessment. The test should be valid for this purpose and for that patient group, disease, and population. If we want to assess the functional disability of rheumatoid hand, the test (scale) should include items for functional disability in hand and it should be valid to assess the rheumatoid hand in that population. The reliability and sensitivity to clinical change (or responsiveness) properties of the scales are already important.

Summary

The hand is extremely involved in our daily life because of its vital and sophisticated functional role. The hand function may be defined basically as the capacity to use the hand in everyday activities depending on the anatomical integrity, sensation, coordination, strength, and dexterity. The accurate assessment of hand function is very important for establishing strategies to maximize functional potential and evaluating treatment and progress of disease. The ICIDH and ICF are two accepted models to make description of the relationship between pathology and functional consequences of diseases. The pinch grip, full hand grip (grasp), nonprehension hand function, and bilateral prehension are four main items to classify and assess the grip. Daily activities are generally the combinations of these different types of grips. There are three main pinch functions of hand such as tip pinch, tri-digit (Chuck) pinch, and lateral (key) pinch. The dexterity (finger and manual) is a very important functional property of the hand. Speed and precision are the criteria used to measure this skill, and the tests require high-level hand–eye coordination as well as fine motor control of the hand. Impairment, disability, and handicap are complementary aspects of function, and we have to assess all three domains separately to have a complete information about hand function in patients with hand involvement. Grasp and pinch strengths can be measured with a dynamometer. There are several scales to assess the hand function. The DHI, MHQ, DASH, and AHFT are some of the most widely used scales in clinical practices. The primary concern of hand functional disability questionnaires is the patient's perception of ability. There is no single assessment method that can be recommended for all clinics, and there is no gold standard to assess the hand function. The test should be valid for the purpose of the study. The simple tests are better than complex ones, and it is better to use hand function test concerning the purpose of the research and the clinical assessment.

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Section II

Hand Function Assessment in Clinical Practice

Hand Function in Rheumatoid Arthritis

4

Janet L. Poole

Rheumatoid arthritis (RA) is a systemic, inflammatory, debilitating disease that can occur at any age. The prevalence increases with age, and the peak incidence is between the fourth and sixth decades of life [1]. Although the disease does occur in men, the frequency is nearly three times more common in women. This chronic form of polyarticular joint disease has its most prominent manifestation within the diarthrodial joints of the body. Inflammation of the synovium of the joints is a precursor in the facilitation of destruction of the tissues of the joint [2]. Following the inflammatory process, the synovium becomes hypertrophic from proliferation of blood vessels and synovial fibroblasts and from multiplication and enlargement of the synovial lining layers. The destruction of the tissues progresses when the granular tissue extends into the cartilage and develops pannus. It is this tissue that is effective in the invasion and destruction of periarticular bone and cartilage at the margin between synovium and bone [2]. The supporting structures of the joint, such as the capsule and ligaments, are also damaged in the inflammatory process. The effect on the joints in the hand may lead to the frequent occurrence of boutonnière deformities, swan-neck deformities, ulnar subluxation, and dislocation (radial deviation deformity), the latter contributing to ulnar drift of the metacarpophalangeal (MCP) joints [2]. Chronic metacarpal joint synovitis is also a cause of the ulnar drift deformity.

In the boutonnière deformity, French for buttonhole, chronic synovitis of the joint capsule and lengthening of the central slip lead to the displacement of the lateral bands over the proximal interphalangeal (PIP) joints [2]. This results in a flexion deformity of the PIP joint and hyperextension of the distal interphalangeal (DIP) joint. Slow progression of the disease can lead to a fixed contracture of the PIP joint that consequently affects grasp patterns. The deformity is considered to be the hardest of the deformities to treat conservatively because once the deformity has occurred, the supporting structures have become displaced and stretched [2]. Thus, the surrounding supportive tissues have lost their ability to maintain the integrity of the joint.

Swan-neck deformities occur secondary to synovitis at the MCP, PIP, or DIP joints [2]. In the swan-neck deformity, chronic synovitis causes the tissue of the synovial membrane to proliferate and become thicker. Thickening of the synovial membrane in the MCP joint causes a stretch in the intrinsic muscles of the hand producing a pull of the extensor mechanism. Contractures of the lumbrical and interossei muscles and the natural hypermobility of the PIP joint can lead to MCP joint flexion and hyperextension of the PIP joints [2]. It is these deformities that give the appearance of a swan, leading to

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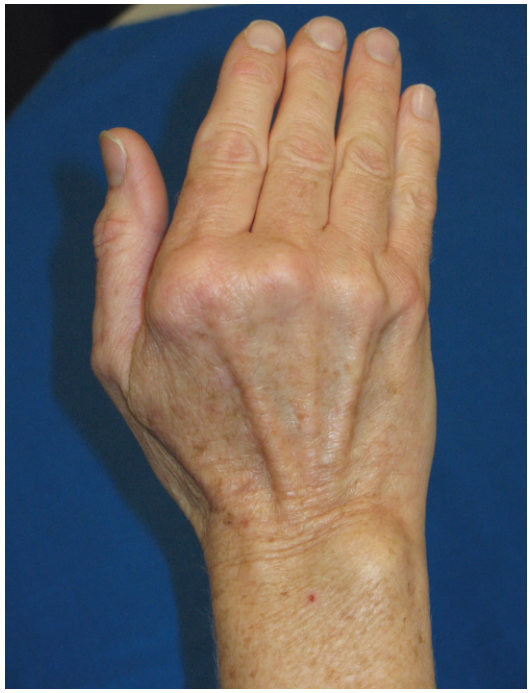

Fig. 4.1 The hand of a 50-year-old woman with a classic RA deformity pattern of radial deviation and volar subluxation of the wrist, MCP volar subluxation, and ulnar drift

its name. Oftentimes with swan-neck deformities, the individual will lose the ability to have effective pad-to-pad pinch, thus leading to the use of a lateral pinch in the manipulation of items during activities of daily living.

The ligamentous structure of the wrist is compromised in the presence of chronic synovitis that can lead to instability of the joint. Ulnar subluxation and dislocation (radial deviation deformity) occur due to the loss of the ligamentous support and fibrocartilage on the ulnar side of the wrist [2, 3]. Displacement of the carpal bones can also lead to instability of the wrist. This occurs when the proximal row of carpal bones rotates in an ulnar direction, or counterclockwise direction, and the distal row of carpal bones rotates in a radial direction, also a counterclockwise direction (Fig. 4.1). The resultant structural change is the hand radially deviating on the forearm, which often contributes to ulnar drift of the MCP joints [2, 3].

MCP ulnar drift is another common occurrence seen in RA (Fig. 4.1). In the healthy hand, ulnar deviation is already present due to the anatomical structure of the hand, i.e., shape of bones and placement and length of the collateral ligaments [2, 3]. Therefore, the ulnar drift that occurs with RA is an abnormal amount of deviation caused by synovitis at the MCP joint resulting in the weakening of the annular ligaments. In the presence of the weak ligaments, the restraining power and the anatomic alignment of the flexor tendons create a strong ulnar component for drift deformity [2, 3]. This is especially apparent during pinch and grasp when the ulnar forces increase across the MCP joint [2, 3].

Deformities of the thumb occur in RA due to the synovial hypertrophy within any of the individual thumb joints which can destroy articular cartilage and stretch collateral ligaments and joint capsules. Thumb deformities can interfere with manipulating objects because of stability in the thumb joints. The most common thumb deformity involves MCP joint flexion and distal joint hyperextension (also known as a type I or boutonniere deformity of the thumb) [4]. Synovitis of the MCP joint stretches the extensor mechanism which leads to flexion of the proximal phalanx and volar subluxation. To compensate, a person radially abducts the first metacarpal and hyperextends the distal joint. In the type II and III thumb deformities, synovitis causes subluxation of the carpometacarpal (CMC) joint which leads to an adducted and flexed position with subsequent flexion of the MCP joint and hyperextension of the interphalangeal (IP) joint [4]. In the type III deformity, a more common occurrence is that with CMC joint subluxation and metacarpal adduction, hyperextension of the MCP and flexion of the IP joint occur. In the type IV deformity (also called gamekeeper's deformity), synovitis stretches out the ulnar collateral ligaments at the MCP joint. This causes the proximal phalanx to deviate laterally at the MCP joint and the first metacarpal to adduct. The first dorsal interosseous and adductor muscles of the thumb may shorten and the web space contracts [4]. Two other thumb deformities, the type V and type VI, have also been described [4].

Hand Impairment, Functional Ability, and Handicap

Many of the deformities that occur with RA affect the ability to grip, pinch, grasp, and flex/extend the fingers and wrists, all of which compromise functional ability. This often leads individuals to adapt their daily activities or cease from performing different activities altogether.

Pain, soft tissue swelling (Fig. 4.2), joint subluxation, and decreased articular mobility are reported to contribute to functional disability and handicap in RA [5–8]. In particular, pain and lack of flexion in the PIP joints have been reported to be related to difficulty manipulating and holding objects or tools needed for eating, dressing, keyboarding, home management, and leisure [9]. A less studied aspect of hand involvement has been handicap. Several studies have shown that the joint deformities lead to concerns about appearance and decreased participation in social activities (handicap) [9, 10].

Furthermore, in early RA, the dominant hand has been shown to have more structural changes (swollen joints, joint tenderness), impairments (strength), and functional ability (decreased dexterity) compared to the non-dominant hand [11]. These findings were also observed by Horsten et al. [12] who found that after 2–4 years of disease duration, at least one hand or wrist impairment was observed in 70 % in the dominant hand and 66 % in the non-dominant hand. The most frequent impairments were limitations in passive joint motion, stenosing tenosynovitis, and CMC. While disease duration was not associated with functional ability, some impairments (limited passive motion in the fingers of both hands, Z-deformity of the non-dominant thumb, tendinitis of extensor tendons of the dominant hand) increased with disease duration. Johnsson and Eberhardt [13] also found that decreased joint motion or hand deformities were developed in the first year of the disease and resulted in significantly higher disease severity and functional disability.

Several studies report that grip strength correlates with measures of functional ability such as the upper limb tasks on the Arthritis Impact Measurement Scales 2 (AIMS) [8, 14], the Health Assessment Questionnaire [8, 15, 16], the Disability of the Arm, Shoulder, and Hand (DASH) Questionnaire [12], and the Duruöz Hand Index (DHI) [17]. In particular, dominant hand strength appears to be an indicator of hand function and, thus, might be important to evaluate and maintain in persons with RA [18].

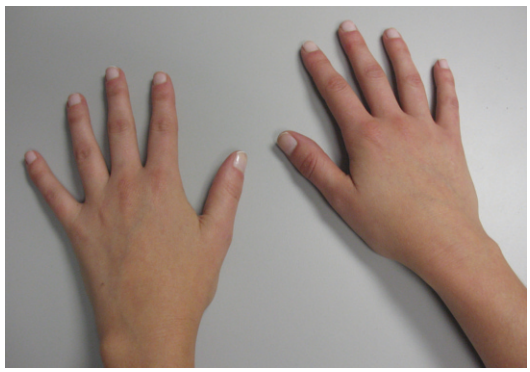

Fig. 4.2 Soft tissue swelling in a 29-year-old woman with RA

Assessment of Hand Function

An assessment of the hand in persons with RA should consist of measurements of disease activity, joint motion, joint stability, pain, grip and pinch strength, and hand function.

Joint Motion and Stability

Joint motion in the hand and wrist joints can be measured with a standard manual or electric goniometer (see the American Society of Hand Therapists for procedures [19]) (Fig. 4.3). Joint instability or laxity is assessed by applying stress to individual joints in a medial/lateral and anterior/posterior direction when the joints are in a close packed position. For example, to test laxity of the MCP joint, the MCP joint should be in flexion (closed packed position in which the collateral ligaments are tight). The examiner should stabilize the metacarpal with one hand and hold

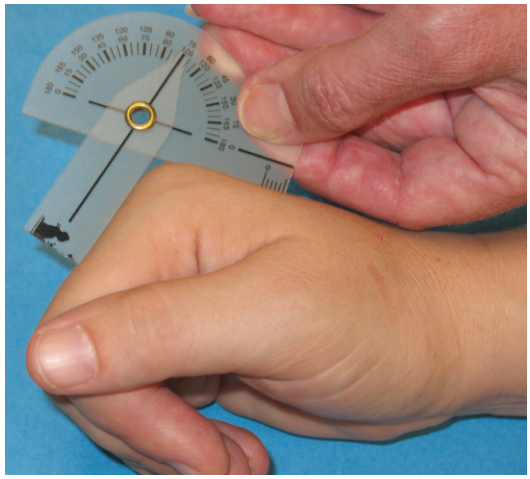

Fig. 4.3 Measuring joint range of motion of the MCP joint with a goniometer

the corresponding proximal phalanges with the other hand and move the joint in the medial/lateral direction and then anterior/posterior. Laxity is noted if the joint moves more than 5–10° in excess of normal. To test laxity of the proximal and distal interphalangeal joints, the joints should be in extension as extension is the position in which the collateral ligaments are tight.

The Hand Functional Index

The Hand Functional Index (HFI) consists of the nine wrist and hand items from the Keitel Function Test (KFT) that measures patterns of joint motion: thumb and individual finger flexion, wrist flexion and extension, and forearm pronation and supination [20]. Each item of the HFI is scored according to specific criteria from 0 (item performed fully without delay) to 3 (unable to perform item). Total scores range from 0 to 52 (0–26 for each upper extremity); lower scores on the HFI indicate less impairment in joint motion [20]. Each hand is assessed separately, and the HFI requires about 5 min to administer.

Evaluation of Joint Deformities

Evaluation of joint deformities is done by observation and palpation. The more common joint deformities seen in persons with RA are described earlier in this chapter. The presence of different deformities should be noted. If a deformity can be corrected, either passively or actively, it is considered flexible; if the deformity cannot be corrected, it is considered fixed.

Pain

Pain can be assessed by a 10 cm visual analogue scale (VAS) in which patients indicate the severity of their pain with the anchors from 0 (no pain) to 10 (worst pain possible) [21]. The score is determined by measuring the distance on the 10 cm line from the "no pain" anchor to the line the patient has made to represent pain severity. A higher score indicates greater pain. The VAS can be modified to ask about pain in a specific body part such as the hand and/or thumbs or varied in regard to the recall period for pain.

Measures of Grip and Pinch Strength

For both grip and pinch strength, an individual should be seated, with the shoulder joint adducted and in neutral, forearm in neutral, elbow flexed to 90°, and wrist slightly extended [22]. Three trials are attempted, alternating the right and left hands. The score is the mean score of the three trials. Grip strength is usually measured by a dynamometer (Fig. 4.4); however, if a person has a grip strength of less than 5 lb, an adapted sphygmomanometer or GRIPPIT may be indicated to show changes in grip strength. Pinch strength should include two-point pinch, three-point (three-jaw chuck) pinch, and lateral (key) pinch. Pinch strength is usually measured with a pinchmeter.

Measures of Hand Function

Hand function includes dexterity and the ability to perform activities of daily living that involve the hands. These measures can be self-reports or performance-based tests [23]. Table 4.1 shows assessments used to measure hand function.

Fig. 4.4 Grip strength measured with a dynamometer

Performance tests that evaluate hand function include the Grip Ability Test (GAT) [24], the Sequential Occupational Therapy Assessment [25, 26], the Arthritis Hand Function Test [27], and the Jebsen Test of Hand Function [28].

The Grip Ability Test [24]

The GAT is a simple performance-based test consisting of three items: putting a sock on hand, putting a paperclip on envelope, and pouring water from a pitcher filled with 1 L of water. The score is the sum of the timed scores for each item.

The Sequential Occupational Therapy Assessment (SODA) [25]

The Sequential Occupational Therapy Assessment consists of 12 items: six unilateral and six bilateral. The examiner rates the performance on each item as 0 (unable to perform), 1 (able to perform task in a different way), and 2 (not difficult). The patient is also asked to rate their perceived difficulty with the item from 0 (very difficult) to 2 (not difficult). For the bilateral items, separate scores are calculated for the right and left hands. Scores are summed, and higher scores indicate better function. The short version of the SODA, the SODA-S [26], consists of the six tasks on the SODA that were most sensitive to change.

The Arthritis Hand Function Test [27]

The Arthritis Hand Function Test is an 11-item test that measures hand strength, dexterity, applied dexterity, and applied strength. The hand strength items are grip and two-point and three-point pinch. Dexterity is the time to place and remove nine pegs from a pegboard. The applied dexterity section comprises five tasks: lacing and tying a bow on a shoe, buttoning and unbuttoning four buttons, fastening and unfastening two safety pins from a piece of fabric, picking up and manipulating coins, and using a knife and fork to cut theraputty into four pieces. The applied strength items consist of pouring a measured volume of water from a pitcher and picking up a tray of cans.

The Jebsen Hand Function Test [28]

The Jebsen Hand Function Test consists of seven items that simulate everyday activities: writing a sentence, turning pages (turning over 3×5 in. cards), picking up small common objects (penny, paper clip, and bottle cap), simulated feeding (scooping up kidney beans with a spoon), stacking checkers, picking up large light objects, and picking five large heavy objects. Each item is first performed with the non-dominant hand and then the dominant hand. The score for each item is the time to perform the item.

The Duruöz Hand Index [29]

The DHI is a self-report and consists of 18 questions divided into five categories: kitchen, dressing, hygiene, office, and other. Each item is scored separately on a scale ranging from 0 (without difficulty) to 5 (impossible). Scores from the five total categories are summed to yield a total score ranging from 0 to 90. The DHI takes about 3 min to complete.

Table 4.1 Assessments used to measure hand function

Test	What measured or subscales	Number of items	Reliability	Validity	Responsiveness
Performance-based tests					
Grip Ability Test (GAT)	Put sock on hand Put paperclip on envelope Pour water	3	Intraobserver Interobserver Internal consistency	Content Construct	Low to moderate sensitivity to change
Sequential Occupational Dexterity Assessment (SODA)	Write a sentence Pick up envelope Pick up coins Hold telephone receiver Unscrew tube of toothpaste Squeeze toothpaste Handle spoon and knife Button blouse Unscrew large bottle Pour water into glass Wash hands Dry hands	12 6 unilateral 6 bilateral	Interrater Test–retest Internal consistency	Content Construct	Low to moderate sensitivity to change
Arthritis Hand Function Test (AHFT)	Grip strength Pinch strength Dexterity Applied dexterity Applied strength	11	Interrater Test–retest	Construct	No evidence for responsiveness
Jebsen Hand Function Test (JHFT)	Writing Simulated page turning Picking up small objects Simulated feeding Stacking checkers Picking up large light Picking up large heavy objects	7	Interrater Test–retest	Construct	Moderate responsiveness to detect change
Self-reports					
Duruöz Hand index	Kitchen Dressing Hygiene Office Other	18	Interrater Test–retest	Construct	Moderate sensitivity to change
Michigan Hand Outcomes Questionnaire	Overall hand function Activities of daily living Pain Work performance Aesthetics Satisfaction with hand function	37	Internal consistency Test–retest	Construct	Moderate to high sensitivity
DASH	Symptoms Pain—3 items Tingling/numbness—1 item Weakness—1 item Stiffness—1 item Function Physical function—21 items Social/role function—3 items	30	Internal consistency Test–retest	Content Construct Criterion	Moderate for shoulder conditions

The Michigan Hand Outcomes Questionnaire [30, 31]

The MHQ is a self-report questionnaire that contains six distinct scales: (1) overall hand function, (2) activities of daily living, (3) pain, (4) work performance, (5) aesthetics, and (6) participant satisfaction. Questions are hand specific and can be applied to a wide range of conditions. Questions are scored on a five-point Likert scale from 1 (very good/no difficulty) to 5 (very poor/very difficult) [30]. Scores are normalized to a 0–100 scale using the MHQ Scoring Algorithm as recommended by the authors [30] with higher scores indicating poorer functional status.

The Disability of the Arm, Shoulder, and Hand Questionnaire [32]

The DASH Questionnaire is an assessment of symptoms and function of the entire upper extremity. It has 30 items regarding symptoms (pain, tingling/numbness, weakness, stiffness) and function (physical function, social/role function). Items are scored on a scale from 1 (no difficulty) to 5 (extreme difficulty/unable to do). The DASH is scored using the original formula [(sum of items − 30)/1.2]. An 11-item version of the DASH, the *Quick*DASH, is also available [33]. It consists of three items for symptoms and eight for function.

Functional ability and handicap can also be measured using standard questionnaires used in rheumatology practice such as the Health Assessment Questionnaire, the SF-36, the Arthritis Impact Measurement Scale (AIMS-2), or observation of performance during daily activities. However, these questionnaires address broader areas of function besides hand function. Both self-reports and performance-based tests can guide health professionals in assessing hand function in persons with RA. Performance-based tests require training and personnel and equipment to administer. However, they do allow the examiner to observe deficits and adaptive methods used to perform different tasks. Self-reports are quick and easy to administer and can cover a wider variety of skills than performance tests. The validity studies done with the different measures show that in general, hand strength, motion, and dexterity measure different aspects of hand function which may not correspond to what people can do or perceive they can do with their hands. Therefore, evaluation of hand impairment should be supplemented by measures of hand function. Hand strength, in particular, may be important for persons with RA as strength correlates with functional ability.

Summary

The structural changes, deformities, and pain from rheumatoid arthritis can lead to decreased hand function which affects all aspects of daily life such as self-care, work, and leisure. A thorough assessment of the hand is imperative to preserve hand function and prevent deformities and disability.

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Hand Function in Osteoarthritis

5

Roy D. Altman

Heberden [1]: "What are those hard knobs, about the size of a small pea, which are frequently seen upon the fingers, particularly a little below the top near the joint … and being hardly ever attended with pain, or disposed to become sore, are rather unsightly than inconvenient, though they must be some little hindrance to the free use of the fingers".

Epidemiology

Osteoarthritis (OA) of the hand is common, with an estimated radiographic and clinical prevalence of 43 % in the adult population [2]. Although women have a higher prevalence of symptomatic and erosive changes, overall population surveys indicate a near-equal overall prevalence of hand OA in men and women [3].

The initial changes of OA of the hand are most commonly noticed between 40 and 50 years of age. In women, the onset often coincides with the perimenopausal period, but a clear relation to reduced estrogen concentrations has not been established. There is a tendency to involve the dominant hand, hence the right hand, earlier and more with more prominent changes. There is a tendency for women with hypermobility to involve the first carpometacarpal (first CMC; trapeziometacarpal) joint. There is a strong tendency for hand OA to be present in other family members, most often of the same sex. Although a high heritability has been suggested [4], at this time, no single gene has been consistently identified.

Clinical Presentation

Patients may present only for unsightly enlargement of the hands (Fig. 5.1). Symptomatic hand OA was 8 % in the United States by American College of Rheumatology (ACR) criteria [5, 6]. Some will present with pain or tenderness in or around the involved joints. OA of the hand typically involves distal interphalangeal (DIP) joints, proximal interphalangeal joints (PIP), the first CMC, and the interphalangeal joint (IP) of the thumb (IP thumb). A predominant palmar subluxation of the DIP or the IP joint may appear as a "mallet" finger. There may be some loss of dexterity. DIP involvement may induce vertical ridges on the adjacent fingernails. In a genetic study of nearly 2,000 subjects, nodular changes of the DIP of the second digit were most common with the IP thumb second most common [7]. There was a strong correlation between radiographic OA of the hand and clinical findings of OA. Controversy continues on whether those with predominant hard tissue changes (mostly of the DIPs) and those with erosive changes (commonly involving both DIP and PIPs) are separate diseases

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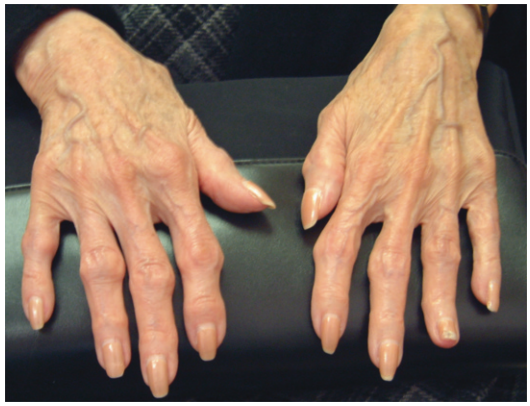

Fig. 5.1 Photograph of osteoarthritis of the hands with significant distal interphalangeal hard tissue enlargement, proximal hard and soft tissue enlargement with deformity, hard tissue enlargement of the interphalangeal joint of both thumbs, and "knobby" enlargement at the base of the thumb (trapeziometacarpal joint) on the *right*

or the two ends of a spectrum of a single disease. The presence of purely hard tissue changes is often symptomatic only from their size (e.g., change in ring size) and mildly reduced function (e.g., inability to perform certain fine functions such as knitting). However, hand OA may be associated with a significant synovitis and synovial effusion. In the DIP joints, the effusion may rupture on the dorsal radial or ulna side of the joint into a cystic lesion. In the PIP joints the effusion is often associated with a modest synovitis that is palpable on examination. Symptomatic hand OA is associated with self-reported difficulty lifting 10 lb (4.5 kg) (odds ratio (OR) 2.31), dressing (OR 3.77), and eating (OR 3.77) [5]. Changes of the first CMC are often associated with pain, reduced grasp, and "knobby" changes at the base of the thumb (Fig. 5.1). Isolated changes of the first CMC may represent a third subset of OA. Although the first CMC OA mostly involves the trapeziometacarpal joint, the scaphotrapezoid joint is also often involved.

A systematic review was performed of the literature on factors associated with the severity and progression and of a community-based population, where symptoms were related to the hand [8]. Progression of hand pain and loss of function over time related to limited hand function included older age, women, manual occupation, neck and shoulder pain, radiographic osteoarthritis, weak hand strength, hand pain, Parkinsonism, stroke, diabetes or rheumatoid arthritis, and illness perception.

There may be tenderness of any of the involved joints. There is often an associated deformity with subluxation and/or contracture of the involved joints, particularly when erosive changes are present. Hand OA has shown a clinical association with hypercholesterolemia (OR 2.10), autoimmune thyroiditis (OR 1.87), knee OA (OR 1.63), and hip OA (OR 1.87), without an association with systemic hypertension, ischemic heart disease, and, in contrast to the study above, diabetes mellitus [9].

Diagnostic and Classification Criteria

Diagnostic criteria were established by a EULAR working group [10], based on a literature review that emphasizes disease subsets. The diagnostic criteria have not yet been applied in other publications. Classification criteria have been defined by the ACR [6]. The latter were developed through a Delphi technique, physical examinations, and radiographs. They were designed for subject selection for clinical trials and are most useful for characterizing a population for a clinical report or trial. Generally, patients should have symptoms and findings in at least two IP, one first CMC joint, or a combination of one IP and the first CMC to be classified as having symptomatic or radiographic hand OA.

At this time, there is no uniform criteria separating erosive versus nodular hand OA. This has resulted in difficulty in combining results from different clinical trials.

There are no laboratory tests helpful in diagnosis of hand OA. Citrullinated peptides (CCP) are not present. Low-titer rheumatoid factor is common and consistent with an age-matched population.

Imaging

The radiograph may reveal osteophytes, joint space narrowing, subchondral erosions, subluxation, and subchondral sclerosis (Fig. 5.2). The first CMC is often subluxed radially with large osteophytes. Grading of radiographs emphasizes the osteophyte and joint space narrowing. The most often used technique for reading radiographs was developed by Kellgren and Lawrence [11]. More recent measurement techniques by Kallman et al. [12] and the Osteoarthritis Research Society International [13] emphasize the reading of individual radiographic features of each joint. A technique for grading the degree of change in each joint that may lend itself to longitudinal studies was developed by Verbruggen and Veys [14].

One of the limitations of the single anteroposterior radiograph is the hidden osteophyte on the dorsal or the palmar surface. It is suggested that clinical trials include a photograph of the hands in order to avoid missing changes not picked up by the radiograph. High-quality photograph of the hands appears to correlate well with the radiograph and hand symptoms, particularly in women [15].

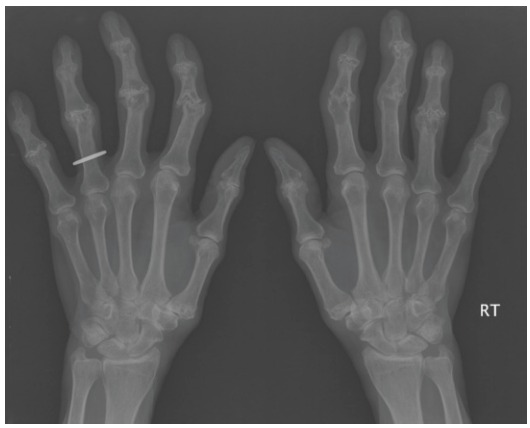

Fig. 5.2 Anteroposterior radiograph of erosive osteoarthritis of both hands demonstrates distal interphalangeal and proximal interphalangeal erosions with central erosions, osteophytes, joint space narrowing, and subluxations

Instruments for Measuring the Impact of Hand OA

Pain can be measured by a 10 cm unmarked visual analog scale (VAS) or a 4–11-point Likert scale. Special pain scales have been available for impaired individuals (e.g.: happy, sad face).

Specific scales have been developed or adapted for use to encompass pain and function for hand OA. These scales can be examiner administrated or patient self-administrated. There are also generic quality-of-life instruments and general-purpose arthritis measures (Table 5.1). These scales may specify specifics of the measure, e.g., over the prior 24 h and maximum pain. References are available, and all are reviewed as part of the guidelines for design for conduct of clinical trial for hand OA (Table 5.1) [16].

Dreiser developed hand OA-specific unidimensional investigator-administered scale which is called functional index for hand osteoarthritis (FIHOA) [17]. The FIHOA contains ten questions,

Table 5.1 Hand function measurements

Osteoarthritis Hand-Specific Indices
Austrian/Canadian (AUSCAN) Hand Osteoarthritis Index
Functional Index for Hand Osteoarthritis (FIHOA)
Indices for Rheumatoid Arthritis often used for hand osteoarthritis
Arthritis Impact Measurement Scale (AIMS1/AIMS2)
Disability of the Arm Shoulder and Hand (DASH) questionnaire
Doyle Index
Duruöz Hand Index (DHI)
Health Assessment Questionnaire (HAQ)
More general measurement indices often used for hand osteoarthritis
European Quality of Life Measure (EuroQol)
Health Utilities Index (HUI)
Hospital Anxiety and Depression Scale
International Classification of Functioning, Disability, and Health (ICF)
Nottingham Health Profile (NHP)
Pain indices
Score for Assessment and quantification of Chronic Rheumatic Affections of the Hands (SACRAH)
Short Form (SF-12, SF-36)

each rated by a four-point Likert scale. It has been validated in multiple languages and takes only a few minutes to administer.

Duruöz Hand Index (DHI) was developed to assess the functional disability and functional handicap for rheumatoid hand [18], and it was validated for hand OA [19]. The DHI has three factor groups [18], examiner-administered scale validated in several clinical trials and in several languages, including French, Spanish, Italian, and English. The DHI was composed of 18 questions on daily activities in a six-point Likert scale that takes only a few minutes to administer.

Bellamy independently developed the patient self-administered Australian/Canadian (AUSCAN) Hand Osteoarthritis Index [20], using the hip and knee Western Ontario McMaster Universities (WOMAC) osteoarthritis index as a template. In both these scales, Bellamy divided the instrument into three subsections of pain, stiffness, and function. It is available in both a five-point Likert or 10 cm VAS format and has been validated in multiple languages. Each of the items in the AUSCAN has been validated separately.

Several instruments developed for use in other settings, e.g., rheumatoid arthritis, are also used in the evaluation of OA of the hand. Most involve patient-reported outcomes. Examples include the Arthritis Impact Measurement Scales (AIMS1, AIMS2, AIMS-2SF), the European Quality of Life Measure (EuroQol), the Nottingham Health Profile (NHP), and the Short Form 36 (SF-36) (Table 5.1). These and others are reviewed in the OARSI guidelines for conducting clinical trials in hand OA [16]. All of the above have undergone extensive validation.

Indeed, all of the above instruments measure pain to some extent. However, function loss in hand OA is often more problematic to the patient than pain. Hence, other instruments have been developed, most combining pain and function in the instrument. Below are several examples on how these instruments have been used in helping to understand the limitations of function in hand OA.

The most commonly used performance-based measure for hand OA are the grip strength and pinch test. Despite extensive use, performance-based measures of hand pain and function still do not have adequate validation to be used as primary outcomes in clinical trials.

All clinical trials of hand OA need to include a measure of pain, function, and a patient global question. The patient global question provides information on the patient's overall impression of improvement combined with tolerance (i.e., adverse events). Examples of the way the question may be worded are as follows: "considering all the ways your hand osteoarthritis affects you, how have you been during the last 48 hours," and "in relation to your hand osteoarthritis, how do you feel today."

Studies Comparing Instruments on Impact of Hand OA

A semi-structured patient interview was conducted on 29, mostly women. Subjects reported embarrassment due to the appearance of their hands and their inability to carry out reportedly normal tasks [21]. A few subjects indicated that work status was affected. Subjects utilized cognitive, behavioral, and avoidance forms of coping with the impairments of hand OA. These coping mechanisms are the same as those used in hip and knee OA. The groups felt that therapy was inadequate and expressed a lack of understanding by themselves and the examiner of their hand OA.

In an Austrian study of 223 women and 30 men, women worked twice as many hours in housework, had a lower income than men, and were more concerned with aesthetic change [3]. However, there were no differences in gender referable to function and health status by SF-36, Moberg Picking-Up Test, grip strength measurements, the AUSCAN, and the Score for Assessment and Quantification of Chronic Rheumatoid Affections of the Hands (SACRAH) questionnaire.

In one study, using Rasch analysis, the AUSCAN, AIMS-2 hand/finger subscale, and the FIHOA were felt to be improved by minor modifications by removal of specific items [22]. It was felt that the AUSCAN subscales should be used

as separate constructs and not be combined into a total score. Similar conclusions were reported for the FIHOA and AIMS-2. In one specific item, removal of "pain at rest" from the AUSCAN improved the performance of the AUSCAN pain subscale.

Radiographic changes of nearly 400 men and women included grading 15 individual hand joints by Kellgren Lawrence criteria [23]. Results of the radiographs were matched to grip strength and function, using the DASH score, and grip/pinch strength of the dominant hand. The sums of the Kellgren Lawrence scores as well as the DASH scores for thumbs and middle fingers were inversely associated with grip and pinch strength. There was no association with the fourth and fifth digit.

In a Belgian group of patients, 167/270 (62 %) were classified by their criteria as having erosive OA of the hand [24]. Those with erosive OA, in contrast to non-erosive OA, used more analgesics and had a worse functional outcome and higher pain score. Both the FIHOA and AUSCAN function scores showed a trend towards more disability. Although functional impairment was correlated with women and number of destructive joints, it was not influenced by involvement of the first CMC. In comparing the FIHOA and AUSCAN, the AUSCAN function subscale was superior to the FIHOA in association with the number of active joints. The AUSCAN was more sensitive for pain, and the FIHOA was better associated with radiographic and structural damage.

In a study of 128 patients with hand OA, the AUSCAN and FIHOA were both reliable and valid [25]. The FIHOA was shorter and had higher test–retest reliability, and the AUSCAN had higher construct validity and data quality.

Several questionnaires of hand OA were evaluated referable to the International Classification of Functioning, Disability, and Health (ICF) [26]. The most disease specific, or lowest diversity, was present in the AUSCAN and the SACRAH. The FIHOA and AIMS2-SF had higher linkage to the ICF categories and demonstrated higher diversity.

The AUSCAN was evaluated in the Genetics of Generalized Osteoarthritis (GOGO) study of 531 subjects with hand OA [27]. The global assessment of change scores was significantly associated with the AUSCAN, grip strength, and right-hand pinch strength. This study supports the use of the AUSCAN for the dominant hand and also supports the use of the global assessment of symptom change over time as a longitudinal assessment tool. The same investigators found a high internal consistency in the AUSCAN in a community-based population [28]. The patient global (VAS), pain scale (VAS), and AUSCAN pain subscale were responsive in a clinical trial, whereas the tender joint count, swollen joint count, AUSCAN stiffness, and AUSCAN physical function were less responsive in a clinical trial [29]. Clinical trials for hand OA can also include the OMERACT/OARSI responder criteria [30].

The examiner-administered Doyle Index was evaluated for pain and function in a 260-patient population with OA of hand and knee/hip [31]. The authors felt the Doyle Index to be reliable and easy to perform when compared to the AUSCAN for hand OA.

Aesthetic discomfort, as measured by a VAS, was a major concern for 172 patients with hand OA in a study measuring tender joint and node count, global and pain scores, FIHOA, SF-12, Hospital Anxiety and Depression Scale, and hand radiographs [32]. Aesthetic discomfort was associated with severity of OA, erosive changes, depression, anxiety, and poor health-related quality of life, more in women than men.

Conclusion

Hand OA is common in the general population, equal in men and women, with women more often symptomatic. Symptoms are often related to the physical aesthetics. In addition to the aesthetics, there is often pain and reduced function. We have outlined several techniques for measuring the severity and impact of hand OA that are useful for a cross-sectional evaluation of individuals

or groups of patients. These instruments are also useful for longitudinal follow-up of individuals, groups, and clinical trials.

Summary

Osteoarthritis of the hand is common. Although often asymptomatic, it may be related to symptoms and signs of deformity, increasing pain and impaired function. There are specific instruments developed that can measure the impact of osteoarthritis of the hand on pain and function that have been developed and validated in clinical trials. These instruments perform as well as or better than simple nonspecific pain scales. The AUSCAN Osteoarthritis Hand Index and the FIHOA have been validated in several languages and are useful instruments for defining the extent of hand osteoarthritis and following the course of involvement.

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Hand Function in Scleroderma

6

Angela Del Rosso, Susanna Maddali-Bongi, and Marco Matucci-Cerinic

Systemic Sclerosis

Systemic sclerosis (SSc) is a connective tissue disease characterized by immunologic abnormalities, microvascular alterations, and excessive collagen production, leading to fibrosis of skin and internal organs (lungs, heart, gastrointestinal tract) [1].

In SSc, the loss of elasticity and the tightness of the skin followed by the cutaneous thickening and hardening (sclerosis), with concomitant changes in subcutaneous tissues, are the distinctive hallmark of the disease [1]. The involvement of skin and subcutaneous tissues usually begins from the extremities and then, in a centripetal mode, may progressively extend to the trunk, leading to prominent disability. The classification in the two main clinical subsets, diffuse cutaneous SSc (dcSSc) and limited cutaneous SSc (lcSSc), is based on the extent of skin involvement [skin sclerosis extending proximally to the elbow and potentially involving truncal areas in dcSSc, and restricted to hands (sclerodactility), face, forearms, and feet in lcSSc]. The two subsets of SSc also differ for the presence of specific antinuclear autoantibodies [antitopoisomerase 1 (anti-Topo1 or Scl70) antibodies in dcSSc and anticentromere antibodies in lcSSc] and for organ involvement.

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Causes of Hand Functional Impairment in Systemic Sclerosis

In SSc, hands and fingers are notable targets of the disease [2]. SSc evolves through three consecutive phases in which the hands are differently affected.

In the early *edematous phase*, edema of fingers (puffy fingers) and hand prevails (sometimes coexisting with edema at feet and face), often associated with or preceded by Raynaud's phenomenon (Fig. 6.1a, b). In this phase, arthralgia of the fingers is often present. Edema limits the range of movement of metacarpophalangeal (MCP) and proximal interphalangeal (PIP) joints, and arthralgia and Raynaud's phenomenon attacks (that may cause digital ulcers since early phases of the disease) may contribute to pain and impaired manual function [3]. Tendon friction rubs can be present since this phase [4].

In the following *sclerotic phase*, edema turns into sclerosis. The affected skin is thickened, indurated, and bound to the subcutaneous tissue. In the hands, these findings are more frequently observed over the fingers (sclerodactyly). This feature is highly disabling and leads to MCP reduced flexion and, consequently, to reduced extension of PIP and distal interphalangeal (DIP)

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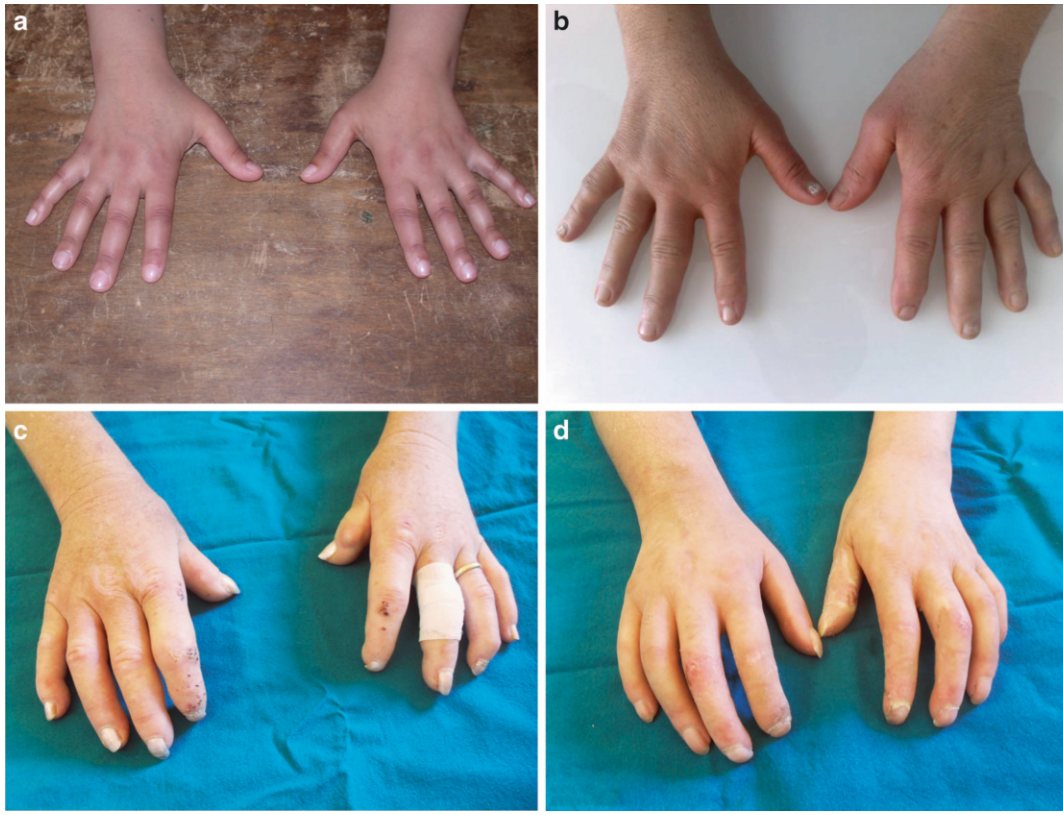

Fig. 6.1 Systemic sclerosis (SSc) hands according to the different phases of the disease. (**a**) Early edematous phase: puffy fingers and Raynaud's phenomenon. (**b**) Edematous phase: edema of the fingers and whole hands. (**c**) Sclerotic phase: sclerosis and induration of the skin on the fingers (sclerodactyly) and on the whole hand leading to flexion contracture and "claw-type deformity" of the fingers. An extensive calcification on the dorsum of the thumb on left hand is present. (**d**) Atrophic phase: atrophy of the skin, worsening of the claw-type deformity of the hands

joints and to thumb adduction and flexion. These modifications, together with the impairment of flexion/extension of the wrist, result in the typical claw-type deformity of SSc [5, 6]. Digital ulcers at fingertips and on the extensor surface of MCP joints may be present and can heavily contribute to pain and disability (Fig. 6.1c).

In the further *atrophic phase*, skin thickening is substituted by skin atrophy, and claw-type deformity worsens. Wrist movements are further impaired, with problems also in pronation and supination. Digital ulcers and their complications (such as infection, auto-amputation) may cause pain and affect hand function (Fig. 6.1d).

Hand disabilities in SSc are due to skin and subcutaneous tissue involvement, microvascular impairment (Raynaud's phenomenon and digital ulcers), and musculoskeletal and peripheral nervous system changes [7]. These modifications, evolving and differently overlapping during the three phases (edematous, sclerotic, atrophic) of the disease, lead to hand dysfunction, deformities, and pain and are responsible for the altered hand function.

Skin

SSc is characterized by thickening, hardening, and tightening of the skin, changing throughout the disease course. In the early phase, skin thickness is caused by increased collagen, intercellular matrix formation in the dermis, and edema due to microvascular injury, changes in lymphatic circu-

lation, and inflammation. Since this early phase, the skin becomes thickened and impossible to be pinched into a normal skin fold. In the following sclerotic phase, besides its thickening, the skin also becomes shiny, taut, hard, hidebound, and adherent to the subcutaneous tissues, especially at fingers (sclerodactyly). In the further atrophic phase, the skin becomes thin, atrophic, and tightly tethered to the underlying tissue [8].

At now, the most used and validated method for measuring skin thickness is the *modified Rodnan skin score* (mRSS) [9]. Skin thickness, evaluated by palpation, is rated on a scale of 0 (normal), 1 (weak), 2 (intermediate), or 3 (severe skin thickening), and the total skin score, resulting from the sum of the skin assessments in 17 body areas, ranges from 0 to 51. mRSS areas consider four sites at hand level: the fingers and the hands, assessed bilaterally, with a partial score ranging from 0 to 12. Thus, a high mRSS in these sites may account for a high impairment of hand and finger mobility in SSc patients.

Skin histology, although not widely feasible in clinical practise, is used to confirm SSc diagnosis. Dermis thickness and collagen amount in skin punch biopsies are related to mRSS and confirm its validity [10]. However, biopsies are made at the forearm and only rarely at the hands and fingers.

Durometry is a noninvasive method assessing skin hardness [11, 12], at least partially distinct from thickness or elasticity, that may be affected by skin thickness, skin density, elasticity, and edema. The measurements are made at predetermined sites including also fingers and hands. Despite its good correlation with skin thickness, its reliability, and sensitivity to changes, it is not included yet in the routine assessment of the total and hand skin involvement in SSc.

Ultrasound (US) is a noninvasive, reliable, and sensitive-to-change technique, used to assess SSc dermal thickness also in the hand. Recently, dermal thickness was evaluated by US in SSc fingers over the dorsum of the phalanxes, according to disease phases (edematous, sclerotic, atrophic). It resulted higher in the edematous than in the fibrotic patients and higher in these groups than in the atrophic patients. Thus, US performed at hand level is able to detect digital dermal thickening in SSc and to distinguish SSc phases according to cutaneous thickness and is potentially useful in following up disease course [13].

Recently, *ultrasound elastography*, assessing tissue elasticity, was able to distinguish between SSc patients and controls at forearms but gave interlocutory results at fingers [14].

Contrast-enhanced *magnetic resonance imaging* (MRI) of the skin of the SSc hand, performed by a unit dedicated to the study of limbs (Artroscan), was able to distinguish patients with inflammatory disease from those with sclerotic disease [15]. However, this technique is not feasible in clinical practice because of little availability of Artroscan and because of its cost.

At the moment, studies assessing in SSc a correlation between the findings at skin US, durometry, ultrasound elastography, and manual function are not available yet.

Subcutaneous Tissues

Subcutaneous involvement in SSc is characterized by progressive *thickening of subcutaneous tissue* (hypoechoic on US and showing low signal intensity on T1-weighted MRI images). Also *resorption of subcutaneous tissue*, usually at fingertips, and calcifications (calcinosis), may be found.

Subcutaneous calcifications are frequent, especially over the palmar aspect of the fingertips (10–30 % of cases [7]), where extrusion of calcific material, constituted by calcium hydroxyapatite deposits, can occur through the skin. They may be minute, extensive, and more or less dense [16]. When extensive and/or present in the upper layers of subcutaneous, calcifications may be detected by palpation of the fingers (Fig. 6.1c). They can also be shown by X-rays and US of the hands.

Calcinosis is present in almost one-third of SSc patients, with a higher prevalence in patients with lcSSc (formerly known as CREST syndrome; C = calcinosis; R = Raynaud's phenomenon; E = esophageal involvement; S = sclerodactyly; T = telangiectasias) than in patients with dcSSc; it is associated with erosions, and it is most often seen in patients with digital ulcers [17].

Also periarticular calcifications as well as subcutaneous calcifications involving sites of chronic stress, and soft tissues in pressure points (e.g., MCP joints), not only at hands, can be observed.

Articular and Periarticular Involvement

During SSc course, 46–97 % of patients may develop joint and periarticular involvement, representing the onset manifestation in 12–65 % [18–20]. Hands (especially fingers and wrists), together with ankles, are the sites preferentially involved [21].

The most peculiar hand involvement of SSc is represented by *flexion contractures* that may evolve painlessly to "claw-type" *deformities*, characteristic of the fibrotic and atrophic phases. At hands, these changes may be minimal and only involve one phalanx or gross and involve several phalanges, including the middle or even proximal phalanges [22]. They are caused by the lack of vascular supply; by the thickening and loss of elasticity of skin, subcutaneous tissues, and periarticular (tendons, ligaments) and articular (joint capsules, synovium) tissues; and/or by the tethering of the skin to subcutaneous tissue (Fig. 6.1c, d).

Reduction or impossibility in MCP flexion, in PIP and DIP extension, in adduction and flexion of the thumb, and the impairment of flexion/extension of the wrist may severely worsen all the movements of the hands and the manual function [5, 6]. Thus, flexion contractures may lead to a prominent disability [23], contributing to global disability, by altering quality of life (QoL) [24] and affecting activity of daily living (ADL) [25, 26].

Arthralgia and arthritis are also present and may cause both pain and disability. Arthralgia, mainly found at hands, is present in the majority of the cases and, sometimes, since the earliest, edematous, phase of the disease [27, 28]. It has been reported that 66 % of SSc patients experience arthralgia and 61 % have signs of arthritis [19].

Arthritis, occurring mostly at the hand, in particular at MCP, PIP, and wrist joints, and less frequently at the knees or elbows [29], may have a olygo-polyarticular pattern with acute or subacute involvement and an intermittent or a chronic remitting course [27, 28] (Fig. 6.2a). Sometimes, a symmetrical polyarthritis, usually seronegative and non-erosive, may be the presenting manifestation of SSc. In these cases, the clinical features may be similar to rheumatoid arthritis and often be confused with it [30].

Erosive arthropathy is found in 20–30 % of these patients, especially in the wrists [31], and rheumatoid factor may be positive in 26–50 % of the patients [28] (Fig. 6.2b). The coexistence of SSc and rheumatoid arthritis is considered as an overlap syndrome [32].

Bone Involvement

Bone involvement is characterized by distal phalangeal resorption (*acro-osteolysis*), more frequent in the hand than in the foot [7], and by radiological demineralization [6, 32], associated with arthritis and systemic inflammation [17]. *Acro-osteolysis* generally begins at the tuft, particularly on the palmar surface of the bone, and, if persisting, leads to the "pencil-in-cup" deformity or sharpening of the phalanx, and, in severe cases, the distal phalanx might be partially or totally destroyed, resulting in reduction of finger length [33] (Fig. 6.2b). Acro-osteolysis is significantly associated with digital ulcers, extra-articular calcification, and pulmonary arterial hypertension [17]. The association of acro-osteolysis with vascular complications may highlight a potential role of vascular injury in its development [17].

X-rays (especially at hands and feet) are the mainstay for diagnosing and monitoring joint, periarticular, and bone involvement in SSc. The most common X-ray abnormalities are subcutaneous calcinosis (more frequent in lcSSc), digital tuft resorptions, juxta-articular demineralization, joint space narrowing, intra-articular calcifications, erosions, and subluxations [1, 34]. Also osteoarthritis changes were described at the hand [18, 35]. X-rays at hands and feet identified three radiological patterns: inflammatory, degenerative, and fibrotic [34]. Juxta-articular osteoporosis, joint space narrowing, and flexion contractures

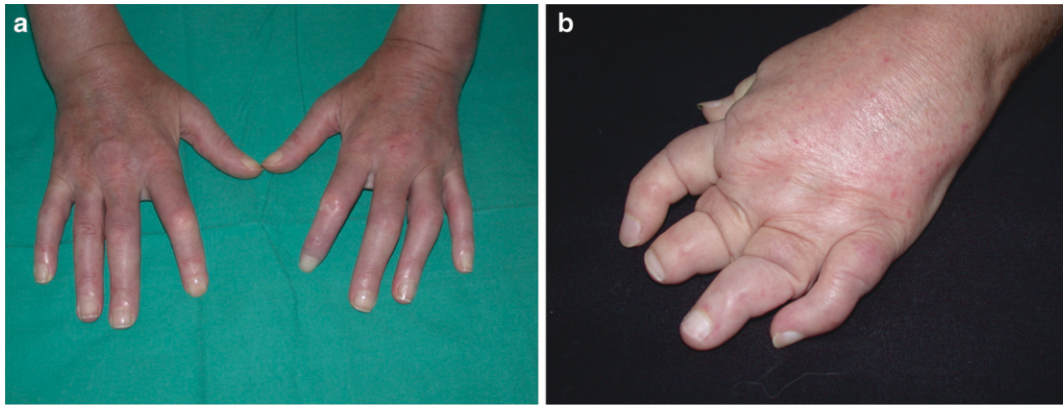

Fig. 6.2 Articular and bone involvement in SSc hands. (**a**) A SSc patient with flexion contractures at fingers and inflammatory arthritis at metacarpophalangeal (MCP) joints. (**b**) A SSc patient (positive for RF) with an erosive arthropathy at MCP and proximal interphalangeal joints and acro-osteolysis that lead to destruction of distal phalanxes and reduction of finger length

of the fingers are more frequent in the hands than in the feet. The hands present a higher frequency of fibrotic pattern, whilst a degenerative pattern is more frequent in the feet. Articular involvement, arthralgia, and finger contractures are more frequent than arthritis, and the finger flexion was prevalent in dcSSc [34].

Over the last years, some studies underlined the role of *US* with Power Doppler and *MRI* in assessing hand characteristics in SSc [36–38]. Taken together, the results from these studies show that the two techniques are useful in depicting the complexity of joint changes in SSc patients, for their ability in detecting features not found at clinical and X-ray examination (such as synovitis, joint effusion, tenosynovitis). MRI was also able to depict bone edema and to show bone erosions more sensitively than X-rays [37, 38]. However, further studies are required to identify the usefulness of US and MRI of hands in the assessment of SSc articular involvement, either in clinical practice or in therapeutic trials.

Tendon Involvement

Tendon involvement is often present in SSc and may affect tendons of wrist, hand, and fingers, contributing to altered range of movements of the hand and to manual disability.

Tendon friction rubs, described as "leathery crepitus" on palpation of the fingers, hands, wrists, elbows, shoulders, knees, and ankles during active and/or passive motion at flexion movement motion in SSc patients [39], are due to edema, thickening, and fibrosis of tendon sheaths [40]. As tendon friction rubs are highly associated with dcSSc and with decreased survival in SSc [41], they should be assessed routinely in all the patients, especially in those with recent onset of Raynaud's phenomenon and puffy fingers, and early SSc [4]. Their finding should lead to a suspicion of SSc and may help to identify patients at risk for severe form of the disease.

The *fibrosis affecting tendons* in advanced SSc (fibrotic and atrophic phases) might be responsible for a cracking noise during joint movements and may contribute to flexion contractures of hands and, sometimes, to tendon rupture.

Muscle Involvement

Skeletal muscle involvement occurs in approximately 70–96 % of SSc and results in myopathy or, much less frequently, in myositis [16, 42]. Proximal muscle weakness is common in dcSSc [42]. An inflammatory myopathy is most prevalent, although overlap with polymyositis, piecemeal infarction due to SSc vasculopathy, and

fibrous myopathy is also described [16, 42]. Weakness might, sometimes, be an adverse effect of therapy or due to joint/tendon involvement, disuse, and/or sedentary activity.

The involvement of hand muscles has not been specifically assessed in SSc. However, the muscle weakness due to the involvement of the muscles of upper limbs may interfere both with the overall function of upper limbs and with the functionality of hands and wrists. Moreover, in the sclerotic and atrophic phases, characterized, at hands, by flexion contractures and claw-type deformity, the fibrosis and atrophy of skin and subcutaneous, periarticular, and articular tissues may encase the muscles of the hand and lead to disuse myopathy, and fibrotic changes may also occur in intrinsic and extrinsic muscles of the hand.

When muscle weakness is present, muscle involvement should be suspected. Thus, serum creatinine phosphokinase, aldolase, and lactate dehydrogenase levels should be assessed, muscle strength evaluated, and electromyography and MRI of the skeletal muscles performed.

Vascular Involvement in SSc

The presence of vascular involvement is, together with tissue fibrosis, the more prominent pathogenic and clinical hallmark of SSc and may represent the earliest manifestation of the disease [40]. Vascular injury, supposedly initiated by events involving endothelial cell damage [40], leads to structural changes of vessels, loss of capillaries (demonstrated with nailfold capillaroscopy [43]), not compensated because of defective angiogenesis and vasculogenesis [60]. Remodelling of the vessel wall with intimal and median layer hyperplasia and adventitial fibrosis causes progressive luminal narrowing and, eventually, occlusion. Also perivascular inflammatory infiltrates may have a role in vessel damage. Involvement of microvasculature is widespread in SSc. Vascular changes found at hand may reflect vascular alterations in other organs, contributing to fibrotic processes [44]. Changes in digital arteries of patients with SSc are similar to those shown in the arteries of the lung, kidney, and heart [45].

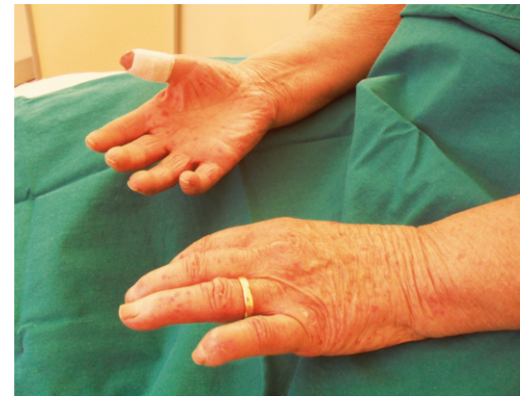

Fig. 6.3 Telangiectasias in SSc hands. Telangiectasias on the dorsal and palmar surfaces of the hands in a SSc patient

Microvascular involvement leads to Raynaud's phenomenon and local ischemia and causes frequently digital ulcers and pitting scars of fingertips [46]. Also calcinosis (Fig. 6.1c) and telangiectasias (Fig. 6.3) are due to SSc vascular damage.

Raynaud's phenomenon (RP) occurs in more than 90 % of patients with SSc (secondary RP). It may be the presenting feature of SSc or it may accompany other manifestations of the disease [47].

RP manifests in the acral parts of the body and consists in recurrent and episodic color changes of the digits (fingers and/or toes), but also of nose and ears, that turn suddenly white (ischemia), then blue (cyanosis), and finally red (reperfusion). Clinically, ischemic and/or cyanosis phases are usually associated with coldness and numbness of digits and reperfusion phase with pain and tingling (Fig. 6.1a).

Digital ulcers (DU) are a frequent and major clinical problem in SSc, occurring in one-third of the patients/year [48] and affecting almost half of them. Various studies revealed that 15–25 % of SSc patients have active DU [49] and 35–50 % had a history of DU [50]. They may appear early in the disease course: the first DU occurs within 1 year and 5 years in 43 % and 75 % of cases [51] from first non-Raynaud symptom, respectively, [48, 52], and are present in 42.7 % of dcSSc and in 33 % of lcSSc patients [52].

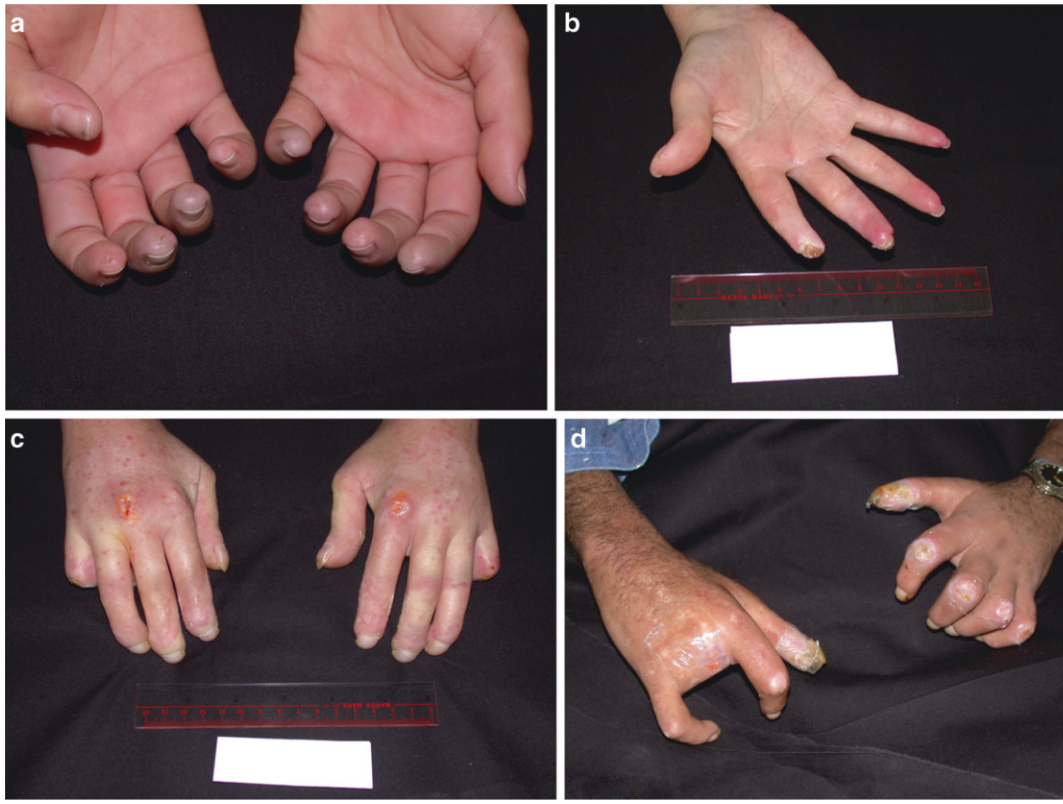

Fig. 6.4 Digital ulcers in SSc hands. (**a**) Digital fingertip ulcers in a patient with SSc. (**b**) Ulceration and tissue loss at the *second* and *third fingertips* of the right hand in a SSc patient. (**c**) Ulcer on the dorsal aspect of MCP joints, pitting scars, and telangiectasias in a SSc patient with a claw-type deformity of the hands (especially at *fifth fingers* of both hands). (**d**) Amputation of the *third* and *fourth fingers* of right hand, ulcer on fingertips and on the dorsal aspect of MCP joints in a SSc patient

Digital ulcers may develop on the fingers (or toes) and can occur over the extensor surface of the joint, on the finger creases, under the nails, and, in the majority of cases, on the fingertips. DU may also develop from a preexisting calcinosis and, sometimes, from digital pitting scars [53].

Digital ulcers presenting as a shallow crater are superficial and involve only the epidermis; the intermediate ulcers also involve the subcutaneous tissue to the underlying fascia and may undermine the adjacent tissues, while those exceeding the fascia may affect muscles, supporting structures such as tendons and joint capsules, and bone [53].

Fingertip DU (Fig. 6.4a, b) are due to the presence of the underlying vasculopathy, persistent vasospasm caused by RP, and intraluminal thrombosis due to platelet activation [54]. Digital ulcers on over the extensor surface of the joint and on the dorsum of the fingers (Fig. 6.4c, d) are, in the majority of cases, due to epidermal thinning and cutaneous retraction leading to cracks on the skin overlying the joints [53].

DU are persistent, difficult to heal, and very painful; may cause tissue loss and autoamputation (Fig. 6.4a–d); and contribute to SSc morbidity. Patients with DU present higher scores in overall [54, 55] and hand disability [52], reduced hand and wrist mobility, and impairment in QoL.

Moreover, DU are frequently infected and, if not treated early, may lead to osteomyelitis, gangrene

(eventually needing amputation of the finger) (Fig. 6.4d), and septicaemia [56, 57].

SSc peripheral microangiopathy can be recognized by *nailfold videocapillaroscopy* (examination of the nailfold capillaries under magnification) able to differentiate healthy individuals from patients with primary RP and from those with signs of microvascular involvement (secondary RP) [58]. According to nailfold videocapillaroscopy, microvascular SSc alterations may be classified into three defined patterns (early, active, and late pattern) [59].

Laser Doppler techniques, such as single-point flowmetry and laser Doppler imaging, allowing an objective measurement of cutaneous microvascular blood flow, are used to assess digital microvascular flow in SSc and RP. Dysfunctional cutaneous blood flow responses in SSc and primary RP patients were shown following temperature stimuli [60, 61] and application of local vasodilators [62].

The combination of nailfold videocapillaroscopy and laser Doppler imaging improves the distinction between primary and secondary RP [63].

Arteriography in SSc hands shows lesions in the digital arteries and less frequently in the ulnar artery, the superficial arch, and the common digital arteries [64, 65].

Magnetic resonance angiography has shown a prominent vascular involvement in the hands of SSc patients demonstrating diffuse lesions, involving both arterial and venous vessels of small caliber as well as microcirculation [66].

Peripheral Nervous System

SSc patients may present the involvement of peripheral nervous system. Mononeuritis and mononeuritis multiplex are described [67], but carpal tunnel syndrome, due to the involvement of median nerve when entering in the carpal tunnel at wrist, is one of the most frequent alterations [68], caused by compression at the wrist by edematous and fibrotic tissues and by microvascular involvement. As SSc median nerve involvement may be disabling for hands, potentially causing pain, paresthesias, and functional manual impairment, its early detection is important to prevent hand disability [69]. Electromyography often discloses significant reduction of distal median nerve sensory and motor conduction rate in SSc [68, 70] also in asymptomatic patients [68]. The involvement of median nerve in asymptomatic SSc patients has also been shown by US of the carpal tunnel, that shows an increasing of median nerve area [3].

Hand Functional Impairment in Different Phases of Systemic Sclerosis

The overlapping and the severe changes of the hands in skin and subcutaneous tissues, microvessels, periarticular and articular structures, and nerves, evolving throughout the course of the disease lead, to impairment of hand functionality in SSc. Disability at the hands also interferes with global ability and QoL [24]. In particular, it is one of the main factors influencing ADL [25], work ability, and employment [26].

In the *edematous phase*, hand perceived disability in SSc patients is mainly due to the difficulties and reduced ability in performing hand movements due to tissue edema. The patient may experience some difficulty in completely closing and opening the fingers and in performing ADL and instrumental activity of daily living (IADL) [71].

In the *sclerotic phase* of SSc, hand disability mainly derives from the thickening of skin and periarticular tissues, reducing the range of motion of fingers, hand, and wrist. The severe functional limitations in the flexion and in the extension of the wrist interfere with the prehension of the hand due to the altered relation between prehension (executed by the hand) and orientation (due to wrist).

The flexion contractures at fingers 2–4 (with the extension of MCP and the flexion of PIP) alter the hand pinch abilities and prehension. In particular, the frequent involvement of the first ray severely impairs the execution of termino-terminal and latero-terminal pinches. Hand disability due to the described changes

results in difficulties in making a fist, in completely extending fingers 2–5, and in a reduction of hand strength, severely impairing the execution of ADL, IADL, and work ability. Hand pain in this phase may be due, sometimes, to articular and periarticular concerns, if arthralgia or arthritis coexist, but it is mainly caused by DU, often present.

In the *atrophic phase*, the moderate flexion of the wrist (having also difficulties in pronation and supination), added to the worsening of finger flexion contractures (with MCP extension, PIP and DIP thumb adduction and flexion), leads to the more severe SSc claw-type deformity, in which the hand, due to the loss of the orientation and the prehension, loses almost completely its function.

Studies about the range of symptoms experienced by patients with SSc and their impact on daily functioning are limited. Patients with SSc report a number of concerns associated with disability and reduced QoL, including gastrointestinal problems, difficulty breathing, pain from various sources, depression, fatigue, and pruritus [72]. An 18-item disease-related stressor questionnaire showed that functional limitations, skin deformities, and disfigurement, together with fatigue and pain, are among the most annoying symptoms [73].

Revised Illness Perception Questionnaire demonstrates that stiff joints, pain, and fatigue are the symptoms most commonly associated with SSc [74]. The five highest rated symptoms in terms of frequency and moderate-to-severe impact on daily activities were fatigue, RP, hand stiffness, joint pain, and difficulty sleeping. Moreover, items related to decreased hand function, such as difficulty making a fist and holding objects and pain intended as muscle pain and joint tenderness, are frequently reported.

These findings confirm the importance of SSc core symptoms, including hand-related issues such as RP and limitations in manual ability in affecting *QoL* and *daily functioning* [72].

In SSc women evaluated for ADL, hand function, perceived symptoms, skin thickness, and finger flexion and extension are the most impaired aspects of hand mobility, while dexterity and grip force are reduced. RP is referred as the predominant self-perceived problem, and activities based on hand and arm function are felt as harder to perform than activities depending on lower limb function. RP, stiffness, grip force, and dexterity are the factors with the strongest associations with ADL difficulties [75].

A longitudinal survey on early SSc patients shows that ADL capacity correlates significantly with grip force, self-assessed hand function, and RP at baseline and also with hand mobility (assessed with hand mobility in scleroderma—HAMIS—Scale) at follow-up [25].

Recent investigations show that hand function is related to *working ability* in SSc. In lcSSc women, 50 % have a reduced working ability: the lower the working ability, the lower their perceived well-being. Greater working ability was associated with better ADL capacity, occupational performance within more occupational areas, and greater satisfaction with occupations [76].

SSc patients were assessed to identify factors influencing work ability and to evaluate the association between work ability (assessed by the work ability index—WAI) and employment status, ADL (evaluated by the UK scleroderma functional score—UKFS), and QoL. 13/48 patients had good or excellent, 15 had less good, and 20 had poor WAI. The correlation between employment status and WAI was good, and patients with good WAI perceived milder symptoms (pain, fatigue, and impaired hand function). These patients had better competence and better possibility of adaptations at work and impact at work than those with poorer WAI [26].

DU have a substantial impact on daily living and professional activities. Global disability (by health assessment questionnaire—HAQ), hand disability, and anxiety were significantly higher in patients with DU (60/189 patients) than in others. Most patients reported a limitation in daily activities related to SSc and an increased need for help at home. Patients with DU reported more need of paid household help in comparison to patients without DU [77].

Correlations Between Hand Functional Disturbances and Other Clinical Parameters

Hand disturbances may be due to different causes, some of which are related to or predictors of clinical parameters.

Flexion contracture of the fingers is associated to Scl70, dcSSc, and arthralgias. As the prevalence of esophageal involvement, pulmonary fibrosis, or heart involvement is significantly greater in the patients with flexion contractures [17, 20], they might be regarded as markers of internal organ involvement.

Flexion contractures significantly correlate to the radiological fibrotic pattern (digital flexion, space narrowing, particularly of the DIP joints, with or without subchondral sclerosis), the severity of peripheral vascular impairment, and the skin involvement [34].

Moreover, flexion contractures are associated with dcSSc and high HAQ scores, reflecting a prominent disability. This is consistent with the tendency to fibrosis and functional impairment of the dcSSc. On its part, dcSSc subset is a predictor of the progression of flexion contracture [78].

Tendon friction rubs are associated with severe skin thickening, joint contractures, and cardiac and renal involvement [79] and highly predictive for scleroderma renal crisis. They may often precede widespread skin thickening, and their modifications predict changes in mRSS and HAQ over 6 and 12 months [4]. Thus, they are both associated with and predictors of a severe disease.

A strong relationship between skeletal *myopathy* and myocardial disease in SSc has been described [80, 81]. Patients with dcSSc frequently develop skeletal myopathy, those with pulmonary fibrosis being at a significantly higher risk [78].

DU predict the progression of acro-osteolysis and calcinosis, suggesting how these features, already found as associated with DU [78], may have a vascular background. DU are also regarded as predictors of internal organ involvement. In fact, patients with DU develop internal organ involvement 2–3 years earlier than patients without DU [57].

On the other hand, male sex, pulmonary hypertension and/or lower DLCO, dcSSc, early onset of SSc, presence of Scl70, and smoking are regarded as risk factors for developing DU [82, 83]. The combination of male gender, early RP onset, erythrocyte sedimentation rate (ESR) >30 mm, Scl-70 positivity, and gastrointestinal and pulmonary arterial involvement showed the highest probability of developing DU (88 %) [57].

Other correlations between disability of the hands, as assessed by different instruments, and clinical parameters are described in the following paragraph.

Evaluation of Hand Function

As manual function impairment has a role in determining global disability and QoL [24], ADL [25], work ability, and employment [26], it should be assessed and followed up in all SSc patients.

Throughout the years, several tools were used to evaluate disability in SSc patients (Table 6.1).

Table 6.1 Tools used to assess hand disability in SSc patients

Questionnaire used to assess global disability
HAQ
S-HAQ
SySQ
SAQ
Symptom burden index (SBI)
Tools to assess upper limb and manual disability in SSc
Questionnaires or tests not adapted to SSc
Arthritis hand function test (AHFT)
Disabilities of the arm, shoulder, and hand (DASH) questionnaire
Duruöz hand index (DHI)
Questionnaires or tests adapted to SSc
ABILHAND
Questionnaires or tests specific to SSc
UK scleroderma functional score (UKFS)
Hand mobility in scleroderma (HAMIS) test
Anthropometric measures to assess finger range of motion
Fist closure (finger to palm)
Delta finger to palm (FTP)
Finger extension
Hand anatomical index (HAI)

The questionnaires addressing global and district disability and organ impairment due to SSc also take into account the self-perceived impairment at upper limbs. However, in SSc tools specifically assessing upper limb and manual disability were also used. These include tools not adapted for SSc, instruments adapted to SSc, and tools specifically designed for SSc. Moreover, hand involvement was assessed by anthropometric measures.

Questionnaires Assessing SSc Global Disability

The disease index (DI) of HAQ (*HAQ-DI*), the most widely used questionnaire to assess and follow up disability in patients with rheumatic diseases, is used in the assessment of disability in SSc since 1991 [84]. It consists of a self-report questionnaire, organized in 20 items divided into eight categories: dressing and grooming, arising, eating, walking, personal hygiene, reaching, gripping, and other activities, thus including questions assessing fine movements of the hands, locomotor activities of the lower extremity, and activities involving both upper and lower extremities.

Each item is rated from 0 (no difficulty) to 3 (unable to do). A score for each category is the highest score for any question in the category. The DI is calculated by adding the scores from each category and dividing by the number of categories answered and rated from 0 (less disabled) to 3 (more disabled). HAQ-DI also contains a VAS used to report the pain experienced in the previous week.

In order to measure specific SSc symptoms, HAQ-DI was supplemented with 5 VAS by which the patient self-assesses how RP, DU, gastrointestinal symptoms, pulmonary symptoms, and overall disease severity interfere with daily activities (*S-HAQ*) [85].

Both HAQ and S-HAQ showed sensibility, reliability, validity, and responsiveness in clinical trials [86]. S-HAQ, although not specifically addressed to score hand function, assesses also the impact of RP and DU; thus, it should be preferred to HAQ in clinical practise to evaluate the self-perceived global disability and the microvascular hand symptoms in SSc patients.

Systemic sclerosis questionnaire (*SySQ*) is a self-administered instrument specifically conceived to cover SSc functional limitation and symptoms. It comprises 32 items grouped into 12 scales addressing general (pain, stiffness, coldness), musculoskeletal (complex functions, strength of hands, rising, walking), cardiopulmonary (shortness of breath, upper airway symptoms), and upper gastrointestinal symptoms (eating, swallowing, heartburn/regurgitation). All the items are scored from 0 to 3, and 7/11 items assessing musculoskeletal symptoms are derived from HAQ [87]. Although SySQ appears as a valid and reliable condition-specific measure in patients with SSc, able to cover a wide spectrum of general and organ-specific SSc symptoms and functional limitation, its use in daily practise and in controlled clinical trials is limited.

Scleroderma assessment questionnaire (*SAQ*) consists of 23 questions divided into four groups related to symptoms of vascular, respiratory, gastrointestinal, and musculoskeletal dysfunction. Answers are assessed on a 0–3 scale, and index of vascular status (IVS), index of respiratory status (IRS), index of gastrointestinal status (IGS), index of musculoskeletal status (IMMS), and index of disease status (IDS) are calculated. The scores of the single indexes are higher in patients with specific district or organ impairment. IVS score is significantly higher in patients with DU or acro-osteolysis or severe capillary damage. IMSS score strongly correlates with the mRSS and is significantly higher in patients with reduced hand motility, joint contractures, muscle weakness, or arthralgia/arthritis [88]. The scores of SAQ indexes are sensitive in detecting changes of symptoms over time in a 12-month follow-up [89]. For its ability in detecting self-reported symptoms and for its sensitivity in following up disease changes, SAQ appears as a promising tool for SSc evaluation, although, till now, it has been used only by one research group [88, 89].

Symptom burden index (*SBI*), a specific tool assessing in SSc the effect of problems in eight

major symptomatic areas of importance for the patients (skin, hand mobility, calcinosis, shortness of breath, eating, bowel, sleep, and pain), has been recently developed. Each problem area is measured independently by five items, each scored 0–10. The three most widely reported problem areas are pain, hand, and skin, experienced by the majority of the patients. SBI has good psychometric properties, but it should be evaluated more extensively in order to understand its feasibility [90].

Questionnaires Assessing Hand Disability Not Adapted to SSc

The *Duruöz hand index* (*DHI*) is a self-report questionnaire that contains 18 items assessing hand ability in the kitchen, in dressing, in performing personal hygiene and office tasks, and in other general skills. Each question is rated from 0 (no difficulty) to 5 (impossible to do), with a total score ranging from 0 to 90. DHI, taking about 3 min to be completed, is reliable and valid in RA [91] and OA [92].

Reliability and validity of the DHI [93] have been shown in patients with SSc, and its construct validity has been demonstrated in patients concurrently administered with S-HAQ and SF36. The total score of DHI explained 75 % of the variance of the HAQ [94].

The questionnaire is able to evaluate the differences between the patients presenting or not presenting hand involvement (arthralgias, arthritis, flexion contractures, and digital ulcers) and shows a strong correlation with HAQ scores [95].

More recently, the impact of DU on SSc disability and HRQoL was assessed by SF-36, HAQ, DHI, and global hand and wrist mobility. One-third of the patients had at least one DU at the time of evaluation. Patients with DU presented higher scores in HAQ, DHI, reduced hand and wrist mobility, and impairment in the mental component of SF36 [55].

Although nonspecifically created nor adapted for SSc, DHI should be useful in the clinical setting of scleroderma, because it is easy to understand for the patients and to be scored and able to individuate patients with musculoskeletal and microvascular impairment at the hand.

The arthritis hand function test (*AHFT*) is a performance-based test examining the ability to use hands during daily life tasks. It consists of 11 items including grip and pinch strength, dexterity, applied dexterity, and applied strength [96]. The AHFT, not specifically built for SSc, was shown to be reliable and valid to be used in patients with SSc [97].

The disabilities of the arm, shoulder, and hand (*DASH*) *questionnaire* is a 30-item, self-report tool designed to measure physical function and symptoms in patients with different musculoskeletal disorders of the upper limb. The Quick DASH is its shorter version. The strong correlations of the DASH and Quick DASH with the HAQ-DI, and with the scale assessing physical dimensions of the SF-36, show that the disability of SSc patients is mainly caused by the functional impairment of the upper limb. As both questionnaires are valuable in assessing upper extremity function and joint damage in SSc patients, the shorter and simpler Quick DASH may be used in everyday clinical practise [98].

Questionnaires Assessing Hand Disability Adapted to SSc

The ABILHAND questionnaire, developed using the Rasch model [99], offers the advantage of selecting and hierarchizing manual activities that patients with different diseases find as difficult to realize. Thus, SSc patients were administered with the original version of the questionnaire, including 81 manual daily activities, and asked about their perceived difficulty in performing each manual activity on a three-level scale: impossible, difficult, or easy. The 26 selected items defined a reliable, valid, reproducible, linear, and unidimensional measure to assess and follow up the manual ability of patients with SSc. The manual ability was significantly poorer in SSc patients with more severe disease and negatively correlated with the HAQ score.

Thus, the ABILHAND questionnaire could be regarded as a useful promising tool to follow up hand impairment and to assess treatment efficacy [100].

Questionnaires Assessing Hand Disability Specific for SSc

The UK scleroderma functional score (*UKFS*) is a self-administered 11-item functional questionnaire assessing daily activities within self-care and household chores, specifically built for SSc patients. Nine questions relate to upper limb function and two to muscle weakness and lower extremity function. It can be either self-administered or administered by an observer trained in functional assessment. Each item is scored from 0 (able to perform in a normal manner) to 3 (impossible to perform), and all items are summed, yielding a possible maximum score of 33 points [101].

In a study comparing UKFS to HAQ-DI and scleroderma VAS of S-HAQ, 68 % of dcSSc patients have moderate-to-severe disease on the UKFS, compared with 44 % with lcSSc. UKFS and HAQ-DI are significantly related, and both are higher in dcSSc than in lcSsc. The scleroderma VAS correlates with the UKFS and HAQ-DI only in the scales examining overall disease severity, respiratory symptoms, and pain. Several clinical and laboratory measures are associated with higher HAQ-DI and UKFS [102].

In a longitudinal study, the UKFS is able to capture clinically significant changes in SSc-related disability over time. The concurrent validity of the UKFS is asserted through its strong correlation with the HAQ-DI [103].

Thus, the concomitant use of UFKS and HAQ-DI in the daily practise may be useful in assessing and following up functional and global limitation in SSc patients. As both questionnaires can be self-administered, they could be included in the routine assessment of patients with SSc attending the outpatient clinic.

The hand mobility in scleroderma (*HAMIS*) *test* is a performance-based test, specifically created for SSc, found to be as a reliable and valid tool to assess hand function in SSc patients [104, 105]. It is composed by nine items, assessing in both hands finger flexion and extension, abduction of the thumb, dorsal extension and volar flexion of the wrist, pronation and supination of the forearm, and ability to make a thumb pincer grip and to make finger abduction. The different performance areas of HAMIS are composed of different sized grips and different movements, all related to tools and movements that are part of daily occupations. Each exercise is graded on a 0–3 scale (with 0: normal function and 3: inability to perform the task), with a total possible score of 27 for each hand.

HAMIS scores of both hands are related to DHI, finger-to-palm (FTP) distance, hand opening of homolateral hand, and HAQ. HAMIS scores are higher in dcSSc than in lcSSc patients. As demonstrated for DHI, the test is able to distinguish articular involvement, as higher scores are present in patients with hand arthritis and flexion contractures in respect to those not presenting these features [106].

Recently, the association between three tools used to quantify hand impairment (hand anatomic index—HAI, FTP, and HAMIS) and organ involvement has been evaluated in SSc patients. By a cluster analysis, on the basis of organ involvement, cluster A and cluster B, with minor and major extent of organ involvement, respectively, were identified. The extent of organ involvement and the hand impairment were related, and the scores of hand indices were lower in cluster B. Thus, the severity of hand impairment is associated with the extent of organ involvement [107].

An important characteristic of a clinimetric scale is its sensitivity to change and the ability to monitor the modifications over time of the assessed items. Recent evidences from the literature confirm that HAMIS test is able to follow up disease evolution and treatments [24, 25]. In fact, in a longitudinal study evaluating hand involvement and ADL in early SSc patients over time, HAMIS was the most sensitive tool in assessing changes in hand mobility [25]. Moreover, a work of our group showed that a 9-week rehabilitation protocol, treating hands of

SSc patients with connective tissue massage, Mc Mennell joint manipulation, and home exercises, was able to improve HAMIS scores, as well as FTP and DHI [24]. In SSc patients, HAMIS test, as well as DHI and FTP, was also improved by a 9-week physiotherapy program combining hand- and face-specific rehabilitation and global rehabilitation technique [108].

Anthropometric Measures of the Hands

The FTP distance, sometimes referred as fist closure, is the distance from the tip of the third finger to the distal palmar crease in maximal active flexion. It assesses (by a ruler, usually in centimeters) the distance between the tip of the pulp on the third finger and the distal palmar crease while the patient attempts to make a full fist (maximal finger flexion at all three finger joints: MCP, PIP, and DIP). Although recommended as a secondary outcome measure for clinical trials in SSc, the FTP has been validated in only one study [109]. To date, the FTP has been shown to be only a fair outcome measure [110].

The finger extension, defined as the distance between the third fingertip and the distal palmar crease while the patient attempts full finger extension, is seldom assessed in studies evaluating the mobility of hand in patients with SSc. In two recent works of our group evaluating the efficacy of rehabilitation programs tailored for patients with SSc, fist closure, but not finger extension, was improved at the end of rehabilitation periods [24, 108].

Recently, to assess more properly the range of motions of the fingers in SSc, *the delta FTP*, as a new measure of finger range of movement (ROM), was proposed. The delta FTP combines both finger joint flexion and extension and is calculated as the difference of the distance measured between the third fingertip and the distal palmar crease with fingers in full extension minus the distance with fingers in full flexion (FTP). Although the FTP provides a summation of flexion of all three finger joints (MCP, PIP, DIP) it does not represent full finger motion because limitations in finger extension are not considered. The delta FTP may help especially in assessing SSc patients with fingertips fixed in palmar flexion without the ability to extend, having a severe hand dysfunction but, paradoxically, showing a "falsely normal" traditional FTP measurement [111]. The delta FTP is a valid and reliable measure of finger motion in patients with SSc, which outperforms the FTP [111].

The HAI is a quantitative measure of hand deformity, defined as a measure of open hand span minus closed hand span/lateral height of hand. HAI, evaluated in SSc patients, was confirmed as a reliable measure, able to distinguish patients with increasing hand deformity and to separate patients with dcSSc and lcSSc. The HAI correlated significantly with HAQ, hand strength, and hand grip and accounted for 25 % of the total global disability (as measured by HAQ). Thus, in SSc, the HAI is a reliable and objective measure reflecting variable degrees of hand deformity and functional impairment [112].

Conclusions

In SSc patients, the function of hands is altered since the first phases of the disease due to the changes of skin and articular and periarticular structures and the involvement of microvasculature and peripheral nervous system, differently overlapping. For its high prevalence and its impact on daily chores, general disability, QoL, and working abilities, hand function should be taken into account, ruled out, and scored in all SSc patients by clinical examination, imaging methods, and questionnaires.

Hand function could be partially preserved and improved by medical therapies that may act on microvessels (both systemic drugs and local medications) [49] and by drugs acting on inflammatory articular involvement and arthralgia (ranging from NSAIDs to novel biological therapies) [113].

However, only rehabilitation may prevent and reduce the involvement of skin and periarticular tissues in the hand that leads to puffy fingers in the edematous phase and finger contractures and

claw-type deformities in the sclerotic and atrophic phases. From the results obtained in recent works, SSc patient rehabilitation should be global and tailored on disease phases and on patients' own necessities [108, 114]. Manual lymphatic drainage is efficacious in patients with edematous hands by improving hand mobility and local and global disabilities [3]. In patients with flexion contractures, home exercises of finger stretching [115] are useful, and, interestingly, a protocol including connective massage, specific exercises of hands, and Mc Mennell technique improves finger flexion and hand disability and ameliorates global disability and QoL [24].

Recently, a 12-week patient multidisciplinary intervention (including individual treatments, group exercises and group education, and outpatient clinic care) resulted in a greater improvement of grip strength, mouth opening, 6-min walking test, and HAQ and a moderate improvement of the HAMIS than regular outpatient care [116].

Summary

Hands are prominent targets of SSc, whose involvement (including skin, microcirculatory, and musculoskeletal changes) is early, evolves throughout the course of the disease, and leads to disability.

This chapter describes SSc hand involvement, focusing on dysfunction in different disease stages; relation between hand impairment and clinical parameters; and tools assessing hand function.

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Functional Assessment in Hand with Flexor and Extensor Tendon Injuries

7

K. Banu Kuran

Hand function is the ability to use the hand in daily activities. These daily activities are accomplished by various kinds of grips like cylindric, spheric, platform which require enough hand volume plus space and also by various kinds of precision grips which require dexterity together with power. The interaction between bones, joints, nerves, muscles, and tendons of the hand is essential for prehension. Tendon lacerations adversely affect normal hand function by disrupting the synergy between extension and flexion of the hand.

As the hand muscles contract, they shorten and exert force on the joints and bones by producing tension on the tendons. The tendons must glide proximally to transmit the tension and must glide distally to let the muscle to stretch or elongate. Hand function is the resultant of the harmony between muscle contraction and relaxation in an otherwise normally innervated, painless hand with an integrated bony architecture.

After tendon repair, the immature scar tissue attaches to the tendon and moves with it during hand motion. The immobilized tendon loses gliding function due to peritendinous adhesions starting from the first 10 days after repair. Several contributing factors have to be considered to the formation of adhesions around the flexor tendons that travel within the fibro-osseous digital sheath. Tendon sheath injury, tendon suture, edema, and postoperative immobilization are unavoidable consequences of the injury and the repair process.

For optimum function the bond between the tendon and the scar tissue should be broken by applying force through various exercises. The outcome of tendon gliding is experimentally described as tendon excursion and clinically described as joint range of motion (ROM). Tendon excursion is mainly limited by adhesions within the digital fibro-osseous sheaths and extensor retinaculum.

The repaired tendon also loses tensile strength in the first two weeks after repair. While 50 % of the repair strength decreases in the first postoperative week, 20 % is lost at the end of the sixth week. The decrease in the tensile strength causes tendon gapping if an uncontrolled stress is applied during mobilization of the tendon. Tendon gapping more than 2 mm causes friction which prevents gliding and rupture [1].

Evaluation of Function in Flexor Tendon Injuries

Superficial and profundus flexor tendons originate from the muscles in the proximal one-third of the forearm. In the carpal tunnel and in the digits and thumb, they are surrounded by a synovial sheath. Flexor pollicis longus has its own sheath called the radial bursa. The synovial sheath which surrounds the flexor tendons in the carpal tunnel

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continues to the small finger and forms the ulnar bursa. The index, middle, and ring fingers have their own digital synovial sheaths.

The fibro-osseous tunnel extends from the metacarpal heads to the distal phalanx. The flexor retinaculum is thickened and oriented transversely to form five annular pulleys. Between them, there are three cruciform ligaments. Their function is to hold the tendons close to the bone. The superficial and profundus tendons enter together into the fibro-osseous tunnel with superficialis lying volar to the profundus. At the proximal phalanx level, the superficial flexor divides into two slips, allowing the profundus to travel in between. The two slips join dorsally in a chiasm (Camper's chiasm) at the level of the proximal interphalangeal joint.

Normal tendon function requires free gliding of the tendon without hindrance from surrounding tissues. The tendon must also be strong enough to withstand the normal forces without rupture or gap formation due to unnecessary elongation. Following a flexor tendon injury, active and passive range of joint motion is evaluated to assess smooth gliding. If active joint flexion is less than the passive joint flexion, tendon may not be strong enough to flex the joint or it may have been elongated. If distal joint flexion is possible when the proximal joints are held in extension and it is impossible when the proximal joints are in flexion, then limitation in the excursion of the tendon may be the problem.

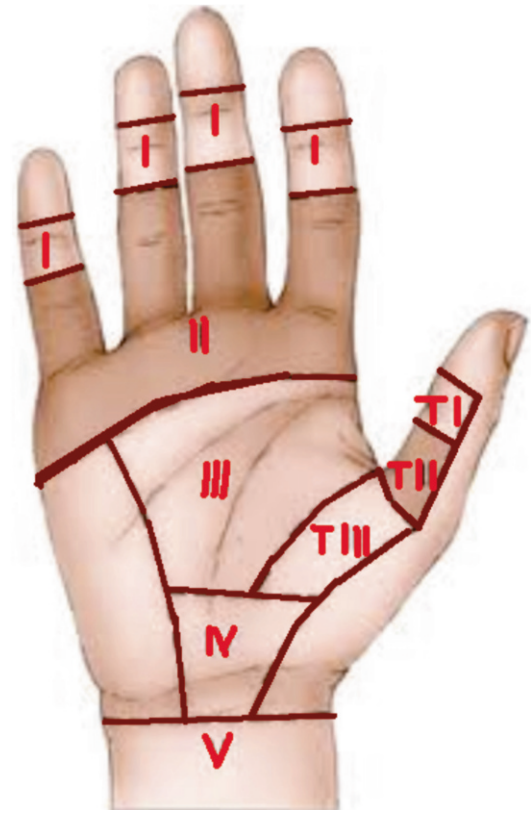

Fig. 7.1 Flexor tendons are divided into five zones according to the International Federation of Societies for Surgery of the Hand (IFSSH). Zone I is from the insertion of FDS to the insertion of FDS at the base of the distal phalanx. Zone II begins proximally from the digital synovial sheaths and extends to Zone I at the middle phalanx. Zone III begins proximally from the flexor retinaculum at distal carpal row. Zone IV is known as the carpal tunnel that overlies flexor retinaculum. Zone V is the distal third of the forearm. Thumb, which has FPL as the flexor tendon, is also evaluated by the corresponding zones

Description and Functional Significance of Flexor Tendon Injuries (Fig. 7.1)

Zone I

Zone I extends from the terminal portion of the FDS insertion on the middle phalanx to the tip of the finger where FDP inserts. It contains only one flexor tendon, FDP, which is the flexor of the DIP joint. A4, C3, and A5 pulleys are found in zone I. A4 pulley is the most functionally significant pulley in this zone. It is function is to provide a moment arm for FDP and prevent bowstringing of the tendon. It may also contribute to DIP flexion contracture if resected. FDP is the dominant flexor of the digits in composite flexion of all fingers. While FDS is more important in powergrip and is essential for finger flexion when the wrist is flexed, loss of distal joint flexion of the index or long finger compromises pinch activities that necessitate precision. The loss or limitation of distal joint flexion may adversely affect people like musicians and tailors who has to work meticulously. On the ulnar side, FDS tendon of the fifth finger may congenitally be absent. In this case, the role of FDP in flexion of the little finger

is much more appreciated. If lacerated FDP tendon is not repaired, it may retract proximally and block FDS function. In this case PIP joint may not flex beyond 90°. Retracted FDP tendon may also pull proximally and increase the tension on the lumbrical muscle from which it originates. In this case lumbrical muscle contraction increases and upon finger flexion, PIP joint extends causing the "lumbrical plus" deformity [1].

Functional outcome following tendon injury is determined by active IF joint flexion and calculated by the following formula [2].

$$\text{PIP} + \text{DIP flexion-extensor lag} \times 100 = \frac{\%\text{normal PIP} + \text{DIP flexion}}{175°}$$

Result is expressed as excellent (>150° or 85–100 % of normal motion), good (125–149° or 70–84 %), fair (90–124° or 50–69 %), and poor (<90° or less than 50 % of normal motion).

Undesired results after FDP repair in Zone I injuries are limited excursion of FDP tendon, repair site gapping, unsatisfactory distal joint flexion, PIP flexion contracture, and incomplete FDS glide. In the case of limited FDP excursion, distal interphalangeal joint may actively be flexed if PIP joint is held in extension. If PIP joint is left free, the excursion of FDP may not be enough to flex all IP joints and joint motion is limited. If the DIP joint extends freely when the wrist and MP joints are flexed but begins to flex when the wrist is extended while MP joint is still in flexion, this means that FDP is tight or tethered by the surrounding tissues. In the case of an adherent FDP tendon, the tendon can neither actively glide during fisting nor passively glide in passive composite hand extension.

In order to prevent tightness, the profundus tendon should not be advanced more than 1 cm during surgery.

Distal joint motion is essential to maintain differential glide between FDP and FDS. If FDS cannot glide freely and PIP joint is not allowed to move 90° between full extension and flexion by early mobilization, flexion contracture at the PIP joint may develop. PIP joint is also more prone to flexion contracture than DIP joint because of the presence of a volar plate which is tightly attached to the bone. Volar plate is less distinct in DIP joint.

Without differential gliding between the flexor tendons, combined IP joint function is not satisfactory. It has been shown that at least 35° of DIP motion is necessary to provide 3–4 mm differential gliding of the FDP on the FDS and to prevent adhesion formation [3]. Among other fist positions, hook fist position provides the greatest differential excursion between the two tendons. Meanwhile, one should also be aware that MP joints should be placed at 30° of flexion to reduce the pull of lumbrical muscles on the profundus tendon.

Following FDP repair, flexion contracture of the DIP joint may lead to swan neck deformity with hyperextension of the PIP joint. Flexion contracture of the DIP joint puts the extensor mechanism under great tension. The lateral bands of the extensors apparatus move dorsally and exert an extension effect on the PIP joint rather than the DIP joint. Lumbrical and interosseous muscles are also extensors of the PIP joint. Normally volar plate and the flexor superficial tendon act to balance the extension forces. As the DIP joint contracture increases, superficial flexors, with the help of the tight lateral bands, overcome the strength of the central slip that extends the middle phalanx, especially in the case of a slack volar plate [4].

Zone II

Zone 2 is the region between the beginning of the separate digital synovial sheath and insertion of FDS tendon. The fibro-osseous tunnel that overlies the synovial sheath of the tendons includes the annular pulleys A1, A2, and A3 and cruciate pulleys C1 and C2. These pulleys guide tendon gliding by keeping the tendon close to the phalangeal bone.

Following flexor tendon injury in Zone 2, the main problems are restricted PIP joint flexion due to insufficient tendon gliding, gap formation between the repaired ends of the tendon, flexion contracture of the PIP joint, or lumbrical plus position upon attempted flexion. To provide the

most optimal result, both superficial and profundus tendons are advised to be repaired. This zone requires that the surgeon knows the flexor tendon anatomy, is aware of the suture techniques that provide a strong repair, and that he tries very hard to preserve all pulleys of the flexor retinacular sheath.

One of the methods to measure the degree of adherence is to measure the lag of the tendon. The lag is defined as a percentage (%) difference between passive ROM (PROM) and active ROM (AROM). If there is a minimum 15 % difference between PROM amd AROM, the difference is defined as the lag [5].

Zone III

The synovial sheath of FPL and of the flexors of the fifth finger continues respectively as the radial and ulnar bursae. Injuries in this zone have favorable outcomes since this zone is out of the digital fibro-osseous sheath, but adhesions to adjacent tendons, lumbricals, and interossei are expected. One of the most common injuries that may accompany tendon injuries is digital nerve lacerations.

Zone IV

This is the carpal tunnel zone where the tendons travel in the vicinity of the flexor retinaculum. Flexor retinaculum protects the superficial and profundus flexor tendons as well as the median and ulnar nerves, ulnar artery, and the superficial palmar arch. Since this region is protected by bony tuberances and the carpal ligament, injury is less often encountered. Yet intertendinous adhesions between the flexor retinaculum and tendon sheath that limit differential glide occur quite often and may compromise individual digit function. Bowstringing due to the insufficiency of transverse carpal ligament on attempted wrist flexion may also be a problem.

In the case of tendon laceration, if surgery is not undertaken primarily, muscles may retract proximally which may hinder end-to-end anastomosis of tendon ends.

Zone V

Zone V is the region proximal to the transverse carpal ligament. In this region FPL and FDP form the deep muscle layer on the volar surface of the forearm. The profundus tendon divides into two bundles: the radial bundle that goes to the index finger and the ulnar bundle that goes to the last three digits. Profundus tendons move as a unit. There are adhesions between the tendon and paratenon, overlying skin and fascia.

Extensor Tendons

Since grasping an object has been considered more important than dropping it and due to the very delicate balance between the superficial and profundus flexor muscles which causes serious problems perioperatively and postoperatively, flexor tendons have gained more attention than extensors. Injuries of the extensor tendon are usually underestimated although opening the hand is necessary during manipulative activities. Among impaired grip ability, various joint deformities may develop following extensor tendon injuries. When flexor tendons which are more powerful than extensors work unopposedly in the absence or weakness of extensors, flexion contracture of the finger joints is inevitable.

Extensor tendons are relatively thin and broad structures. They have a large surface area and travel very close to the skin. These factors make them easily vulnerable and prone to restricted scar formation.

If finger extension is restricted due to the adhesions, active extension lag may occur. Active extensor lag is defined as a loss of full active extension of a digit when passive extension of the finger exceeds the active motion.

Extrinsic extensor tendons of the hand originate from the lateral epicondyle. At the wrist level, extensor tendons are covered by a fibrous sheath called the extensor retinaculum and travel in six separate compartments formed by septa from the superficial layer of the extensor retinaculum. By these vertical separations, the extensor tendons are positioned and maintained in accordance with

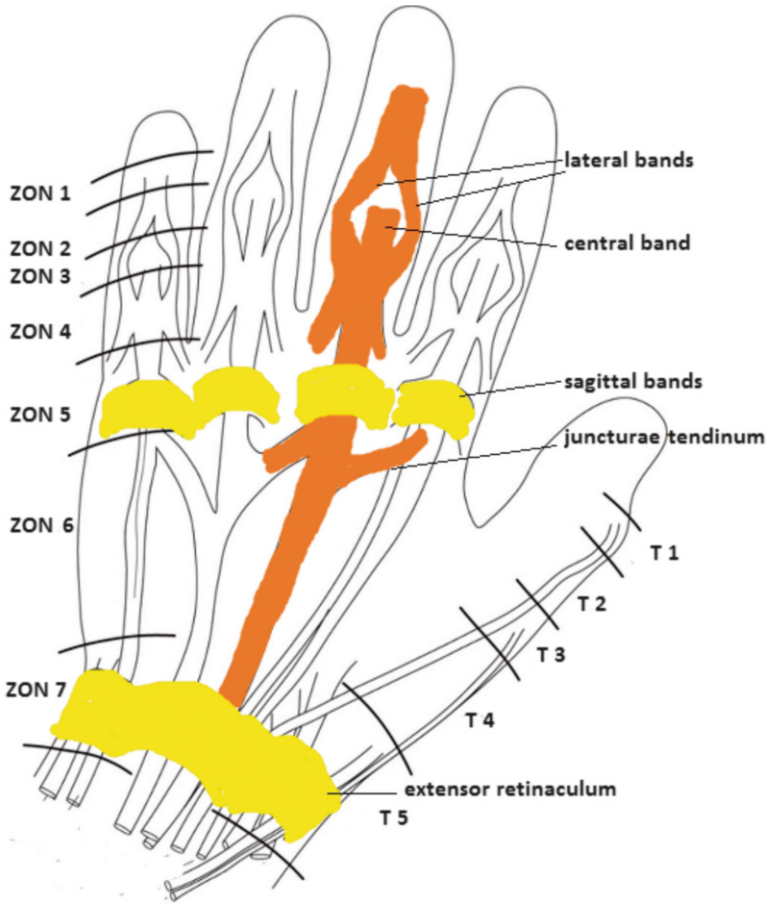

Fig. 7.2 Extensor tendons are divided into eight zones. Zones with odd numbers (1, 3, 5, 7) cover joints; zones with even numbers cover the tubular bones: Zone 1 : DIP joint, Zone 2 : Middle phalanx, Zone 3: Proximal interphalangeal joint, Zone 4: Proximal phalanx, Zone 5: MCP joint, Zone 6: Metacarpal bones, Zone 7: Extensor retinaculum, Zones 8 and 9: Forearm level; musculotendinous junction and muscle bellies

the axis of wrist motion [6]. The tendons that travel in the six compartments are as follows (Fig. 7.2):

Compartment 1: Abductor Pollicis Longus (APL) and extensor pollicis brevis (EPB)

Compartment 2: Extensor Carpi Radialis Brevis and Longus (ECRB, ECRL)

Compartment 3: Extensor Pollicis Longus (EPL)

Compartment 4: Extensor Digitorum Communis (EDC), Extensor Indicis Proprius (EIP)

Compartment 5: Extensor Digiti Quinti Proprius (EDQP)

Compartment 6: Extensor Carpi Ulnaris (ECU).

The deep layer forms the floor of the 4th and 5th compartments. On the ulnar side, superficial and deep layers are not attached to each other to allow free rotation of ulna during pronation and supination.

The skin and fascia over the dorsum of the hand is loose during extension and tightens during finger flexion. As it tightens, it compresses the underlying veins and lymphatics and serves as a pump for an efficient venous and lymphatic drainage. At the metacarpal level they are very close to the skin and hence very vulnerable to any kind of blunt or sharp trauma including human bite. Extension of the MCP joints is accomplished by extensor digitorum communis, and due to the fibrous connecting bands within the common extensor muscle belly, independent

extensions of the index, middle, and little fingers are lacking. On the other hand, index and little fingers are also supplied by separate muscle bellies that extend these fingers irrespective of the flexed position of the other fingers [7]. At the metacarpal head level, extensor tendons are connected with each other via juncturae tendinea which keeps the tendons together as they glide distally upon flexion of the MCP joints. Juncturae tendinum which emerges from the ring finger extensor tendon helps extension of middle, ring, and little fingers by transmitting the extension force. At the MCP joint level, horizontal sagittal bands attach to the ulnar and radial side of the joint to stabilize and centralize the tendon. As the MCP joint flexes beyond 60°, extensor tendons displace ulnarward. It is the sagittal band that prevents further displacement to the ulnar side of the hand.

On the base of the proximal phalanx, the intrinsic muscles (lumbricals and interosseous) join the common extensor tendon. While the medial interosseous slip assists in flexion of the MCP joint, the lateral slip unites with the lumbrical on the radial side and contributes to PIP joint extension as well as MCP joint flexion.

PIP joint extension is accomplished by the extrinsic extensor tendon as well as the contribution of lumbricals and interosseous muscles. On the proximal phalanx the extensor tendon divides into three bands, two lateral and one central band. The central band attaches to the proximal and dorsal part of the middle phalanx. The right and left lateral bands that coalesce with the lateral slips from the intrinsic muscles insert to the base of the distal phalanx as a single terminal tendon. The triangular ligament connects the converging lateral bands and prevents them from luxating volarly. The transverse retinacular ligaments are located on the palmar side of the lateral bands and prevent them from luxating dorsally.

According to the anatomic and physiologic characteristics, extrinsic extensor tendons are divided into seven zones by the Committee on Tendon Injuries for the International Federation of the Societies for Surgery of the Hand [8].

Description and Functional Significance of Extensor Tendon Injuries

Zone I and II

Zone I is the area over the DIP joint, and Zone II is the area over the distal phalanx distal to the PIP joint. When an injury at the level of DIP joint disrupts the terminal extensor tendon, extensor forces concentrate on the PIP joint, and FDP pull on the DIP joint remains unopposed. The resulting deformity is flexion in the DIP joint, called Mallet deformity and hyperextension at the PIP joint. Transposition of dorsal lateral bands and the yield of the palmar volar plate at the PIP joint further increase the deformity. The lesion may be purely related to the tendon, or an avulsion fracture of the distal interphalangeal joint may be associated. In closed injuries, if loss of active extension may be corrected passively, the lesion is purely a tendon lesion and treated conservatively by 6 weeks of uninterrupted splinting. In the case of an articular fracture that involves >50 % of the joint surface, reapproximation of the distal and proximal fragments may be performed by a K-wire. Open injuries that include the laceration of the terminal tendon are also treated by pinning [9].

Flexion deformity of the DIP joint is associated with some complications like extension lag, scarring of the terminal tendon, restriction of the DIP joint flexion due to tendon scarring, ischemia of the dorsal skin apparent upon passive hyperextension of the DIP joint, maceration of the dorsal skin during the immobilization period in the splint, thinning of the overlying skin, nail bed and pulp problems.

Zone III and IV

Zone III is over the middle phalanx, and Zone IV is over the PIP joint. Interruption of the extensor tendon at the PIP joint may result from traumatic, mechanic, and inflammatory causes.

Primary extensor of the PIP joint is the central tendon. Lateral bands of the extrinsic extensor tendon assist in extension by displacing dorsally. Intrinsic tendons also contribute to PIP extension while flexing MCP joint. The multiple points of connection between the intrinsic and extensor mechanism at Zone IV prevent tendon shortening due to repair. During mobilization, less force is required to flex the PIP joint.

Following injury to the central tendon, terminal extension (last 15–20°) of the PIP joint is lost. Besides central tendon disruption, edema following injury also contributes to the flexion of the PIP joint. PIP joint is more comfortable in the flexed position. Skin over the dorsum of the PIP joint is distended in cases of increased edema formation. While dorsal skin requires 12 mm of lengthening for 90° of flexion, it requires 19 mm of lengthening for the same joint range in the presence of 5 mm edema. The collection of fluid may thus cause an increased demand on the central tendon by adding extra tension, decrease the strength of the repair, and also cause lagging of the repaired extensor tendon.

To test the integrity of the central tendon, wrist and MCP joints are kept in flexion, and the patient is asked to extend the PIP joint actively. Failure to fully extend the PIP joint is a sign of central tendon injury. If central tendon is interrupted, the extensor tension slides proximally, leaving the flexor superficialis tendon pull unopposed. This unopposed tension in the superficial flexor tendon displaces the lateral tendons palmarly and increases the flexion in the PIP joint. The deformity where the PIP joint is in flexion and DIP joint is in hyperextension is called the boutonniere (buttonhole) deformity. If the triangular ligament which keeps the lateral bands together on the dorsal surface of the phalanx is also torn, palmar displacement of the lateral bands is inevitable, and this movement further accentuates the PIP joint flexion. The joint moves upward through the defect in the extensor apparatus as a button that passes through the hole. If PIP joint can be extended passively and passive DIP flexion is possible when PIP joint is in extension, this means that lateral bands may be positioned dorsally. In this case, nonsurgical treatment can proceed.

In the case of a fixed deformity where volarly displaced lateral bands are tight and have coalescence with the joint capsule and collateral ligaments, PIP joint cannot be passively extended. DIP joint hyperextends in response to contracture of the oblique retinacular ligament. Established fixed deformities are difficult to treat.

As the flexion deformity at the PIP joint increases, the degree of functional impairment also increases. A flexion deformity more than 30° is associated with significant loss of DIP joint flexion. At least 6 weeks of continuous splinting with the PIP joint in neutral position while DIP joint is allowed to flex actively should be considered initially.

Zone V

Zone V is the area over the MCP joint. There is a direct relation between extensor tendon excursion on the dorsal side and the motion of the MCP joint. Extensor tendons which have an excursion of 2 mm with PIP joint motion have an excursion of 12–15 mm for an average of 90° of MCP joint motion in this zone. The extensor strength generated by the extensor tendons over the proximal phalanx is 2.99 kg for the index finger and decreases ulnarly to 1.97 kg for the small finger. These forces depend on the position of the wrist and while increasing in wrist extension decrease with wrist flexion. During mobilization of the joint after tendon surgery, 300 g of force is required to extend the MCP and PIP joint for 30°. During the rehabilitation period, extensor tendon should be mobilized with enough tension that will not form gapping and also should displace 10–15 mm without being limited by adhesions for a functional ROM.

Zone V is one of the most frequently injured sites on the dorsal hand where bony structures and soft tissues may extensively get injured. Injuries like “fight bite” are common and prone to contamination by mouth flora and hence infection besides tendon laceration.

Nonfight injuries due to blunt traumas or MCP joint synovitis in arthritic diseases like rheumatoid arthritis may disrupt the sagittal band and cause ulnarward luxation of the extensor tendon during flexion. Upon active extension MCP joint angulates to the ulnar side and is associated with finger supination. Injuries at this level are classified into three types:

Type I involves contusion without a tear, Type II involves subluxation of the extensor tendon within the borders of the bone, and Type III involves displacement of the tendon between the metacarpal heads. It becomes difficult for the patient to achieve full extension, and progressively tightness develops in the extensor tendons and surrounding structures that accentuates ulnar deviation deformity [10].

Zone VI

In this zone extensor tendons travel over the metacarpals. They have a large surface area and are connected by the bands called juncturae tendinum which transmit extensor forces. Both of these structures and the confinement of the dorsal fascia are the reasons of severe adhesion formation at Zone VI. The peritendinous scar tissue that forms after the injury is inelastic and restricts the excursion of the extensor apparatus. If the scar is fixed to the dorsal fascia, interphalangeal joints extend passively as the metacarpophalangeal joints come into flexion. Flexion of the PIP joints extends the MCP joints passively. MCP and PIP joint cannot be flexed simultaneously. This tenodesis is called the extensor plus phenomenon.

Another factor that may cause limited excursion is the suture that brings the lacerated tendon ends together. The average repair in zone VI shortens the tendon almost 7 mm and this acquired shortness is another factor that necessitates early mobilization during rehabilitation. While approximately 600 g of force is required for maximum finger flexion, increased tension may cause tendon elongation and gapping.

Zone VII

Injuries at Zone VII are at the level of wrist and involve the extensor retinaculum. Extensor retinaculum covers the fibro-osseous tunnels which contain the extensor tendons. Wrist motion is very important for extensor tendon glide. 31 mm of the extensor tendon glide which has a total displacement of 50 mm is provided by wrist flexion and extension. The same ratio is true for the thumb extensors as well. Extensor pollicis longus tendon, which has a total excursion of 58 mm, displaces 35 mm with wrist motion.

The close relationship between the extensor tendons and the retinacular system causes skin adherence and restrains scar formation that blocks tendon glide. If the adhesion is proximal to the extensor retinaculum, simultaneous wrist and finger flexion is limited. Wrist flexion invokes a tenodesis effect, and fingers extend prematurely. If the adhesion is distal to the extensor retinaculum, simultaneous wrist and finger extension is limited. In order to extend the wrist, fingers must flex first.

Impairment of Hand Function due to Tendon Injuries

Impairment is defined as the deviation from normal in a body part and its functioning. In the upper extremity, tendon injuries may diminish the capacity of an individual to carry out daily activities [11]. Hand flexor and extensor tendons may be injured by trauma, inflammation as in rheumatoid arthritis, or by constricting tenosynovitis. Traumatic injuries may be crushing, sharp, or dull. Crushing or blunt injuries usually harm the surrounding tissues and also the vascular supply of the tendons which may impair the healing of the tendon. Formation of adhesions is also more common after crushing injuries. Sharp injuries may result with more isolated tendon lacerations. Additional injuries like bone fractures, pulley, sheath, and neurovascular bundle lacerations, complete cuts rather than partial lacerations, and involvement of more than one

tendon (including superficial and profundus tendons) are factors that negatively affect healing and prognosis of tendon function.

Tendon injuries may affect the anatomic, cosmetic, and functional status of the hand. Hand has a posture that is related with the transverse arches formed by carpal and metacarpal bones and with the longitudinal arches that are formed by the digital rays. Among skeletal system, the status of the tendinous system is very important in the preservation of the normal hand posture. Hand, with the thumb ray on one end and the ring and little finger rays on the other end, must open widely on the stable index and middle finger rays to grasp large objects. Longitudinal arch that has been formed by the phalanges and metacarpal bones is especially necessary for pinch and precision activities. Muscles, tendons, and other soft tissues are supporters of this bony construction and prevent it from collapsing. They also provide the flexibility of the hand. Tendon laceration, rupture, inflammation, or any other kind of disorder that prevents proper tendon functioning may distort wrist and finger joint motion and adversely affect the strength and dexterity of the hand.

Joint inflammation, the pathognomic feature of inflammatory diseases like rheumatoid arthritis, may result with extensor tendon subluxation that causes ulnar deviation and intrinsic muscle tightness. Tendon ruptures that are the consequences of bony attritions developed by synovitis are also commonly observed in rheumatoid hands. Pain which is usually associated with inflammatory or stenosing tenosynovitis is another contributing factor for diminished hand function.

Impairment may be measured by joint ROM, grip and pinch strengths.

Disability After Tendon Injuries

Tendon injuries may result in a certain disability. Disability means that the individual's capacity to meet his/her personal, social, or occupational demands has decreased and he/she has inability to perform some tasks. The patient may also be handicapped which means he/she has inability to participate in normal roles. A tendon injury impairs the physiological functioning of the affected musculotendinous unit in the hand. Injuries may be complicated and usually are not isolated only to the tendon. Preoperative evaluation which includes the nature and location of the tendon laceration and the presence of additional injuries is important with respect to both surgical reconstruction and the recovery of function after the repair. The severity of the injury is assessed preoperatively and classified according to Boyes' method [12]:

Preoperative evaluation (Boyes)	
Grade	Preoperative condition
I	Good, minimal scar and mobile joints
II	Notable scar tissue formation, mild contracture
III	Joint damage with decreased passive/active ROM
IV	Nerve damage
V	Multiple system injury (combination of II, III, and IV)

According to ICF, body function and body structure that has been affected in tendon injuries are ROM, strength, and tendon integrity. Activity and participation of the individual is measured by his/her capacity and performance. While outcome measures of capacity are dexterity and functional tests, activities and self-reported actual roles are the outcome measures of performance. Besides the severity of the injury, age-related changes, psychosocial factors like symptom magnification, painful conditions like complex regional pain syndrome or arthritis may adversely affect objective evaluation. Due to these limitations, evaluation of hand function in an injured patient should frequently be repeated and filtered by the objectivity of the examiner.

Examination of Range of Motion

Motion is the primary physical impairment resulting from a tendon injury. The arc of motion of finger joints is defined by two numbers that

represent the extremes of extension (the numerator) and flexion (the denominator). By using a 180-degree finger goniometer for the fingers and 360-degree universal goniometer for the wrist, 14 finger joints and the wrist joint should be measured and assigned a numerator and a denominator. Ulnar and radial deviation of the wrist and metacarpophalangeal joints may also be recorded. ROM measurements of the finger joints are taken by placing the goniometer laterally on the midaxis of the adjacent phalanges. If swelling and/or finger deformity is not apparent, the goniometer may also be placed on the dorsum of the finger joint. Both active motion done by the patient and passive motion done by the examiner should be recorded to estimate tendon lag, gapping, or lack of patient compliance. While active flexion and hyperextension are positive, extension deficits are represented by a minus sign. The recordings are compared with the normal values of the uninjured hand and expressed as the percentage of the normal value [13].

A number of rating systems are available which have been mostly developed for studies on flexor tendons. Some commonly used measurement systems are listed below (Table 7.1) [14]. These systems can be applied to both flexor and extensor tendon injuries since they assess both flexion motion and extension deficits. Total active motion (TAM) is usually measured while the hand is in the composite grip position. If the involved joints form the major component of the score, for example in zones III, IV, and V, it is logical to include active motion of all three finger joints (MCP, PIP, DIP) and then combine them to have the TAM. For zone II injuries, the MCP joint is not affected, and the focus is on the PIP and distal interphalangeal (DIP) joints. In zone I or thumb injuries, the focus is only on the distal joint. The outcomes after surgery and rehabilitation may be reported as the percentage of normal.

Another method to measure finger motion is Boyes' linear measurement from the fingertip to the distal palmar crease. Swanson has further calculated combined angular impairment and correlated it with linear measurement of Boyes. Finger flexion degree is measured for each joint and combined impairment is calculated by the formula $A\ \% + B\ \% \ (100\ \% - A\ \%)$ where A represents the MCP joint and B represents the PIP joint. The sum is the A for next calculation where B is the DIP joint. The correlation between angular impairment and linear measurement is such that a 2-cm lack of flexion from fingertip to palmar crease corresponds to 30 % impairment and a 4-cm one corresponds to 53 % impairment.

Excursion of flexor pollicis longus tendon is evaluated according to different criteria (Tables 7.2–7.4).

Evaluation of Strength

Strength is related to the cross-sectional area of the muscle fibers and distance through which it can be used. This distance is called the excursion of the muscle. The strength also depends on the number of joints it crosses and how far the tendon is from the joint axis. Grip strength reflects the global impact of the injury, including tendon, nerve, vessel, and bone. It is assessed according to a standard method recommended by the American Society of Hand Therapists. Grip strength is usually measured by Jamar dynamometer which is a sensitive and repeatable test instrument. The elbow should be at 90° flexion, the forearm should be in neutral position, and the fingers should be placed in the second handle position. Similarly, Haldex orthotic gauge can be used to measure the strength of the individual finger. In order to eliminate subjectivity, patient is asked to maximally contract his/her hand muscles three times with a few seconds of interval between each trial. The injured hand may be compared with the opposite uninjured hand, or the difference between the initial and follow-up values may be compared [18].

Assessment of Disability and Patient Satisfaction

Disability after extensor tendon injuries depends on the complexity and severity of the injury, involvement of the dominant hand, complications due to the injury or surgery, compliance

Table 7.1 Methods for assessment of flexor tendon outcome in the fingers [13]

Fingers				
The Louisville method	Grade1	Grade 2	Grade 3	Grade 4
Pulp to distal palmar crease	0–1 cm	1.1–1.5 cm	1.5–3 cm	3 cm+
Extension deficit	0–15°	16–30°	31–50°	50°+
Excellent: both deficits grade 1		*Good: both deficits at grade 2*	*Fair: both deficits at grade 3*	*Poor: either deficit worse than grade 3*
Total active motion (TAM) method ASSH	TAM = (MCP + PIP + DIP)			
	Active flexion (MCP + PIP + DIP) − extension deficits (MCP + PIP + DIP)			
	Expressed as percentage of the normal contralateral finger (for which TAM = 260 (80 + 110 + 70)			
Excellent: 100 %		*Good: >75 %*	*Fair: >50 %*	*Poor: <50 %*
Zone II				
Strickland I and II	TAM = (PIP + DIP)			
	Active flexion (PIP + DIP) − extension deficits (PIP + DIP)			
	Expressed as percentage of the hypothetical normal finger (for which TAM = 175			
I. Original				
Excellent:. 85–100 % or >150°		*Good: 70–84 % or 125–149°*	*Fair: 50–69 % or 90–124°*	*Poor: <50 % or <90°*
II. Adjusted				
75–100 % or >132°		*50–74 % or 88–131*	*25–49 % or 45–87°*	*<25 % or <44°*
Buck-Gramcko	Fingernail to distal palmar crease	0.0–0.5 cm	6 points	
		0.6–1.5 cm	5 points	
		1.6–2.5 cm	4 points	
		2.6–4.0 cm	3 points	
		4.1–6 cm	2 points	
		>6.0 cm	0 points	

(continued)

Table 7.1 (continued)

Fingers				
The Louisville method	Grade1	Grade 2	Grade 3	Grade 4
	Total extension lag	0–30°	3 points	
		31–50°	2 points	
		51–70°	1 point	
		>70°	0 points	
	Modified TAM	>400°	8 points	
	(MCP + 2PIP + 3DIP)	>320°	6 points	
		>280°	4 points	
		>240°	2 points	
		<240°	0 points	
Excellent: 16–17 points	*Very good: 14–15 points*	*Good: 11–13 points*	*Fair: 7–10 points*	*Poor: 0–6 points*
Zone 1				
Moiemen–Elliot	TAM = (DIP)			
	Active flexion (DIP) − extension deficits (DIP)			
	Expressed as percentage of the hypothetical normal finger for which TAM = 74			
Excellent: 85–100 % or >62°		*Good: 70–84 % or 52–62°*	*Fair: 50–69 % or 37–51°*	*Poor: <50 % or <37°*

Table 7.2 Evaluation of recovery of the FPL according to the criteria of Buck-Gramcko et al. [15]

	Degrees	Points
Flexion of IP joint	50–90	6
	30–49	4
	10–29	2
	<10	0
Extension deficit	0–10	3
	11–20	2
	21–30	1
	>30	0
Total active movement	>40	6
	30–39	4
	20–29	2
	<20	0
Evaluation		
Excellent: 14–15		
Good: 11–13		
Fair: 7–10		
Poor: 0–6		

Table 7.3 Evaluation of the recovery of the FPL according to the criteria of Tubiana et al. [16]

	Degrees	Assessment
Flexion of IP joint	>60	F1
	>30	F2
	<30	F3
Extension deficit	<15	E1
	<30	E2
	>30	E3
Evaluation		
Excellent: F1E1		
Good: F2E1		
Fair: F3E1 or F2E2		
Poor: F3E2 or E3		

Table 7.4 Evaluation of FPL recovery according to Fitoussi [17]

	Degrees	Points
Flexion of IP joint non-injured side–flexion of IP joint of involved side	0–20	6
	21–40	4
	41–50	2
	>50	0
Extension deficit (comparison with contralateral side)	0–10	3
	11–20	2
	21–30	1
	>30	0
Evaluation		
Excellent: 8–9		
Good: 6–7		
Fair: 4–5		
Poor: 0–3		

with rehabilitation program, and requirements of daily living or occupation.

In hand rehabilitation, patient-centered care and patient satisfaction related with the disability are as important as other test instruments that measure the physical properties of the hand. It is an essential part of the outcome evaluation. Some of the most commonly used generic and specific evaluation tools that may be used to measure upper extremity dysfunction are *Medical Outcomes Study (MOS) 36-Item Health Survey (SF-36), the Upper Extremities Disabilities of Arm, Shoulder, and Hand (DASH), Patient Evaluation Measure (PEM), Michigan Hand Outcomes Questionnaire, and Duruöz Hand Index (DHI).*

Short-Form 36 (SF-36) which is a part of MOS measures general health status. It is composed of 36 questions related to everyday life [19]. *DASH* consists of 30 items that are rated from 1 to 5. It is designed to measure the level of disability experienced by a patient and record differences in symptoms and functional ability [20]. *QuickDASH* is the short version of the DASH and includes 11 items. It is responsive for most of the upper extremity pathologies including ulnar-sided wrist problems and distal radius fractures. Social and emotional health is also evaluated extensively by DASH.

PEM consists of three sections on treatment and overall assessment. Scoring is done by using a visual analogue format and expressed as a percentage of the maximum score possible [21].

Michigan Hand Questionnaire is a hand-specific outcome questionnaire that includes six categories inquiring hand function, daily living activities, pain, work, aesthetics, and patient satisfaction with his/her hand. The questionnaire includes 72 questions and evaluates the dominant and the nondominant hand separately [22].

Duruöz Hand Index (DHI) has been recently validated for traumatic hand on patients with combined flexor tendon and nerve injuries [23].

Assessment of Performance

Jebsen–Taylor Hand Function Test is a seven-part test. By using common items such as paper clips, cans, pencils seven activities (writing, card turning, picking up small objects, simulated feeding, stacking, and picking up large light and large heavy objects) are tested. It is a unilateral test that measures the dominant and non-dominant hand separately. It does not take into consideration the pattern of prehension [24].

Box and Block Test is a manual dexterity test that requires moving 1-in. blocks from one box to another in 60 s. It is simple, inexpensive and assesses eye–hand coordination as well [21].

Sollerman Hand Function Test measures hand and grip function during daily activities. In 20 activities of daily living (ADL), the ability of the patient to perform 7 of the 8 most common handgrips defined by Sollerman in 1978 are evaluated. These common handgrips are volar, transverse volar, spherical volar, and pinch positions like pulp, lateral, tripod, and the five finger. Certain ADL's are using a key, picking up coins from a flat surface, writing with a pen, using a phone, and pouring water from a jug [25].

Crawford Small Parts Dexterity Test measures the success and efficiency in jobs demanding manual dexterity and precision. Different from the other assessment methods, it introduces tools into the test protocol. Tweezers are used to insert small pins into close-fitting holes and screwdrivers are used to place small screws into threaded holes. The test should be reevaluated with respect to psychometric properties because reference values have been changed [26].

Minnesota Rate of Manipulation Tests, Purdue Pegboard Test, Functional Dexterity Test, Grooved Pegboard, *Nine Hole peg test* are other hand coordination and dexterity testing instruments.

Summary

Integrity of flexor and extensor tendons is a major prerequisite for dexterous hand function. While flexor tendons on the volar side of the forearm and hand flex the fingers for grasping, extensor tendons on the dorsum straighten the wrist and the fingers to release or reach the objects. Flexor tendons are usually injured by lacerations. Extensor tendons travel close to the skin on the dorsal surface of the hand. They are susceptible to crush injuries, as well as lacerations, burns, bites, or blunt trauma. Both tendons are divided into zones according to the anatomical characteristics of the structures they overlie or travel with. Flexor tendons are classified into five zones, while extensor tendons are evaluated and treated in seven zones. These accompanying structures which enable perfect hand function in healthy people may cause severe adhesions that may hinder tendon gliding after an injury. The primary aims of rehabilitation after tendon injury are to gain maximum tendon gliding, to ensure effective joint motion, and to restore hand function. It is also very important to prevent tendon rupture, contracture, and excessive scarring. In order to achieve these goals various early active and passive mobilization methods for the first four postoperative weeks have been described. While the major advantage of early active mobilization protocols is to provide controlled active mobilization of the repaired tendon, it necessitates maximum cooperation of the patient and the rehabilitation team. The patient must understand that the optimum result depends on both home based and also supervised exercises repeated daily for a few times. He/she should also be cautioned against the risk of tendon rupture during the first weeks of the repair. Strengthening exercises and splinting to prevent contractures are implemented after the eighth week. While therapy focuses on maintaining the motion and strength of the injured hand, rehabilitation physician and the team members should direct the patient to use the unaffected body regions to decrease his/her disability due to trauma or disease. Disability may result both from physical limitations and also from distortion of social and occupational roles. Although each has some limitations, hand function and disability is measured by validated and reliable methods and scales.

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Hand Function in Stroke

8

Osman Hakan Gündüz and Özün Bayindir

Introduction

Stroke is a common health problem and is one of the main causes of disability among adults [1], and the most prevalent impairment in stroke is hemiparesis. Nearly 30–60 % of stroke survivors with upper limb paresis do not have proper arm function 6 months after stroke, while complete recovery occurs in 5–10 % [2].

Upon the completion of rehabilitation, 41–45 % of the patients remain permanently disabled [3], and deficits are especially prevalent in the hand. Disabilities of the hand due to motor impairments, spasticity, and contractures cause particular difficulties to perform activities of daily living (ADL) [4]. Up-to-date rehabilitative approaches have only limited effectiveness in improvement of upper extremity function, which emphasizes the need for effective treatment regimens. Also, it has been accepted that the lower extremity recovers faster and more completely than the upper extremity [5]. Accordingly, new studies should be focused on hand therapy techniques to gain greater hand functions.

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What Happens to the Hemiparetic Hand?

It is important to understand the underlying mechanisms causing hand disability, in order to provide an effective treatment protocol. Among the rehabilitation professionals, many neurological mechanisms have been investigated to reveal the contributing factors of impaired hand function after stroke, and biomechanical malformations were also used to admit the major contributors [6].

In hemiparetic hand, spasticity, contractures, and muscle weakness are the main factors causing impairment, by restricting range of motion (ROM) and limiting function [7]. Contractures can reduce the passive ROM and can also hinder the active ROM of the hand. Spasticity of the forearm flexor muscles restricts voluntary extension of the fingers. And involuntary co-activation of the flexors and extensors may block relaxation of grip [8]. In early stages after stroke, inability to activate agonist muscles is responsible for hand weakness [9], whereas after years of disuse, weakness leading to muscle atrophy further contributes to hand disability.

Patients suffering from stroke tend to regain flexion more than extension, so that voluntary extension results elevated flexor activity [10]. Hemiparetic hand generate compression forces with a higher than normal proportion during grip. It has been thought that this misdirect digit force may be the reason of slips and difficulty in stable

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grasps [11]. Studies showed that rehabilitation programs that are focused on independently activating and strengthening extensor muscles might help to overcome this process [12].

Outcome

The functional recovery rate after stroke was reported to be rapid in the first 3 months [13]. Lesion type and location, and initial severity of paresis after stoke are well-known factors that influence outcome at 6 months. Early return of voluntary motion like measurable grip function is also considered as indicative of good functional recovery. It is also reported that the optimal prediction of outcome can be made within the initial 4–5 weeks. And a low score on measures of arm function at 1-month post stroke indicates a small probability of gaining hand function [2]. On the basis of the importance of hand function in the ADL, hand dexterity related to stroke directly reduces independence and quality of life.

Outcome Measures

Since the improvement of dexterity is a major goal of stroke rehabilitation, it is important to identify appropriate measures to determine functional recovery. There are a number of scales, assessments, and tests that have been described to examine qualitative properties in patients with stroke.

The WHO International Classification of Functioning, Disability, and Health (ICF: WHO, 2001, 2002) identified and revised a multidimensional framework for health and disability of outcome measurements [14]. In this framework three levels of human functioning were identified: Body functions (impairment), Activities (limitations to activity, disability), and Participation (handicap). We will only discuss the first two: impairment and disability outcome measurements.

Body Functions/Impairment Outcome Measures

Brunnstrom's Stages

Proximal Arm:

- Stage 1: Flaccidity, no voluntary movements
- Stage 2: Flexor synergies, spasticity develops
- Stage 3: Voluntary movement begins but only in synergy, spasticity increases
- Stage 4: Some movements such as;
  a. Shoulder flexed to 90 while elbow is fully extended
  b. Pronation and supination while elbow is flexed to 90
  c. Hand is on the back
- Stage 5:
  a. Overheaded arm
  b. Pronation and supination while elbow is fully extended
  c. Arm is in the horizontal position
- Stage 6: Isolated movements with good coordination

Distal Arm:

- Stage 1: Flaccidity, no voluntary movements
- Stage 2: Little finger flexion might be seen
- Stage 3: Hook grasp
- Stage 4: Lateral prehension
- Stage 5: Palmar prehension, cylindrical grasp, and also voluntary thumb extension
- Stage 6: Individual finger movements

Ashworth and Modified Ashworth Spasticity Scale

This is a 5-point nominal scale, ranging from 0 to 4. This part of the clinical examination should be performed on a relaxed supine positioned patient. The muscle is assessed by rating the resistance to passive ROM of a single joint.

0: No increase in muscle tone

1: Slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of the ROM

1+: Slight increase in muscle tone, manifested by a catch, followed by minimal resistance, less than half of the ROM

2: More marked increase in muscle tone through most of the ROM

Table 8.1 Most frequently used tests for the assessment of hand activities and disabilities

Most frequently used tests	Duration (min)	Advantages	Disadvantages
Box and block test	5	Used to measure gross manual dexterity Quick and simply to administer	Administering might be noisy and distracting
Nine hole peg test	5	Simple, portable, and inexpensive test	Not able to detect loss of proximal strength
		Sensitive in patients with late stage of recovery	Very large floor effects
		Timed test	May be influenced by age
Jebsen–Taylor hand function test	20	Inexpensive and easy to administer	Evaluate the speed, but does not rate different strategies of task performance
		Includes some tasks that are commonly performed in daily living	
Action research arm test	10	Most aspect of arm function, including proximal control and dexterity	An extensive collection of items and a specialized table are required
		Performance level is easily understood	In patients with severe or slight impairments, the scale may not be able to assess change in performance
Wolf motor function test	30	Timed test	Time consuming test and also time may be excessive for severe stroke patients
		Simple equipment is required	

3: Considerable increase in muscle tone, difficult passive movement
4: Rigid in flexion or extension

Fugl-Meyer Assessment

This assessment is one of the most widely used quantitative instruments for measuring sensory-motor stroke recovery [15]. This test requires tennis ball, spherical shaped container, and an administrator to test reflexes. Five major domains assessed include motor function, sensory function, balance, joint ROM and joint pain. Takes approximately 20–30 min.

Activity/Disability Outcome Measures (Table 8.1)

Although there are some scales to assess upper extremities function in patients with stroke, there are few for assessment especially hand function.

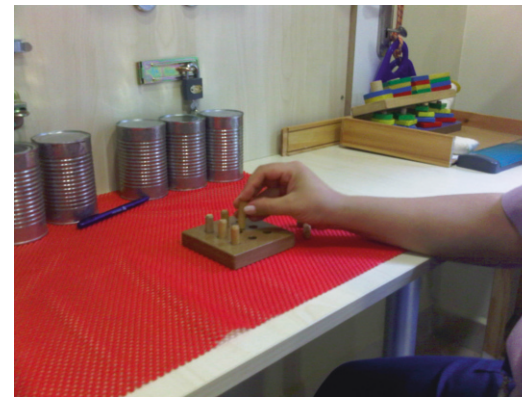

Fig. 8.1 Nine hole peg test

Box and Block Test

Takes approximately 5 min, important feature is to evaluate the gross manual dexterity; with grasp function, transport speed and release [16].

Nine Hole Peg Test

Takes approximately 5 min. It is a kind of timed test to assess motor coordination; by placing nine pegs in nine holes (Fig. 8.1) [17].

Jebsen–Taylor Hand Function Test

Takes 20–30 min. This test has seven parts and evaluates dexterity of hand using everyday utensils like paper clips, cans, and coins [18]. This test is found to be effective to measure upper limb function after stroke (Fig. 8.2) [19].

Action Research Arm Test (ARAT)

Takes approximately 10 min and only requires nonstandard equipment like various sized wood blocks, stone, cricket ball, glass. It is not a timed test and was developed to assess recovery in hemiparetic hand after stroke with four subtests (grasp, grip, pinch, and gross arm movement).

Wolf Motor Function Test

The test consists of 16 items grouped in performance ranging from simple movements to functional movements and ADL [20]. This test was designed to quantify motor ability of patients with stroke and traumatic brain injury [21].

Duruöz Hand Index (DHI)

A self-questionnaire with short administration time, including 18 hand activity questions. This scale was validated to assess the hand functional disability in patients with stroke [22].

Both Functional Independence Measure (FIM) and Barthel Index might be used to evaluate disability related to stroke: Effects of paretic hand, related to stroke, on daily living activities.

Treatment

An important issue in hand rehabilitation in stroke patients has been how to regain the best function. During the first few days, addition to lifesaving treatments (like thrombolytic agents etc.), patients should be motivated to exercise in order to activate recovery and reorganization processes [23].

For practitioners early predictors and outcome knowledge have an essential role while optimizing the treatment goals. The importance of this is well expressed by Kwakkel et al. in 2003: "in which some return of dexterity is expected, training the paretic arm is justified. However, if the prognosis is poor, teaching the patient to deal with existing deficits may be more realistic, thus allowing for the use of compensating strategies" [2].

Various approaches could be used, for better functional recovery. Rehabilitation protocols should be aimed at modifying neural plasticity to improve motor performance and maintain the interactions between them. But the optimal frequency and intensity of these protocols to achieve this have not been established yet.

Some of the exercises for hand dexterity in hand rehabilitation in stroke patients are shown in Figs. 8.3–8.6.

Fig. 8.2 Jebsen–Taylor hand function test (moving heavy objects)

Fig. 8.3 Exercises to improve activities of daily living

Fig. 8.4 Exercises to improve activities of daily living

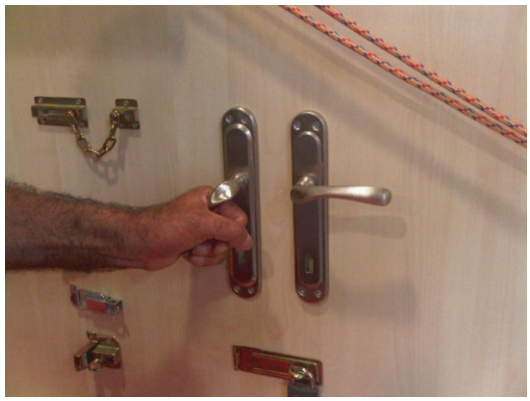

Fig. 8.5 Exercises to improve activities of daily living

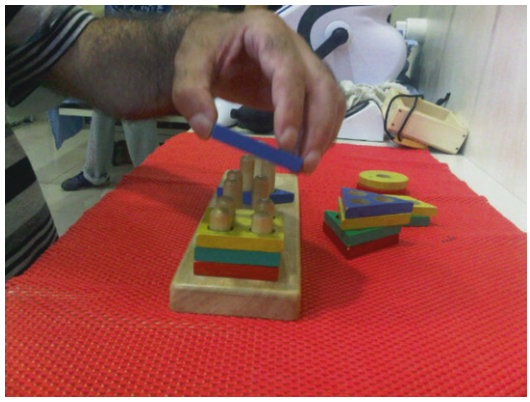

Fig. 8.6 Exercises for hand dexterity

Conventional Therapy

Conventional therapy is based on neurophysiologic theories and aims to control spasticity, inhibit synergistic movements, and integrate hemiparetic side into normal movement patterns and correct posture [24]. A recent systematic review showed no significant differences between Bobath concept and other approaches [25].

CIMT (Constraint Induced Movement Therapy)

This technique consists of restraining the unaffected upper limb while intensively using the affected limb to improve functional motor recovery [26]. CIMT has been used in patients with stroke, cerebral palsy. The effectiveness of CIMT in chronic stroke patients—reducing spasticity and improving the arm function—has been well established [27]. It has also been shown to improve upper limb function in both acute and chronic stages after stroke, and according to one comparison study it is found to be more effective in early groups rather than delayed ones, where results showed no significant difference in a 24-month follow-up [28]. Even though there are reported positive outcomes just after the treatment, there is no clear evidence of persisting benefits [29].

Bilateral Arm Training

In this technique patients use their both hands to complete a task; movements might be symmetrical or asymmetrical. Studies showed this technique improved paretic limb functions [30] and has been found to be beneficial for improving motor functions during the subacute and chronic phases of recovery [31]. According to comparison studies, bilateral training provides greater improvement on the proximal arm function, compared to unilateral training [32].

Fig. 8.7 Mirror therapy

Fig. 8.8 Robot-aided therapy

Motor Imagery

Mental imagery, also called visualization, is an active process of brain. In this procedure patients experience sensations by imaging an action without any real movement [33]. According to mental simulation theory both (real action and imagination of action) activate the same areas of brain so that it can be applied as a therapeutic modality in rehabilitation and also for strengthening [34]. Also some studies have indicated that this may provide the same neuroplasticity modulation [35]. As an advantage this technique allows patients to practice independently, despite the weakness at early stages they can attend the rehabilitation program. Although positive effects on stroke patients are limited to a few studies, it has been assented that this therapy provides additional benefits to conventional physiotherapy or occupational therapy [23].

Mirror Therapy

Moving the unaffected limb and looking at its reflection limb presents visual feedback. This leads to cortical reorganization [36] and restoration of function [37] (Fig. 8.7). Current studies suggest that this therapy has beneficial effects on impaired hand function, pain, and also ADL after stroke [38]. However, dimmer effects on spasticity have not been well established yet [39].

Robot-Aided Training

Robot-assisted rehabilitation provides sensory motor support [39] which is related to activity-based therapy. This technique allows the patient to train independently with repeatable exercises and increase compliance to the treatment protocol by adding visual stimuli such as games [40] (Fig. 8.8). According to recent studies, when added to other neurorehabilitative treatment protocols, robotic therapy increases the benefit of rehabilitation [41].

A recent meta-analysis showed significant improvement in functional recovery and strength of the upper paretic limb with upper arm robotics, even without any significant improvement on functional ability (ADL) [40, 42]. Knowledge is based on limited few studies, and currently there is no available data investigating the optimal design, efficacy of their usage [43].

Effects of Hand Splinting

It has been known that keeping the extremity in tonic stretch position may help to reduce tonus. Post stroke splinting has been widely used to avoid contractures, improve ROM, reduce spasticity, and manage pain [44], although the evidences are inadequate [45]. It is an indisputable fact that rehabilitation approaches might be effective only if the peripheral joints are kept at functional length [46].

Summary

Stroke is still one of the leading causes of long-term disability. Approximately half of the patients remain with permanent upper extremity problem in spite of rehabilitation program. Deficits are especially prevalent in the hand, and these physical limitations affect activities of daily living directly. Early predictors for dexterity of the hand inform treatment plans targeted at effective recovery. The key principles of hand rehabilitation in stroke patients include accelerated early rehabilitation, a functional approach targeted at task-oriented activities and intense practice.

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Hand Function in Tetraplegia

9

Şafak Sahir Karamehmetoğlu
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Introduction

Impairment or loss of motor and/or sensory function in the cervical segments of the spinal cord due to damage of neural elements within the spinal cord is referred to as *tetraplegia* and preferred to the term quadriplegia. Tetraplegia results in impairment of function in the arms, as well as the trunk, legs, and pelvic organs [1].

The clinical evaluation of hand and arm function of tetraplegics is extremely important, as this is assumed to play a key role in the activities of daily living (ADL) and independence [2]. For instance, persons with tetraplegia at the level of C5, C6, or C7 have little active movement below the elbow, which limits not only arm and hand movement but also their ability to perform ADL, such as eating, grooming, and communication. Generally, on discharge from a rehabilitation program, persons with C5 tetraplegia are able to feed themselves with assistive devices, but remain dependent for transferring into and out of a wheelchair, for bladder and bowel care, and will usually use a power wheelchair for community mobility. That is why establishing a good rehabilitation policy is important. And, for a good rehabilitation program, an insight into the functional deficits, recovery process, and rehabilitation outcome is necessary.

Hanson and Franklin found that 75 % of tetraplegics would prefer restoration of their upper limb function to that of any other lost function [3]. In patients with cervical spinal cord injury (C-SCI), we cannot think of hand function apart from arm function since arm function may also be severely damaged in these patients. So, unlike the other diseases discussed in this book, we will discuss hand and arm function together.

Assessment of Spinal Cord Injury

The most accurate way to assess a patient who has sustained a spinal cord injury (SCI) is by performing a standardized physical examination as endorsed by the International Standards of Neurological Classification of Spinal Cord Injury (ISCSCI) patients, also commonly called the standards of American Spinal Injury Association guidelines (ASIA) [1].

The neurologic examination of the patient with SCI has two main components, sensory and motor, with certain required and optional elements. The required elements are composed of the determination of the sensory, motor, and neurologic levels; determination of the completeness of the injury and classification of the impairment. The information obtained from this examination can be recorded on a standardized flow sheet that can easily be obtained from the official Internet site of ASIA (Fig. 9.1).

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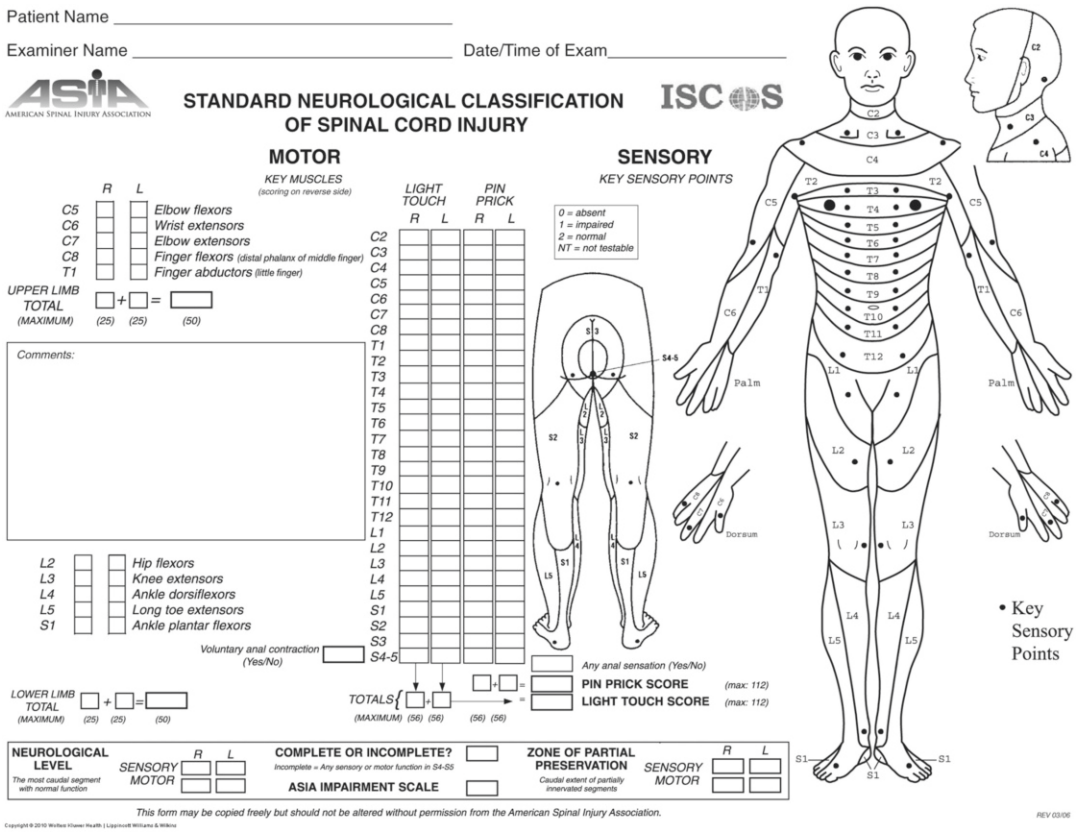

Fig. 9.1 The flowchart of the International Standards of Neurological Classification of Spinal Cord Injury

The Sensory Examination

Twenty-eight specific skin locations, referred to as key sensory points, are tested for sharp–dull (with a safety pin) and light touch (with a cotton-tip applicator) sensations on both sides of the body. A three-point scale (0–2) is used and face is accepted as the normal control point.

For the light touch sensation, if the patient does not correctly or reliably report being touched, a score of zero (absent) is given. If the patient correctly reports being touched, but describes the feeling as different than on the face, a score of "1" (impaired) is given. The score of "2" (normal or intact) is only given if the patient correctly reports being touched, and describes the feeling as the same as on the face.

For the sharp–dull discrimination, if the patients has no feeling of being touched or does not reliably distinguish between the sharp and the dull ends of the pin, a score of zero (absent) is given. If the patient reliably distinguishes between the sharp and dull ends, but states that the intensity of the sharpness is different in comparison with the face, a score of "1" (impaired) is given. The score of "2" (normal or intact) is only given if the patient reliably distinguishes between the sharp and dull ends, and states that the intensity is the same as the face.

The sensory level is the most caudal dermatome to have intact sensation for both pinprick and light touch on both sides of the body.

It is also important to test the S4–S5 dermatome, which represents the most caudal segment of the spinal cord, for pinprick, light touch, and deep anal sensation.

The Motor Examination

The required part of the ASIA motor examination consists of testing ten key muscles: five in the upper and five in the lower limb on each side of the body. Testing of all key muscles must be done when the patient is in the supine position, and graded on a traditional six-point manual muscle testing (MMT) scale from 0 to 5.

The key muscles and their corresponding spinal cord roots or segments are shown in Table 9.1.

The traditional six-point manual muscle scale is shown in Table 9.2.

Voluntary anal contraction should also be tested as a part of the motor examination by sensing contraction of the external anal sphincter around the examiner's finger.

The motor level is the lowest key muscle that has a grade of at least 3, providing the key muscles represented by segments above that level are judged to be normal (grade 5).

The neurologic level of injury (*NLI*) is the most caudal level at which both motor and sensory modalities remain intact.

Incomplete injury is defined as preservation of motor and/or sensory function below the neurologic level that includes the lowest sacral segments, while *complete injury* is the absence of sensory and motor function in these segments.

The ISCSCI motor and sensory examinations are important since they have been the primary indicators of recovery of neurological function [4–9]. Waters et al. reported that in 1-year follow-up while the muscles of patients with C-SCI with initial motor scores of grade 1 or 2 increased to at least grade 3, the muscles with initial motor scores of grade 0 (complete paralysis) never exceeded grade 3 [4].

Table 9.1 The key muscles and their corresponding spinal cord roots or segments

C5 Elbow flexors	L2 Hip flexors
C6 Wrist extensors	L3 Knee extensors
C7 Elbow extensors	L4 Ankle dorsiflexors
C8 Finger flexors (distal phalanx of the middle finger)	L5 Long toe extensors
T1 Finger abductors (little finger)	S1 Ankle plantar flexors

Table 9.2 The traditional six-point manual muscle scale

Grade 0	No visible or palpable muscle contraction is noted in the muscle being examined
Grade 1	A visible or palpable muscle contraction is noted in the muscle being examined
Grade 2	The muscle is able to move, at least once, the part of the extremity to which it is inserted through a full range of motion (or the maximum available range of motion), in the position in which gravity is eliminated
Grade 3	The muscle is able to move, at least once, the part of the extremity to which it is inserted through a full range of motion (or the maximum available range of motion), in the position in which gravity must be overcome
Grade 4	The muscle is able to move, at least once, the part of the extremity to which it is inserted through a full range of motion (or the maximum available range of motion), and in addition, provides some resistance against the efforts of the examiner to oppose it
Grade 5	The muscle is able to move, at least once, the part of the extremity to which it is inserted through a full range of motion (or the maximum available range of motion), and to the examiner's judgment, exerts a normal amount of resistance against the efforts of the examiner to oppose it

The motor level and upper extremity motor score relative to the NLI reflect the degree of function and the severity of impairment and disability better after complete tetraplegia since the sensory level may place the neurologic level more cephalad, thereby incorrectly implying poorer function [10].

International Classification for Surgery of the Hand in Tetraplegia

While the ISCSCI remains the most commonly used motor and sensory assessment in tetraplegia, the International Classification for Surgery of the Hand in Tetraplegia (ICSHT), an alternative classification scheme, has been introduced specifically for surgical planning in the upper limb in tetraplegia [11, 12]. Like the ISCSCI, the ICSHT involves both examination of motor and sensory function and classification of neurological status. As

Table 9.3 Modified international classification for surgery of the hand in tetraplegia

Motor	
Group	Functional muscles[a]
0	Weak or absent BR (grade 3 or less)
1	BR
2	BR, ECRL
3	BR, ECRL, ERCB
4	BR, ECRL, ERCB, PT
5	BR, ECRL, ERCB, PT, FCR
6	BR, ECRL, ERCB, PT, FCR, Finger extensors
7	BR, ECRL, ERCB, PT, FCR, Finger extensors, Thumb extensors
8	BR, ECRL, ERCB, PT, FCR, Finger extensors, Thumb extensors, Finger flexors
9	Lacks instrinsics only
Sensory	
0	Two-point discrimination in thumb >10 mm
Cu	Two-point discrimination in thumb ≤10 mm

BR brachioradialis, *ECRL* extensor carpi radialis longus, *ECRB* extensor carpi radialis brevis, *PT* pronator teres, *FCR* flexor carpi radialis
[a]Functional muscle: grade 4 or 5

opposed to five key muscles tested in ISCSCI, the motor examination of ICSHT consists of the evaluation of all upper limb muscles. Unlike the motor examination of ISCSCI which accepts muscle strength of grade 3 as functional, ICSHT accepts grade 4 [13]. The ICSHT sensory examination involves testing two-point discrimination on the thumb and index finger; sensation is considered intact if two-point discrimination is ≤10 mm and these patients are classified as "O-Cu" (ocular–cutaneous). When two-point discrimination is >10 mm, these patients are considered to only have ocular input for hand function and classified as "O" (ocular). This classification takes into account the motor groups that are functioning and available for transfer, as well as sensibility. While the ICSHT was designed to aid planning of surgical reconstruction, it may be more sensitive than the ISCSCI, at least for assessment of strength, since it evaluates more key upper limb muscles [14].

Modified international classification for surgery of the hand in tetraplegia is shown in Table 9.3.

Expected Functional Outcomes by Neurologic Level of Injury [15]

C1–C4 Tetraplegia

Patients with injuries from C1 to C4 are considered to have high tetraplegia. Persons with injury level above C4 are unable to clear secretions and ventilator dependent while C4 tetraplegic persons may be able to breathe without ventilators. For the bowel and bladder management: management of elimination, maintenance of perineal hygiene, and adjustment of clothing before and after elimination, these patients need total assistance. For the bed mobility and bed and wheelchair transfers, total assistance is needed. For the pressure reliefs and positioning they may need total assistance or they may be independent with equipment. Both manual and power wheelchairs are required. C1–C3 tetraplegics can only use power wheelchairs with control devices, including chin, head, and voice activation, while C4 tetraplegics can use them without the equipment independently. For the propulsion of the manual wheelchair, high tetraplegics need total assistance. Standing can be possible with total assistance on tilt table and hydraulic standing table, and ambulation is not usually needed. Total assistance is needed for eating, grooming, dressing, and bathing. They need 24-h care to include homemaking, meal planning and preparation and home management.

Functional goals typically focus on the use of environmental controls and other technological aids like page turners, door openers, emergency call systems, speaker telephones. Computers are typically accessed via breath or voice control. Environmental control units can be controlled with breath, mouthsticks, or tongue switches.

C5 Tetraplegia

They have low endurance and vital capacity secondary to paralysis of intercostals and they may require assistance to clear secretions. Total

assistance is needed for the management of bowel and bladder. Some assistance is needed for the bed mobility while total assistance is needed for the bed and wheelchair transfers. The elbow flexion present in C5 tetraplegia can be combined with orthotic management to allow performance of self-care and mobility skills. Therefore, they can do the positioning and pressure reliefs independently with equipment. They can use manual wheelchairs independently to some assistance indoors on non-carpet level surface, some to total assistance outdoors. Standing is possible with total assistance on hydraulic standing frame. Ambulation is not indicated. Static splints (long opponens splints) with utensil slots and pencil holders are used to assist with tasks such as writing, typing, and feeding. By this way, after total assistance for setup, they are independent while eating. They need some assistance while dressing. They need assistance of the caregiver 10 h/day for their personal care and 6 h/day for the homemaking activities.

C6 Tetraplegia

Patients with C6 level of injury have low endurance and vital capacity secondary to paralysis of intercostals, and they may require assistance to clear secretions like C5 tetraplegics. They need some to total assistance for the bowel management and some to total assistance with equipment for the bladder management. They may be independent with leg bag emptying. For the bed mobility some assistance is needed. Bed and wheelchair transfers to level surfaces require some assistance or can be done independently; transfers to uneven surfaces require some to total assistance. C6 tetraplegics can do radial wrist extension. Therefore, they can do pressure reliefs and positioning independently with equipment, and/or adapted techniques. The manual wheelchair is propelled independently in indoors and with some to total assistance in outdoors. Standing is possible with total assistance on hydraulic standing frame. Ambulation is not indicated. These patients eat independently with or without equipment, except cutting which needs total assistance. They dress their upper body independently and lower body with some to total assistance. They need some assistance with light meal preparation and total assistance for all other homemaking. They require assistance for 6 h/day for their personal care and 4 h/day for the homemaking activities (Fig. 9.2).

Fig. 9.2 A tetraplegic patient trying to unscrew the lid from a jar

C7 and C8 Tetraplegics

The triceps function found at the C7 level results in significant improvements in transfer and mobility skills. Finger extension and wrist flexion strength are present and further assists ADL. The flexor digitorum profundus at the C8 level greatly improves hand function.

Patients with C7 and C8 level of injury have low endurance and vital capacity secondary to paralysis of intercostals and they may require assistance to clear secretions like C5 and C6 tetraplegics. They need some to total assistance for the bowel management and no to some assistance with equipment for the bladder management. They may be independent in bed mobility, or they may need some assistance. They may do bed and wheelchair transfers to level surfaces independently, to uneven surfaces independently or with some assist. They move independently on all indoor surfaces and level outdoor terrain and with some assistance on uneven terrain with manual wheelchair. They can do pressure reliefs

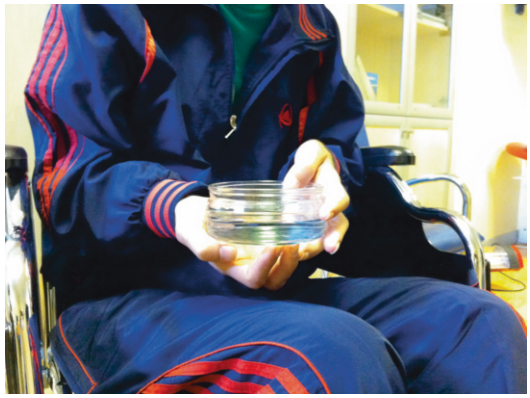

Fig. 9.3 A tetraplegic patient holding a bowl

and positioning independently. They stand independently to some assistance with hydraulic standing frame. Ambulation is not indicated. Persons at this level are independent in eating, dressing the upper body. Many of them need no to some assistance to dress lower body. They are independent during light meal preparation and homemaking. Some to total assistance is needed for complex meal preparation and heavy house cleaning. They require assistance for 6 h/day for their personal care and 2 h/day for the homemaking activities (Fig. 9.3).

The Use of International Classification of Functioning, Disability, and Health and Outcome Measures in Tetraplegics

To establish a good rehabilitation policy for arm and hand in patients with C-SCI, evaluation of and insight into the outcome of arm and hand, as well as insight into training programs for arm and hand according to the different levels of the International Classification of Functioning, Disability and Health (ICF), are necessary [16]. The International Classification of Impairments, Disabilities, and Handicaps (ICIDH) was first developed in 1980 by the World Health Organization (WHO) in order to provide a common language for health [17]. Later, WHO published a revision called the ICF, in 2001, to represent concepts of health and disease as interactions [18].

There is increasing recognition of the need to measure health outcomes for clinical, academic, and financial reasons. It is essential to be able to measure outcomes accurately to determine how effective our rehabilitation program and interventions. The ICF offers some practical assistance when faced with the choice of measurement tools available and the objectives of measuring [19].

According to the ICF, "functioning" can be described on the level of: (1) structure and function, (2) activity, and (3) participation [20] (Fig. 9.4). The term "arm hand function" (AHF) refers to the ICF "function" level. Outcome at this level was described by evaluating, among other factors, muscle strength, neurological level, and motor score [4, 21–26]. However, clinicians and patients are more interested in the performance of arm and hand activities, termed "arm hand skilled performance" (AHSP), which refers to the "activity" level in accordance with the ICF nomenclature [26]. They want to know what patients eventually will be able to do with their arms and hands. At the activity level a distinction is made between "basic activities" such as grasping and reaching and "complex activities" (ADL) such as dressing oneself and eating. Functional Independence Measure (FIM), Modified Barthel Index (MBI), and Quadriplegia Index of Function (QIF) are examples of outcome measures that measure AHSP at the level of "complex" activities. On the other hand, the Van Lieshout Test and Grasp Release Test are examples of outcome measures, specifically designed for tetraplegics, which measure AHSP at the level of "basic" activities. We can classify the upper extremity motor tests of tetraplegics as "general tests" and "specific tests" (for tetraplegics) at the activity level. It is also possible to divide each test category as "basic" and "complex" activities [16] (Table 9.4).

Although there are many tests to evaluate arm and hand function of tetraplegics, only a few of them has been studied for their reliability and validity. Among the general basic tests, only "The Sollerman Test" has been showed to have reliability and validity in tetraplegics [27]. However, since it was first developed to evaluate normal hand functions, its correlations with different levels of injury are poor [28]. "The Grasp

Table 9.4 Upper extremity motor function tests in tetraplegics at the level of activities

General tests		Specific tests	
Basic activities	Complex activities	Basic activities	Complex activities
Minnesota Rate Of Manipulation [32, 33]	Barthel İndex [45]	Standardized Object Test [60]	Quadriplegia Index of Function [63–66]
Upper Extremity Motor Function Test [34, 35]	Modified Barthel İndex [46–48]	Vanden Berghe Hand Function Test [61]	Quadriplegia Index of Function—Short Version [23]
The Purdue Pegboard Test [36]	Functional Independence Measure [49–54]	Grasp and Release Test [29]	Common Object Test [67]
Jebsen Hand Function Test [37–39]	Ranchos Los Amigos Hospital Functional Activities Test [55]	The Capabilities of Upper Extremity Instrument [2]	Van Lieshout Test [68–70]
The Nine-Hole Peg Test [40]	Spinal Cord Injury Independence Measure (SCIM) [56–58]	Thorson's Functional Test [62]	Tetraplegia Hand Activity Questionnaire [71]
Smith Hand Function Evaluation [41]	Valutazione Funzionale Mielolesi [59]	Motor Capacity Scale [31]	
Box and Block Test [42]			
The Physical Capacities Evaluation of Hand Skill [43]			
The Action Research Arm test [44]			
Sollerman Hand Function Test [27]			

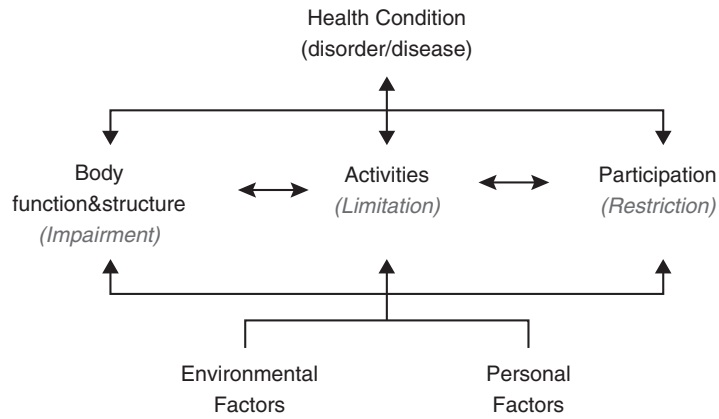

Fig. 9.4 International Classification of Functioning, Disability, and Health (ICF)

and Release Test" was first developed to evaluate the use of neuroprosthesis in C5-6 tetraplegics [29]. It evaluates the hand functions at the level of basic activities according to ICF level. Although its test–retest reliability after tendon transfer and functional electrical stimulation has been documented, its validity has not been studied [30]. Taking place in the same category, "The Capabilities of Upper Extremity Instrument" has been found to be a valid and reliable method to evaluate hand functions in tetraplegics [2]. However, it has a limited use while it is especially preferred in USA. Although "Motor Capacity Scale" has also been found to be valid and reliable among tetraplegics that had surgery, it does not have a worldwide use [31].

Among the tests specifically designed for tetraplegics, the most commonly used test at the

complex activity level is "Quadriplegia Index of Function". Its validity, reliability and responsiveness has been well documented [65, 72]. "Quadriplegia Index of Function-Short Version" is also preferred because of its high correlations with the long version and easy applicability [23]. "Van Lieshout Test" is also a test of ADL, specifically designed for tetraplegics [69, 70, 73]. Although "Van Lieshout Test-Short Version" has been found to be valid and reliable, its use is limited to Holland [68, 73]. The clinical use of "Tetraplegia Hand Activity Questionnaire" is unknown [71, 73]. "Spinal Cord Independence Measure (SCIM)" is the only comprehensive skill test that is specifically designed for people with spinal cord injury [57, 73]. Since the original version, it was lastly revised in for the third time [57, 73]. The importance of SCIM seems to increase gradually and its reliability and validity studies are carried out at international extent. Self-care activities of SCIM-III have been showed to reflect the upper extremity performance of tetraplegics successfully [58, 73].

The Upper Extremity Motor Function Tests

Strength Tests

These tests include MMT, handheld dynamometry, pinch and grip strength measurement, and isokinetic dynamometry.

Manual Muscle Testing (MMT)

In this test the examiner counteracts the force of a subject manually. It is graded on a traditional six-point MMT scale proposed by the Medical Research Council [74]. MMT is used to evaluate the strength of key muscles as a part of ASIA motor examination.

MMT depends on the examiner's judgment of the amount of resistance applied during the test [75]. The experience of the examiner can also influence the consistency of MMT scores [73]. Savic et al. [76] examined the inter-rater reliability of motor examinations performed according to ASIA standards and found out that the overall agreement in assignment of MMT grades was over 80 % on both sides with the strongest agreement for grade "0" and the weakest for grade "3". Noreau et al. [77] stated MMT was not sufficiently sensitive to assess muscle strength, at least for grade 4 and higher and to detect small or moderate increases of strength in SCI persons over the course of rehabilitation. On the other hand, they found that measurement with dynamometry allows for greater accuracy.

Handheld Dynamometry (HHD)

Handheld dynamometries, also known as myometers, have several advantages over other types of dynamometers, including lower cost, greater ease of use, and better acceptability in clinical settings. Several HHDs have been used to test muscle strength in tetraplegics, for example Penny and Giles dynamometer [77, 78]. To test a muscle with a HHD a minimum MMT score of 3.5 is necessary [75].

Disadvantages of the HHDs include that they are capable of measuring only one point in the range of motion (ROM) at a time. The examiner must be able to provide appropriate stabilization during the examination [79].

Marciello et al. [80] showed that HHD of wrist extensors appeared to be a better indicator than the MMT for some self care activities in tetraplegic patients. All the other investigators [75, 77–80] emphasized that HHD may identify effects of therapeutic interventions, missed by MMT, especially for grades 4–5.

Grip and Pinch Strength Measurement

Grip dynamometers may be used to quantify strength changes in persons with lower cervical lesions who retain finger motion [79] as well as to measure outcomes in clinical trials of upper-limb tendon transfers [81].

Pinch dynamometry appears to be useful to measure improvement in grip strength after hand surgery in tetraplegics [61].

Isokinetic Dynamometry

Isokinetic dynamometry is a method of measuring muscle strength that involves hydraulic or motor-driven devices that impose a constant

velocity. Unlike HHDs that measure the force at one particular point in the ROM, isokinetic dynamometers measure torque produced at the anatomical joint throughout the available ROM [79].

However, it has a limited clinical use since it is expensive and it occupies a large space. Furthermore a MMT grade of at least 3 is necessary to perform the desired movement, whereas muscles with MMT grade 2 and below cannot overcome gravity and therefore cannot move the dynamometer over the entire ROM [82].

While testing positions are standardized, some testing positions for persons with SCI are cumbersome. May et al. [83] measured shoulder strength of SCI persons with both handheld and isokinetic dynamometry. They concluded that while HHD can be used reliably to measure shoulder rotation in paraplegic and tetraplegic patients, the relationship between HHD and isokinetic measurement is poor for the participants with tetraplegia which may be a function of the method of isokinetic measurements. So further study with a modified isokinetic testing protocol is needed to clarify the results of the participants with tetraplegia.

The Standardized Object Test (SOT)

Investigators: Thrope et al. [60] (1989)

Purpose: evaluation of the minimal criteria of functional hand grasp necessary to use a functional nerve stimulation (FNS) neuroprosthetic hand system.

Test composition: the test consists of six objects each having various weights, sizes, and textures, including a block, disk, videotape, pegs, cylinder, and fork. The subject is asked to acquire, transport, and release each object as many times as possible in a 30-s period.

Scoring method: number of objects transported.

Psychometric properties: the test was sensitive enough to detect an increase in hand function in tetraplegics when using a hand system [82].

The Vanden Berghe Hand and Arm Function Test

Investigators: Vanden Berghe et al. [61] (1991)

Purpose: evaluation of the effect of reconstruction surgery

Test composition: nine unilateral items, including transfer of bowls of different weights, grasp and transfer of different objects, and writing a sentence

The duration of the test: dependent on the speed with which a subject performs the subtests

Scoring method: time necessary to perform each subtest

Psychometric properties: not available.

Normative data: mean times necessary to perform each subtest for 13 tetraplegics were reported without distinguishing between subjects with different injury levels [82].

The Quantitative Hand Grasp and Release Test (GRT)

Investigators: Stroh Wuolle et al. [29] (1994)

Purpose: assessing the use of a hand neuroprosthesis in C5 and C6 level tetraplegic persons.

Test composition: measures three variables: pinch strength, grasp strength, and hand function. For the assessment of hand function, the GRT requires the person to unilaterally acquire and then carry and release five objects (peg, paperweight, block, can, and videotape) of varying weight and size; the "carrying" of objects does not require midline crossing and therefore eliminates proximal contributions to function. A sixth object, the fork, is used for simulating pinching of a fork handle and stabbing of food.

Scoring method: the number of completions and failures within each 30-s trial. Each subtest includes a pretest and five attempts to transport as many objects as possible.

Psychometric properties: Wuolle et al. first reported on the psychometrics of the GRT, which were further established by Mulcahey et al. In Mulcahey et al.'s [30] study, intraclass correlation coefficients were high for repeated GRT test measures; the GRT scores were stable over time for chronic stable hand-function measurement and were sensitive to changes in hand function via functional electrical stimulation (FES) and tendon transfers. Clinically, the GRT has been an effective outcome measure for intervention studies of FES

and tendon transfers [14, 30, 81, 84–87]. Like all tests of hand function, the GRT requires the person to sit upright in the wheelchair; this prerequisite limits GRT use in clinical trials involving persons with acute SCI who are not medically stable for sitting. Another limitation of the GRT may be that its original intent was the evaluation of changes caused by FES lateral and palmar grasp; therefore, it may be insensitive to other grasp patterns and/or injury levels that typically do not use current FES systems (e.g.; high and low cervical SCI) [14].

The Capabilities of Upper Extremity (CUE) Instrument

Investigators: Marino et al. [2] (1998)

Purpose: measurement of upper extremity functional limitations in individuals with tetraplegia.

Test composition: is a 17-item questionnaire.

Scoring method: patients rate on a 7-point ordinal scale representing self-perceived difficulty in performing the action, varying from "1" unable to perform and "7" can perform without difficulty.

Psychometric properties: Homogeneity of the scale was excellent. Test–retest reliability was high. Analysis of variance indicated that the CUE distinguished between motor levels of tetraplegia more than one level apart. The CUE was correlated highly with both motor scores and FIM. Regression analysis indicated that the CUE was better than upper extremity motor scores for predicting FIM scores.

Normative data: Mean CUE values are provided for tetraplegic persons with different levels of injury and by best motor level [82].

Thorson's Functional Test

Investigators: Thorson et al. [62] (1999)

Purpose: evaluation of hand functions when using a stimulation device, the myoelectrically-controlled FES.

Test composition: eight unilateral tasks which are divided into four groups, including moving flat objects, namely, CD covers of different weights and a thin book, moving cylindrical objects, drinking, and eating with a spoon. The total experiment, including preparation, takes less than 1.5 h.

Scoring method: the performance of the grip is rated on a three-point scale (0 ± 2).

Psychometric properties: not available [82].

The Van Lieshout Test

Investigators: Van Lieshout [69, 88] (2000)

Purpose: to assess the quality of a movement of arm and hand in persons with C-SCI.

Test composition: Basic arm and hand function modalities: positioning and stabilizing the arms; development of the opening and closing of the "function hand"; grasp and release; and manipulation using thumb and fingers were made explicit in 19 tasks. Based on extensive patient observations, standards of excellence were made explicit for all 19 tasks.

Scoring method: The possible ways of performance of each task were described in six hierarchical levels, resulting in a score from "5", the highest level of accomplishment, down to "0", representing that accomplishment of the task is not possible at all. The score valuing principles of performance were, ranging from low to high level of performance. Administration of the VLT provides a detailed and standardized assessment of tetraplegic hand function that allows therapeutic goal setting and monitoring of progress. Such an assessment takes about 60–90 min.

Psychometric properties: The VLT is responsive in measuring changes in AHSP during rehabilitation in persons with C-SCI. The VLT can be used to measure changes in AHSP in C-SCI persons with ASIA score A-D, as well as with a lesion C3-C6 or C7-T1. The responsiveness of the VLT is significantly correlated to the GRT, but not to the FIM and the QIF [68].

Additional information: In order to reduce the total administration time, short version of VLT [70] (VLT-SV) is developed. The VLT-SV includes 10 of the 19 tasks, and the level of performance of each task is scored.

The total VLT-SV score is the mean of the item scores, ranging from "0" (worst arm/hand function) up to "5" (best arm/hand function). Administration time of the VLT-SV is 25–35 min. The criterion validity, the inter-rater reliability, the intra-rater reliability, and the internal consistency of the VLT-SF were found to be very good [70]. The VLT-SF is sensitive to detect changes in AHSP during rehabilitation in people with C-SCI [68].

Motor Capacities Scale (MCS)

Investigators: Fattal et al. [31] (2004)

Purpose: To study the validity and the reliability of MCS specifically designed for tetraplegics who undergo a functional surgery of upper limbs. The purpose of the MCS is to focus on elementary motor abilities required to achieve ADL.

Test composition: MCS includes six functional categories, each with a different number of tasks: transfers, repositioning on Bobath couch, repositioning on wheelchair seat, locomotion in a manual wheelchair and in an electric wheelchair, motor capacities of spatial exploration, and motor capacities for grasping and gripping.

Scoring method: From diverse sources (observation of patients, review of literature, discussions with occupational therapists and physicians), a list of 300 activities relating to daily living tasks were compiled. The following three experimental stages were proposed: An open study, an intermediate study, a prefinal study. In all, 52 tetraplegics were included in the prefinal study. At each stage, the scale was applied to different patients who had functional surgery and to patients who had not undergone functional surgery. Assessment was performed by occupational therapists on the basis of an external evaluation and direct observation. A score, ranging from 1 to 5, was assigned for each task in the first four domains–transfers, repositioning on Bobath couch, repositioning on wheelchair seat, and locomotion. For motor exploration and for grasping and gripping, a two-point and four-point scales were, respectively, chosen. A total score was calculated by summing the subscores of each functional category.

Psychometric properties: MCS displays a good apparent and content validity, and excellent reproducibility and constructible validity.

Dutch Interview Version of the Barthel Index (IV-BI)

Investigators: Post et al. (1995) [45].

Purpose: assessing ability to cope in ADL by SCI persons.

Target population: SCI persons.

Test composition: 10 items, including personal care, toileting, bladder and bowel management, eating, transfers, ambulation, dressing, stair climbing, and bathing.

Scoring method: items are scored on two to four point scales (0–1 to 0–3), a maximum score of 20 can be obtained, in which a higher score implies greater independence.

Psychometric properties: the interview version of the BI appeared to be a reliable test to measure ADL independence in SCI persons. In persons with complete SCI a strong correlation between level of injury and adapted BI scores existed. The mean IV-BI score of complete tetraplegics was significantly lower than the scores in incomplete tetraplegics and paraplegics. The IV-BI was also sensitive enough to differentiate between a C3-5 and a C7-8 level group and between a C6 and a C7-8 group. However, it was unable to differentiate between the C3-5 and C6 group.

Additional information: Post et al. translated Collins version of the BI in Dutch and made it suitable as a patient questionnaire. Collins version of the BI [89] is a slightly modified version of the original BI [90] in which mainly the scoring system was adapted [82].

Modified Barthel Index (MBI)

Investigators: Granger et al. [46] (1979) and Yarcony et al. [47, 48] (1987).

Purpose: measurement of severity of disability and monitoring of rehabilitation progress in severely disabled persons [46] or assessment of functional abilities [48].

Target population: traumatic SCI persons.

Test composition: the MBI consists of 15 tasks [48], including drinking from a cup, feeding from a dish, upper body dressing, lower body dressing, donning a brace or prosthesis, bathing, grooming, bowel continence, bladder continence, chair transfers, toilet transfers, tub/shower transfers, walking, stair-climbing, and wheelchair propulsion (only if not walking). In Yarcony's investigation published in 1987 the item "donning brace or prosthesis" was not included.

Scoring method: items are rated as independent, assisted, or dependent. Items that are considered more important for independence, such as eating without assistance, are weighed more heavily than less important items, like grooming.

Psychometric properties: the MBI was able to identify statistically significant improvement from discharge to 3-year follow-up in both complete and incomplete tetraplegics [48].

Normative data: self-care and mobility subscores of the MBI at admission and discharge for patients with complete and incomplete tetraplegia are provided [47], as are mean MBI scores during 3-year follow-up [48, 82].

The Functional Independence Measure (FIM)

Investigators: Hamilton et al. [86, 90] (1987 and 1991).

Purpose: rating severity of patient disability and the outcomes of medical rehabilitation.

Target population: patients who undergo medical rehabilitation.

Test composition: 18 items, concerning self-care (eating, grooming, bathing, dressing upper body, dressing lower body, toileting), sphincter control (bladder and bowel management), mobility (transfers to bed, chair or wheelchair, to toilet, and to tub or shower), locomotion (walking or wheelchair propulsion, stair climbing), communication (comprehension and expression), and social cognition (social interaction, problem solving, memory).

Scoring method: the items are scored on a seven-point scale, varying from "1" total assistance to "7" complete independence.

Psychometric properties: the FIM appeared to have good clinical interrater agreement in patients undergoing inpatient medical rehabilitation [51]. FIM scores were significantly lower in complete C4 tetraplegics than in C6 tetraplegics [52], which indicated that the FIM is sensitive enough to differentiate between different levels of injury. In incomplete tetraplegic persons FIM scores appeared to change significantly between admission and discharge. In complete tetraplegics no significant change was found [49]. The FIM is useful in detecting changes in function in time. FIM motor gains were greatest between admission and discharge for all neurologic levels.

Normative data: mean FIM scores by injury level and age [52], and by injury level and Frankel grade over time [53] are available. Caution has to be paid when comparing the FIM score of an individual patient to these norms, because several factors may influence the FIM score, namely age, length of stay, and level of education.

Additional information: The first version of the FIM used a four-point rating scale (0–4) to score each item [50]. A revised version of the FIM has been developed, which uses the abovementioned seven-point scale [82].

The Ranchos Los Amigos Hospital (RLAH) Functional Activities Test

Investigators: Rogers and Figone [55] (1980).

Purpose: assessment of self-care skills in tetraplegics.

Target population: tetraplegic persons.

Test composition: eight categories are included, namely feeding, grooming, toileting and bathing, upper extremity dressing, lower extremity dressing, written communication, desk skills and transfers. Three to seven items are tested within each category.

Scoring method: the items are rated on a three-point scale, namely independent, assisted or unable. The test also assesses the use of upper extremity orthotic and assistive devices.

Psychometric properties: not available [82].

The Quadriplegia Index of Function (QIF)

Investigators: Gresham et al. [63] (1980).

Purpose: provide a more specific and sensitive instrument to document the functional improvements achieved during the rehabilitation of tetraplegic patients.

Target population: tetraplegic persons.

Test composition: the index is composed of ten variables: transfers, grooming, bathing, feeding, dressing, wheelchair mobility, bed activities, bladder program, bowel program, and understanding personal care. Administration of the test takes 30 min or less.

Scoring method: the items are graded on a five-point scale (0–4) in order of increasing independence.

Psychometric properties: the interrater reliability of the QIF was good [64]. The QIF appeared to improve significantly in both complete and incomplete tetraplegics between admission to and discharge from medical rehabilitation [65, 66]. Comparison of the total QIF to the total FIM resulted in a high correlation [66]. Comparison of subgroups of the QIF and FIM also resulted in high correlations between the subtests, except for the feeding subtest [91]. The QIF seemed to assess functional ability in the category of feeding more accurately than the FIM.

Normative data: average scores on the QIF at admission and discharge are provided for persons with complete and incomplete tetraplegia [66].

Additional information: in 1999 Marino and Goin [92] developed a short-form version of the QIF (sf-QIF). The sf-QIF consists of six items and is also graded on a five-point scale. The following items were selected: wash/dry hair, turn supine to side in bed, put on lower body clothing, open carton/jar, transfer from bed to chair, and lock wheelchair. Contrary to the original QIF the individual items in the sf-QIF were not weighted when determining the total score. There was a high correlation between the sf-QIF score and the 37-item QIF score [82].

The Common Object Test (COT)

Investigators: Stroh et al. [67] (1989).

Purpose: evaluation of the use of FNS.

Target population: tetraplegic persons.

Test composition: the COT uses a task analysis approach to evaluate a person's ability to perform specific phases of an activity. Each ADL is broken down into phases, including acquire and release phases and several performance phases unique to each activity. For example, the performance phases of eating are stab, lift-lower, and bite.

Scoring method: the subject is scored on (1) independence of performance; (2) quality of performance; (3) preference; (4) frequency of an activity; (5) frequency of method; (6) frequency of method at the observed level of independence for both systems; and (7) importance of the activity to the subject. The scoring of independence of performance, i.e., physical assist, adaptive equipment, self-assist, or independent, is assigned for each phase of the activities.

Psychometric properties: not available.

Additional information: Mulcahey et al. [93] also used this test to evaluate FES in adolescents with C5 or C6 level tetraplegia [82].

Name: The Spinal Cord Independence Measure (SCIM)

Investigators: Catz et al. [56] (1997).

Purpose: disability scale developed specifically for SCI persons in order to make the functional assessments of persons with paraplegia or tetraplegia more sensitive to changes.

Target population: persons with SCI.

Test composition: the SCIM covers three areas of function: self-care (score range 0–20), respiration and sphincter management (0–40), and mobility (0–40). The time needed for the evaluation is 30–45 min.

Scoring method: 16 items are scored on an ordinal scale varying from three to nine classes. The final score ranges between 0 and 17.

Psychometric properties: the interrater reliability of the total SCIM scores was good. Sensitivity of the SCIM appeared to be higher than the sensitivity of the FIM. In tetraplegic subjects the FIM missed 22 % of the functional changes detected by the SCIM [94].

Additional information: in 2001 the developers of the SCIM presented a revised SCIM (SCIM-II) [95]. The interrater reliability of total SCIM-II scores was also high, but no distinction was made between paraplegics and tetraplegics. Now, the most recent version of the SCIM is the SCIM-III [57, 96] (2007). In a study of Rudhe et al. [58] the relationship between upper extremity muscle strength tests, capacity tests, and the SCIM III in persons with tetraplegia was explored. A total of 29 individuals with tetraplegia (motor level between C4 and T1; sensory–motor complete and incomplete) participated. The total score, category scores, and separate items of the SCIM-III were compared to the upper extremity motor score, an extended manual muscle test for 11 upper extremity muscles, and 6 functional capacity tests of the hand. The SCIM-III sum score correlated well with the sum scores of the three tests. The SCIM-III self-care category correlated better with the tests compared to the other categories. The SCIM-III self-care item "grooming" highly correlated with muscle strength and hand capacity items.

The Tetraplegia Hand Activity Questionnaire (THAQ)

Investigators: Land et al. [71] (2004)

Purpose: To construct a disease-specific questionnaire to evaluate interventions to the arm–hand of tetraplegics in terms of gained and lost activities relevant to the patient.

Target population: tetraplegic persons.

Test composition: All arm–hand function-related activities were inventoried by examining existing scales and interviewing SCI patients and professionals in the field. Subsequently, item reduction was achieved; first, in the technical construction by incorporating all activities in an item list, then reducing the list by selecting the items most likely to be sensitive to change after surgical or functional electro stimulation interventions on the arm–hand as judged by an expert panel, using a Delphi method. The arm–hand-related activity inventory comprised 652 activities. The technical construction of the items and the Delphi procedure resulted in a questionnaire with 153 items.

Scoring method: to each item three scores (of ordinal level) were assigned; performance (0–3): this score represents the difficulty in performing an activity, aid (0–3): this score assesses the utilization of an aid, importance (0–2): this score shows the importance that the patient attributes to performing the activity independently.

Psychometric properties: not available.

Although there are many outcome measures to evaluate hand functions in patients with tetraplegia, none of them could reach an international acceptance so as to be referred to as a gold standard. The reason for this is that none of them meet the criteria for the ideal outcome measure in tetraplegics. The necessary criteria for choosing an appropriate test have been stated and include:

1. Activities appropriate for tetraplegic individuals representing their ability to perform actual ADLs requiring hand function
2. Insensitivity to learning
3. Standardized administration
4. An unambiguous scale that does not combine too many aspects of function (i.e., level of independence and time for completion scored concurrently)
5. Multiple trials to help ensure reliability
6. Sensitivity to changes provided by treatment or intervention to restore upper extremity function [82, 97].

Among the tests reviewed in this chapter, "Spinal Cord Independence Measure-III, Quadriplegia Index of Function (both original and short versions) and The Capabilities of Upper Extremity Instrument" appeared to be the most useful ones. However, while choosing the appropriate test for tetraplegics, the most important issue is to decide whether the examiner wants to evaluate isolated hand function or overall body function in the level of activity and/or participation. So, as no patient is similar, the most appropriate test should be chosen for each individual tetraplegic.

We have recently investigated the reliability and validity of the "Duruöz Hand Index (DHI)" in assessing hand function in traumatic tetraplegic patients [98]. We assessed 40 patients with the DHI questionnaire, sf-QIF, visual analogue scale of hand function, and Health Survey Short Form-36, respectively. At the end of the study, DHI was found to be a valid method for the assessment of hand function in tetraplegics. We concluded that since DHI is a practical and time-efficient method, it can easily be used in the follow-up period during the rehabilitation of tetraplegic patients in the future [99].

Summary

To establish a good rehabilitation policy for arm and hand in patients with C-SCI, evaluation of and insight into the outcome of arm and hand are necessary.

Although there are many tests to evaluate arm and hand function in tetraplegics, only a few of them has been studied for their reliability and validity. Among the general basic tests, "The Sollerman Test" and among the special basic tests, "The Capabilities of Upper Extremity Instrument" and "Motor Capacity Scale" have been found to be valid and reliable in tetraplegics. However, none of them has gained worldwide use.

Among the tests specifically designed for tetraplegics, the most commonly used test at the complex activity level is "Quadriplegia Index of Function" which has a well-documented validity, reliability and responsiveness. "Short-form version of the Quadriplegia Index of Function" is also preferred because of its high correlations with the long version and easy applicability. Taking place in the same category "Van Lieshout Test" and its short version have been found to be valid and reliable. "SCIM" is the only comprehensive skill test that is specifically designed for people with SCI. The importance of SCIM seems to increase gradually and its reliability and validity studies are carried out at international extent. Self-care activities of SCIM-III have been showed to reflect the upper extremity performance of tetraplegics successfully. "DHI," which has recently been found to be a valid method in the assessment of hand functions in tetraplegics, can be commonly used in the future.

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Hand Function in Parkinson's Disease

10

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Physiology of Hand Function

Parkinson's disease (PD) is a chronic, neurodegenerative disease whose primary pathophysiology is the loss of the dopamine-containing cells in the basal ganglia [1]. Deprived of their normal dopaminergic inputs, nuclei within the basal ganglia become dysfunctional leading to abnormal neural oscillations and synchronization within multiple basal ganglia–thalamic–cortical circuits [2]. These circuit disturbances lead to the clinical manifestations of the disease, which include such motor impairments as bradykinesia (slow movements), muscle rigidity, resting tremor, and postural instability. The impairment in voluntary movement in PD is characterized by a number of specific sensorimotor processing deficits, including a generalized slowness of movement [3]; a difficulty in carrying out sequential movements [4]; a reliance on sensory input, particularly visual input, to guide and correct movement [5, 6]; and difficulties in timing, synchronizing, and coordinating movements [7–9]. Control of hand function can be quite compromised. This portion of the chapter reviews the behavioral manifestations of impaired hand function in PD established by experimental data, and discusses insights gained from these and related studies into neural control of hand function.

Role of the Basal Ganglia in Grasp Function

The fine motor skills of the hand, specifically for grasping and object manipulation, are thought to involve interactions among networks that include the anterior intraparietal area (AIP) of the posterior parietal lobe, the rostral portion of the ventral premotor cortex (PMrv), and primary motor cortex (M1) [8, 10, 11]. The basal ganglia receive massive inputs from most of cortex, including inputs from AIP, PMrv, and M1, and project back to AIP [12], PMv [13, 14], and M1 [13, 15, 16]. The basal ganglia are strategically connected to cortical regions responsible for the planning and execution of hand movements and thus play an important role in coordinating activity within this network. The basal ganglia have been implicated in the control of predictive grasp planning during goal directed movements and scaling of parameters such as grip amplitude and rate in precision

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grip (for review, see Prodoehl et al. [11]). The loss of dopaminergic cells in the basal ganglia disrupts the discharge patterns of important neural signals across entire basal ganglia–thalamic–cortical circuits [17], thus compromising the functionally of many cortical areas important for skilled hand function.

Sensorimotor Deficits of Hand Control in PD

The coordination of sensory information with motor planning is crucial for appropriate execution of hand movements. The regulation of force control, an important parameter for proper hand function, relies on appropriate activation of the basal ganglia [18, 19]. In PD patients, the latency and rate of isometric force generation is impaired during both the generation and release phases of force production [20, 21]. Isometric force control in PD is also associated with increased variability in grip force with increased force magnitude, or with removal of visual feedback [22]. Specifically, amplitude of corrective responses to visual feedback of force production is found to be greater for PD patients, which in turn corresponds to a greater variability of force output during the task. This variability may be due to increased response of long-latency stretch reflex processes [23, 24], delayed long-latency cortical inhibition of the motor potentials [25], and/or abnormal motor unit recruitment as seen in subjects with action tremor [26, 27]. However, it is not a function of decreased muscle strength [22]. Motor dysfunction in PD is also related to a dissociation between sensory feedback and motor output [28]. Sensory information about the hand in space is vital for the maintenance of dynamic goal directed movements [29]. PD patients exhibit sensory deficits such as decreased spatial [30] and temporal [31] tactile discrimination thresholds of the fingertips, and deficits in proprioceptive acuity [32–34]. The integration of sensory information for the planning of an expected motor output is also impaired in PD [34–36]. Deficits of sensorimotor integration in PD have been proposed to underlie patients' reliance on external cues, such as visual feedback, to perform motor tasks [6, 34]. Impaired sensorimotor integration may also be responsible for PD deficits in hand dexterity [37]. For instance, when asked to produce a repetitive finger movement, PD patients have difficulty maintaining a synchronous response to an auditory tone [38], and exhibit a decrease in movement amplitude over time [39], and an increase in finger lift duration [40]. Maintenance of a repetitive tapping rhythm also relies heavily on visual feedback of the hand during the task [41]. The spatial and temporal accuracy with which subjects are able to tap varies with medication [42–45] and is not a result of muscle fatigue [46]. This lends support the idea that difficulties with sensorimotor control are a function of impaired central processing rather than faulty peripheral signals.

Grasping and Functional Hand Control

Much of what we know about hand function in PD stems from studies on grasp control. Although a seemingly simple task, to grasp an object one must appropriately shape the hand to the object by spatially and temporally coordinating multiple digits to the shape, size, and orientation of an object during reach ("preshaping"), and choose contact points on the object allowing successful grasping and lifting the object. After interacting with the object, it is imperative that the force exerted on the object is large enough to avoid slip, but at the same time not so large as to result in destruction, while also allowing the freedom of individual digit modulation to successfully manipulate the object to meet task demands. There are many facets within the process of grasping where small deficits could lead to major adverse consequences.

Reach-to-grasp. Impairments of reach are seen from the very start as patients tend to exhibit difficulty in movement initiation to a target [47–49]. During the reach, PD patients exhibit deficits in hand preshaping to object geometry. Unlike healthy individuals where hand shaping to object geometry begins early after reach onset [50, 51],

PD is associated with a delayed preshaping of hand configuration [8, 52, 53]. When objects are positioned are various locations in the workspace, PD patients correctly specify movement direction while simultaneously mis-specifying hand shape [52]. Grip aperture closure also is delayed [52, 54–56] and amplitude of maximum grip aperture is reduced [56–58]. In addition to grip aperture, abduction between the index and middle fingers which increases with grip aperture in control subjects is essentially nonexistent in PD patients until the end of the reach [8, 52]. In other words, PD patients do not open there grasp to the same extent that control subjects while also waiting to close their hand until it is near the object. This is indicative of a dissociation between the timing of the reach and grasp components [59] and can affect the ability to manipulate objects properly. This is partially due to loss of predictive control of voluntary movements in PD patients [60, 61]. Grasp planning for object manipulation is also impaired as seen as lack of adjustment of hand shaping to meet the task goals. For instance, healthy individuals produced different grasp configurations depending on whether a liquid was to be poured out of a bottle or whether it was to be thrown [62]. However, PD patients do not modulate hand shaping during the reach to meet task demands [53]. Corrective responses to object perturbations are also impaired in PD as seen by delayed motor adaptations to on-line changes in object size [63]. Consistent with their overall dependence on visual cues to control movement, PD patients also rely heavily on visual feedback to guide the movement of the hand to the object [8, 52, 54]. This overreliance on vision may well be due to an impaired ability to extract critical proprioceptive information and integrate it with vision and motor commands [6, 36]. Thus, when visual feedback of the object and/or the hand is removed during the reach, PD patients take significantly longer to transport the hand to the object, especially at close range to the target, while producing a greater than normal grip aperture [64]. Removal of visual feedback of the hand during the reach also exacerbates inappropriate hand preshaping and results in significantly more failed grasps [8].

In addition to hand transport during reach, choice of digit placement on an object is important for successful manipulation [65, 66]. PD patients exhibit impairments in the planning of where to place their digits resulting in suboptimal performance of object manipulation compared to health controls [67]. Specifically, when lifting an object whose center of mass is shifted to the left or right side (Fig. 10.1a), PD patients exhibit poorer modulation of digit placement to counteract the distribution of the object's weight. Furthermore, PD patients exhibit less independence of contact points across digit pairs (Fig. 10.1b), suggesting impairments of fine motor control of digit individuation. Impairments in the planning of digit placement in PD patients are combined with an inability to anticipate appropriate forces in order to lift the object vertically. Figure 10.1c shows the average trial-by-trial performance of peak object roll for the PD and control groups tested in Lukos et al. [67]. Although the PD patients exhibited the ability to learn to anticipate the object weight distribution to some extent (i.e., object roll decreased over trials), they still failed to implement a grasp with the same degree of effectiveness as the control group. Thus, PD patients generated systematically greater object rolls across the entire block of trials. These data suggest impairments in the acquisition and/or utilization of the sensorimotor memories associated with the planning of digit placement and force coordination for object manipulation (for more details, see Lukos et al. [67]).

Force control during object manipulation. Force control when interacting with objects entails complex coordination between the magnitudes of the force used to squeeze the object (grip force) and the force used to lift the object (load force), as well as in the temporal transitions between grip, lift, and manipulation. Many studies have looked at PD coordination across these grasp phases. The temporal coupling of grip and load force development prior to lift is delayed in PD [55, 68–70]. This latency not only affects force production, but also increases the lift duration, thus slowing movement. Concurrently, the scaling of multi-digit force sharing patterns to object

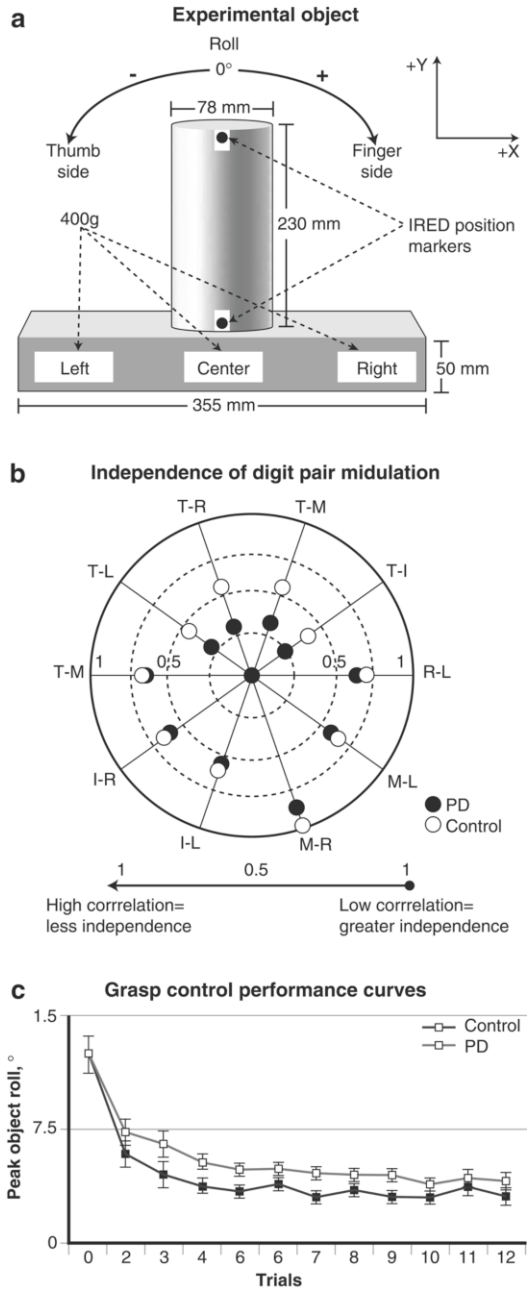

Fig. 10.1 Anticipatory control of digit placement is impaired in PD. (**a**) is an illustration of the object used in Lukos et al. [67]. The graspable object (frontal view) was affixed to a horizontal base where a mass was added to the *left*, *center*, or *right* slots. Markers were placed on the object to record object roll, a measure of task performance caused by incorrect planning of digit placement and/or forces to counteract the added mass. (**b**) is a polar plot with each *solid line* representing the axis of magnitude of a digit-pair correlation. The correlation coefficient (Pearson's *r*) of each digit pair is shown as a *white* and *grey circles* for the PD and control subject groups, respectively. Values near the center of the plot (closer to zero) are indicative of greater independence of digit pair planning. *T*, *I*, *M*, *R*, and *L* denote thumb, index, middle, ring, and little fingers, respectively. (**c**) shows the performance curves of peak object roll across trials for the PD and control groups (*white* and *black symbols*, respectively). This figure was adapted from Lukos et al. [67]

properties during whole hand grasp is impaired during grasp development [71]. Specifically, differentiation of the force sharing patterns of the digits prior to lift was not adapted to the object weight distribution to the same extent as age-matched controls. However, after lift, subjects were able to use sensory feedback grasp performance (i.e., visual feedback of the object's position and haptic feedback of the forces exerted) to correct force sharing patterns. This suggests impairment in anticipatory force modulation to meet task demands. It is hypothesized that predictive force control deficits are a result of central impairments associated with the generation and/or retrieval of sensorimotor memories for movement planning [71, 72]. However, these deficits in anticipatory grasp control are variable in PD and depend on task complexity, patient severity, and whether or not patients were tested on or off anti-parkinsonian medication [73–75].

Once an object is lifted, PD patients tend to produce greater grip forces than healthy age-matched controls [69, 76], regardless of whether they have explicit knowledge of how heavy the object is [74, 75]. This may be due to impairments in tactile discrimination [30, 31] or sensorimotor integration [34, 35] described above, since cutaneous information from peripheral afferents has been shown to be vital for normal force production during precision grip (for review, see Johansson [77]). However, the coordinated relationship between grip force and load force which is present in healthy controls [78] is also apparent in PD patients during object manipulation [69, 74, 75]. Force sharing patterns across digits during the hold phase of whole-hand grasp is also maintained in PD [79]. Multiple factors including inappropriate generation and/or retrieval of

sensorimotor memories, deficits in the coordination of multiple effectors, and impairments in sensorimotor integration likely contribute to the observed deficits in grasping and object manipulation in PD.

Pathophysiology of Motor Dysfunction in PD

Neuroimaging studies in healthy individuals have shown that activation of the basal ganglia is associated with multiple grasp functions, including planning [19, 80, 81], execution [82, 83], and coordination [84]. Activation of brain networks in PD patients both at rest and during movement is altered and reorganized. During the execution of complex movements, PD patients show hypoactivation of rostral supplementary motor area, which has been proposed to underlie akinesia [85–89]. Abnormal hyperactivity of motor cortex [87, 90], sensorimotor cortex, dorsal premotor cortex, and cerebellum [91] has been proposed to underlie bradykinesia and difficulties with movement amplitude and velocity. Decreased activation of the medial frontal cortical areas is also thought to underlie an inability for PD patients to initiate motor actions [92–94]. The reorganization of brain networks in PD also involves increased activations in parietal and premotor cortices [85–87, 95], as well as hyperactivity of cerebellar circuits [96] as mentioned above. The abnormal activation of many cortical regions in PD patients, especially those associated with motor planning of hand actions, reflects the importance of the functioning of the basal ganglia in maintaining the integrity of the entire circuit responsible for hand function.

As a general consideration, the basal ganglia output could be abnormal in PD either due to the amount of output or its pattern [97]. Constant hyperactivity or hypoactivity could act as a constant facilitator or brake upon target structures. One leading current view is that the output of the basal ganglia becomes excessively synchronized at low frequencies in PD or the MPTP model of PD [98–102]. Excessive synchronization means that abnormal network properties reduce responsiveness to the specific signals related to a particular context or action. In addition, the output may lose topographic specificity, with a loss of finely differentiated parallel processing [103]. In most general terms, the signal to noise ratio of basal ganglia function is impaired in parkinsonism [104]. In addition to abnormal activation of many cortical regions, PD patients exhibit distorted and slowed oscillations of brain activity as observed through electroencephalography (EEG) recordings of scalp potentials [105]. There is distorted cortical and subcortical activity that is thought to result from disruptive activity and abnormal rhythmic synchrony within the basal ganglia circuitry, particularly in the beta frequency band (10–30 Hz) [106]. Abnormal synchronous firing patterns of neurons in the basal ganglia are present in parkinsonian monkeys [107–109] and human patients [110–112]. A recent study recorded scalp EEG in PD patients while modulating subthalamic nucleus activity via deep brain stimulation [113]. Therapeutically stimulating the subthalamic nucleus at high frequency improved the ability of patients to inhibit a motor response, while at the same time modulating task-related beta band activity recorded over (right) frontal cortex towards the pattern seen in controls. One current hypothesis of the pathophysiology of PD is that increased "neural noise" in the basal ganglia underlies motor variability, movement delays, difficulties with prehension and other motor actions [114, 115].

The reorganization of firing patterns in the cortical circuits of PD patients favors externally guided feedback of motor control as a compensatory alternative to the dysfunctional internally guided anticipatory control circuits. The behavioral correlates of this neural reorganization include: increased reliance on visual feedback for movements of the arm; a reduced ability to preshape the hand while reaching for an object reflects impaired internal prediction in mapping dynamically changing hand configurations onto object properties; and a reduced ability to coordinate multiple body parts (hand and arm) during movement. Such deficits in PD have been well documented [6–8, 52, 116].

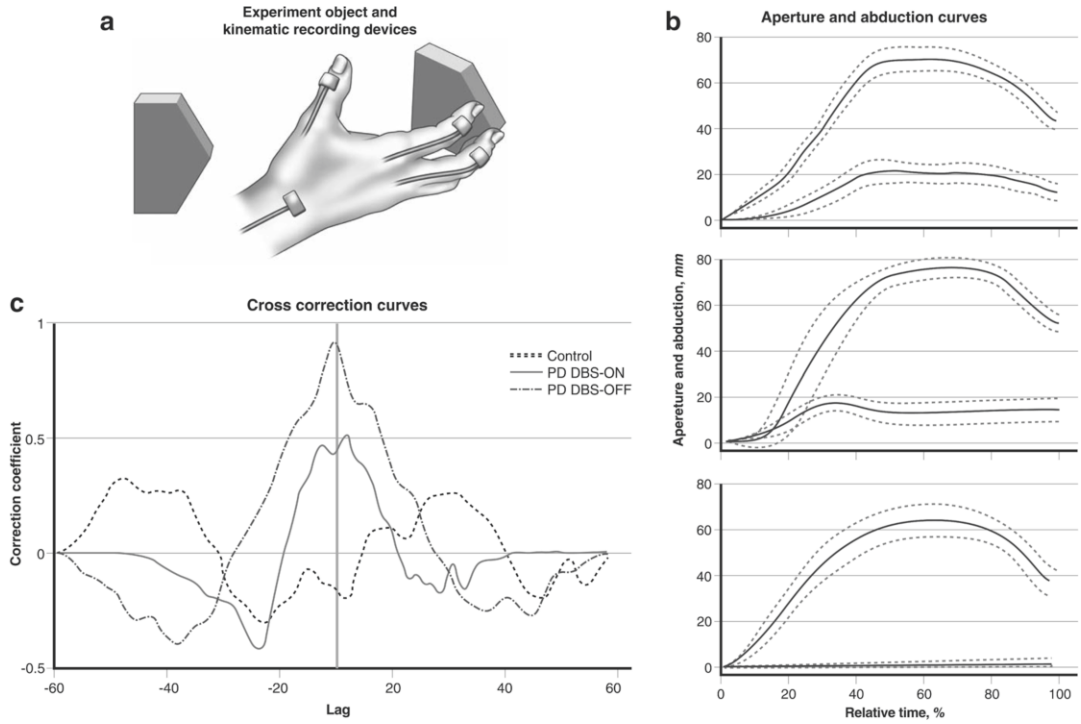

Fig. 10.2 Deep brain stimulation improves coordination of hand preshaping during reach. (**a**) Shows the object used in (*right*) and motion capture sensor positioning of the subjects' hand (*left*) in Schettino et al. [124]. (**b**) Displays the mean (±standard deviation) curves for aperture and abduction (higher and lower amplitude curves, respectively) for a representative age-matched control subject, a PD patient with DBS on, and the same patient with DBS off (*top*, *middle*, and *bottom* plots, respectively). (**c**) Shows the cross-correlation curves for a representative age-matched control subject, a PD patient with DBS on, and the same patient with DBS off (*dashed*, *solid*, and *dotted lines*, respectively). A temporal lag of zero between the coordination of aperture and abduction is centered around 100 on the horizontal axis. This figure was adapted from Schettino et al. [124]

Deep brain stimulation. Recently, there has been a significant shift in the therapeutic strategies in common use to treat PD. After a period dominated almost entirely by the use of pharmacologic treatments, relying for the largest part on dopaminergic medications (the dopamine precursor levodopa and varied dopamine agonists), surgical interventions have come back into favor. Beginning with targeted lesions (pallidotomy, subthalamotomy), there has now been a substantial shift towards the use of deep brain stimulation (DBS). Most recently unilateral or bilateral subthalamic stimulation (STN) has become the surgical procedure of choice [117–121], more effective even than optimal pharmacotherapy in the advanced patient [122]. Invasive procedures, such as DBS of the subthalamic nucleus show improvements of motor performance in many patients (for meta-analysis, see Boucai et al. [123]). A recent study by Schettino et al. [124] showed that STN DBS resulted in a more normal pattern of hand preshaping when reaching to grasp an object, a pattern not seen with dopaminergic therapy in a previous study [8]. Specifically, when reaching towards an object that was convex on one side (Fig. 10.2a), healthy control subjects tended to generate temporally coordinated trajectories of grip aperture (between the thumb and index finger) and abduction (between the index and middle fingers). This is shown in Fig. 10.2b (top plot) as an increase and decrease in aperture and abduction at similar times throughout the reach. This pattern was not true for PD patients without DBS. Although changes in aperture were

present, abduction remained static throughout the reach (Fig. 10.2b, bottom plot). However, when stimulation was turned on, coordination between aperture and abduction was partially regained (Fig. 10.2b, middle plot). The temporal synchrony of the aperture and abduction trajectories can be assessed through cross-correlation analyses. Figure 10.2c displays a peak in the correlation curve at the midpoint (100th point) for the control subject (dashed line), which corresponds to zero latency in the coordination between the aperture and abduction curves. Conversely, there is no significant correlation between the trajectories for the PD patient off DBS (dotted line), thus no temporal synchrony between aperture and abduction. Yet the curve when DBS was turned on shows a peak at the midpoint (solid line). Although the peak was not as high (i.e., the correlation was not as strong), the PD patient(s) with DBS on exhibited temporal synchrony for the coordination of the aperture and abduction. Therefore, DBS resulted in increased spatiotemporal coordination of hand shaping during grasp. For more details, see Schettino et al. [124]. Other groups have looked at force regulation with DBS and have shown improvements of force regulation during grasp [125, 126]. Specifically, the overexertion of forces on an object traditionally associated with PD was partially remedied with DBS. However, others have noted improvements in hand mobility and dynamics, but with minimal enhancement or even worsening of performance during grasping tasks [74, 75, 127]. Thus, this method deserves further investigation to reveal the processes by which improved motor function is obtained. With continual improvements of medical devices for the localization of optimal insertion of electrodes for stimulation of the basal ganglia, better understanding of the ideal parameters with which to provide stimulation, and the increasing knowledge of the neural circuitry responsible for motor function, the mechanisms by which the basal ganglia are affected by DBS and its efficacy could be greatly enhanced in the future.

Noninvasive electrocortical stimulation. Cortical electrical stimulation has become an experimental treatment of PD motor symptoms aimed at altering the output of the brain networks through the application of an electrical current. Noninvasive brain stimulation techniques, such as transcranial magnetic stimulation (TMS), electroconvulsive therapy (ECT), and transcranial direct current stimulation (tDCS) have shown to modestly improve motor deficits in PD [128, 129]. Repeated rTMS therapy sessions (eight sessions over 4 weeks) have also shown gradual improvement of complex hand movements with after effects lasting 1 month post treatment [130]. Others have combined techniques by following tDCS by repetitive TMS (rTMS) over the motor cortex and found improvements of bradykinetic hand movements, yet no influence on hand coordination [131]. Still, more work needs to be done to determine the appropriate stimulation sites, duration of the treatment and intensity of the stimulus, as well as determine effectiveness. For instance, rTMS can cause either excitation [132] or inhibition [133] of cortical excitability depending on the stimulation frequency. Thus, noninvasive stimulation has the potential to be a means of PD therapy, yet the particular methods by which to transmit the appropriate signals are still under investigation.

Clinical Aspects of Hand Function

Tremor

Tremor in one hand is often the initial manifestation of Parkinson's disease that is obvious to the patient or family. It usually is present at a frequency of 4–6 per second and may be confined to a small part (for example, one finger). Some patients note that the tremor begins in the index finger or the thumb. Typically the tremor occurs when the affected hand is at rest. The shaking is regular and rhythmic. A simple, small to-and-fro motion of the arm may be all that is obvious. More often, there is a complex movement, with slight turning of the forearm and a back and forth movement of the thumb and fingers reminiscent of a hand counting coins or of rolling a marble between the thumb and forefinger. Hence, the tremor has been described as "pill-rolling" in quality [134].

The tremor disappears during sleep or when the patient is relaxing quietly. Thus it may be present only intermittently, and its presence reflects the patient's state of mind. Nervousness or stressful situations or even the alertness induced by concentrating on a mental task regularly enhances the tremor. The patient may be sitting a home reading a book until some excitement in the storyline or the arrival of a visitor makes the tremor reappear. Resting tremor is often more embarrassing than functionally problematic for many patients because it tends to disappear with action [134].

A characteristic feature of tremor in PD is its variability. It seems to come in bursts and then subsides. The tremor in one part need not be synchronous with that in another. In fact, tremor may appear in one hand for a few minutes or less, and then quiet down only to appear in the other hand or another limb. Most patients are able to stop the tremor by an act of will. Many learn various tricks to stop it. A slight movement or change of posture may arrest the tremor for a while; eventually it reappears after some minutes or longer. Other patients keep the tremulous hand in a pocket, moving it slightly to keep the tremor at bay [135].

Tremor in one hand while walking disappears if the patient remembers to swing the arm. It reappears when the patient forgets and allows the arm to hand idly at the side—as if the tremor were a substitute activity. Holding something in the hand can also stop the tremor. We have seen patients who carry a package in the hand while out walking, just to stop the tremor [134].

So far, we have discussed the resting tremor of PD. Nearly half of all patients, however, have a postural and/or action tremor. Many patients have both a resting and action/postural hand tremor, but some patients have only the latter. Like the resting tremor, postural and action tremors may be unilateral or, if bilateral, are usually worse on the more involved side. They are generally more functionally disabling than the resting type, since they become most prominent when the patient is doing something with the involved hand. Simple activities such as using a screwdriver, eating a bowl of soup or even holding a newspaper can become major sources of discomfort or disability [136]. There seems to be a subset of Parkinson patients who have prominent action/postural tremors, often in conjunction with a prominent resting tremor, who have a slower progression than the usual patient. This group can be labeled "benign tremulous parkinsonism." These tremor types can unfortunately be relatively unresponsive to anti-parkinsonian medications (vide infra).

Patients may feel a tremor that they describe as internal to the affected hand or arm. Sometimes it is a tremor that is simply too fine to be noticeable to either the patient or the family. It may be felt as a quivering or vibrating sensation. Some patients say it is a tremor that is felt in the muscle but many patients describe a feeling of quivering in the bone of the limb. The sensation is usually felt in the forearm or the upper arm and rarely in the hand itself. These internal tremors are often more uncomfortable and therefore more disabling than outright resting or postural/action tremors [137].

Bradykinesia and Rigidity

Strictly speaking, rigidity of the hand or arm is not a symptom the patient feels but an objective sign that can be appreciated only by another person examining the patient for evidence of resistance to passive motion of the limb. Patients with rigidity, however, often complain of a feeling of stiffness, which is perhaps the subjective appreciation of rigidity. It is surprising that many patients with clear-cut rigidity do not complain of stiffness. To examine the arm for rigidity, the physician takes the patient's arm and gently bends and straightens it a number of times while asking the patient to relax. Rigidity can be tested best at the elbow or the wrist. When testing at the elbow the movements can be increasingly rapid flexion and extension maneuvers. At the wrist, a slow, gentle rotational movement is best to elicit signs of rigidity. If there is no rigidity noted after a number of trials, facilitation strategies are employed to elicit it. The usual way to facilitate the chances of finding a rigid arm is to ask the patient to open and close the other hand.

This should immediately bring out the rigidity in the arm under examination. A persistent resistance to passive motion of the wrist or elbow with a plastic or lead pipe quality is what is meant by rigidity. There is often a regular, jerky quality to the resistance as if there were a ratchet gear or cogged wheel in the joint being manipulated. That feeling represents the underlying tremor acting on the rigid limb and is known as "cogwheel rigidity." One can also look at rigid muscles and note that they are tensed constantly in a state of sustained contraction. The tightness and firmness of the muscles can be palpated.

Rigidity in the arm needs to be distinguished from the increased tone associated with spasticity. Arm spasticity is best elicited if the examiner passively pronates and supinates the forearm. The resistance tends to increase with movement and then gives way (the clasp knife reaction). This is in marked contrast to the plastic rigidity of Parkinson's disease.

Rigidity certainly slows movement, but bradykinesia in Parkinson's disease is a phenomenon that should be separated from mere rigidity. Slowness of movement can be seen in an arm that is not rigid at all, and fairly rapid movement can be seen in limbs that have significant increased tone. One of the commonest manifestations of bradykinesia in the arm is loss of automatic, associated movements. The patient does not swing the affected arm or swings it less than the unaffected arm. Furthermore, a normal person does not keep the arms perfectly still while sitting. We tend to move the arm, perhaps even tapping the fingers or fidgeting a little. A patient with Parkinson's disease, on the other hand, may leave the arm perfectly still at his side or in his lap for long periods of time. There is an extreme poverty of spontaneous movement in the arm and hand. This poverty of motion can lead to frozen shoulders, elbows or even wrists in the untreated patient and even in some patients who are being treated with anti-parkinsonian medications.

Another aspect of bradykinesia is hesitation on initiating movements with the affected arm. There may be rapid fatigue that severely limits the amount and type of manual activity that a patient can do. Repetitive movements with the fingers or the whole arm tend to be difficult to accomplish. It can be difficult for a patient to do two things in succession such as putting an arm into a sleeve and then using the same arm to button the coat. This in part may be due to concomitant problems with executive function but can simply be related to bradykinesia. At any rate, it makes ordinary activities that require the use of the arms, such as dressing or eating, take longer time and give them the appearance of being done in a too deliberate manner [134].

Bradykinesia varies considerably from moment to moment and in different circumstances. The phenomenon is especially striking in severely affected patients. A patient who can barely use his arms suddenly and inexplicably is able to dress himself. In general, automatic acts of daily life are most affected by bradykinesia and learned acts less so. This has been called paradoxical kinesia. Hence a severely bradykinetic patient may play the piano tolerably well but does not swing the arm at all while walking [134].

Hand Function in Activities of Daily Living

Characteristic changes in handwriting occur in Parkinson's disease patients. These changes may be of diagnostic value to the physician and are often early and problematic for the patient. The handwriting tends to get smaller (micrographia). The letters are generally well formed but get progressively smaller as the patient continues to write; by the end of a sentence or phrase, the letters may be so small as to be difficult to read. In addition, if one looks closely, tremor may be evident in the writing in the form of small squiggles in each letter [134].

With the increasing importance of computers in everyday life, difficulties with keyboard operations have become important to patients with Parkinson's disease. The most frequent early complaint is that patients tend to hold down a single key with the affected hand for much longer than they might wish. This leads to multiple, repeat letters in the text they are working on. Patients also miss keys, hit the wrong key or are

unable to move easily from one key to another. Speed of typing is severely affected.

There are many other problems with living activities that are impacted by the abnormal hand and arm function of Parkinson's disease. Deficits in fine motor coordination lead to problems getting wallets or other objects out of coat or pants pockets. Extricating money from a purse or wallet may be nearly impossible. Toileting and shaving become a chore and putting on makeup can be messy at the very best. To tie a shoelace may take forever, as can buttoning. Poverty of movement, stiffness, and movement initiation difficulties, may make it difficult for a patient to get his arm into a coat or jacket sleeve without help from another person.

Examination of the Hand and Arm

Hand function is assessed best using reproducible and organized rating scales. The most widely used ratings scale is a modification of the unified Parkinson's disease rating scale (UPDRS) [138]. Part II of the UPDRS measures activities of daily living. The two most relevant questions ask about hand writing and cutting food or handling utensils. The ratings are on a scale of 0–4.

Handwriting
0 = Normal
1 = Slightly slow or small
2 = Moderately slow or small; all words legible
3 = Severely affected; not all words legible
4 = The majority of words are not legible

Cutting food and handling utensils
0 = Normal
1 = Somewhat slow and clumsy, but no help needed
2 = Can cut most foods, although clumsy and slow; some help needed
3 = Food must be cut by someone, but can still feed slowly
4 = Needs to be fed

Two other more indirect measures of hand and arm function are the ability to dress oneself and hygiene. The dressing question covers the ability to button and to get the arm into a sleeve.

Dressing
0 = Normal
1 = Somewhat slow but no help needed
2 = Occasional assistance with buttoning, getting arms into sleeves
3 = Considerable help required but can do some things alone
4 = Helpless

The question on hygiene covers bathing, brushing of teeth, washing, combing hair, and going to the bathroom

Hygiene
0 = Normal
1 = Somewhat slow, but no help needed
2 = Needs help to shower or bathe; or very slow in hygienic care
3 = Requires assistance for washing, brushing teeth, combing hair, going to the bathroom.
4 = Requires mechanical aids or Foley catheter

Direct examination of motor hand function is accomplished by Part III of the UPDRS, which includes sections devoted to tremor, rigidity, and motor coordination of the hand and arm.

Tremor at rest
0 = Absent
1 = Slight and infrequently present
2 = Mild in amplitude and persistent. Or moderate in amplitude, but only intermittently present
3 = Moderate in amplitude and present most of the time
4 = Marked in amplitude and present most of the time

Action or postural tremor of hands
0 = Absent
1 = Slight, present with action
2 = Moderate in amplitude, present with action
3 = Moderate in amplitude with posture holding as well as action
4 = Marked in amplitude; interferes with feeding

Rigidity
0 = Absent
1 = Slight or detectable only when activated by mirror or other movements
2 = Mild to moderate

3 = Marked, but full range of motion easily achieved
4 = Severe, range of motion achieved with difficulty

Rigidity should be measured with the patient sitting and relaxed and should ignore cogwheeling, which is an indication of underlying tremor rather than rigidity.

Finger taps (Patient taps thumb with index finger in rapid succession with widest amplitude possible, each hand separately)
0 = Normal
1 = Mild slowing and/or reduction in amplitude
2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement
3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
4 = Can barely perform the task

Hand Movements (Patient opens and closes hand in rapid succession with widest amplitude possible, each hand separately)
0 = Normal
1 = Mild slowing and/or reduction in amplitude
2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement
3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement
4 = Can barely perform the task

Rapid Alternating Movements of Hands (Pronation/supination movements of hands, vertically or horizontally, with as large an amplitude a possible, each hand separately)
0 = Normal
1 = Mild slowing and/or reduction in amplitude
2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movements.
4 = Can barely perform the task.

In addition to poverty of spontaneous hand and arm movements such as a diminished unilateral or bilateral arm swing when walking, Parkinson patients have a typical hand posture that is evident even early in the disease. The outstretched hand in held flexed at the metacarpal/phalangeal joints and is also slightly flexed at the elbow. Full range of motion at the shoulder is often not possible and the shoulder may be lower on the more involved side in comparison to the less involved side.

Sensory Symptoms

Various types of pain syndromes can interfere with hand function in Parkinson patients [139]. Diminished spontaneous movement of the arm, as described in the previous section, often leads to frozen shoulders or less frequently frozen elbow. This condition not only causes poor movement of the involved joint but also causes significant and sometimes disabling pain. Dystonia, usually drug induced from levodopa preparations, but sometimes spontaneously, can cause painful cramps [140]. These dystonias can involve any combination of hand and arm muscles and sometimes resemble those seen with writer's cramp or other occupational dystonias. Another not uncommon complaint is pseudoradicular pain mimicking cervical radiculopathy [141]. The pain may start in the elbow and radiate both distally and proximally to the shoulder or may start in the shoulder and radiate to the hand. Finally a host of nonspecific symptoms cause functional hand problems. These include numbness, soreness or the muscles or bones, aching, tightness, and feelings of abnormal temperature sensations in the arm or hand (cold or hot) [142]. As with many symptoms of Parkinson's disease, the hand or arm on the more affected side is usually more likely to display these sorts of symptoms.

Dyskinesias Associated with Treatment

Choreiform movements and dystonic hand postures often are the consequences of treatment with dopaminergic agents for Parkinson's disease

[143]. These most commonly occur with peak dose concentrations of levodopa (high dopa dystonia) but also can occur with inadequate levels of levodopa during "off" periods (low dopa dystonia) [144]. Both types of involuntary movements interfere with fine motor tasks such as eating, shaving, buttoning, writing, keyboard maneuvers, etc. Occasionally, they are more disabling than the bradykinesia and poor motor coordination directly related to the Parkinson motor signs [145].

Future Directions

Studying PD patients is an important way to understand the role of dopaminergic pathways originating in the basal ganglia for the regulation of hand function. Although our knowledge on hand function in PD has been greatly enhanced in the last few decades, there are still many aspects of PD hand dysfunction that are yet to be understood. Technological advancements are now allowing a more detailed examination of the behavioral deficits and the neural processes responsible. For instance, improvements in signal extraction in EEG through use of high density recordings with active electrodes and advanced signal processing techniques during movement now permit the recording of dynamic brain activity simultaneously with kinematic movements during motor tasks to gain a better understanding of how the hand is controlled [146]. Furthermore, combining EEG with functional magnetic resonance imaging (fMRI) provides both temporal and spatial resolution of cortical activity [147–149], which will greatly increase our knowledge about the reorganization of the basal ganglia circuitry. Directly recording from the STN and other brain regions in humans during surgery is providing direct evidence of altered neuronal firing in key circuits underlying PD (e.g., Wingeier et al. [150]). These and other methods are leading to new insights into the pathophysiology of PD and effect of current pharmaceutical and surgical therapies on the control of movement.

Summary

Parkinson's disease patients have a number of functional hand impairments. Major deficits include poor hand preshaping to object geometry, abnormal latency of force generation, lack of coordination between the timing of the reach and grasp components, dependence on visual cues and suboptimal object manipulation.

Clinical aspects of hand dysfunction include resting, postural or internal tremor, bradykinesia, rigidity, and drug-induced dyskinesias, best measured by the Unified Parkinson's Disease Rating.

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Hand Function in Children with Congenital Disorders

11

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Congenital Upper Limb Differences

Congenital differences of the upper limb are relatively common. Their prevalence is estimated at 16 per 10,000 live births but varies within different populations and ethnic groups. In frequency they are second to congenital heart malformations. In approximately 75–80 % of cases, the difference is unilateral. Associated anomalies are seen in up to 53 % of cases, with musculoskeletal defects found most frequently. Several other congenital-associated abnormalities occur in about one-third of all cases affecting different systems, including defects in head and neck, cardiovascular, gastrointestinal and genitourinary tract systems [1].

The precise causes of congenital upper limb differences are unknown in 60 %, but in 20 % of cases, a genetic cause exists, and in the remaining 20 %, the difference is due to an environmental cause [2].

The upper limb difference can either be isolated (confined to the upper limb, possibly bilateral) or part of a syndrome. Most isolated differences are not caused by genetic factors. Although occasionally a genetic cause is found for an isolated difference, most differences that are genetically based are part of a multiple congenital syndrome.

Most upper limb differences are isolated, and in most cases, other affected family members are absent. This suggests that most of these differences are caused by vascular problems during embryogenesis, either from vasoconstriction, haemorrhage, thrombosis or embolisation especially when transverse terminal defects are present [1].

A number of different classification systems have been proposed, but the currently used classification of congenital differences of the upper limb is based on the Swanson classification [3], the latter being modified by the Congenital Malformations Committee of the International Federation of Societies for Surgery of the Hand (IFSSH) in 1983 (Table 11.1) [4]. This classification scheme consists of seven main categories that are divided into subcategories, level of anomaly, diagnosis and sub-classification [3]. Most differences can be classified using this classification [5], but in cases of occurrence of various types of differences within the same limb, classification may be difficult. Failures of differentiation and duplications are the most common differences [6].

Although classifications can be useful to analyse groups of patients, they are of little practical value in the everyday management of these differences, because each case stands on its own and should be analysed and treated with a client-centred approach (Table 11.1).

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Table 11.1 Modified Swanson classification

I.	Failure of formation of parts (arrest of development)
	A. Transverse arrest (common levels are upper third of forearm, wrist, metacarpal, phalangeal)
	B. Longitudinal arrest (including phocomelia, radial/ulnar club hands, typical cleft hand, atypical cleft hand otherwise referred to as part of the spectrum of symbrachydactyly)
II.	Failure of differentiation of parts
	A. Soft tissue involvement
	B. Skeletal involvement
	C. Congenital tumorous conditions (includes radio-ulnar synostosis, symphalangism (stiff PIPJs with short phalanges), camptodactyly, arthrogryposis, syndactyly)
III.	Duplication
IV.	Overgrowth
V.	Undergrowth (thumb hypoplasia, Madelung's deformity)
VI.	Congenital constriction band syndrome
VII.	Generalised skeletal abnormalities

Impact of Congenital Hand Differences on Hand Skills Development

A century of research on infant motor development has provided a detailed description of the sequence of hand skills development and conceptual knowledge of how normal infants develop their hand function. However, the impact of having a congenital hand difference on the development of hand skills has rarely been studied. Understanding the normal sequence of hand skills development helps to identify the problems that children with congenital hand differences may encounter.

Hand motor function is of extreme importance to the developing child. The child's desire to understand and master his/her surrounding world results in exploration and manipulation of objects and different materials [7], and therefore the child's hand function is important for the child's total development. It is not only important for babies and toddlers, but it has also a major impact on the child's school performance. McHale and Cermak found that children in kindergarten spend almost one-half (46 %) of their in-class day in some type of fine motor activity [8], and later in school life, that percentage even increases. Due to a continued learning process, it takes a very long time for hand motor function to achieve its final state. Global gripping patterns that emerge in the first 12 months of life change gradually in fine manipulatory patterns, which fine-tuning continues into adolescence.

This is a traditionally based view on motor development, which has been practised for decades. Now there is much debate regarding this basis for intervention approaches. A paradigm shift towards the Dynamic Systems Theory of motor development has brought new insight in the treatment of children, although it is not extensively tested for children with congenital hand differences. The Dynamic Systems Theory (DST) is a theoretical framework in paediatric physiotherapy. It views movement as resulting from the interaction of many subsystems within the individual, features of the functional task to be accomplished and the environmental context in which the movement takes place. These subsystems are interdependent and work together, for example; strength in one system (e.g. visual) can support the weaknesses in others (e.g. kinaesthetic). In children with congenital hand differences, the underlying pathology (e.g. aberrant anatomical structures) causes functional problems, and this so-called mechanical disturbance can normally be compensated through other subsystems.

Normally, children with congenital hand differences alone overcome their hand function problems very well, sometimes using alternative strategies sometimes with surgical treatment or with the help of aiding tools. Psychological problems that arise from emotional problems with the hand difference are harder to overcome.

When treatment of the functional problems is not as successful as expected, one should be aware that some of these children next to their congenital hand difference might suffer from developmental coordination disorder (DCD). Even in the overall population of children, the prevalence of DCD is 13 % [9]. This comorbidity may affect the functioning of the child with the congenital hand difference. Children with DCD

manifest motor deficits in virtually every motor domain. They tend to work more slowly than their typically developing peers [10] 11and display deficits in gross motor (i.e. balance, gait) [12, 13] and fine motor skills.

Although the DST is very promising, no sufficient descriptions of hand skills development exist yet. Therefore, we will describe it based on the reflex, hierarchical and maturation theories.

A distinction can be made in two different stages of hand skills development:

1. Basic hand skills: reach, grasp, hold, transport, controlled release and support
2. Development of more complex hand skills: complementary two-hand use, "in-hand manipulation" and the use of utensils [14]

Basic Hand Skills

Reaching

Although the first swiping at objects tends to be unilateral, bimanual reach towards an object may be observed as early as 2 months after birth [15]. Children suffering from, for instance, arthrogryposis multiplex congenita (AMC) or a severe ulna dysplasia (UD) will already have difficulties with only reaching for objects.

Grasping

An infant's earliest grasping is a reflexive grasp, which relates to the physiologic flexor muscle tone characteristic of the full-term neonate. Between 4 and 6 months, the infant starts to develop control of grasping, using both tactile and visual information. Visual input is used to prepare the hand for grasping. This first ability to grasp, orient and adjust is the beginning of the purposeful grasp. In clinical practice, treatment of grasping problems is interwoven with treatment of "voluntary release" problems and "in-hand manipulation" problems.

The first purposeful grasp to be developed is the palmar grasp. This grasp is described as a pronated underarm with flexion of all fingers and thumb holding the object. Although in the past research, ulnar palmar grasp was said to emerge first, more recent research shows that the index finger is active first [16]. At the stage of developing a radial palmar grasp, an infant already starts to differentiate in function between the radial and ulnar side of the hand, and the forearm will be positioned in more supination. This radial palmar grasp is a milestone in the development of grasping [15].

Between the age of 6 and 7 months, manipulating an object is done more with the fingers than with the palm of the hand. At the age of 12 months, the infant can use a pincer grasp with the tip of the thumb and index finger.

Grasping in Children with a Transverse Arrest

In children with a transverse arrest, when thumb and fingers are completely absent, the affected hand can participate in grasping bilaterally only by assisting the bilateral hand. In children with a transverse arrest distal to the carpal bones, sometimes grasping is possible between the wrist and forearm. The affected hand can be very useful in fixating objects, stabilising the object by weight or support, while the other hand manipulates the object. If the level of amputation is more distal and there are rudimentary fingers and a rudimentary thumb, grasping and holding may be possible with this hand, but manipulation skills will be very limited.

Grasping in Children with a Longitudinal Arrest: Radial Dysplasia

Radial dysplasia is the name given to a wide variety of abnormalities on the radial side of the arm, the spectrum varies from a mild hypoplasia of the thumb to a complete absence of the radius with complete absence of the thumb and accompanied by stiff fingers (the ulnar fingers having the best ROM). This anomaly can be either unilateral or bilateral.

Children with a minor degree of thumb hypoplasia will not be impeded in grasping or

releasing activities in early childhood. The thumb hypoplasia may affect "in-hand manipulation skills" later on in life. Children suffering from a severe kind of radial dysplasia, e.g. type 4, will most certainly have major problems with grasping and releasing objects because of stiff fingers and thumb absence. Grasping in these children is very often performed with the ulnar fingers. The child develops deviant grasping patterns such as an interdigital grasp to compensate the absence of an opposable thumb. Because there is diminished ability to grasp with one hand, the child will grasp bimanually if necessary. These children develop grasping by using it in all kinds of activities, not only for self-care but also in playing and learning, while they discover ever so quickly an efficient method to accomplish their tasks.

Grasping in Children with Syndactyly

Syndactyly has diverse forms of severity. The most severe form is part of a syndrome as in Apert syndrome or acrocephalosyndactyly (ACS). This is a rare syndrome characterised by severe syndactyly and craniosynostosis. Upton has classified the Apert syndrome hand into 3 types for ease of clinical decision making [17]. In the type 1 hand, there is a radially deviated small thumb with a shallow first web, and the index, middle and ring fingers are joined by a complex distal syndactyly and the little finger by a simple syndactyly. In the type 2 hand, the thumb is included in a simple syndactyly, and there is splaying of the central metacarpals of the long and ring fingers. In the type 3 hand, skeletal union of all digits exists which is often complicated; radial deviation of the thumb may not be present. Very often the mid-digital bony mass has a confluent nail, and therefore only movement in the MP joint is possible [1]. Range of motion of both the shoulder and elbow joints is also limited. In the type 2 and 3, without surgical intervention, grasping is only possible bimanual, and holding can be performed using a stabilising surface (table or body). Surgery normally is performed before the end of the first year of life. Normally the thumb is released firstly, followed by the border digits. After all surgical procedures, the best case scenario is that the hand will be a four-fingered hand, with mobility only in the MP joint, and a radially deviated thumb despite the surgical adjustments. Due to early surgery, grasping possibilities are obtained, and the infant is able to perform all kinds of prehension activities in early childhood. The in-hand manipulation will not be possible or will be very difficult. The acquisition of self-care, for example, holding a cup for drinking or grasping a spoon for eating, will be delayed.

"Controlled Release" or Voluntary Release

Release is an integral part of prehension and manipulation, as with the grasp, the first object release is based on reflexes. Finger extension and a slight withdrawal are observed in response to the touch of the neonates hand, which is called an avoiding reaction [18]. From 5 to 6 months, the transition begins from a reflexive release to purposeful release. The infant begins to release objects from one hand to pass it to the other. This object-transfer first takes place by pulling the object, and later it becomes a coordinated release. At the age of 10 months, the infant will drop food and toys from his/her highchair and will take great pleasure in this new acquired skill [15]. Object- releasing activities are now reinforced by auditory and visual consequence of the object. Gesell et al. in 1947 already stated that release is one of the most difficult activities to master in early life [19]. They pointed out that a child's ability to release a cube with the exact timing of force and position made this child successful in its attempt to build a tower, whereas the child who cannot regulate this force or position will drop the cube or may press rather than place the cube and the structure will fall.

Controlled release is an important component of the in-hand manipulation. In many in-hand manipulation tasks, an object is grasped and repositioned by delicate grasp-release movements of the fingers.

When grasping is difficult, controlled release will also be diminished. The compensation strategy

that is most often used for this problem is to release the object with the help of the other hand [20].

Children will use this strategy automatically and quickly, and one must be a trained observer to notice this behaviour. Another strategy is to drop the object, but the result of this is unpredictable and not precise, so therefore not very often used in daily activities.

Controlled Release in Children with a Longitudinal Arrest: Radial Dysplasia

Children with a radial dysplasia will mostly have to release their objects from an interdigital grasp. Release from this grasp can be quick and effective. If the object is larger than the active range of the interdigital grasp permits, and the object is pushed into this space passively, releasing the object becomes difficult. In radial dysplasia with a pollicised index, releasing an object after a whole-hand grasp can also be constrained, because of the reduced opening of the hand. However, this also depends on the object's size.

Controlled Release in Children with Failure of Differentiation of Parts with Soft Tissue Involvement: Finger Flexion Contractures

Children with extreme flexion contractures of the fingers, which might be the case in a windblown deformity (e.g. Freeman–Sheldon syndrome, severe cases of camptodactyly or arthrogryposis), will have functional problems in developing an adequate active release of objects.

Complementary Two-Hand Use

Complementary two-hand use is an important skill that develops between 12 months and 2 years of age [21]. At first the child picks up a toy, holds it with one hand and just explores it with the other hand. Bilateral hand use implies that the child is capable to initiate and control two different motor programmes for the hands. This ability means much more than performing simultaneously holding and doing, but there is a continuous monitoring of the interaction between hands, and the movements of the hands complement each other in this performance.

A task that requires complementary use of the two hands is bead stringing. Almost all studies place the successful accomplishment of this task around 2 years of age [7]. For example, for development of the Peabody Developmental Scales, the ability to string three beads was examined. The authors found that 16 % of the 18–23-months-old children were able to string three beads, in contrast to the 70 % of the 24–29 months-old children. This represents a significant change in behaviour over a relatively short time. Probably this change is caused majorly by the development of successful two-hand use. Bimanual actions are more complicated than unimanual actions as the movements of both arms and hands must be coordinated temporally and spatially to complete a task or achieve a desired goal [22].

Many children with congenital hand differences will have problems with bilateral hand skills. They will have problems stabilising an object with one hand while manipulating it with the other hand. Problems can be seen in stabilising the object with a grasp or stabilising the object without a grasp.

Complementary Two-Hand Use in Children with a Transverse Arrest

Depending on the level of amputation, the object will be held in the hand or stabilised on a surface. The efficacy of a performance depends on the stability of the object in the hand and readjustment possibilities of the grip.

Complementary Two-Hand Use in Children with a Longitudinal Arrest-Radial Dysplasia

Many children with a severe form of radial dysplasia have limited range of motion of the elbow. Most surgeons will not surgically correct radial deviation of the wrist in children with a stiff

elbow joint, because the hand–hand and hand–mouth interaction will be hindered if the wrist deviation is surgically corrected.

The forearm will often be positioned in pronation, because supination is impossible or limited. Hand–hand orientation in many activities needs some supination in the elbow, and therefore the ability to position the hand in the right position will be difficult. In children with a unilateral difference, the bilateral hand will use compensation movements in order to enable the task.

Complementary Two-Hand Use in Children with a Syndactyly: Apert Syndrome

Many two-hand activities, for example, buttoning, tying shoes and stringing beads, demand a lot of in-hand manipulations skills. To accomplish these tasks, readjustment of the grip is continuously necessary. Therefore, children with Apert syndrome, who lack movement in the IP joints and only have possibility to move the MP joint, will have problems with these readjustments. They will more often lay down the object and recapture it in the right position to continue the action, which influences the bimanual skills. The lack of in-hand manipulation affects the success of the bimanual task performance.

In-Hand Manipulation

Exner defines in-hand manipulation as the capacity to manipulate objects in the fingers and in the hand [23]. The purpose of these adjustments is to allow more efficient placement of an object in the hand for use or voluntary release [7]. In-hand manipulation skills seem to be the most complex of all fine motor skills.

A 12-month-old infant can very well pick up one pellet and bring it to its mouth. But when the infant is placed before a heap of pellets, it will grasp a lot of pellets, bringing the entire hand to the mouth rather than moving the pellets in the hand and eat the pellets one by one. Exner has called this ability the in-hand manipulation of which three components have been described:

1. Translation movement, which is the ability to move an object from the fingers to the palm or reverse to move an object from the palm to the fingers.
2. Simple or complex rotation movement, which is the ability to rotate an object in the pad of the fingers. This movement requires independent movements of the fingers and the thumb.
3. Shift, the object moves in a linear direction on the finger's surface. This movement is performed by the thumb and radial fingers.

In addition to these three different components, one more form of "in-hand manipulation" exists, which is accomplishing one of these three components while stabilising another object in the ulnar side of the hand. The hand performs two different actions at the same time, which is the most complex form of in-hand manipulation and requires control of both sides of the hand.

Another important factor for the development of in-hand manipulation is the development of the regulation of grip strength. The coordination of manipulatory forces in 1-year-old children is poorly developed. For example, a 1-year-old child easily squashes an ice cream cone, whereas a 2-year-old child can handle the ice cream cone without crushing it.

In-Hand Manipulation in Children with Congenital Hand Differences

It goes without saying that children with a severe congenital hand difference, such as Apert syndrome or radial dysplasia (type 3 and 4), normally never develop in-hand manipulation skills, while others with a moderate congenital hand difference will develop in-hand manipulation but with delay.

In general, children who lack in-hand manipulation skills will compensate this by using different strategies. For example, a child who picks up a pencil to draw and cannot bring the pencil into an efficient dynamic tripod position to stabilise

the pencil will quickly use the other hand to manipulate the pencil into the right place and start drawing.

Function, Activity, Participation Reported Problems

Diagnosis does not predict function. Congenital hand differences are associated with compromised or altered functional status that may be indicative of more significant health problems.

The International Classification of Functioning, Disability and Health (ICF) provide a common framework and terminology to describe human functioning at three levels: body function, activity and participation. In October 2007, International Classification of Functioning, Disability and Health-Child and Youth version (ICF-CY) was published, which is designed for use with children and youth and allows for coding of more developmental aspects of functioning.

A person's functioning and disabilities, including his/her participation, are considered to arise from the interaction among health conditions and contextual or environmental factors and personal factors. The ICF provides a model of functioning and disability in which the interactions among these concepts are visualised (Fig. 11.1).

The ICF has adopted a biopsychosocial model of disability to capture the complexity of disability that involves both appreciation of the medical and social aspects of the individual and society [24]. According to this model, functioning is classified as all body functions, activities and participation. The ICF-CY has 2 parts (health condition and contextual factors), each consisting of 2 separate components: (1) body functions and structure, and activity and participation and (2) environmental and personal factors. The ICF-CY provides codes that represent categories to describe the child's integrity of body functions and structures, the ability to perform daily life activities and the scope of the individual's participation, and environmental factors that might facilitate or impede functioning and personal factors.

Children with congenital hand difference can experience problems in all domains of the ICF-CY. It is therefore important to evaluate functioning of these children on all these domains.

It is impossible to mention all possible problems in all kinds of congenital hand differences on all ICF-CY levels. This even becomes more difficult if children suffer from a congenital hand difference that is part of a syndrome.

Beside the levels of functioning, there is also the distinction between capacity and performance.

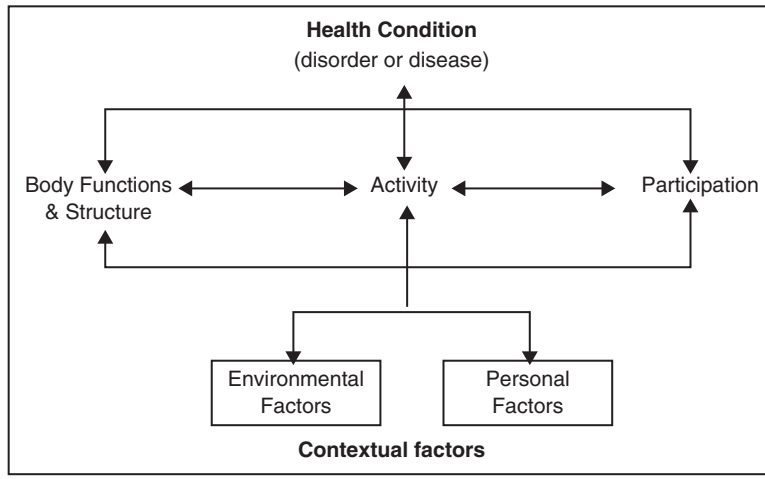

Fig. 11.1 The WHO model of functioning and disability

Capacity reflects what a child can do and performance what a child does in daily life. The difference between what a child can do and what it actually does is well known [25].

Assessment of Function

Assessment of function is essential as the base for interventions to reduce functional limitations and improve well-being. Evaluation of a child's hand function is different from that of an adult. Clinicians require expert knowledge in fine motor and developmental milestones to identify whether the child's deficits are true or reflective of developmental skill. Functional expectations change with maturation, and the child's age determines what they are expected to do. Therefore, the evaluation must reflect the child's age and developmental level as well as the diagnosis [26].

Among children with chronic conditions, variability occurs in their ability to perform individual activities as well as in the ways that they participate in society. Moreover, the contexts in which children live, that is, their physical, social and psychological environments, influence their functioning [27, 28].

History and Status Praesens

After referral of a child and its parents, the hand therapist or physician performs an interview. Hereby they obtain information obtained about the child's medical, family, emotional, educational and social history, but also developmental, environmental and personal aspects should be addressed.

Outcome Measures at Function Level

Range of Motion

Precise numerical documentation of active and passive range of motion of upper extremity joints is essential. At the time of initial assessment, documenting active and passive range of motion is of importance, because changes can occur as a result of therapy, but also result from growth and development [29]. Measuring hand range of motion in a child is technically not different from measuring an adult's hand, because it is performed with a finger goniometer using the dorsal measurement technique. In younger children, only the passive range of motion can be assessed.

Thumb range of motion is a special domain of measuring children with congenital hand differences. The opposition can be measured by the Kapandji thumb range of motion, and recently a device for measuring palmar abduction was developed and validated in children with congenital thumb differences [30].

Strength

Grip and strength should be assessed with standardised, commercially available dynamometers. Normative values are available to compare the children's performance with their peers. However, using these normative data as reference values can be difficult, because when measuring a child at follow-up, the outcome is influenced by both the intervention and growth. Therefore, Molenaar et al. suggested growth diagrams for grip strength in children between 4 and 12 years of age [31].

Besides grip strength, pinch strength should be measured whenever correct positioning of the fingers and thumb is possible. Assessment of pinch strength should include tip-tip pinch and lateral pinch to evaluate thumb opposition strength. In some congenital hand differences, tripod pinch strength may be included in the evaluation.

In the case of grip or pinch strength, a combination of extrinsic and intrinsic hand muscle strength is used, and a large number of joints are involved. At present, there are tools capable of assessing intrinsic muscles strength of the child's hand and of which Molenaar et al. presented growth diagrams in which strength is plotted against age [32].

Measurement of muscle strength around the larger joints of the upper extremity can be obtained by hand-held dynamometers. These measurements should include elbow flexion and extension as well as wrist flexion and extension force.

Sensibility

Sensibility can be tested in different ways, and much controversy exists concerning the neurophysiologic basis of sensory testing. This fact combined with the lack of control of certain variables in our testing which comprises accuracy together with the young age of the children tested, the results should be interpreted with care.

Threshold tests as Semmes–Weinstein monofilaments for touch and pressure or vibration can be used in children with congenital hand difference. Functional sensibility can be measured through established tests that have normative data on the population tested [33].

Dexterity

Dexterity is described as the ability to manipulate objects with the hands. Accuracy and speed can be measured through established tests that have normative data on the population tested. Clinical observation of the child picking up and manipulating different objects is also a way to obtain information on dexterity.

Although there is a need for a classification system for hand functions, to date, no valid and reliable one is available.

Outcome Measures at Activity Level

In contrast to the worldwide accepted core set for hand function measurement on the ICF-function level, selecting assessment tools for measuring limitations on activity level with congenital hand difference is extremely difficult and undergoing a lot of research at the moment. Several functional tests and questionnaires have been developed on this domain, but to date there are no disease-specific tools for children with different kinds of congenital hand differences. Therefore, it is impossible to give the golden standard on testing limitations in activity and participation in children with congenital hand difference. The observer should also keep in mind the difference between capacity and performance. Observational assessments show an individual's capabilities, but they may not reflect typical performance of the diverse activities performed in real life. Therefore, both aspects should be measured [34].

Tests to measure limitations in activity level can be divided into different groups: performance tests, questionnaires or semi-structured interviews.

The below-mentioned questionnaires and functional tests were all developed for children with hand disorders, including cerebral palsy and congenital transverse reduction deficiencies. Children with bilateral affected hands as well as unilateral affected hands encounter the most problems in daily life when performing bimanual activities. Examples of questionnaires used in children with congenital hand difference that measure bimanual activities are Prosthetic Upper Extremity Functional Index (PUFI) [35], AbilHand-Kids [36], Children's Hand-Use Experience Questionnaire (CHEQ) [37] and Child Occupational Self-Assessment (COSA) [38]. The Unilateral Below Elbow Test (UBET) [39] and University of New Brunswick Test of prosthetic function (UNB Test) [40] are examples of performance tests, and the Canadian Occupational Performance Measure (COPM) [41] and Goal Attainments Scale (GAS) [42] are examples of semi-structured interviews.

Outcome Measures at Participation Level

As in measuring activity limitations in children with congenital hand differences, no disease-specific tools for measuring limitations in participation in these children exist.

However, if information on participation is needed, general participation measures could be used. Examples of participation measures are the CAPE (Children's Assessment of Participation and Enjoyment) [43].

Research in children and youth with CP has shown that manual ability (classified according to the Manual Ability Classification System, MACS) was related to participation in leisure activities [44]. Better handling of objects and better fine motor function were associated with

greater participation in leisure activities. Further research is needed in children with congenital hand differences.

Aesthetics

Many parents of children with congenital hand differences are concerned about the aesthetics of their child's hand. It is important that this is recognised. However, surgical interventions for aesthetics should never compromise function and, if possible, vice versa. Visual analogue scales (VAS) can be used to measure the appearance objectively by the children if they are old enough or by the parents.

Psychological Implications of a Congenital Hand Difference

Due to advances in prenatal detection of congenital differences, along with the evolving technology and widespread use of ultrasonography in prenatal screening, congenital hand differences are increasingly detected before birth. Parents whose child is diagnosed to have a congenital hand difference on prenatal testing, or whose child is born with a visible congenital hand difference, may go through a process that is akin to bereavement. The early responses differ from denial and anger to distress, but they also have questions on how this happened. Although the mother may have done everything to live healthy during the pregnancy, she was not able to prevent a birth defect.

Many emotions are focused on themselves and on their babies, and most parents are concerned mostly about the child's psychological and social development. Parents respond differently on coping with the congenital hand difference. Some parents are able to accept the congenital difference rapidly, but some need more time to adjust to an unexpected situation. When parents seem to get lost in their grief, and the physicians treating the child feel like the reaction is no longer in relation to the difference of the child, they may consider psychological help for the parents and their children. The emotional development of the child and their parents should be followed over the years [45].

Summary

This chapter describes normal development of hand function and the impact of congenital differences of the upper limb. Additionally, outcome measures at ICF-CY levels are provided. Taking into account functioning on all levels, treatment of each single child is optimised, and maximum results will be received with well-informed, motivated children and their parents.

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Hand Function in Juvenile Idiopathic Arthritis

12

Erbil Ünsal

Juvenile idiopathic arthritis (JIA) is the most common chronic rheumatic disease of childhood. It is an important cause of short- and long-term disability. JIA is an umbrella term for both "juvenile rheumatoid arthritis" and "juvenile chronic arthritis." Brewer et al. published the juvenile rheumatoid arthritis classification criteria in 1972 [1]. European League Against Rheumatism criteria used the term juvenile chronic arthritis [2]. The latter classification included juvenile psoriatic arthritis (JPsA), juvenile ankylosing spondylitis, and inflammatory bowel disease. Pediatric Standing Committee of ILAR (International League Against Rheumatism) proposed a new classification in 1993, which was discussed in Durban (1997) [3] and Edmonton (2001) [4]. The term JIA is the final form following the related meetings. It includes oligoarthritis, systemic arthritis, polyarthritis, enthesitis-related arthritis, and psoriatic arthritis.

Hands are mainly involved in systemic arthritis, polyarthritis, and psoriatic arthritis. This chapter will focus particularly on these subtypes, regarding hand involvement.

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Physical Examination in the Differential Diagnosis of Rheumatic and Non-rheumatic Hand

There are several non-rheumatic conditions mimicking arthritis in the hand. The fingers might be shorter than usual in severe polyarthritis, but achondroplasia should be kept in mind. There is diffuse edema of the hand in some patients with polyarthritis; it might be a feature of myxedema on the other hand. JPsA sometimes presents itself with sausage-like finger as asymmetrical arthritis; this is a similar finding in neurofibromatosis and local arteriovenous fistula causing hypertrophy of the related finger. Typical fusiform swelling of the proximal interphalangeal joint (PIP) is commonly a finding of chronic arthritis; however, collateral ligament tears as a result of trauma and less commonly tuberculosis, sarcoidosis, and syphilis are the other possibilities. Loss of active extension in the thumb (mallet finger) is usually the result of rupture of extensor pollicis longus tendon, a complication of distal radius fracture, rarely the result of rheumatoid arthritis. Boutonniere deformity presents as the flexion of the PIP joint and extension of the DIP joint. A wound of the dorsum of finger, traumatic avulsion, or rheumatoid arthritis is the cause. Symmetrical flexion of the fifth fingers in the PIP joints is seen in congenital contracture of the related fingers, rather than chronic arthritis

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deformity. Similarly, flexion of interphalangeal joint of the thumb in infants and young children is due to tenovaginitis involving flexor pollicis longus. Tenosynovitis of the flexor tendons at the wrist level in chronic arthritis causes flexion deformity of the thumb and fingers; however, it is also the result of damage of the brachial artery in supracondylar fracture, leading to Volkmann's ischemic contracture. Rarely, familial camptodactyly, congenital synovitis of the PIP joints with fibrosing serositis, causes flexion contractures of the hands. In severe polyarthritis, there are numerous nodules palpated over the dorsum of the hand as a result of synovial swelling; enchondroma, one of the commonest bone tumors of the hand, might be the other cause [5].

Systemic Juvenile Idiopathic Arthritis

It is one of the most difficult diseases among childhood arthritides. The diagnosis requires exclusion of a detailed list of diseases listed in the differential diagnosis of "fever of unidentified origin." The diagnosis requires arthritis in any number of joints together with a fever of at least 2 weeks duration that is documented to be daily for at least 3 days. The following signs/symptoms are usually found: erythema circinnatum (Fig. 12.1), hepatosplenomegaly, serous inflammation (pericardium, pleura), and generalized lymphadenopathy. Regarding arthritis, any number of joints can be affected at onset or during the course, but eventually most of the children have polyarthritis. The knees, wrists, and ankles are the most involved joints, but hips, temporomandibular joints, and small joints of hands have inflammation in more than half of the patients (Fig. 12.2). In a group of children, they have severe arthritis leading to destruction of joint space and loss of function leading to marked disability in the first 2 years of the disease. Schneider et al. showed that about one third of patients demonstrated destructive polyarthritis after a mean follow-up of 5 years [6]. In others, the disease can go to clinical remission with mild joint involvement. Bekkering et al. [7] studied the relation between impairments in joint function in 21 children with systemic arthritis. The relationship between loss of joint motion in the leg and disabilities in leg activities appeared to be strong. However, the relationship between impairments and disabilities in the arm appeared to be moderate. The author explained the lesser impact of loss of motion to disability in the hand in terms of coordination in daily activities such as eating, grasping, and writing. Tenosynovitis is a frequent and important finding, particularly in polyarticular course in systemic arthritis. Extensor tendon sheaths in the dorsum of the hand and finger flexor tendon sheaths are the sites that are commonly involved in the hand. Some children develop synovial cysts in communication with the wrists [8].

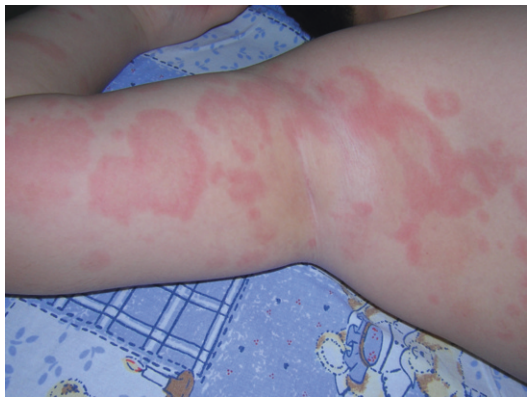

Fig. 12.1 Erythema circinnatum in systemic juvenile idiopathic arthritis

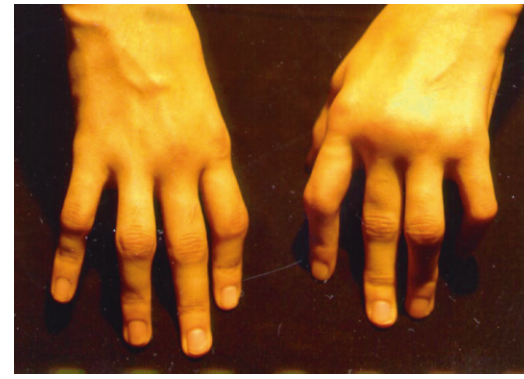

Fig. 12.2 Polyarthritis in systemic juvenile idiopathic arthritis

Polyarticular Juvenile Idiopathic Arthritis

It is defined as chronic arthritis in children affecting more than four joints in the first 6 months of the disease. It accounts approximately 20 % of all JIA subgroups. ILAR classification categorizes this subgroup as rheumatoid factor (RF)-positive and RF-negative arthritis [4]:

Rheumatoid Factor-Negative Polyarthritis

This subtype is predominant in children regarding polyarthritis as 85 % of them are RF (−) [9]. The incidence has two peaks in age: 1–3 years and adolescence. It affects girls four times and up to ten times more during teenage years.

Clinically, RF (−) polyarthritis has less severe extra-articular manifestations when compared to RF (+) polyarthritis, i.e., fever, fatigue, and weight loss. Regarding joint disease, the onset of arthritis is often insidious. Morning stiffness typically lasts for hours. Symmetrical involvement of the joints is the result. Swelling due to intra-articular fluid and synovial hypertrophy with warmness are the usual symptoms; the joints are rarely tender or red. Small joints of hands are typically involved; the most commonly affected are the second and third metacarpophalangeal (MCP) and PIPs. Distal interphalangeal joint involvement is unusual (Figs. 12.3 and 12.4). Temporomandibular joint is more likely to be involved compared to RF-positive patients; the reason might be the earlier age onset of the former subtype [10].

Rheumatoid Factor-Positive Polyarthritis

This subtype differs from the RF (−) polyarthritis by the presence of rheumatoid factor positivity. RF is defined as positive, when its presence is demonstrated in two positive tests performed at least 3 months apart. It forms about 15 % of children with polyarthritis and 3 % of all JIA patients [8]. It has the similar characteristics with adult rheumatoid arthritis, as immunogenetic profile, serology, and clinical phenotype. Its mean age is 10 years, and girls outnumber boys from 4 to 13 in large series [8]. Arthritis is mainly found in large as well as small joints, which are symmetrically involved. Micrognathia does not occur in contrast to RF (−) polyarthritis because of the late age development of the former. Only cervical spine is affected, and sacroiliac joints and thoracolumbar vertebrae are spared. Rheumatoid nodules similar to that of adults are found on the bony prominences. Hand involvement is serious and mostly destructive leading to multiple deformities. The characteristic pattern is the symmetrical arthritis affecting MCP and PIP joints and the wrists (Fig. 12.5). Ulnar deviation, boutonniere,

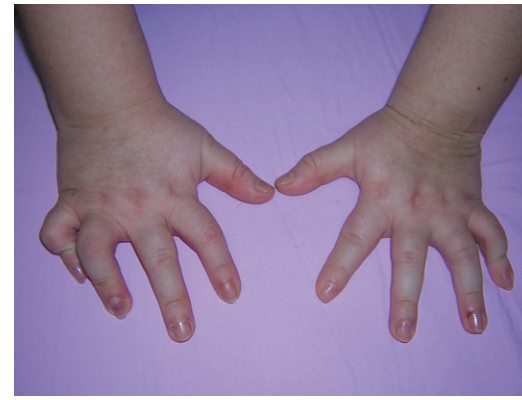

Fig. 12.3 Polyarthritis

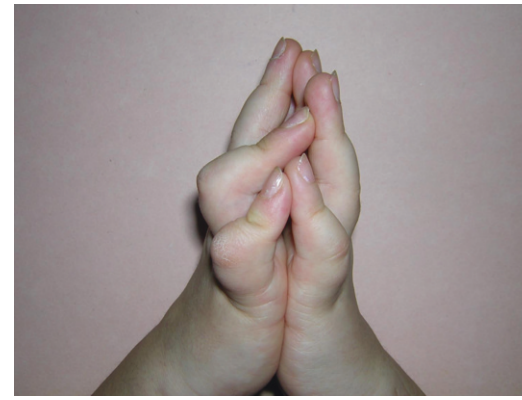

Fig. 12.4 Polyarthritis and flexor tendon contractures

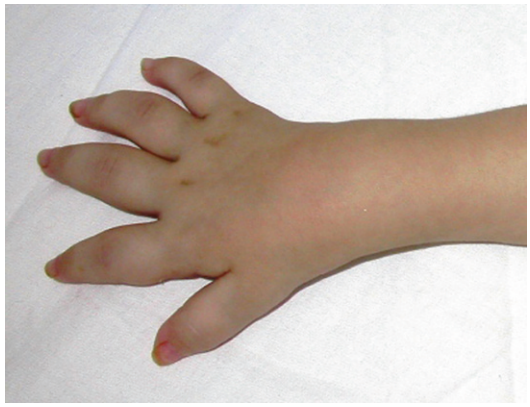

Fig. 12.5 Polyarthritis and fusiform swelling

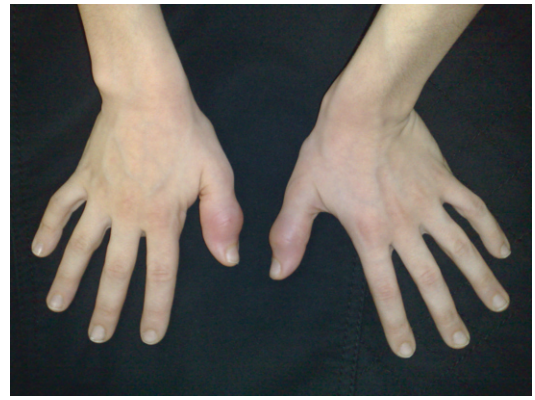

Fig. 12.6 Dactylitis in juvenile psoriatic arthritis

and swan neck deformities are typical for this subtype as in adults. Systemic symptoms accompany the arthritis, fatigue, and weight loss.

Juvenile Psoriatic Arthritis

JPsA is defined as chronic arthritis with psoriasis, or two of the following: dactylitis, nail pitting, onycholysis, or psoriasis in a first-degree relative (Fig. 12.6). Skin manifestations are subtle, mostly diagnosed as eczema. Typical psoriatic lesions are found in 0.5–1 % of children and up to 2 and 3 % in adults [11]. The lack of dermatological findings makes the diagnosis difficult and challenging. Regarding all subtypes, JPsA represents about 7 % of JIA. Etiopathogenesis is somehow different; environmental factors are shown to a play role. Streptococcus is a known precipitant factor for guttate psoriasis, and these sorts of factors seem to trigger the joint inflammation, as well as enthesitis, a typical finding found in enthesitis-related arthritis [10].

JPsA is clinically heterogeneous. The peak age distribution is around age three and adolescence. Younger girls tend to have dactylitis and antinuclear antibody positivity. Dactylitis is the sausage-like swelling of any digits of hand or feet. Distal interphalangeal joint is involved as well as the proximal one. Regarding hand involvement, oligoarticular onset finally leads to progressive and destructive bilateral wrist and small joints of the hand involvement, a typical polyarticular course in about 60–80 % of untreated children. Nail changes such as pitting, onycholysis, horizontal ridging, and discoloration are found in approximately 30 % of children. They are almost always found with distal interphalangeal involvement. However, the relation of nail pitting with severe arthritis in adults is not found in children [10].

On the other hand, adolescent onset has the equal sex ratio, and axial involvement with enthesitis predominates the articular features [12]. This type resembles to adult psoriatic arthritis. Fortunately, the "arthritis mutilans" type which often leads to serious destructive arthritis in adults is rarely found in children. However, this does not mean that JPsA has relatively a benign course; it has worse outcome than oligoarthritis and polyarthritis. There are discrepant results regarding the course and prognosis. Roberton et al. followed patients at least for 5 years and demonstrated 70 % ongoing arthritis and restricted joint movement in one third [13]. A more recent study by Stoll et al. documented achievement of remission on medication in about 60 % of children, for both the early and the late onset [14].

The Role of Hand in Quality of Life and Functional Assessment of Hand in JIA

Hands are the most frequently used instruments of the body during daily life. Their restricted use due to arthritis has a major impact on the quality of life. Quality of life is defined as individuals' per-

ceptions of their position in life in the context of culture and the value systems in which they live and in relation to their goals, expectations, standards, and concerns. Children with arthritis have longer life span when compared with the last century, particularly following the development of the disease modifying drugs and biologic agents. Most of the pediatric arthritides is not fatal; however, they have a negative effect regarding the quality of life. As there is not a unique way of understanding the etiopathogenesis of JIA, the term "cure" cannot be used. The disease could only be put into remission. World Health Organization (WHO) developed the International Classification of Functioning and Health (ICF) in order to provide a common vocabulary for the consequences of the disease [15]. The framework of ICF is particularly applicable to chronic arthritis. The ICF model defines the health condition in a child's life in three domains: structural and functional anatomy, activities in daily life, and social participation. A child with JIA has to overcome the difficulties in daily life which are mainly caused by the circumstances of he or she arthritis, and he or she has to cope with he or she peers. In the last 20 years, specific instruments are developed in order to measure the effects of all the related conditions on the child with arthritis, namely, health-related quality of life (HRQoL). One of the most widely used is the "core outcome variables." They constitute of physician global assessment, patient/parent global assessment, number of joints with active arthritis, number of joints with limited range of motion, ESR as acute phase reactant, and childhood health assessment questionnaire (CHAQ). Improvement is defined as at least 30 % improvement in three of the six items and no worsening of any of the items for more than 30 %. This is called as ACRpedi 30, which can be increased to ACRpedi 50, or ACRpedi 90. There are numerous important instruments for measuring physical function and health-related quality of life other than CHAQ:

Juvenile Arthritis Assessment Scale (JAFAS) and Report (JAFAR)

JAFAS and JAFAR measure physical function. JAFAS requires a health professional, who measures the child's performance on ten physical tasks [16]. It has limitations because of requiring professional and standardized equipment.

JAFAR contains 23 items when measuring physical function and three-point scale (0–2) is used [17].

JAFAS and JAFAR have good reliability and validity; the limitation is being applicable to children over 7 years of age.

Juvenile Arthritis Self-Report Index (JASI)

JASI is used mainly for rehabilitation purposes [18]. It measures physical function in five categories, with 100 items, higher scores reflecting better function. It can be completed in about 50 min.

Juvenile Arthritis Quality of Life Questionnaire (JAQQ)

JAQQ measures health-related quality of life [19]. It measures gross and fine motor functions, psychosocial functions, and a pain on a 100-mm visual analogue scale. It is found as responsive as CHAQ, CHQ (Childhood Health Questionnaire), and Peds QL (Pediatric Quality of Life Inventory).

Childhood Arthritis Health Profile (CAHP)

CAHP is a parent report which consists of three modules [20]. It measures gross and fine motor function along with role activities between friends and family members.

Quality of My Life Questionnaire (QoMLQ)

QoMLQ is short and easy to use, measuring disease related as well as generic difficulties, thus demonstrating the differences between both factors [21].

Child Health Questionnaire (CHQ)

CHQ has numerous forms of which parent form 50 is used for JIA [22]. It measures global health, physical activities, daily activities, pain, behavior, well-being, general health, and family. Two scores are found, for physical and psychosocial activities, respectively. It is chosen for JIA patients along with CHAQ, for its widespread use (32 languages) and good reliability and validity.

Pediatric Quality of Life Inventory (Peds QL)

Peds QL is applicable to patients between ages 2 and 18 years [23]. It has 23 items including physical, emotional, social, and school functioning. It has separate parent and patient forms. It has a definitely positive contribution to studies with JIA patients.

Composite Disease Activity Scores for JIA

A composite disease activity score (JADAS) is developed [24], because JIA core set and pediatric response criteria only describe the improvement or deterioration in disease status. It includes four of the core set criteria (active joint count, physician's global assessment of disease activity, parents'/patient's assessment to overall well-being, and ESR as acute phase reactant). There are three assessments of joint groups, measuring 10, 27, and 71 joints, respectively. It has a great contribution to the studies with JIA.

Childhood Health Assessment Questionnaire (CHAQ)

CHAQ [25] has two parts: disability and discomfort. Disability Index assesses function in eight areas (dressing and grooming, arising, eating, walking, hygiene, reach, grip, and activities) distributed among a total of 30 items. In each functional area, there is at least one question that is relevant to children of all ages. Each question is rated on a 4-point scale of difficulty in performance, scored from 0 to 3. The Disability Index is calculated as the mean of the eight functional areas. Discomfort is determined by the presence of pain, as measured by a 100-mm visual analogue scale (VAS). In addition, a 100-mm VAS measures patient or parent global assessment of arthritis. CHAQ is translated into several languages, and it is one of the most widely used instruments in JIA. It lacks psychosocial measuring in its current form. Regarding measuring hand functions, the questionnaire measures hand functions to an extent. For example, dressing and grooming part includes "tying shoelaces and doing buttons"; eating part has "open a new cereal box"; grip part includes "push open a doorknob." It does not have a particular assessment for hand including every aspect of hand functions.

Current literature does not have a specific instrument for measuring hand functions in children with arthritis. There are numerous items for adults, which will be discussed briefly.

Arthritis Hand Function Test (AHFT)

AHFT is an 11-item performance-based test designed to measure hand strength and dexterity [26]. The items include grip and pinch strength, pegboard dexterity, lacing a shoe and tying a bow, fastening/unfastening four buttons, fastening/unfastening two safety pins, cutting putty with a knife and fork, manipulating coins into a slot, lifting a tray of tin cans, and pouring a glass of water. It is mainly used for rheumatoid arthritis, osteoarthritis, and systemic sclerosis.

Basically, AHFT is a performance-based test which measures unilateral and bilateral hand functions, opposite to most of the other related tests. However, predictive validity and responsiveness to change have not been documented. Another disadvantage is that it does not have a summative score [27].

Grip Ability Test (GAT)

It is modified from a general test for hand function [28]. It includes only three items: putting a sock over one hand, putting a paper clip on an envelope, and pouring water from a jug. Patients with rheumatoid arthritis have the test and informed to complete in a timed session. A GAT score is formed by the sum of seconds while performing three items. A total score less than 20 s is normal. GAT test is used for only rheumatoid arthritis, and it has not been validated with other standardized performance-based tests for hand function. There are no reliability or validity studies that are performed with other forms of arthritis [27].

Jebsen Test of Hand Function

This test aims to measure a broad spectrum of hand functions [29]. Target groups are children over 6 years and adults with hand impairment. There are seven subscales: writing, turning over 3 by 5 in. cards (simulated page turning), picking up small common objects, simulated feeding, stacking checkers, picking up large light cans, and picking up large heavy cans. Each subscale is scored by recording the amount of time it takes the person to complete each task. Scores can be summed to obtain a total score. Subscale scores are evaluated according to the same sex and age normal results. Score range depends on the severity of the disability. The test is easy to administer; however, the norms should be revised using the commercially available version of the test. More studies about validity and sensitivity are needed [27].

Duruöz Hand Index (DHI)

The aim of this test is to measure the functional ability of the hand [30]. It includes five subscales with a total of 18 items: kitchen tasks include holding a bowl, a plate full of food, pouring liquid, cutting meat, and peeling fruit. Dressing items include buttoning and opening/closing a zipper. Hygiene items include squeezing a tube of toothpaste and holding a toothbrush. Office items include two writing tasks. Items in the "Other" category include turning a doorknob, cutting with scissors, and turning a key in a lock. Time to complete the test is less than 3 min. It is administered to patients with rheumatoid arthritis (RA), osteoarthritis (OA), systemic sclerosis (SSc), patients in hemodialysis, and patients with stroke [27, 31, 32].

The validation study of DHI in patients with JIA has recently completed by the author of this chapter. According to the study it has good correlation with CHAQ, grip strengths, and disease activity parameters. The Duruöz Hand Index is a useful scale to assess hand function in JIA (unpublished data).

Summary

Hands are mainly involved in JIA, namely, systemic arthritis, polyarthritis, and psoriatic arthritis. Specific instruments are developed in order to measure the effects of all the related conditions of the child with arthritis, namely, health-related quality of life (HRQoL). Specific instruments for assessment of hand functions in daily life are mandatory.

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Hand Function in Geriatric Conditions

13

Nurgül Arıncı İncel

Focus on Aging Hand

Prolonged longevity with an increase in the numbers of elderly and disability-free life expectancy focused the impact on geriatric population [1]. In the United States in 2005, one out of ten persons was 60 years and older; it is predicted that one person out of five will be 60 years or older by 2050 [2]. Apparently a larger geriatric population will result in a greater proportion of geriatric hand therapy patients.

The elderly population (persons 65 years old and over) is classified for specific purposes, and these proportions are labeled as "old" for those aged 65 years to 75 years, "older" for those who are 75–85 years of age, and "oldest" for those who are 85 years of age or older.

The normal aging process involves gradual decreases in organ system capabilities and homeostatic controls that are relatively benign in the absence of disease. However the end result of these age-related declines is an increased vulnerability to disease and injury. Characteristic features of aging are reviewed in the table (Table 13.1).

Functional ability seems to remain stable until age 65 years, after which it diminishes slowly. It has been reported that a 15 % loss in strength per decade occurs in 50–70-year-old individuals. Also hand function seems to remain stable until age 65 years. After age 75 years, age-related differences in performance are most apparent [3]. Aging has been reported to have a negative effect on hand function, including declines in hand and finger strength and ability to control submaximal pinch force and maintain a steady precision pinch posture and manual speed. The decline in hand function has been postulated to be due to deterioration in muscle coordination, finger dexterity and hand sensation, and degeneration of the central nervous system [4]. Studies on hand function have reported increased difficulties in performing everyday tasks such as tying shoelaces, fastening buttons, manipulating earrings, retrieving objects from a purse, and writing a note. Deterioration in hand function reduces quality and independence of life of senior citizens [4].

Hand assessment in elderly has special issues for both the physiatrist and the hand therapist. This chapter is supposed to highlight these specific conditions and to bring in an insight to the older hands. We must not forget that geriatric issues refer to problems not only affecting the aged but to the whole society as well.

In general the four principal domains of comprehensive geriatric assessment are functional ability, physical health, psychologic health, and socioenvironmental factors. Assessment of each can be achieved by using certain assessment instruments. They make the process more reliable and easier. They also aid communication of

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Table 13.1 Major changes in aging

Decreased reserve capacity of organ systems, which is apparent only during periods of maximal exertion or stress
Decreased internal homeostatic control
Decreased ability to adapt in response to different environments
Decreased capacity to respond to stress

clinically relevant quantitative information among health-care providers and permit tabulation of clinical data and measurement of change over time. Several issues need to be considered in selecting an assessment instrument for a specific population: instrument reliability and validity, patient acceptance, time and personnel needed to administer the tests, and relevance and usefulness of the data to be collected.

Functional performance can be viewed as a measure of overall impact of health conditions in the context of a patient's environment and social support system. Participation restriction formerly known as handicap is defined as limited fulfillment of an individual's role based on age, sex, and social-cultural factors. A loss or decline in hand function is the major cause of activity and participation restriction with a negative impact to the quality of life.

It is essential to assess the geriatric patient's functional status at the initial visit, and any change in functional status should prompt further investigation. This can be assessed at 3 levels: basic activities of daily living (BADLs), instrumental activities of daily living (IADLs), and advanced activities of daily living (AADLs). The BADLs are the tasks that patients need to be able to complete on their own, or have assistance to complete, in order to be able to live in their own residences: transferring, toileting, bathing, dressing, continence, and feeding. The IADLS are the abilities one needs to maintain an independent household: shopping for groceries, driving or being able to use public transportation, telephone skills, meal preparation, housework, home repair, laundry, taking medications, and handling finances [5].

Changes Associated with Aging

Some of the physical changes and decline in function most affecting the hand in the elderly population are:
Neuromuscular changes
Sensibility changes
Skin and wound healing
Cognitive changes

Neuromuscular Changes

With increasing age, declines in strength, speed of movement, and coordination occur, and all are related to a decline in neuromuscular function. Nervous system changes include decreases in nerve conduction velocity, sensory activity, rate and magnitude of reflex responses, and arousal threshold. The decline in motor control with age, which results in part from age-related changes in cortical control of voluntary movement, is particularly pronounced for fine hand movements [6]. Sarcopenia, defined as the slow, progressive, and apparently inevitable loss of muscle mass and strength, is one of the most important physiological changes that occur with advancing age [7]. Sarcopenia is clinically defined as two standard deviations below the mean appendicular muscle mass of young healthy adults of a reference population, similar to osteoporosis [2]. It is estimated that aging is associated with 20–40 % of the decrease in muscle strength and power at 70–80 years of age and with still greater reductions (50 %) at 90 years of age [7]. However, this diminution is not linear and does not occur at the same rate and age in both sexes. Muscles that are most frequently used have less loss in strength.

Also changes in the contractile properties of muscle (e.g., normalized force, contraction time, half relaxation time) cannot explain the entire age-related decline in strength. Rather, some features of muscle activation also seem to contribute to the decrease in strength. Older adults, for example, exhibit greater levels of antagonist

coactivation compared with young adults, which, while helping to stabilize the joint, also reduces the net torque exerted about a joint. Therefore, age-related differences in strength are due not only to changes in the size and quantity of muscle but also to changes in muscle activation [8]. These data suggest that steadiness measures may be more strongly associated with functional hand measures than measures of hand muscle strength. Therefore, measures of steadiness comprise an adequate index of hand function and, when complemented by other neurophysiological recordings, can provide insight into the mechanisms responsible for age-related differences in motor performance [8].

Another point of interest for the elderly population effecting motor function is the "laterality." Laterality is a phenomenon in which an organ with bilateral symmetry contains one half that is superior to another half in achievement of motor or cognitive tasks. The hand in which laterality is found is the dominant hand, and it is generally superior in muscle strength, quickness, accuracy, and dexterity. The degree of difference between the dominant and nondominant hands may differ between young adults and the elderly [9]. In their study Saimpont et al. showed that elderly subjects were less accurate and slower than their younger counterparts in their left–right hand judgements which is positively correlated with task difficulty (coarse versus fine motor performance) [10]. The hemispheric asymmetry reduction in older adults (HAROLD) model states that prefrontal cortex activity tends to be less lateralized in older adults than in younger adults. Indeed, a number of studies have demonstrated bilateral prefrontal activations in older subjects, whereas in younger subjects the activations were clearly lateralized. In other words, during the same tasks, older subjects activate both hemispheres, whereas younger subjects preferentially activate only one hemisphere [11]. This hemispheric asymmetry reduction in older subjects can be interpreted in two ways: either by a compensatory phenomenon which allows older subjects to maintain their performances or by a phenomenon of dedifferentiation, meaning that older subjects have more difficulty recruiting specialized neuronal mechanisms [11].

Desroiser and colleagues study pointed out that a gender-based difference is observed in the hand preference of elderly too. The dominant and nondominant arm–hand usage of 40-year-old adults was quantified according to gender, and women demonstrated a significant preference of using the dominant hand, whereas men presented more bilateral usage of their hands of using their nondominant hand [12].

Changes in Special Senses

Warabi et al. suggested that impairment of sensory processes is a key component of decreased motor coordination and function [13]. Visual changes that can affect hand function include decreased acuity, accommodation, color differentiation, sensitivity to light, depth perception, impaired eye–hand coordination, and accommodation to light and dark.

Screening for hearing loss is strongly recommended for all elderly persons. Decreased auditory acuity frequently develops. With hearing loss progression, the lower frequencies are affected also, making it difficult to understand what is being said, especially in a loud setting. Besides old persons often hide their hearing loss, embarrassed by it and equating it with aging [14].

Hearing or vision aids to improve functioning are often available, and elderly people must be encouraged to use them to improve their hearing- or vision-related quality of life.

Skin and Wound Healing

During the aging process, influenced by extrinsic and intrinsic factors, the three-layer skin system changes markedly. These changes provoke the skin to lose its ability to act as a physical and mechanical barrier against exogenous factors. Because of its decreased mechanical properties, aged skin not only shows typical signs of aging, like wrinkles and furrows, but also tends to a

higher violability by mechanical exposure and skin diseases. A reduction of the water content in the outermost layer of the skin makes the skin drier and may in turn decrease the friction at the object–digit interface. The consequence of these skin changes is an increased slipperiness of the fingers during object handling, increasing the likelihood of dropping the object. This proposal is supported by studies showing that the slip force (i.e., the minimum force required to prevent an object from slipping) is increased in the elderly. The lower the friction at the object–digit interface (due to either a slippery object surface or increased skin slipperiness), the higher the grip forces necessary to maintain object stability [15].

Tactile thresholds in the elderly are also significantly increased. This is thought possibly to be attributable to a decrease in the density and distribution of Pacinian and Meissner corpuscles and Merkel's discs in the skin causing decreased spatial acuity. The spatial acuity of skin at the fingertip deteriorates noticeably with age as assessed by two-point threshold measurement. Tactile acuity thresholds in the finger are on average about 80 % higher in the older subjects (aged >65 years) than in the younger subjects (aged 18–28 years) [16]. For all these reasons, skin aging has to be understood not only as a cosmetic problem but also, especially in an aging population, as a serious medical problem [17].

Cognitive Changes

Some researchers have assumed that there are little or no age relations on cognition until age 65 or older [18]. About 3 % of community dwelling elders between ages 64 and 74, 14 % between 75 and 84, and >20 % over 85 have moderate degrees of cognitive impairment. To evaluate cognitive impairment, the physician can use the Mini-Mental State Examination test (MMSE). The MMSE is useful in quantitatively estimating the severity of cognitive impairment, in serially documenting. Age-related declines in cognitive functioning might be expected to have a greater role in decreases in quality than in decreases in quantity [18].

Frequent Problems to Deal with in Elderly Population

Apart from the clinical conditions irrespective of age like traumatic conditions, elderly population suffers from various pathologies in their hands. Age-related changes are often accompanied by underlying pathological conditions that are common in the elderly population. There are conditions a physiatrist/clinician must take into account while dealing with a geriatric hand patient. Assessment of hand function and prehension patterns is needed in order to determine specific treatment approaches [19]. For adults aged over 55 and 50 years in two different studies, respectively, the 1-month and 1-year period prevalence of hand pain was estimated at 17 and 30 % with reports of loss of hand function and difficulty in completing everyday tasks [20].

Comorbid diseases or conditions not directly related to the primary upper extremity problem but negatively affecting the patients' general health status or the therapy period can be present, like a patient with flexor tendon repair accompanied by a severe dementia. These problems not only interfere with the evaluation and diagnostic process but seriously and negatively affect the therapy and rehabilitation period, especially in the absence of social support.

Some systemic pathologies common in the elderly population have marked impact on hand function. Parkinson's disease with rigidity and tremor, type II DM with neuropathy and Dupuytren's contracture, and stroke with flask or spastic extremities are the most recognized ones. Impairment of hand function in such conditions also overlaps with the concept of "accelerated aging" in patients with chronic physical conditions and disabilities.

Below are the examples of medical conditions resulting in with functional deterioration of hands:

Fractures

Fractures in the elderly may result in prolonged pain and disability. Especially fractures of the

distal radius in postmenopausal women are a well-known entity with multiple complications, ending up with a decline in upper extremity functional status. A different aspect of the fractures in the geriatric group is that they may tolerate greater degrees of residual deformity because of a more sedentary lifestyle [21].

Osteoarthritis

Primary osteoarthritis (OA) is characterized by a slow progression of intermittent or constant joint pain that may be accompanied by limited movement and joint deformity. Changes both intrinsic to the joint and extrinsic (such as sarcopenia, altered bone remodeling, and reduced proprioception) contribute to the development of OA. The concept that aging contributes to, but does not directly cause OA, is consistent with the multifactorial nature of this condition and the disparity in which joints are most commonly affected [22].

Hand OA primarily affects the distal and proximal interphalangeal joints and first carpometacarpal joint. Hand OA has an enormous socioeconomic impact because it affects 60–70 % of the population above the age of 65 and, in particular, women already above the age of 47. Since almost 80 % of the population can expect to live through most of their seventh decade of life, the socioeconomic impact of OA is likely to increase even further in the future. Hand osteoarthritis has considerable functional consequences in terms of pain, reduced hand mobility, reduced grip force, and problems in many domains of activity and participation. As a consequence, rehabilitation programs should be both multidisciplinary and multidimensional, aiming at reducing hand impairment, improving occupational performance, and enhancing the self-efficacy and coping strategies of the individual [23].

Diabetes Mellitus

Diabetes mellitus (DM) is a chronic disease characterized by hyperglycemia with various complications including diabetic hand syndrome, limited joint mobility also known as diabetic cheiroarthropathy; Dupuytren's disease; flexor tenosynovitis; and carpal tunnel syndrome resulting in significant morbidity and mortality [24]. Age and duration of diabetes are clearly related to these changes. The association between rheumatic disorders and DM is gaining attention, and with recent data showing that more than 30 % of patients with type 1 or type 2 diabetes have some hand or shoulder diseases, the magnitude of this problem is becoming more evident. The exact mechanisms by which the specific metabolic abnormalities of diabetes impact on the pathogenesis of its rheumatic manifestations are not clear [25]. Also symmetrical distal sensorimotor polyneuropathy (PNP) is important in patients with diabetes interfering with hand function [26].

Recognition of the association between DM and musculoskeletal complications facilitates their correct diagnosis in the setting of DM and prompt initiation of appropriate treatment, which may include optimizing glycemic control. Conversely, awareness and identification of the characteristic musculoskeletal manifestations of DM may facilitate earlier diagnosis of DM.

Stroke

Stroke is the second leading cause of death in the world and the leading cause of serious, long-term disability in adults. The incidence of stroke increases dramatically with advancing age, doubling with each decade after the age of 45 years. Over 70 % of all strokes occur above the age of 65 [27]. Progressive carotid atherosclerosis, cardiac arrhythmia and emboli, and vascular changes all contribute to this increasing incidence of stroke in the elderly [28]. About half of those who survive are dependent on others for assistance with personal activities of daily living. This disability is mainly due to loss of hand and/or upper extremity function [29]. Apart from the expected hypotonic and spastic states of hand during the disease course, it is not uncommon to

have severe pain and neglect or dystonia of upper extremity and hand for these patients.

Rheumatic Diseases

Aging and arthritis have two main conflicting aspects: aging with a rheumatic disease and having rheumatic diseases frequently affecting older people. The former group mostly covers the rheumatoid arthritis patients. Suffering from a rheumatic disease is related to negative perceptions with regard to the physical aspect of aging earlier in the life course. This group of patients suffer from hand functional disturbances resulting from their primary disease, and as they get older, their disease gets older too. So secondary deformities and expected complications appear in early periods of their old age. As a result for these patients, feeling physically old starts in the middle of their life [30]. Rheumatic disorders mainly affecting older patients are late onset RA, polymyalgia rheumatica, giant cell arteritis, crystal arthropathies, etc. Hand joint involvement is fortunately scarce for these patients [31].

Parkinson's Disease

Parkinson's disease is present in 1 % of people older than 65 and clinically manifests with tremor and rigidity where upper extremities and hands are mostly affected. The tremor is present at rest and increases with stress. Voluntary movement is slow. All of these negative symptoms result in loss of hand functions and difficulties in everyday tasks [32].

Dementia

Dementia is found in 1.5 % of people aged 65–70 years and increases to 25 % of people aged 85 years and older [33]. Patients with dementia experience difficulties for both the diagnostic and rehabilitative periods of hand management. Also severe dementia itself is a risk factor for trauma or self-destruction for all body parts including hands if left unattended.

Pain

The elderly deserve adequate pain management no less than any other age groups. Older adults represent a subgroup of the general population with a greater risk of hand pain [34]. Risk factors for progression of hand pain and functional difficulty in older adults may differ from those in younger adults [35].

Unique characteristics for geriatric pain include difficulty in completing one of the most widely used pain measures, prolonged and impaired recovery from tissue and nerve injury, and age-specific interrelationships of psychosocial factors important in adjustment to chronic pain [35].

Senile Tremor

Senile tremor refers to cases in which essential tremor begins in old age, yet despite its name senile tremor is not a normal concomitant of aging. Most patients develop the tremor in the seventh decade. At first it occurs only with voluntary movements, and later it becomes more constant and even occurs at rest. This can be embarrassing even debilitating with daily living activities and upper extremity tasks [36].

Evaluation of the Geriatric Hand

Clinicians should be prepared to spend more time interviewing and evaluating elderly patients and should tailor the interview to the individual patient [37]. Aphasia, cognitive dysfunction, or sensory deficits such as hearing or vision loss can interfere with the interview process. Aids to improve functioning are often available to the patient but may not be consistently or appropriately used. If the patient uses a hearing aid, ensure it is worn and working; ensure glasses are worn [37].

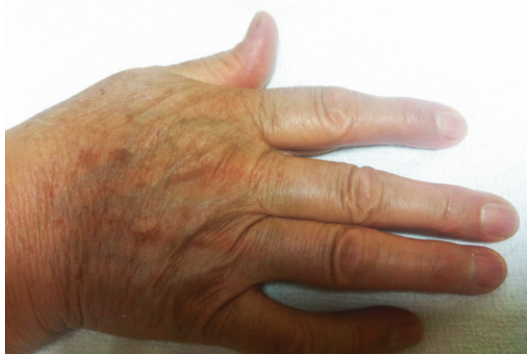

Fig. 13.1 Elderly hand

Interviewing with geriatric patients requires attention as they may omit important symptoms, rationalizing them as an inevitable consequence of aging or fearing that admitting to problems may lead to placement in a care home. Clinical features of diseases may differ from those seen in younger patients; disease may manifest as functional decline. While exploring activities of daily living, make the distinction between what the patient wants to do, what they can do, and what they actually do—with the last descriptor being the most important [37]. Assessment of hand function and prehension patterns is needed in order to determine specific treatment approaches [19].

Inspection

Heberden and Bouchard nodes occur in patients with OA. Nails may represent many abnormalities due to systemic conditions like clubbing, spoon nails, pitting, and color changes. Nails are thicker in the elderly, so thin brittle nails can be a feature of metabolic abnormality. Palm examination may reveal Dupuytren's contracture, callus formations, or unusual color change as in cyanosis, pallor, rash, or palmar erythema. Petechiae, livedo reticularis, or telangiectasias must not be underestimated. General sarcopenia may manifest as thenar or interosseous atrophy in the aged men and women (Fig. 13.1).

Range of Motion

The range of motion examination is very important in the elderly. All upper extremity should be thoroughly checked. Even relatively minor losses in range of motion can affect function. In hand OA limitations in range of motion can go unreported in some instances, because the older person might be unaware that range of motion has declined due to its gradual progression. Examiner must record both active and passive range of motion and note the presence of contractures for every joint. Wrist extension and flexion, finger flexion, and extension limitations can have important ramifications.

Grip Strength

Grip strength measures only one component of musculoskeletal performance and requires little cognitive function. However it is accepted to be the major predictor of hand function and with a high correlation to daily living activities. An advantage of handgrip strength could be that it is easy to use in clinical practice [38].

It was clarified that muscle strength in the elderly generally decreases with age. Maximal handgrip strength and controlled force exertion (CFE) in the elderly were about 70 % and about 50 % of young adults, respectively [9]. The number of muscle fibers, the number of recruitable units and a firing rate of motor units, nerve impulses conduction velocity, and shortening velocity in single skeletal muscle cells decrease with age [39]. In addition, the information processing time in the central nerve system becomes longer. From the above, it is inferred that both maximal handgrip strength and CFE decrease with age, but the CFE which is affected by a decrease in nerve function and other factors besides muscle function shows a larger decrease than the maximal handgrip strength which is primarily influenced by a decrease in muscle function [9]. The decline in overall muscle in the geriatric population might also be responsible for fading away of both age and side-based variations as reported [40].

Grip strength is measured with different types of dynamometers (e.g., Jamar®, a prototype of manual dynamometer). Pinch strength is also determined by manual hydraulic pinch meters in different types of pinch positions (pulp, lateral, key, three-point pinch).

It is widely accepted that grip strength measurement could be substituted for the physical exam-based joint impairment measure to predict impairment as hand function has a high correlation to ADL. Lower handgrip strength predicts an accelerated decline in ADL disability and cognition, thus contributing to increasing dependency in old age. However, for very frail elderly people, measuring handgrip strength might be difficult to perform, and general results could not be applicable to this group of patients.

Laterality

As mentioned in previous sections, a functional right and left difference called laterality is found in each body part with bilateral symmetry like hands. This asymmetry is expected to be diminished in the aged population. Hand preference can be determined with the Edinburgh Handedness Inventory which classifies handedness on the basis of a short interview on hand preference in the performance of routine practical tasks [41] (Table 13.2).

Table 13.2 Edinburgh Handedness Inventory used for assessing laterality

Task/object	Left hand	Right hand
1. Writing		
2. Drawing		
3. Throwing		
4. Scissors		
5. Toothbrush		
6. Knife (without fork)		
7. Spoon		
8. Broom (upper hand)		
9. Striking a match (match)		
10. Opening a box (lid)		
Total checks	LH=	RH=
Cumulative total	CT = LH + RH=	
Difference	D = RH − LH=	
Result	R = (D/CT) × 100=	
Interpretation (Left handed: R < −40) (Ambidextrous: −40 ≤ R ≤ +40) (Right handed: R > +40)		

Functional Evaluation

Jebsen Test of Hand Function

The Jebsen Test of Hand Function is a commonly used standardized test for assessing a person's functional hand use. Both the dominant and nondominant hands are evaluated using a series of seven subtests related to activities of daily living. The Jebsen test may be a useful mean of quantifying any decline in hand function with age. Normative values for adults have been published for ages 20–59 and 60–94 years. It is reasonable to assume that changes in hand function could occur at varying rates between the ages of 60 and 94 years; this large age grouping therefore may be a poor representation for clinical comparison. In general, the elderly subjects had lower mean peak acceleration. Also, the elderly persons' movements were slower and less automated.

It appears that gender has only a minor influence on the decrease in hand function. In each age group, men and women were not significantly different for the majority of tasks. Women in their 60s and 70s, however, did perform the "writing" subtest with the dominant hand significantly faster than did men in the same age groups. Perhaps this may be attributed to a tendency for women to perform writing tasks more frequently than men [42]. Because another factor that might influence the relationship between age and task performance is familiarity with the task, notably, the difference between elderly and younger people was less evident when it came to signing their names, a highly automated task [43].

Upper Extremity Performance Test for the Elderly (Test d'Evaluation des Membres Supérieurs de Personnes Agées: TEMPA)

The TEMPA was developed to evaluate strengths and weaknesses in the upper extremity function of patients aged 60 and older. Because normal aging may contribute to an increase in the length of execution of the tasks, normative data were developed to help clinicians using the TEMPA differentiate between normal and pathological aging. This test is composed of nine standardized tasks representing daily activities: five tasks are bilateral (open a jar and take a spoonful of coffee; unlock a lock and open a pill container; write on an envelope and stick on a stamp; shuffle and deal playing cards); and four are unilateral (pick up and move a jar; pick up a pitcher and pour water into a glass; handle coins; pick up and move small objects) for a total of 13 different items. All the test material is placed in precise, predetermined positions on a set of shelves designed to ensure a high level of standardization in performing the tasks. Each task is measured according to three criteria: length of execution, functional rating, and task analysis. For length of execution, each task is timed to the nearest tenth of a second, beginning as soon as the subject's hands leave the table and ending the moment the task is completed. The functional rating refers to the subject's independence on each task; it is measured using a four-level scale: (0) the task is successfully completed, without hesitation or difficulty; (1) some difficulty with the task; (2) great difficulty in completing the entire task; and (3) the individual could not complete the task, even when assistance was offered. The task analysis section quantifies the difficulties experienced by the subject according to five dimensions related to upper extremity sensorimotor skills: strength, range of motion, precision of gross movements, prehension, and precision of fine movements [44]. According to normative data obtained from TEMPA results, the length of execution is shorter for women on the tasks more related to fine dexterity than the other tasks. In contrast, men are faster on the tasks least related to fine dexterity and sensibility and most related to grip strength. Age is the best predictor of upper extremity performance (UEP) in this elderly sample. Other predictors vary according to the task requirements. Current activity level plays an important role in the performance of many tasks [44].

Pegboard Tests

For a comprehensive assessment of upper extremity function, dexterity is an important component that must be considered. Dexterity has been defined as "the fine, voluntary movements used to manipulate small objects during a specific task," as measured by the time to complete the task and considered as essential for successful performance of tasks of daily living, work, school, play, and leisure [45]. Most commonly used tools for determination of dexterity are pegboards. Purdue pegboard and nine-hole pegboard are the most frequently studied ones in the literature in different pathologies regarding the elderly population [46]. A decline in scores for elderly adults has been recorded up to 7–8 % in studies indicating a loss of fine dexterity [12].

Functional Reach (Maximal Safe Standing Forward Reach)

This is an easy to perform test and an indicator of frailty for the aged population. According to the measuring method devised by Duncan et al., participants stand with their feet together, their bodies perpendicular to and with one shoulder adjacent to, but not touching, a wall which had a measuring yardstick affixed to it horizontally [47]. They raise their arms in front of them to a horizontal position with their tips of the middle fingers positioned at the zero end of the measuring yardstick. They reach forward as far as possible, bending as necessary but keeping their arms straight and horizontal and their feet in the starting position. The distance from beginning position to ending position as measured at the tips of the middle fingers is the FR value. Although the FR test was originally developed as

a measure of dynamic balance, not hand function, it involves movement of the upper extremities and is required for many upper body tasks. FR can be accepted as a determinant of independency for the elderly.

Finger–Nose Test

Upper extremity motor coordination can be estimated by the finger–nose test. The subject has to move her/his upper extremity in a specific trajectory as quickly as possible in 20 s. A high score indicates a good performance [12]. In Courtesier's study the decline in this test in the elderly is comparable to the decline in the pegboard test, which is a fine dexterity test (loss of 7–8 % depending on the subtests) [12].

Questionnaires

In contrast to the so-called hand function tests, which require trained observers and a specific setting in time and place, self-reported questionnaires may be considered more feasible in busy clinical settings because they do not need the presence of professional staff when administered. But, it must be kept in mind that self-report does not directly measure musculoskeletal or cognitive function; rather the questionnaire measures the subjects' perceptions of hand function.

With regard to length of questionnaires, some are relatively long, whereas others are relatively short. In the elderly, it may be hard to maintain concentration for a prolonged time. This can be an issue for the observer too, since time is a precious commodity in health care today. Another factor is the time it takes to score the scale. Also other important aspects to consider selecting a scale are the overall dimensions of the scale and the specific items it contains. The clinician and researcher first need to identify what dimensions they are interested in assessing in their patients and then select the scales that include those domains [48].

GERI AIMS-Dexterity Scale

The self-measure report of hand function, GERI AIMS, is a modification of the Arthritis Impact Measurement Scale (AIMS) for use in geriatrics (GERI AIMS) [49]. GERI AIMS is an interview administered comprehensive measure of functional status and consists of 44 health status items arranged into eight scales of functional status, one of which is the dexterity scale. The dexterity scale contains five questions about the ease with which the person can write, turn a key, button clothing, tie shoes, and open a jar [50].

Duruöz Hand Index (DHI)

This scale was developed by Duruöz et al. as a practical functional disability scale for rheumatoid hand [51]. The developers proposed that it would also be valid and reliable for sufferers of osteoarthritis of the hand and have validated it for use in OA. This scale comprises 18 questions on ADL for the hands [52]. It was already validated to assess hand function for geriatric population [53].

Australian Canadian Osteoarthritis Hand Index (AUSCAN)

The AUSCAN was developed jointly between Australia and Canada to provide a multicultural assessment of hand function, pain, and stiffness in OA. The AUSCAN contains 15 items that capture a combination of common symptoms in HOA and those that occur frequently and are important to symptomatic individuals practically over 45 years. The AUSCAN uses a 48-h time frame and comprises subscales of hand pain (5 items), hand stiffness (1 item), and hand function (9 items) [54].

Upper Extremity Function Scale (UEFS)

Pransky et al. developed the Upper Extremity Function Scale (UEFS), an eight-item, self-administered questionnaire, to measure the

impacts of upper extremity diseases on function. UEFS is easy to use and can be completed in a self-administered written format in less than 5 min [55]. Older individuals have decreased ability to maintain steady submaximal forces, difficulty in determining the slipperiness of objects, an increase in time required to manipulate small objects, and a decrease in finger pinch strength by an average of 14 %.

Activities of Daily Living (ADL)

UEP is tightly associated with a person's functional status because several common ADLs, such as dressing, eating, and personal hygiene, are mostly upper extremity-related tasks. Notably, the vast majority of women also engage in upper extremity-related IADLs tasks (e.g., cooking, housekeeping, and doing the laundry) [56, 57].

Although several UEP measures are widely used in older adults, it is unclear whether any or all of them provide a similar, additive contribution to our determination of functional status. Compared to one measure alone, combining several UEP measures may capture more manifestations of disability; however, it has yet to be determined which, if any, combination of UEP measures is most efficient at detecting functional limitation and disability. UEP components for performing ADLs included upper body strength, flexibility, and dexterity [54].

Disability status is assessed using IADLs and ADLs scales [58, 59]. The ADLs include aspects of eating, moving from bed to chair, grooming, toilet use, bathing, ambulation, negotiating stairs, dressing, and emptying bowels and bladder. The IADLs include the ability to use the telephone, shop, prepare food, perform housekeeping chores, do laundry, use a mode of transportation, maintain responsibility for own medications, and handle finances. IADLs and ADLs disabilities were defined as a participant being unable to perform or needing human help with one or more IADL or ADL tasks, respectively.

Although the study of McGuire et al. shows that hand motor function and (I)ADL need not be related, studying the relationship between the two is of clinical relevance, as the level of (I) ADL might be maintained or improved by training hand motor function itself. In healthy aging persons, training for pinch force, hand steadiness, and moving small objects has proven successful. Also, the elderly persons have slow and less automated movements, and these can be improved too. This is an important finding since many (I) ADL tasks involve hand manipulation, and improvements in these areas could enhance quality of life. That said, not all aspects of hand motor function are easy to train. For example, elderly people have more problems with releasing grip force which is one aspect of the hand motor function that is not easy to exercise. This is unfortunate, since a decrease in releasing grip force plays a particularly important role in the impairment of hand function in elderly persons.

Summary

Studies in elderly population reported difficulties in performing everyday tasks and a reduction in quality of life partially related to a decline in hand function. This decline can be due to deterioration in muscle coordination and strength, finger dexterity and sensation, as well as the degeneration of the CNS. Also systemic pathologies like Parkinson's disease, DM and stroke have marked impact on hand function. Different conditions irrelevant to the primary hand problem also negatively affect the elderly patients' therapy period, like severe dementia. The impact of aging and age-related comorbid conditions on hand function along with clinical examination and functional evaluation of the hand in the elderly population will be reviewed.

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Hand Function in Common Hand Problems

14

Lynn H. Gerber

Introduction

Positioning the hand in space and placing it in functional positions is critical for us if we are to interact effectively with our environment. Our hands are our most important tools for survival and fun. Diseases with hand involvement affect its functional status and quality of life.

This chapter presents a discussion of several commonly seen hand impairments that are likely to influence function. The goal of this chapter is to provide a brief, practical guide to evaluation of some common, non-traumatic, functional hand problems.

It is important to proceed in a systematic way in evaluating these problems, using standardized assessments and considering possible contributions of posture and ergonomics of the work, home, and leisure activities. Included in this chapter are syndromes of various etiologies, but overuse is often a common component.

Included are the following:

Carpal tunnel syndrome is the most common compressive neuropathy of the hand. Its symptoms, often nonspecific, usually include dysesthesias along the median nerve distribution.

Trigger finger is characterized by a snapping or locking sensation and limitation of full flexion of the finger. Often it is the third, fourth, or fifth digit. Occasionally it remains in a fixed flexion position.

De Quervain's tenosynovitis is associated with pain on the radial aspect of the thumb. There is usually pain on palpation or on movement when one is using the thumb for pinching or gripping.

Dupuytren's contracture is the result of hypertrophy of palmar fascia affecting the fifth digit in about 70 % of people so affected. It is a clinical diagnosis made with the presence of palpable nodules and cords in the palmar fascia and associated with flexion contracture of the fourth and fifth digit.

Chronic regional pain syndrome is a chronic, neuropathic pain syndrome characterized by autonomic dysfunction and severe pain that may lead to crippling contractures of the limbs. The patient often presents with a cool extremity, color changes (ruddy or bluish), swelling, and allodynia.

Focal dystonia, also called writer's cramp/musician's cramp, is maladaptive response of the brain to repetitive performance of stereotyped hand movements. Usually, the individual presents with cramping and pain when they repeat the inciting task. When not used in that fashion, the hand appears normal.

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Measurement

A comprehensive hand evaluation, which includes descriptive and quantitative assessment, is essential to understand the impact of impairments on function. The use of standard imaging (x-ray, computed tomographic, magnetic resonant imaging, real time ultrasound, Doppler ultrasound blood flow) and standardized measurement are essential for proper treatment [1].

Carpal Tunnel Syndrome

Carpal tunnel syndrome (CTS) is one of the most frequently encountered problems and the most common compressive neuropathy in the upper extremity [2]. The median nerve and the flexor tendons pass through a tunnel at the wrist limited by carpal bones and the transverse carpal ligament (Fig. 14.1). Numbness and paresthesias are felt in the distribution of the median nerve (Fig. 14.2). In the United States, 15 % of the general population has symptoms consistent with CTS for which they seek medical attention. Symptoms are often non-diagnostic, because those associated with CTS are similar to radiculopathy, wrist arthritis, and tendonopathies. Therefore, electromyographic studies are usually considered necessary for confirmation. Using this as the diagnostic criterion, CTS has a 3 % prevalence in women and 2 % in men. Prevalence is greatest in women >55 years [3], in those who are obese, smoke, or have diabetes mellitus [4, 5]. A phenomenon called the "double-crush" syndrome has been reported, which has established the association between cervical spine radiculopathy, thoracic outlet abnormalities, and CTS [6].

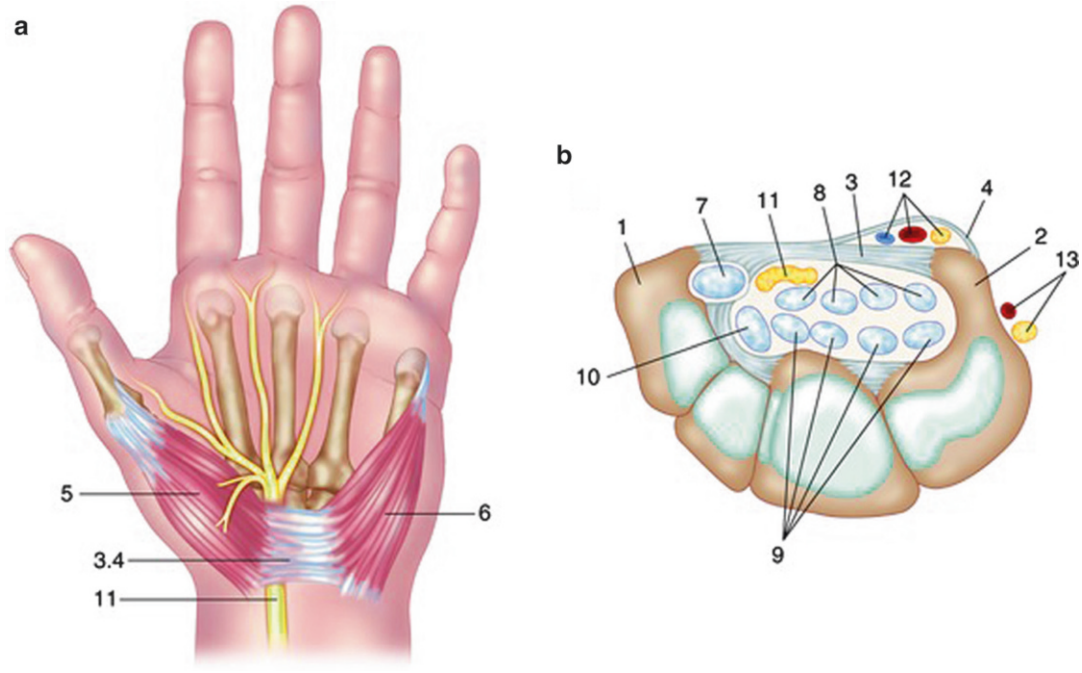

Fig. 14.1 Carpal tunnel syndrome: Anatomy of the carpal canal. (**a**) Typical median nerve and hand anatomy at the level of the transverse carpal ligament. (**b**) Carpal tunnel cross-sectional anatomy. (*1*) Trapezium tubercle, (*2*) hook of the hamate, (*3*) transverse carpal ligament, (*4*) palmar carpal ligament, (*5*) thenar muscles, (*6*) hypothenar muscles, (*7*) flexor carpi radialis tendon, (*8*) flexor digitorum superficialis tendon, (*9*) flexor digitorum profundus tendon, (*10*) flexor pollicis longus tendon, (*11*) median nerve, (*12*) ulnar artery, vein, and nerve superficial branches, (*13*) ulnar artery, vein, and nerve deep branches (With kind permission from Springer Science+Business Media: *Reoperative Hand Surgery*, Reoperative Options for Compressive Neuropathies of the Upper Extremity, 2012, Kang JR and Gupta R)

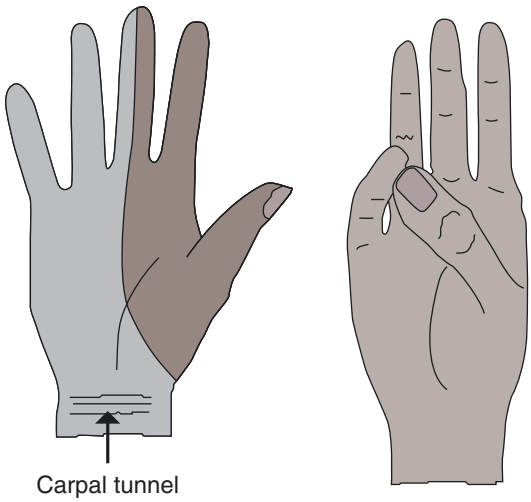

Fig. 14.2 Carpal tunnel syndrome: Area of sensation (*dark gray* in the *left picture*) and motor function (opposition of the thumb in the *right picture*) supplied by the median nerve

The diagnosis of carpal tunnel syndrome is based on history and clinical evaluation. Electromyogram (EMG) is often used for diagnostic confirmation of CTS. It can measure the extent of damage and demyelination of the median nerve [7]. In mild cases, there may be an absence of electromyographic and nerve conduction changes. As symptoms progress, sensory distal latency is usually the first abnormal EMG finding. Therefore, the diagnosis of CTS is first established on history and clinical findings and then may be confirmed by EMG evaluation. Recently there have been multiple reports about the usefulness of ultrasound evaluation of the median nerve to diagnose CTS. These studies have shown that there is a change in the cross-sectional area of the median nerve when CTS is present [8–10].

The carpal tunnel is located just distal to the palmar wrist crease. It is surrounded on three sides by the carpal bones, creating a fixed volume of space. The radial wall is bordered by the scaphoid and trapezium and the ulnar by the hamate and dorsally by the lunate and capitate. The boney arch is covered by a thick fibrocartilaginous band called the *flexor retinaculum* (or transverse carpal ligament). Tendons of the flexor superficialis (FDS) and flexor profundus (FDP) and pollicis longus (FPL) course through the carpal tunnel [11]. The median nerve travels with these innervating the thenar muscles and providing sensation to the radial three and one-half digits. CTS is therefore associated with motor and sensory findings.

Normal pressure within the carpal tunnel is 7–8 mm Hg with the wrist in neutral. Increased pressure of 30 mm Hg can result in symptoms of CTS and 90 mm Hg can be observed with wrist flexion and extension [12, 13]. This pressure increase causes relative ischemia and impaired nerve conduction of the median nerve [14, 15].

The prevalence of CTS increases with pregnancy, inflammatory arthritis, distal wrist fracture, amyloidosis, hypothyroidism, diabetes, and acromegaly and in individuals who use corticosteroids and estrogens [16]. One third of all cases of carpal tunnel are associated with these medical conditions [17]; diabetes is the most commonly associated diagnosis [16].

Cervical radiculopathy has been thought to potentiate CTS, causing the “double-crush” syndrome. The “double-crush syndrome” is a condition in which compression of an axon at one location makes it more sensitive to effects of compression at another [18]. For this to be true, one would need to show that there is compression of an axon at a primary location which causes sensitization at another location due to impaired axoplasmic flow [19]. There have been several review articles casting doubt on this, both from the theoretical physiological basis and from physical findings. Mechanical explanations, stemming from muscle imbalance due to positioning and/or postural changes, have been discussed as potential explanations [20, 21]. CTS is frequently associated with specific occupational activities. The repetitive use of tools that vibrate, such as drills and equipment used in food processing plants and mills, may cause CTS. Continuous compression of the median nerve with the wrist in flexion is also associated with CTS [22]. Debate remains as to the association of CTS and computer keyboard work [23, 24]. There remains considerable debate about whether CTS is a result of repetitive stress without other factors being present [24, 25].

The typical symptoms of CTS are numbness, tingling, pain, burning, or a combination of these [16]. These symptoms occur in the radial three and one half digits: the thumb, index, middle, and half of the ring finger. CTS often causes nocturnal awakening secondary to the hand paresthesias. These nocturnal symptoms are 51–77 % sensitive and 27–68 % specific for CTS [26]. Gripping, driving, holding vibrating objects, or prolonged pinching, such as holding a book, may result in increased paresthesias. Many patients describe relief of their symptoms with shaking of the hands, a phenomenon called the "flick sign" [27]. With progression, patients may describe an awkward feeling or weakness of the hand and begin dropping objects.

Physical examination usually begins with the exclusion of any cervical, shoulder, or elbow pathology, which may produce similar symptoms. C-6 radiculopathies are often confused with CTS because the sensory symptoms involve the radial aspect of the hand. Strength testing should include wrist flexion-extension, grip, and thumb opposition. Specific CTS provocative tests include Phalen's test, in which the wrist is held in full passive wrist flexion. This position increases pressure within the carpal tunnel and may reproduce paresthesias in individuals with CTS. This test has a wide reported range of sensitivity and specificity (40–80 %) [28]. The time to the development of paresthesias should be noted because it can be used to monitor change with treatment. Tinel's test involves tapping the median nerve just proximal to the transverse carpal ligament [29]. Reproduction of the paresthesias into the hand by the Tinel's test is 20–60 % sensitive and 67–87 % specific for CTS [28, 29].

Carpal tunnel compression involves pressure placed with the examiner thumbs or indexes or long fingers over the carpal tunnel. This pressure is maintained for 30 s to 1 min and if positive will reproduce paresthesias. Durkan [30] believes that this test is more sensitive and specific for CTS than Tinel's or Phalen's test.

The function in CTS is commonly assessed by Disabilities of the Arm, Shoulder, and Hand (DASH) scale, Boston Questionnaire (BQ), and Michigan Hand Outcome Questionnaire (MHQ). These questionnaires are valid, reliable, and responsive in CTS [31, 32] (Table 14.1).

Table 14.1 The carpal tunnel syndrome assessment

Maneuvers	Phalen's maneuver (Hold wrist in flexion 60 s); carpal tunnel compression, percussion along median nerve (Tinel's sign)
Neurological tests	2-point discrimination, Semmes-Weinstein filament test (threshold of >2.83 in radial digits)
Electromyography	Fibrillation potentials, sharp waves; sensory latency >3.4 ms; motor latency >4.5 ms compared with unaffected hand
Functional tests	Disabilities of the Arm, Shoulder, and Hand (DASH), Boston Questionnaire (BQ), Michigan Hand Outcome Questionnaire (MHQ)
Physical findings	Wasting of thenar muscles, decreased pinch (thumb/index finger), and/or grasp

A review of nonsurgical interventions is available for the reader. Their application is clinically accepted, and there is evidence of a moderate therapeutic effect [33]. Treatment of CTS begins with modification of repetitive or awkward activities that precipitate paresthesias. Splinting the wrist in a neutral position at night has been demonstrated to reduce symptoms in 80 % of patients [34]. Nonsteroidal anti-inflammatory drugs (NSAIDs), diuretics, vitamin B_6, and oral steroids have been tested, but no specific recommendations have been given for their prolonged usage [16]. Therapeutic interventions such as ultrasound, iontophoresis, gentle stretching and strengthening exercises, ice, and carpal tunnel protection principles may be employed. Protection principles stress avoidance of positions or activities that increase pressure within the carpal tunnel. Nerve and tendon gliding exercises have been described and are thought to be useful [35]. Acupuncture and yoga have also been demonstrated to decrease symptoms [36].

Corticosteroid injections into the carpal tunnel are recommended if splinting and other conservative measures fail to reduce the symptoms.

They have been shown to decrease symptoms in 75 % of patients and improve nerve conduction [37]. One study suggests that procaine is as effective as triamcinolone in controlling symptoms [38]. These injections are performed in a sterile fashion with needle placement ulnar to the palmaris longus. The needle is directed dorsally, distally, and radially at a 45° angle. In patients with severe CTS, 80 % have return of symptoms in 1 year despite appropriate conservative care.

If the patient has signs or symptoms of constant numbness, loss of sensation, or thenar muscle atrophy lasting longer than 1 year, serious consideration of surgery is recommended [11]. Surgery has been shown to be an effective intervention for CTS. The techniques, using open carpal tunnel release or endoscopic release, have been reviewed and compared [39]. Long-term surgical outcomes have some persistent symptoms, such as pain, inability to perform full wrist extension, and persistent numbness and tingling in some [40]. Postoperative rehabilitation versus home exercises seem to have the same outcomes, except that it has been shown that rehabilitation hastens the time to return to work [41].

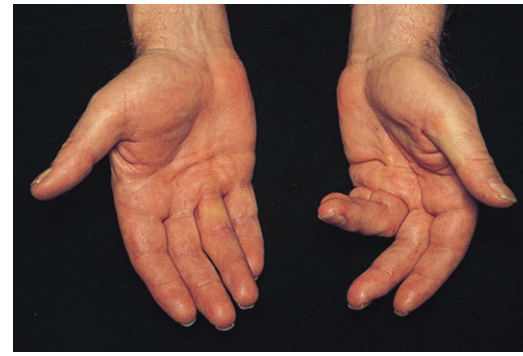

Fig. 14.3 Trigger finger: Stenosing tenosynovitis (trigger finger). (**a**) Synovitis of the tendon sheaths can lead to swelling, limitation of motion, and tendon rupture. Stenosing tenosynovitis can lead to "trigger finger," evident in the fourth finger of the left hand. Triggering occurs when the inflamed tenosynovial tissue cannot move through the tendon sheath. Stenosis of the A-1 pulley can be palpated in the palm just proximal to the affected metacarpophalangeal joint. (**b**) Stenosing tenosynovitis. Tenosynovitis of the flexor tendon can lead to the trigger finger syndrome. With tenosynovitis, the digit is blocked in the flexed position, making extension difficult or even impossible. If the affected tendon is able to pass through the fibrous tendon sheath, a palpable "pop" may be detected. The action may be painful. The tendon may also be blocked in the extended position. Swelling of the tenosynovium proximal to the stenosed annular ligaments may be palpable in the palm as swelling (Courtesy of Alan T. Bishop, MD.)

Trigger Finger or "Stenosing Tenosynovitis"

The sensation of a finger catching or locking in a fixed position is common. This so-called trigger finger or stenosing tenosynovitis is a disorder characterized by snapping of the flexor tendon of the digit (Fig. 14.3). This includes both the profundus and superficialis, acting as pulleys to maintain the position of the tendon [42]. The trigger finger is now thought to be a chronic rather than acute problem and has been described as a disproportion between the sheath and its contents [43]. The most commonly affected area is the distal metacarpal. Sometimes a small nodule can be palpated. On physical examination, one may find a mild flexion deformity of the proximal interphalangeal joint and limitation of full flexion, with the inability to reach the fingertip to the mid-palmar crease. When the condition is chronic, it may progress to a situation in which the finger (often the middle and/or ring finger) becomes fixed in flexion and extension is limited [44]. Pain is not the most frequent presenting symptom.

The pathomechanics include a thickening of the A-1 pulley or flexor tendon owing to sheer or compression forces with inflammatory changes occurring during the acute phase [44, 45]. In chronic conditions, no inflammatory changes are noted, but the tendon is often attenuated [46]. For this reason, the nomenclature of "stenosing tenosynovitis" has lost favor. Chronic conditions result in degenerative changes consistent with fibrocartilaginous proliferation of the A-1 pulley or tendon. The pathologic thickening results in a disparity of the tendon pulley configuration [42]. This size differentiation causes a mechanical locking of the tendon proximal to the A-1 pulley

with finger flexion. Once the tendon is locked in the flexed position, the weaker finger extensors have difficulty overcoming the resistance [47]. When the stuck tendon does release during extension, there is a painful snapping in the region of the MCP joint.

When children have trigger finger, they are usually younger than 6 years [48]. In adults, it is more common in people over 40 years, women, and those with diabetes mellitus and limited joint mobility [49, 50]. The thumb of the dominant hand is most commonly affected, followed by the middle and ring fingers [49]. The symptoms usually consist of a snapping or locking sensation with full flexion of the digit. This sensation is usually painful, but nonpainful conditions have been described. The onset is usually gradual, over several months, but in certain situations can be due to trauma or carpal tunnel release [42]. The symptoms of locking or clicking phenomena are usually worse in the morning and after repetitive gripping or pinching-type activities.

Examination of the finger is usually unremarkable unless reproduction of the locking phenomena can be observed. Most often, a tendon nodule or crepitus can be felt over the palmar aspect of the MCP joint in the region of the A-1 pulley [42]. Grip strength can be diminished secondary to pain. Ligament and neurovascular integrity is normal. No diagnostic tests are confirmatory for this condition. X-rays have not been found to show any abnormality correlated with trigger finger [51]. Serologic testing should be done to check for the presence of underlying conditions such as diabetes mellitus, hypertension, and inflammatory arthritis, which are risk factors for trigger finger.

A trigger finger can lead to disabling pain and may influence work. Symptom control has been reported and ultrasound, iontophoresis, and ice may relieve symptoms [52]. Evans and associates further reported 73 % success in using a flexion-blocking splint at the MCP for 3 weeks [52]. Their protocol also included limiting activities requiring grasp, active flexion or repetitive stress, and hooked-fish exercises. Colbourn et al. confirmed these findings but required 6 weeks of continuous splint usage [53].

Corticosteroid injections have been reported to be somewhat efficacious in the treatment of trigger finger [54, 55]. There have been two small, randomized studies. Newport and associates [56] reported that one to three injections of local anesthetic and cortisone were associated with resolution or improvement in 77 % of 338 fingers. Marks [57] reported that 84 % of trigger fingers and 92 % of trigger thumbs responded to a single injection. This increased to 91 % and 97 %, respectively, with a second injection. Beneficial effects with cortisone are superior to those of placebo and last up to 12 months [56].

Surgical intervention has been advocated if injection therapy does not offer benefit. There has been a plethora of surgical information regarding A-1 pulley releases for the treatment of trigger finger. Thorpe [58] reported that of 53 operations, 60.4 % were completely successful and 11.3 % had incomplete resolution with persistence of clicking and pain within the first year after surgery. Long-term outcomes from these procedures are not well documented.

De Quervain's Tenosynovitis

De Quervain's tenosynovitis is an inflammatory process involving the extensor pollicis brevis and abductor pollicis longus tendons on the radial aspect of the wrist. It is characterized by radial-sided wrist pain at the first dorsal compartment (Fig. 14.4). Presenting symptom is usually pain on palpation or on movement, typically pinching or gripping movement involving the thumb. This most commonly affects women between the ages of 35 and 55 years [59, 60], at a 10-fold increase compared with men. Repetitive, prolonged unaccustomed posturing of the thumb or non-neutral wrist movements usually provokes symptoms [61]. Waitresses, nurses, garment workers, maids, assembly line workers, and machine operators are at greater risk for development of this condition [61, 62]. Pathogenetically, the process starts as inflammation within the first dorsal compartment. Not uncommonly, it recurs or fails to fully heal/repair the tendon pathology, leading to thickening

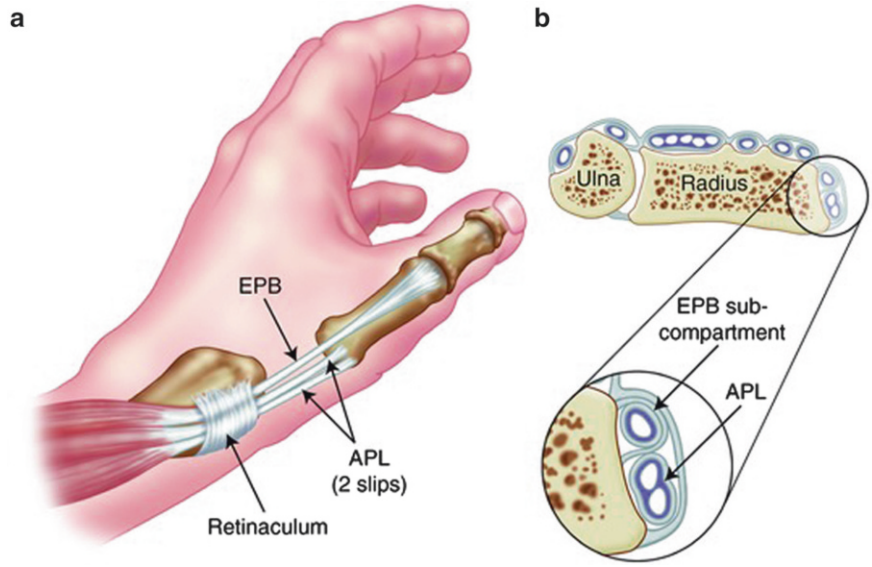

Fig. 14.4 De Quervain syndrome: (**a**) The first extensor compartment includes the abductor pollicis longus (APL) and extensor pollicis brevis (EPB) tendons. (**b**) The EPB tendon is often located within a separate subcompartment (With kind permission from Springer Science+Business Media: *Reoperative Hand Surgery*, Reoperative Tenosynovitis, 2012, Haase SC and Chung KC)

of the extensor retinaculum and synovial tendon sheath [63].

The extensor tendons to the fingers and wrist travel through six dorsal compartments of the wrist. The first (most radial) dorsal compartment contains the extensor pollicis brevis and the adductor pollicis longus. These tendons course through an osteofibrous canal to their insertion on the metacarpal and proximal phalanx of the thumb. A significant angulation is present as these tendons traverse over the radial styloid, placing the tendons at risk for repetitive injury [61, 63]. The function of these muscles is to position the thumb in extension and abduction in preparation for gripping and pinching. In these chronic states, inflammation is absent [59, 60]. The thickening results in a mechanical stenosis within the first dorsal compartment, causing impingement of the two tendons [63].

On physical examination, patients usually have tenderness with palpation over the fibro-osseous first dorsal compartment. Pain is commonly elicited with resisted thumb extension and abduction. A positive Finkelstein's test is pathognomonic for de Quervain's tenosynovitis [64]. This test is performed by flexing the thumb into the palm and making a fist around the thumb. The wrist is then *passively* deviated in the ulnar direction. Increased pain in the region of the radial styloid with this maneuver is considered positive. Pain increases with grasping, adduction of the thumb, or ulnar deviation of the wrist [65]. The symptom complex is usually gradual in onset, but traumatic etiologies have been described [59, 60].

De Quervain's tenosynovitis is a clinical diagnosis. Plain x-rays have not been found to be beneficial. Ultrasound, however, has been able to identify tendon pathology [66]. Other conditions with a similar presentation include peripheral neuritis, collagen vascular diseases, sprains of the CMC joint, arthritis of the CMC joint, fracture of the distal radius, ganglions of the wrist, acute calcific tendinosis, and aberrant CTS.

Non-pharmacological intervention, including education and environmental and ergonomic adaptation, is extremely important for treatment and prevention of de Quervain's and its recurrence. Interruption of highly repetitive activities that include pinching or gripping is

beneficial [61]. Immobilization of the thumb in a forearm-based thumb spica splint offers protection and rest. Heat modalities, stretching of the first dorsal compartment muscles, and ice may offer relief of symptoms during the acute stage. To date, there has not been an outcome study on the use of modalities and exercise for this condition.

Injection of local steroids has been shown to be of benefit [67]. Anderson and colleagues [68] reported that 81 % of individuals undergoing injections for this condition described symptom relief at 6 weeks. At 4-year follow-up, 58 % remained asymptomatic, and 33 % had complete reoccurrence. If conservative treatment is not effective, surgical release of the first dorsal compartment can be performed [69].

Dupuytren's Disease

Dupuytren's disease (DD) is a process of unknown etiology that leads to shortening and thickening of the palmar fascia and a flexion contracture of the digits (Fig. 14.5). Established risk factors include an autosomal dominant inheritance pattern [70, 71] and Caucasians of northern European origin, male, and older age [72, 73]. Smoking, high levels of alcohol intake, trauma, diabetes, epilepsy, and use of anticonvulsant drugs have all been implicated, with varying levels of evidence [74]. Theories of pathogenesis have included abnormal immune responses or tissue hypoxia secondary to the presence of oxygen-free radicals. The digital contracture is caused by myofibroblasts in the palmar fascia. The mainstay of treatment is surgical release or excision of the affected palmodigital tissue, but symptoms often recur. Nonsurgical correction of DD contractures can be achieved by anti-fibrotic substances and clostridium histolyticum collagenase injection, although the long-term safety and recurrence rate of this procedure requires further assessment [75, 76].

The contracture is a benign hypertrophy of the fascia. The first signs may be the palpation of almost imperceptible nodules in the area of the palmar crease, which progress to thick cords that form along the linear cord-like fascial lines of the palm [77]. The underlying tendons, synovial sheaths, and skin layers are not affected [78].

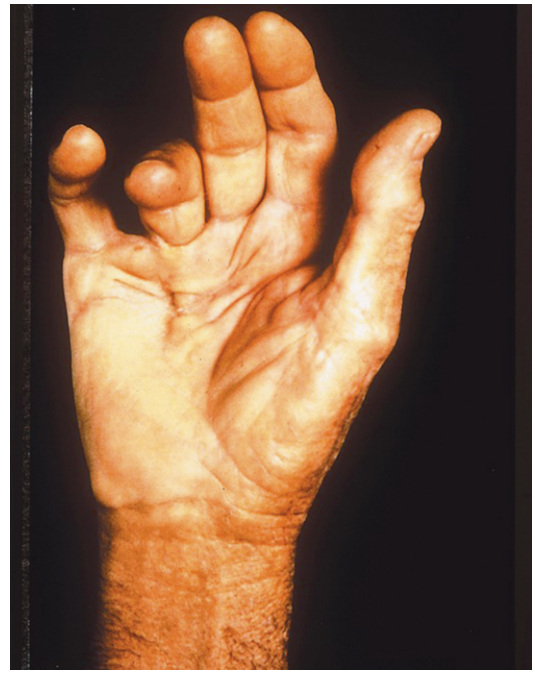

Fig. 14.5 Dupuytren's disease: Dupuytren's contracture involves the palmar fascia and can result in nodules in the hand and a fixed flexion contracture of any of the digits of the hand. As shown in this case involving the ring finger, the central cord proximal to the base of the metacarpophalangeal joint results in flexion contractures of both the metacarpophalangeal joint and the proximal interphalangeal joint

The pathophysiology of Dupuytren's is not fully understood. The palmar fascia thickening is caused by an abnormal proliferation of fibroblasts [74]. This proliferation is closely correlated with that observed in scar formation and healing. Three stages in the nodule and cord formation have been described. The first stage is proliferation. During this stage, the numbers of myofibroblasts within the palmar fascia spontaneously increase. The second stage is involution, when the myofibroblasts align along the tension lines of the palm and digits. The fascia enlarges owing to contraction of the myofibroblastic activity. In the third phase, the myofibroblasts resolve, leaving contracting collagen, which is perceived as nodules and matures into cords

[78, 79]. As the process progresses, these may become somewhat tender. The first finger to be affected, in 70 % of those with Dupuytren's, is usually the fifth digit. All digits, however, may be affected. Rheumatic diseases, synovitis, and Type 1 diabetes may be associated with similar symptoms [80].

Dupuytren's contracture is a clinical diagnosis made with the presence of palpable nodules and cords in the palmar fascia. It is often a diagnosis of exclusion. The anatomical distribution of the findings usually establishes the diagnosis. Joint deformity, including flexion contractures of the MCP, PIP, and DIP, is usually present in advanced conditions. Transverse or webspace contractures may also occur. These contractures can result in significant functional limitations necessitating treatment.

There has been minimal effectiveness of interventions, including splinting, radiation, vitamin E, anti-gout medications, physical therapy, and therapeutic ultrasound [75, 81]. Definitive treatment of advanced Dupuytren's is surgical fasciectomy. Advanced Dupuytren's is usually determined based on the performance of a "tabletop test" [82]. In this test, the individual places the palm on a flat surface and attempts to extend the involved finger actively. A positive test is noted if the MCP joint cannot be placed flat against the surface. This usually correlates with a greater than 30° fixed flexion contracture of the MCP joint. The goal of surgery is to restore function, not to cure the disease [83]. Despite surgical treatment, this condition can be quite recalcitrant, and reoccurrence rates range from 28 to 80 % [84].

Recently, there has been a great deal of interest in percutaneous or enzymatic fasciotomies as an alternative to surgical fasciectomy. Hurst [75] has demonstrated that by injecting collagenase into the fibrous cords, joint contractures can be improved. They report that 90 % enjoyed excellent results at an average of 9-month follow-up. Although no long-term studies have been completed, this procedure does offer promise. Additionally, an 8-year follow-up has recently been reported. While it consists of a relatively small sample size, a relatively high benefit and low risk over the long term was observed to prove long-term follow-up has been reported [85].

Postoperative surgical rehabilitation is extremely important following fascietcomy, with concentration on maintaining skin integrity, restoration of joint range of motion, and overall improvement of function [84].

Complex Regional Pain Syndrome

Reflex sympathetic dystrophy (RSD), causalgia (minor and major), algodystrophy, shoulder-hand syndrome, and Sudeck's atrophy are now considered complex region pain syndrome. The cause of CRPS is not fully understood. One theory, developed from an ischemia model in animals, suggests that symptoms are the result of microvascular injury leading to release of inflammatory cytokines [86]. Complex regional pain syndrome (CRPS) is a neuropathic pain syndrome characterized by autonomic dysfunction and severe pain that may lead to crippling contractures of the limbs. Mitchell first described CRPS during the American Civil War when he observed wounded veterans who had burning pain in an injured limb [87]. The term shoulder-hand syndrome described a variant of CRPS in which the entire upper limb was affected.

In 1993, at the meeting of the International Association for the Study of Pain (IASP), a task force proposed a unifying classification for these syndromes [88].

The task force of the IASP proposed two types of regional pain syndromes [89]:

Type 1, formerly known as reflex sympathetic dystrophy (RSD), Sudeck's atrophy, reflex neurovascular dystrophy (RND), or algoneurodystrophy, does not have demonstrable nerve lesions.

Type 2, formerly known as causalgia, has evidence of obvious nerve damage.

The two types share two features in common:

1. There is a history of edema, skin blood flow abnormality, or abnormal sweating in the region of the pain since the inciting event.
2. No other conditions can account for the degree of pain and dysfunction.

The diagnosis of Type 1 CRPS is based on four criteria:

1. The presence of an initiating noxious event or a cause of immobilization.
2. Continuing pain, allodynia (perception of pain from a nonpainful stimulus), or hyperalgesia (an exaggerated sense of pain) disproportionate to the inciting event.
3. Evidence at some time of edema, changes in skin blood flow, or abnormal sudomotor activity in the area of pain.
4. The diagnosis is excluded by the existence of any condition that would otherwise account for the degree of pain and dysfunction.

The diagnosis of Type 2 CRPS is based on three criteria:

1. The presence of continuing pain, allodynia, or hyperalgesia after a nerve injury, not necessarily limited to the distribution of the injured nerve.
2. Evidence at some time of edema, changes in skin blood flow, or abnormal sudomotor activity in the region of pain.
3. The diagnosis is excluded by the existence of any condition that would otherwise account for the degree of pain and dysfunction.

Patients who develop motor and/or trophic changes may complain of inability to initiate movement, weakness, tremor, or muscle spasms. Sometimes it is difficult to assess the function because of severe pain. Contractures can occur in late-stage disease.

The primary treatment for CRPS requires a combined approach using pharmacological and nonpharmacological agents. One approach has been to use an algorithm for guidance. Bisphosphonates have been studied in multiple controlled trials, based on theoretical benefit of relief of bone pain and bone resorption [90]. These have been only marginally successful. Many current rationales in treatment of CRPS (such as topical agents, antiepileptic drugs, tricyclic antidepressants, and opioids) are used because of their proven efficacy in other pain syndromes. Nerve blockade, sympathetic block, spinal cord and peripheral nerve stimulation, implantable spinal medication pumps, and chemical and surgical sympathectomy have also been reported, have been shown to provide some relief, but have not been demonstrated to be consistently therapeutic. The use of gabapentin and pregabalin has shown therapeutic benefit in controlling pain [91]. In treating CRPS, one follows the classic order of rehabilitation beginning with pain and edema control, followed by range of motion, and then strengthening followed by function. It is important to convey to the patient that immobilization is not an effective treatment for the pain and swelling; in fact, it may be instrumental in the pathogenesis and chronicity of the process [92].

Edema control entails elevation, decongestive massage, and various forms of compressive wrapping or garments. Pain control may be difficult using physical modalities alone. However, physical modalities should be the first line of defense. Contrast baths, Fluidotherapy, transcutaneous electrical nerve stimulation (TENS), and desensitization may be used before and after therapy session or exercise. If these are unsuccessful in adequately controlling the pain to the point at which therapy can be progressed, then one may consider further pain-relieving measures. Typical oral medications that may be used are tramadol, gabapentin, amitriptyline, and various α_1-blockers. In about half of all cases, further augmentation of analgesia may be attained by injections such as stellate ganglion blocks. One may also use injections such as intravenous regional blocks, axillary blocks, and cervical epidural injections. These blocks may provide temporary pain relief, enabling the patient to begin more aggressive hand therapy. Once pain is controlled to the level that patients can tolerate therapy, then one may begin exercises [92, 93].

The next goal of CRPS treatment is to restore normal range of motion. Often, the enduring disabilities resulting from CRPS are hand contractures. Gentle active or active-assisted range of motion should begin in a pain-free fashion. Any advancement in therapy should proceed slowly and carefully, keeping in mind that an overly aggressive approach may increase pain and swelling, which would be counterproductive.

When recognized early and treated carefully, CRPS generally runs its course in 6–12 months with complete or nearly complete recovery.

About 5 % of cases may turn into chronic CRPS with ongoing issues of pain, dysfunction, and disability. These patients may be on long-term pain medications or often are severely disabled by pain, contractures, or both. Reviews of current thinking about the pathophysiology and management or CRPS are available [92, 93].

Focal Hand Dystonia

Writer's cramp (Figs. 14.6 and 14.7) and musician's cramp (Fig. 14.8) are both focal dystonias that affect a discreet anatomical area of the hand. Focal hand dystonia is maladaptive response of the brain to repetitive performance of stereotyped hand movements. However, not all patients have a strict history of excessive hand use [94]. The focal hand dystonia is characterized by disabling cramps, contractions, or spasms during specific activities [95]. When not so engaged, the hand appears and functions normally. The flexors are more commonly involved than the extensors. Among the flexors, the flexor digitorum superficialis and profundus, the flexor pollicis longus, and the lumbricals may be involved. The extensor pollicis longus, extensor indicis, and digitorum communis may be involved among the extensors. Dystonia may occur sporadically in the population or may be genetically transmitted. The gene for early onset dystonia (DYT1) has been sequenced. Approximately 10 % of people with dystonia have a family history of tremor or dystonia [96]. Others report that a higher percentage of those affected have a family history of dystonia [97].

The pathophysiology of dystonia seems to be a loss of inhibitory function. The anatomical locus has been demonstrated at spinal, brainstem, and cortical levels. There seems to be some mild sensory and sensorimotor deficits. The abnormality leads to unwanted muscle spasms. Increasing inhibition may be therapeutic [98].

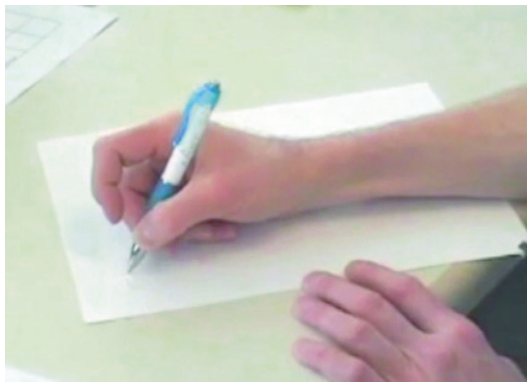

Fig. 14.6 Writer's cramp: The patient exhibits involuntary extension at the metacarpophalangeal joint of the index finger while writing (With kind permission from Springer Science+Business Media: *Movement Disorders*, Writer's Cramp, 2012, Bhidayasiri R and Tarsy D)

Fig. 14.7 Writer's cramp mirror movements (With kind permission from Springer Science+Business Media: *Movement Disorders*, Writer's Cramp, 2012, Bhidayasiri R and Tarsy D)

Fig. 14.8 Musician's cramp: Musician's cramp, analogous to writer's cramp, is a focal dystonia of the arm induced with the action of playing a musical instrument. This patient has a pianist's cramp that is manifested when she attempts to perform piano-playing movements on top of the desk (With kind permission from Springer Science+Business Media: *Atlas of Clinical Neurology*, Movement Disorders, 2009, Fahn S, Greene PE, Ford B, Bressman SB and Frucht SJ)

The incidence of writer's cramp is reported to be 2.7 per million in Rochester, MN [99]. It tends to affect male young adults. It is usually idiopathic and not a result of overt trauma, although it may follow a traumatic episode. Patients frequently have mirror dystonia, demonstrated by inducing the writer's cramp in the dominant hand even when attempting to write with the nondominant [96]. Focal dystonias tend to remain focal and do not become generalized dystonias over time.

The pathophysiology of dystonia is not entirely understood. However, there seems to be some evidence for abnormalities in the basal ganglia [95] or problems with cortical organization [100]. Electrodiagnostic studies show a co-contraction of muscle and a loss of alternation of agonist/antagonist muscle contractions. There are prolonged bursts of muscle contractions and overflow contraction seen in those muscles not activated by the motor task [101].

The use of botulinum toxin for focal dystonia has been demonstrated to be effective and safe even for chronic application [102].

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Hand Function in Metabolic Disorders: Hemodialysis, Diabetes Mellitus, and Gout

15

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Introduction

Musculoskeletal Involvements of the Hand (Hemodialysis)

Patients with renal failure, especially those treated with maintenance dialysis, frequently develop musculoskeletal manifestations, which may considerably impair their quality of life.

Dialysis-related musculoskeletal abnormalities often present with carpal tunnel syndrome (CTS), destructive arthropathy, juxta-articular bone cysts, or erosions that occur in the patients with chronic renal failure [1]. Chronic accumulation of β_2 microglobulin (β_2M) in patients who have undergone long-term HD has been believed to play a key in the pathogenesis of articular and periarticular disorders. β_2M amyloid deposits preferentially in bone, articular cartilage, synovium, muscle, and ligaments [2]. Patients with β_2M amyloidosis commonly display musculoskeletal signs and symptoms. The prevalence of musculoskeletal symptoms associated with β_2M amyloidosis increases with longer survival on dialysis treatment [3]. In addition to the duration of HD, an older age at the initiation of HD is an independent significant risk factor for the development of β_2M amyloidosis [4].

CTS has been reported to occur with increased frequently in the patients receiving HD. The incidence of CTS in the dialysis patients has ranged from 2 to 31 % [5, 6]. Hand pain, numbness, dysesthesias, and paresis in the hand distribution of the median nerve were symptoms of CTS. Previous contributions to the literature on CTS have implicated a variety of factors including edema of the flexor retinaculum, venous pooling associated with superficial vein valvular destruction distal to the fistula, and amyloid deposition in the transverse retinacular ligament [7–9]. Symptoms of CTS occur more frequently on the side of the longest functioning vascular access [10].

Destructive arthropathy is a common feature of dialysis-associated amyloidosis. This arthropathy appears to be related to β_2M microglobulin deposition in both the bone and surrounding soft tissues of the joint [11]. Joint involvement is usually symmetric and most commonly affected is the shoulder, but other joints including the thoracic and lumbar spine, knee, wrist, and small joints of the hands may also be involved [11]. Patients typically present with joint pain, swelling, and loss of motion.

β_2M amyloid may deposit along the digital flexor tendons of the hands, causing irreducible flexion contractures of the finger, trigger finger,

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and tendon rupture. Spontaneous tendon rupture is uncommon in dialysis-associated amyloidosis, but has been reported by several authors. The largest series was reported by Kurer et al. [12], who evaluated 83 renal failure patients who had undergone dialysis for more than 10 years. Kurer identified four patients with flexor tendon contractures and six patients with various tendon ruptures after slight trauma; two involved the upper extremity with a digital flexor tendon and extensor tendon rupture. Flipo identified two patients with destructive arthropathies of the metacarpophalangeal and interphalangeal joints who had associated flexor tenosynovitis [11]. The presence of both a destructive arthropathy and tenosynovitis was significantly debilitating and resulted in persistent pain and swelling and an inability to fully extend the involved digit.

Destructive spondyloarthropathy was described by Kuntz et al. [13]. It may occur early and late in the course of dialysis and is mainly cervical [14]. The disc spaces between the 4th and 5th cervical vertebrae and between the fifth and sixth cervical vertebrae are those most frequently involved [15]. Symptoms may occur due to radiculopathy and myelopathy. Radiological early changes erosions of the anterior corners of vertebral bodies and end plate erosions with subchondral cysts followed by collapse [13]. Spondylolisthesis is common and may be severe, causing compressive myelopathy.

Direct amyloid invasion with replacement of subchondral bone results in the formation of cysts that are often referred to as "intraosseous amyloidomas" [16]. The most common upper extremity "amyloidoma" locations include the distal clavicle, anatomical neck of the humerus, and carpus but also seen in the cervical spine, glenoid, radius, ulna, metacarpals, and phalanges [12, 16–18]. Bone cysts are usually juxtaarticular and surrounded by a thin sclerotic margin. Carpal cysts tend to localize to the radial side and most commonly involve the scaphoid and lunate [19]. The most of the cysts were asymptomatic. Pathologic fracture through amyloidomas has been reported in both the upper and lower extremities [18].

Beside the musculoskeletal abnormalities, hemodynamic and neuropathic problems may impair the hand function. The reported hemodynamic complications in the hand include venous hypertension marked by swelling and discoloration and vascular insufficiency from shunting of the blood flow from the hand [20]. Coexistence of muscle weakness and atrophy, areflexia, sensory loss, and graded distribution of neurological deficit in a patient with renal disease suggests the presence of uremic polyneuropathy.

Hand Function Assessment

Handgrip Strength and Pinch Strength Tests. In patients with chronic renal failure, receiving HD had diminished handgrip and pinch strengths [21]. Muscle strength was diminished because of neuropathy, myopathy, physical inactivity, tendinopathy, and pain. In patients undergoing HD, high values of ultrafiltration may lead to hypotension and a poor general condition, negatively affecting muscle function whenever handgrip strength is performed after the dialysis session [22]. Additionally, muscle wasting is one of the best markers of protein-energy wasting which means the reduction in the stores of energy and protein in patients with chronic renal failure [23]. Handgrip strength was measured with hydraulic hand dynamometer and pinch strength with a standard pinch gauge as outlined by the American Society for Surgery of the Hand. The measurements were performed while the patients were seated with the shoulders adducted, elbows flexed to 90°, and forearms in neutral position [24]. While evaluating the muscle strength, the presence of vascular access and the site of the body must be considered.

Range of Motion. Range of motion of the wrist and digits was assessed with a standard goniometer and a finger goniometer, respectively.

Two-Point Discrimination Test. This test was assessed with esthesiometer. Stimulation of one or two points was applied randomly along the longitudinal axis of the tested digit while the subject's eyes were closed. Threshold was

established when seven out of ten responses were correct at the minimum millimeter distance. A 2-min rest period occurred between each trial. The subject's thumb and index digit were tested as representative of the median nerve, and the little digit was tested for the ulnar nerve. Both static and moving 2PD were measured. Before the test, the subject was shown the procedure and asked to make the appropriate response.

Edema was evaluated with a hand volume water displacement tank with a drip spout. The displaced water was accumulated in a graduated cylinder and measured to the nearest milliliter.

Hand dexterity and coordination were assessed by Purdue Pegboard Test. Five subtests comprise the test: right hand (RH), left hand (LH), both hands (BH), right + left + both (R + L + B), and assembly. Performance of the RH and LH subtests require participants to first use their right hand (dominant) and then left hand (nondominant) to place as many pins as possible down the respective row within 30 s. Each stage of the test is administered three times [25].

Daily Activity Tests. In the previous studies, Sollerman test, Grip Function test (GFT), Hand Functional Index (HFI), and Duruöz Hand Index (DHI) were used for evaluating function with daily activities [21, 26–30]. Although there are some scales to assess hand function, none of them was developed specifically for hand involvement in patients receiving HD.

The GFT consists of 20 items that incorporate the seven major handgrip types into activities of daily living. Each subject was scored according to the amount of time required to complete the task and the handgrip pattern used. The reliability of this test has previously been examined in patients with hand disorders.

DHI was developed and validated as a self-report questionnaire that can be routinely used to assess the functional disability concerning hand-related activity limitation in patients with RA, osteoarthritis, systemic sclerosis, stroke, and those receiving hemodialysis [21, 31]. It contains 18 items on hand ability in the kitchen, during dressing, while doing personal hygiene, office tasks, and other general items. A higher score indicates greater activity limitation or more difficulty.

Sollerman test uses 20 items comprising activities of daily tasks, 15 items test bilateral handgrip function, and seven of the grips assessed are essential for normal function. Points are assigned to each item on a five-level scale; the final score is the sum of all items. Possible scores range from 0 to 80; subjects with normal hand function should achieve scores of 80 and 78–80 in the dominant and nondominant hands, respectively, [29].

HFI consists of the first nine questions of the Keitel Functional Test. It is an observational hand scale which assesses finger and wrist motion, and the total score ranges from 4 to 42.

Despite the knowledge about hand involvements in the patients receiving dialysis, there is limited knowledge about functionally assessment of the hand involvement [21, 26–30]. Chazot et al. assessed hand function with medicolegal techniques based on sensitivity and amplitude of angulations [27]. Limaye et al. [30] used Sollerman test, the handgrip test. The mean Sollerman test score of the patient receiving HD was lower than the normal values. The Sollerman test accurately reflects patient function as measured by Health Assessment Questionnaire (HAQ), grip strength, but less so pain. Duruoz et al. [21] reported that DHI was significantly correlated with HAQ, HFI, Purdue Pegboard scores, grip strength, and pinch strengths, while no significant correlation was found with non-functional parameters. They concluded that DHI is a practical scale which is efficient in assessing accurately the functional disability of the hand in patients receiving HD.

Diabetes Mellitus

Musculoskeletal Involvements of the Hand

Diabetes mellitus (DM) is associated with an increased incidence of functional disability, which is likely to further erode health status and

quality of life. In several epidemiological studies, it has been reported that arthritis, obesity, older age, coronary and peripheral vascular disease, nephropathy, neuropathy, retinopathy, stroke, depression, and cognitive impairment are predictors of disability seen in diabetics [32–39]. There are a wide variety of diabetic complications involving bones, joints, and periarticular soft tissues. The upper extremity complications, known as "diabetic hand," include not only more specific diabetic-related conditions such as limited joint mobility (LJM) but conditions related to the non-diabetic hand, such as trigger finger, Dupuytren's disease (DD), and CTS [40, 41]. Complex Regional Pain Syndrome type-1 is the complication seen in the diabetic patients.

Limited joint mobility (LJM), also termed diabetic stiff hand syndrome or diabetic cheiroarthropathy, is characterized by skin thickening over the dorsum of the hands and restricted mobility of multiple joints including metacarpophalangeal, proximal, and distal interphalangeal joints, generally beginning in the ulnar digits and spreading radially. Positive preacher's sign indicated the inability to approximate the palmar surface of the digits. Passive range examination of each joint to assess limited extension is a useful screening tool.

DD is a spontaneously occurring chronic and idiopathic thickening of the palmar aponeurosis, leading to various degrees of flexion deformity of the fingers. Unlike most cases of LJM, DD may be seen relatively early in the course of the disease, with a 23–30 % prevalence [39, 42]. Top table test is positive which indicated that the palmar surface of the digits should not contact the table. For screening test, passive range of motion examinations of the digits is useful.

Trigger finger, a catching and snapping of the fingers, occasionally painful, is also frequent in diabetic patients and is due to flexor tenosynovitis. The prevalence is found approximately 20 % in the diabetic population [42, 43].

Hand Function Assessment

Musculoskeletal involvements of the hand impair range of motion of fingers, wrist, muscle strength, sensory input, coordination and dexterity, and hemodynamics. The assessments of these impairments must be considered during the following and planning of treatment.

Hand weakness has been demonstrated in the diabetic population, compared with normal control subjects [44, 45]. Reduced grip and pinch strength have been found to be independent of LJM, DD, and trigger finger. Because of described numerous hand complications, functional disability is not amazing. Hand weakness is assessed by dynamometer and pinch meter. The procedures of them were mentioned above in hand function assessment of the patients undergoing HD section.

Monofilament testing is an inexpensive, easy-to-use, and portable test for assessing the loss of protective sensation, and it is recommended by several practice guidelines to detect peripheral neuropathy [46, 47]. Monofilaments, often called Semmes-Weinstein monofilaments, are calibrated, single-fiber nylon threads, identified by values ranging from 1.65 to 6.65 that generate a reproducible buckling stress. The higher the value of the monofilament, the stiffer and more difficult it is to bend. Three monofilaments commonly used to diagnose peripheral neuropathy are the 4.17, 5.07 and 6.10 [48, 49]. The filament is placed on the patient's skin; when there is considerable loss of sensation, the patient will not be able to detect the presence of the filament at buckling. The 5.07/10-g monofilament has been described as the best indicator to determine loss of protective sensation [50]. Despite the frequent use of monofilament testing, Dros et al. [51] do not recommend the sole use of monofilament testing to diagnose peripheral neuropathy.

Moberg Pick-up Test, Minnesota Rate of Manipulation Test, and Purdue Pegboard Test were used to assess motor dexterity and coordination of the hand [52, 53]. Impairments in tactile sensory, joint mobility, and muscle strength do affect manual dexterity.

Measurements with the dynamometer and various scales are used to evaluate hand functions, but there is no specific functional disability scale developed for diabetic hand. DHI was validated for diabetic hand dysfunction and found a

practical scale in the assessment of hand dysfunction in diabetic patients [54].

In a study, disability was related to impaired muscle function and carpal tunnel syndrome in the patients with hand syndromes associated with diabetes. Obesity and overall physical functioning influenced hand disability, particularly in women [55].

Gout

Musculoskeletal Involvements of the Hand

Gout is a monosodium urate crystal deposit disease. It is characterized by deposition of the crystals in joints and extra-articular tissues such as tendons, nerves, and kidney. The clinical stages of the gout are acute gout arthritis, intercritical gout, and chronic tophaceous gout. Fifty percent of the acute arthritis develops the first attack in the first metatarsophalangeal joint. In about half of the disease may start in other joints such as wrist, metacarpophalangeal, and interphalangeal joints of the hand (Fig. 15.1). Chronic gout is characterized by the development of tophi in connective tissues. The tophi lead to destructive arthropathy. Tophi present on the fingers, volar surface of the hands in the upper extremity. Tophaceous gout in flexor tendon of the hand is a rare form of tenosynovitis.

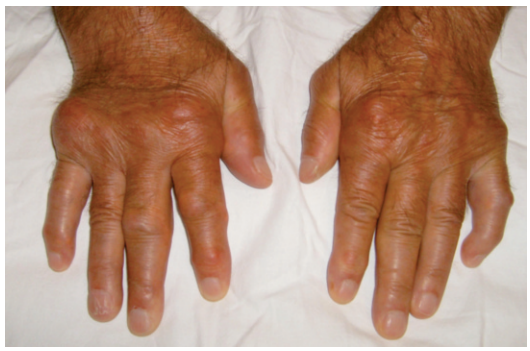

Fig. 15.1 Metacarpophalangeal, proximal interphalangeal involvements in the patient with gout

Hand Function Assessment

Upper extremity involvement has been described especially in the patients having extensive involvements or long history of gout. Functional deficits of the hand caused by gout include decreased joint movement and neurovascular compression [56]. There is limited knowledge about the evaluation of hand function in the patient with gout. This clearly remains an area requiring further work. Dalbeth et al. [56] only investigated the predictors of hand function in gout and demonstrated that tophaceous joint disease is major independent predictors of hand function in patients with gout. Furthermore, others measures of gout disease severity such as disease duration and frequency of gout flares further contribute to hand function. The key predictor of hand function was the number of joints of the hand with overlying gout. Measures of chronic and poorly controlled disease predict hand function [56]. However, there is no validated and specific hand functional disability scale developed for gout; Sollerman hand function test, a validated objective measure of hand function, and Disabilities of Assessment Shoulder and Hand questionnaire (DASH), a validated subjective hand disability questionnaire, were administered by Dalbeth et al. [56].

Summary

Hand involvements can be seen in metabolic disorders because of musculoskeletal abnormalities and hemodynamic, vascular, or neurological dysfunctions. In this chapter, the musculoskeletal and the other involvements of the hand were mentioned. Additionally, the tests evaluating hand functions and index which were used for evaluating hand disability were reviewed.

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Section III

Hand Function and Imaging Outcomes

Hand Function and Imaging Outcomes

16

Atulya A. Deodhar

Introduction

In arthritic conditions affecting hands, imaging tools used for diagnosis, for monitoring disease activity, as well as for predicting hand function need to be sensitive, reproducible, and easily available. Conventional radiography (X-ray) has been the gold standard for imaging hands in patients with rheumatoid arthritis (RA), even though it is unable to detect changes in the soft tissues such as synovitis, and is also insensitive for the early stages of bone damage. Dual energy X-ray absorptiometry and digital X-ray radiogrammetry are two techniques that assess changes in hand bone density and have been used with modest success to monitor disease progression in RA. Modern imaging techniques such as ultrasonography (US) and magnetic resonance imaging (MRI) allow direct visualization of soft tissue and bone in the hand with a much better sensitivity and precision and have been progressively used to assess early changes in inflammatory arthritides in the era of early aggressive treatment. This chapter will review the key aspects of these various imaging modalities with the focus on hand functional outcome.

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Conventional Radiography (X-Rays)

Conventional radiography (simple X-rays) has long been considered the gold standard for the diagnosis and monitoring of various arthritides affecting hands. Simple X-rays can depict juxta-articular as well as generalized osteoporosis, joint space narrowing (indicative of cartilage thinning), bone damage with cysts, erosions, osteolysis, and also joint subluxations, malalignment, and ankylosis [1, 2]. The universal popularity of X-rays is due to their low cost, easy availability and hence familiarity, as well as fairly good reproducibility. Several validated and standardized measurement scales for inflammatory arthritides are available, making X-rays the method of choice for monitoring disease progression in clinical trials [3]. However, there are several disadvantages of X-rays such as exposure to ionizing radiation, inability to assess soft tissue changes and even early bone damage, and the two-dimensional imaging of a three-dimensional pathology [4, 5].

X-ray assessments for various arthritides in clinical trials include measurements of joint space narrowing and bone erosions in hands, wrists, and feet to measure structural joint damage [6]. Two validated scoring methods of radiological damage are available—the Larsen and Sharp methods—but their use is limited to clinical trials alone [7, 8] since they are too time-consuming, tedious, and not reproducible in untrained hands. The Sharp method was later

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modified by van der Heijde and also by Genant, which improved its sensitivity to change, but did not reduce the time-consuming aspect [9, 10]. For routine clinical practice, the less time-consuming "simple erosion narrowing score"—simply counting joints with bone erosions plus joints with joint space narrowing—may be more suitable [11].

The clinical relevance of structural joint damage as seen on X-ray is due to its close relationship with future functional outcome. Since X-ray depicts the time-integrated cumulative joint damage, X-ray scores significantly correlate with functional status and explain approximately 25 % of the disability over long term [12]. In a patient with RA, early bone erosions on plain X-ray of hands and feet as well as serial radiographs showing progression in erosions predict an aggressive course of the disease with poor long-term functional outcome [13, 14]. In early, undifferentiated arthritis, presence of X-ray erosions increases the risk of developing persistent arthritis [15].

It is important to remember a few caveats for this "gold standard." In early disease, X-ray scores do not correlate with functional outcome as measured by the Health Assessment Questionnaire (HAQ) score, though in established disease (disease duration > 8 years) the radiographic damage does correlate modestly with functional outcome in populations of patients. However, in an individual, the relationship between joint damages as seen on X-ray may not predict the functional outcome that well. Also, radiographic erosions are only present in a minority of patients with early RA, with a prevalence of 8–40 % at 6 months [16], and X-rays overall are not effective in identifying future "non-progressors," i.e., patients that will not have increasing structural joint damage [17].

Digital X-Ray Radiogrammetry

Digital X-ray radiogrammetry (DXR), a computer-aided technique for the measurement of cortical bone mineral density (BMD) of metacarpal bones using digitized hand X-rays, has been recently used to assess RA progression and hand function. DXR determines BMD (in gm/cm^2), cortical thickness (in cm), metacarpal bone width (in cm), MCI (an index based on the mean cortical thickness normalized for the mean outer bone diameter of the metacarpal bones), and porosity index (correction factor of DXR-BMD) [18].

The early radiogrammetry technique for the measurement of BMD used ordinary hand radiographs for measuring the total width and the medullary width at the midpoint of the second metacarpal bone of the nondominant hand [19]. The ratio of cortical thickness to total bone width (the metacarpal index) was used to calculate the BMD. The poor reproducibility of the operator-dependent identification of the endosteal margins at the mid-shaft location made the radiogrammetric measurements inaccurate and less reliable [19]. Despite being inexpensive, radiogrammetry never became popular and was rarely used in clinical practice. Apart from the problems of reproducibility, other reasons could be that the dual energy X-ray absorptiometry (DXA) for measuring bone density at the hip and spine had already been widely available, was easy to order, and has much better reproducibility. Semi- and fully automated computerized radiogrammetry techniques developed later reduced the operator dependency of the old technique and improved the reproducibility of cortical bone BMD measurements [20–22]. The intra-radiograph reproducibility (defined as the BMD data variability seen by repeated measurements of the same individual at a set time point) is reported to be between 0.05 and 0.33 %, while the inter-radiograph reproducibility is reported to be 0.26–1.54 % [23].

The hand BMD measured with DXR correlated moderately well with the lumbar spine and femoral BMD measured by dual energy X-ray absorptiometry (DXA) (correlation coefficient for femur neck, $r = 0.59$ and for lumbar spine, $r = 0.45$) [20] and very well with DXA measurements of the hand in two separate studies (correlation coefficients of $r = 0.80$ and $r = 0.88$) [21, 24]. The DXR measurements of hand also correlated moderately well with peripheral quantitative CT (pQCT) measurements ($0.36 < r < 0.71$) [25] and

with quantitative ultrasound (US) measured at the distal radius ($r=0.49$) and phalanx ($r=0.36$) [26]. While this makes DXR a valid measurement tool for the assessment of bone loss, DXA measurements of the spine and hip are the gold standard and have been used in all pharmaceutical studies on osteoporosis. While DXR measurements using hand X-ray are not used to assess postmenopausal osteoporosis, it may have a role in conditions where hand skeleton is predominantly involved such as rheumatoid arthritis.

Along with the feet, hand is the most commonly affected part of the skeleton in RA. Apart from generalized osteoporosis, periarticular osteoporosis in small joints of the hands is one of the typical and earliest features of bone involvement in RA, preceding erosions [27]. Periarticular osteoporosis is important enough to be included in the 1987 American College of Rheumatology revised classification criteria for RA, in addition to erosions [28]. The periarticular bone loss in hands in RA is multifactorial and is thought to be secondary to local and systemic inflammatory cytokines (e.g., circulating and local synovial TNF-α, IL-1, IL-6), loss secondary to lack of hand movements, as well as bone-active medication such as prednisone [2]. The rationale for the use of DXR of the hand to asses bone loss rather than the more established DXA of the spine and hip is based on the fact that the hand is the site of the earliest manifestation of RA with 80 % of the metacarpal joints being involved within the first 2 years of disease [29]. As DXR measures bone loss in proximity to the metacarpal joints, in theory it should be an ideal technique to assess inflammatory bone involvement and bone damage in RA. One could also envisage its use to assess disease progression and also as a predictor of subsequent radiographic joint damage [30].

DXR was shown to have good short-term precision (defined as the BMD data variability occurring with repeated measurements over time) [31]. In one study, the coefficient of variation (CV) of DXR measurements in the hands of premenopausal women was 0.68 % and the CV in the postmenopausal women was 0.61 %. The authors concluded that the short-term in vivo precision error of the DXR method was low in both pre- and postmenopausal women and comparable to data reported in the literature on the performance of peripheral DXA [31]. In a cross-sectional study on patients with RA comparing two techniques for bone mass measurement, (i.e., DXR and quantitative ultrasound), the DXR was found to be superior in differentiating patients with low disease activity from those with high disease activity [26]. The cortical bone mass as measured by DXR was 16.1 % lower in patients with a high disease activity score measured in 28 joints (DAS28 > 5.1) compared to those with lower disease activity (DAS28 < 3.2) [26].

In a 10-year longitudinal study on 136 patients with RA, patients with hand BMD loss at 1 year as measured by DXR had a higher median increase in vdH Sharp score compared to patients without loss at 5 years ($p=0.001$) and 10 years ($p=0.002$) [32]. The linear regression model adjusting for age, gender, baseline C-reactive protein (CRP), anti-cyclic citrullinated peptide (CCP), IgM rheumatoid factor (RF), and radiographic damage showed that absolute hand DXR-BMD loss at 1 year was an independent predictor of radiographic outcome at 5 years ($p<0.01$) and 10 years ($p=0.02$). The odds ratio (95 % CI) for radiographic progression was 3.5 at both 5 and 10 years among patients with hand BMD loss. The authors concluded that hand bone loss in RA precedes radiographic joint damage, and quantitative measurements using DXR may be used as a tool for assessment of bone involvement in RA [32]. In another study hand cortical BMD measurements by DXR were found to be predictive of erosive manifestations in RA [33]. The reduction of DXR-BMD after 1 year was very specific and sensitive (63 %) in predicting erosions after a 4-year observation period in patients with RA [30].

Function is the most important outcome measure from RA patients' point of view, and structural damage as measured by radiographic progression is a surrogate marker of hand function and future disability. Few studies have directly measured the relationship between DXR bone loss and hand function in RA patients. It is argued that as DXR-BMD predicts future radiographic progression—a surrogate marker of

future function—it could also predict the loss of hand function [34]. Two separate studies have shown a significant negative correlation between DXR-BMD and the Health Assessment Questionnaire (HAQ) score (for women, $R=-0.22$; men, $R=-0.35$) [30, 33]. Increased mortality in RA compared to age- and sex-matched general population is well recognized [35]. The association between mortality and DXR-BMD in RA patients was evaluated in a retrospective analysis of 108 patients over a 30-year period. The baseline X-rays were used in the assessment of hand BMD using the DXR technology. The DXR-BMD, along with Steinbrocker functional class III or IV, the physician's global assessment, and ESR were significant predictors of mortality [36].

Dual Energy X-Ray Absorptiometry (DXA) of the Hand

As noted above, the early clinical manifestations of RA are seen mainly in the small joints of hands and feet [37], and the structural damage measured by radiographic scores incorporating joint space narrowing and erosions is known to correlate with the ultimate functional loss [7, 38]. Even though juxta-articular osteoporosis in hands, as seen on plain radiographs, is the earliest radiographic sign before joint space narrowing and erosions become evident [2], the periarticular osteoporosis is rarely measured objectively apart from the DXR technique described above. Despite showing early promise, the DXR technique never became popular in daily practice. Dual energy X-ray absorptiometry (DXA) is the gold standard of measuring bone density at spine and the hip and is readily available around the world. Could periarticular bone loss in hands of patients with RA be measured objectively using DXA and could that measurement serve as a prognostic indicator like the DXR technique aspired to do?

Deodhar et al. described and validated an objective and reproducible technique (CV = 2.3 %) to measure hand bone mineral content (BMC) using DXA to monitor progression of RA in early stages [39]. They decided to use bone mineral content (BMC) rather than bone mineral density (BMD) since the density calculation is dependent on the area of the part scanned. The hand area can change from one measurement to the next dependent upon the person's ability to keep the hand in the same position. The hand position for scanning in a patient with RA may not be identical from one scan to the next because of pain and also because of the interval structural change. This would change the hand area and hence the BMD. They concluded that the hand BMC did not change with change in position [39].

A cross-sectional study by Peel et al. using hand bone densitometry in 70 postmenopausal women with corticosteroid-treated established RA and 20 patients with early disease demonstrated a significant correlation between hand BMD and that of other sites such as the hip and spine [40]. Patients with established RA had a lower BMD in the hands relative to other sites such as femur and lumbar spine when compared with age-matched controls. The authors concluded that in early RA, bone loss is more rapid from hand, a site that is directly involved in the disease process compared to spine and hip, sites that are not directly involved.

In a large study of 202 unselected patients with early RA, Devlin and colleagues demonstrated loss of hand BMD even prior to the onset of systemic disease and before lumbar BMD loss [41]. This group confirmed the correlation between high CRP and loss of hand BMD, a relationship previously reported between markers of inflammation and bone loss at other sites (femur and lumbar spine) [41]. Another prospective longitudinal study from Deodhar's group measured hand bone mineral content in 82 RA patients with a disease duration of less than 2 years [42]. They showed hand BMC continued to worsen despite an improvement in overall disease activity and confirmed that bone loss was maximal in early disease, correlating positively with measures of disease activity and inversely with disease duration.

A 5-year longitudinal study of hand bone mineral content from the same group reported that the significant bone loss continued during the

first 3 years of disease onset despite effective control of the disease activity within the first year [43]. Persistent disease control led to stabilization of the bone mass after 3 years. In this study, patients losing more than 3 % of the hand bone mineral content within the first 6 months had a significantly worse functional outcome at 5 years. This is the only study to use a functional index designed specifically for hands rather than using HAQ, which measures overall functional outcome. The hand function index used in this study was the Duruoz hand index (DHI) described elsewhere in this book [44]. Briefly, the DHI is derived from 18 validated questions to assess functional disability and handicap due to hand involvement in RA. Each answer is scored on a scale of 0 (no difficulty) to 5 (impossible to do), with a maximum score of 90. A higher score indicates worse disability or handicap [44]. This demonstrated for the first time the importance of early bone loss in hands as a predictor of long-term functional outcome [43]. A study by Gough et al. measuring BMD in spine and hip in RA patients was able to establish that controlling disease activity (measured by suppression of CRP level) resulted in a stabilization of the bone loss in axial skeleton [45].

The new strategy on treating RA early and aggressively has been accompanied by the recognition that this approach is best employed in patients with a high probability of rapidly progressive disease [46, 47]. Its rational use requires validated prognostic indicators that predict the outcome in an individual patient in the early stages of the disease. The hand bone densitometry data described above indicate that hand BMC measurements may be useful from the early stages of the disease for selecting patients at risk of future disability for more aggressive treatment and for monitoring the response to therapy [48]. It has the added advantage of being an objective and reproducible measure of outcome for individual patients, is quick to perform, and is relatively cheap. DXA can offer additional information over erosion counts and functional measures—the previous gold standards—in outcome studies for therapeutic trials. Bone densitometry has the potential to become an easy method for assessing disease activity (process marker) and the progression of bone loss (outcome marker) [48].

Musculoskeletal Ultrasonography

Compared to DXR and DXA that assess hand bone density alone, musculoskeletal ultrasound (US) has the advantage to assess all structures directly involved in a rheumatoid process such as the soft tissues (e.g., synovium, tendons, nerves, muscles), bone, and joints. US visualizes structures in real time and has the ability to improve the interaction between the doctor and the patient. It involves no ionizing radiation; the examination is much cheaper compared to MRI, is comfortable to the patient, and is becoming more easily available in rheumatology practices all over the world. The examination can be quick, several joints can be scanned in one session, and the process is easy to repeat. Power Doppler US can assess vascularity of the synovium—a surrogate marker for rheumatoid disease activity. Some limitations of musculoskeletal ultrasound include intra- and inter-reader variability, long and steep learning curve for operators, inter-machine variability, and lack of a universally acceptable scale to assess RA disease activity and damage. Also, US cannot penetrate bone, and hence the image can only assess the bone edge, and at best a small part of it. Its sensitivity for detecting bone erosions is markedly site-dependent—high in easily accessible hand joints, but low in anatomically complicated joints such as shoulder [49, 50].

Within the last two decades, the interest in musculoskeletal US has been growing—both its clinical use and also the number of research studies being conducted—especially to assess hand involvement in rheumatoid arthritis. US can visualize inflammation by detection of thickening of the synovial membrane of inflamed joints, bursae or tendon sheaths by gray-scale, and also by quantifying increased synovial blood flow using power Doppler [5, 51]. It can also visualize destructive RA changes by identifying erosions. These two properties—measurement of disease "process" (synovial vascularity) as well as

"outcome," (erosions)—are making US the imaging modality of choice for hand arthritis, rapidly surpassing the plain X-rays as the "gold standard." Also, several investigators have reported ultrasound's superior sensitivity for visualizing bone erosions in MCP, PIP, and metatarsophalangeal (MTP) joints than X-ray [50, 51].

Apart from detecting synovitis and bone damage in hand joints, US can also detect presence of synovial fluid in joints, bursae and inflammation in tendon sheaths, as well as entheseal insertion (enthesitis), and it can also assess the integrity of tendons and ligaments [52, 53]. Within the past decade, US has been used more and more by rheumatologists to tap the joint synovial fluid under direct visualization.

Studies comparing US and MRI in rheumatoid hands have shown strong agreement between these two modalities in terms of detecting synovial inflammation [5, 51]. Wakefield and colleagues found high specificity (0.98) but moderate sensitivity (0.15–0.44) for detection of finger tenosynovitis, when MRI was used as the reference standard [54]. US, however, is inferior to MRI for detection and follow-up of erosions at the wrists and hands [55]. However, in situations where joint accessibility is optimal (e.g., hands), bone erosions detected by US correlate to a high degree with MRI scans [49, 50] and also with CT scan [56].

Serial musculoskeletal US examinations have been used to monitor RA progression by assessing disease activity as well as by structural damage. Using corticosteroids [57, 58] or TNF-a inhibitors [59, 60] in the treatment of RA leads to decrease in the US scores of synovitis (Doppler signal and B-mode synovial membrane thickness) in parallel with other markers of disease activity, indicating their potential for monitoring joint inflammation [61]. Strunk et al. found that intra-articular injections of methylprednisolone reduced synovial perfusion by power Doppler US after approximately 7 days, while effusions and synovial hypertrophy were often still persistent [62]. However, a study by Boesen, also using intra-articular methylprednisolone, or etanercept, failed to show any change in the degree of synovitis as assessed by power Doppler signal or by MRI after 4 weeks of treatment [63]. Separate studies using etanercept and adalimumab showed that both agents were able to reduce the US scores of localized inflammatory process and/or structural damage [64, 65]. However, they did not separate "inflammation" from "damage," and hence their conclusions should be viewed cautiously.

Backhaus et al. performed repeated X-ray, MRI, and US of fingers to follow the natural course of US bone erosions [5]. By 2 years and 5 years of follow-up, MRI and US signs of synovitis decreased, while the number of bone erosions detected by both modalities increased [5, 66]. More patients showed erosive progression on US than on X-ray, suggesting that US has greater sensitivity to change. Hoving et al. found erosive progression in a similar number of patients by X-ray and US in a 6-month follow-up study of RA wrist and MCP and PIP joints [55]. Bajaj et al. followed 21 early RA patients for 6 months and found US to be much more sensitive in finding erosive and progressive disease compared to X-rays, with excellent interobserver agreement (Kappa 0.96–1.0) [67].

In a small randomized controlled study on an anti-TNF agent use in RA, Taylor et al. found that baseline US-determined synovial thickening and the degree of vascularity in the MCP joints correlated with radiographic joint damage at 1 year in the placebo group, but not in the anti-TNF group [68]. Naredo et al. followed an inception cohort of 42 RA patients starting disease-modifying antirheumatic drug therapy [69]. There was no significant correlation between the baseline ultrasound, clinical, laboratory, and functional parameters with the 1-year DAS28, HAQ, and radiographic scores. However, the time-integrated values of power Doppler US parameters demonstrated a highly significant correlation with DAS28 ($r=0.63$) and radiographic progression ($r=0.59$–0.66) than clinical and laboratory parameters ($r<0.50$) after 1 year. Furthermore, a US power Doppler joint index was the strongest predictor of disease activity at the following visit, whereas pain and HAQ scores were the strongest predictors of functional status at the following visit [69]. Brown et al. [70] reported that US (and MRI) signs of joint inflammation are common in

patients thought to be in clinical remission and baseline US synovial hypertrophy as well as power Doppler scores, and MRI synovitis scores in individual joints were significantly related to progressive radiographic damage. They also demonstrated that there was a significant association between power Doppler scores at baseline and structural progression over 12 months in asymptomatic MCP joints, with 12 times higher odds of structural progression in joints with increased power Doppler signal (OR 12.2).

Musculoskeletal ultrasound is a valid method for monitoring synovitis and, in hands, also for erosive progression. However, questions remain about their reproducibility, intra- and interobserver variability, as well as the "smallest detectable change." The same questions can be asked about power Doppler imaging. Also, it remains to be verified whether US can predict long-term disease progression, joint erosions, and preservation of function better than the traditional clinical or serological scores.

Magnetic Resonance Imaging (MRI) of Hand

Despite magnetic resonance imaging (MRI) technology being available for the last four decades, experience of using it in patients with RA is relatively new [71, 72]. MRI scans show soft tissue abnormalities, such as synovitis, tendonitis, and bone marrow edema that cannot be seen on conventional radiographs. Over the last two decades, a number of studies have reported on the ability of MRI scans to document erosions with a greater sensitivity than conventional radiographs [73–75]. These studies have also demonstrated that bone and soft tissue abnormalities (i.e., bone marrow edema and synovitis noted above) seen by MRI often progress to radiographic erosive disease. Initial investigations were conducted on small numbers of patients using high-field strength (1.5 Tesla [T]) magnets and often provided little or no clinical correlation. Later, extremity MRI units, both low field (0.2 T) and high field (1.0 T), became commercially available. These machines are small enough for use in the clinic and have been used by rheumatologists for the diagnosis and management of patients with RA.

Functional capacity is more dependent on disease activity rather than on structural damage early in the RA disease process, while in longstanding disease, poor function has been more dependent on structural damage, even with improvement in inflammation [76]. Therefore, prevention of joint damage has been a goal of treatment, and identifying those patients whose disease is more likely to progress is critical. MRI technology with its superior sensitivity (compared to traditional radiology) to bone damage, at least in theory, should be able to identify such patients early.

While a lot of literature is available on the unquestioned superior sensitivity of MRI scans compared to conventional radiographs to assess erosions, several questions about the use of this technique in daily clinical practice remain. For example, what is the value of MRI findings of synovitis, bone marrow edema, or erosions in predicting damage on future conventional radiographs? Most of the studies are cross-sectional and indicate that, compared with traditional radiographs, MRI scans are not only more sensitive in identifying erosions but also allow diagnosis of them early in the course of the disease [71, 72, 75]. However, only well-designed longitudinal studies on large cohorts of RA patients can define the prognostic value of MRI findings of synovitis, bone marrow edema, and erosions in predicting radiographic damage, and very few are available. Also, most of these studies use high-field MRI (1.5 T) machines and not the extremity (0.2 T) MRI machines used for scanning peripheral extremity parts, such as wrists and the MCP joints.

McQueen and colleagues studied an inception cohort of 42 patients with early RA from presentation (median of 4 months from symptom onset) to 6 years, using clinical assessments of disease activity and function as well as radiographs and high-field MRI scans of the dominant wrist [73]. At baseline, 45 % of these patients had erosions on MR compared with 15 % on radiographs, and 75 % showed MR erosions compared to only

21 % on plain radiographs by year 1. They scored the MRI scans according to a locally validated scoring system and showed that the total MRI score at baseline (combining scores for erosions, bone edema, synovitis, and tendonitis) was predictive of erosions on radiographs (Sharp scores) at 1, 2, and 6 years.

Studies have shown that the MRI finding of bone marrow edema is even more important than erosions for predicting future erosion on radiographs. Using a site-specific analysis of MRI scans done in the cohort described above, McQueen showed that the baseline MR bone marrow edema at a specific carpal bone was highly likely to be associated with MRI erosion at that site after 1 year and 6 years (OR = 6.5; 95 % CI 2.78–18.1), and the baseline MR bone edema score was predictive of the 6-year total Sharp score [73]. A model incorporating baseline MRI scores for erosion, bone marrow edema, synovitis, and tendonitis, plus the C-reactive protein (CRP) level and the erythrocyte sedimentation rate, explained 59 % of the variance in the 6-year total Sharp score (R2 = 0.59, adjusted R2 = 0.44) [73]. Synovitis as seen on MR imaging can be scored by a validated method and was a predictor of the MRI erosion score at 6 years ($R^2 = 0.15$, $P = 0.03$), but not of the total modified Sharp score in the same cohort. This finding is similar to a study by Østergaard et al., who showed that MR synovitis, measured by estimation of synovial volume, was a predictor of MR erosions after 1 year [77].

Despite this observation, several caveats need to be considered. The positive predictive value of MRI scores in the McQueen cohort was low (67 %), implying that one-third of patients with a high total score on MRI at baseline did not develop erosions on radiographs at 2 years. However, the negative predictive value was high, showing that 90 % of patients with a low initial score did not develop erosions at the wrists by 2 years. Also the MRI findings of erosions, bone marrow edema, and synovitis may not be specific for inflammatory arthritis such as RA. In a study utilizing high-field MRI in assessing osteoarthritis of the hands, at least half of early OA and one-third of chronic OA patients had bone edema. Erosions were even more common and were present in at least 75 % of early OA and 50 % of chronic OA patients. 73 % of OA patients had excess fluid in the joint space and gadolinium enhancement suggestive of inflammation was found in every joint studied in patients with early OA [78].

The MRI scoring system is very complex since it includes the sum of the scores for erosions, bone marrow edema, synovitis, and tendonitis at several areas within the wrist. It is very time-consuming, needs experts for reproducible results, and, hence, is not practical to use for daily clinical studies. Simple presence or absence of bone erosion on MRI or bone marrow edema may not be predictive of long-term radiographic or functional outcome since bone edema may be transient and only 26 % of erosions detected on MRI progress to erosions on radiographs at 2 years. The Outcome Measures in Rheumatoid Arthritis Clinical Trials (OMERACT) group has published a scoring system for high-field MRI systems (RA MRI score or "RAMRIS"), which incorporates MRI features of erosion, edema, and synovitis [79]. This system remains impractical for daily clinical use since it is time-consuming, complex, and exhibits significant variability in scores even with expert readers. The reading variability with the RAMRIS scoring system can introduce a measurement error that is expressed as the "smallest detectable difference (SDD)," and, in general, only changes greater than the SDD are considered clinically important in longitudinal studies.

Ejbjerg and colleagues have compared the SDD of the OMERACT MRI scores (RAMRIS) with the Sharp/van der Heijde score on radiographs in a 1-year longitudinal study [80]. They found that the SDD for the 5-joint (2–5 MCP and dominant wrist) RAMRIS score was 2.1 compared with an SDD of 4.2 for the 15-joint RAMRIS. The SDD for the Sharp/van der Heijde score was 6.1. Defining radiographic progression as patients exceeding the SDD, more patients were detected to progress by MRI of the dominant wrist and bilateral 2–5 MCPs than by radiography. No difference in structural progression between MRI and radiographs was noted if the

dominant wrist was not included in the MRI study and only MCPs and MTPs were scanned. The authors concluded that low-field extremity MRI was more sensitive than radiographic scoring for detecting progressive joint damage [80].

Bird et al. evaluated the progression of joint erosion over 2 years in 47 RA patients with established disease, comparing a large field-of-view MRI of the second through fifth MCP joint with conventional bilateral hand radiographs [81]. The MRI studies were scored using the RAMRIS methodology and the radiographs by the Larsen score. In contrast to the Ejbjerg study, bilateral hand radiographs detected more patients with progressive joint erosion than by dominant hand MRI. MRI did demonstrate greater sensitivity to damage progression in the MCP joints alone, but this advantage was lost when the joints of both hands were evaluated by conventional radiographs. This study suggests that, in established RA, limited field MRI may be no better in evaluating progression of joint damage than conventional radiographs.

While high-field MRIs are more sensitive than conventional radiography at detecting erosions in RA, a significant percentage of these MRI erosions do not appear to progress in longitudinal studies [73]. To date, studies of RA therapy using MRI data have not used the MRI results to guide therapeutic decisions, and it remains to be seen whether erosions detected on MRI alone will have any value in guiding therapy over and above other routine assessments. In one study of early RA (<12 months of disease), comparing methotrexate with methotrexate plus intra-articular steroids, the development of erosions on a 1.5 T MRI with contrast enhancement over the course of a year was found to correlate with the level of synovitis in the MCP joints assessed by MRI [74]. In particular, joints without evidence of synovitis did not develop new erosions on MRI during follow-up. Despite the value of the MRI for predicting and detecting erosions in this study, treatment decisions were driven by clinical evidence of synovitis, and not by findings on MRI. Also, this study used gadolinium enhancement to assess the severity of synovitis, which is not used in rheumatology practices using low-field extremity MRI examination in the office.

In another small, blinded study comparing the outcomes of 20 early RA patients treated with an "induction regimen" of methotrexate with or without infliximab for 1 year, 1.5 T MR imaging of the second through fifth MCP joints was evaluated for synovitis, bone marrow edema, and erosion using intravenous gadolinium enhancement [82]. Despite the small number of subjects in the trial, there was a significant difference between the two treatment groups in both synovitis and bone edema on MRI examinations obtained as early as 14 weeks and sustained through 54 weeks. Findings on MRI did correlate with measurements of clinical outcomes, including ACR response, Disease Activity Score (DAS), and Health Assessment Questionnaire (HAQ).

In areas other than RA, MRI may be an effective element of clinical management. A study was able to show that even a mid-field 0.5 T MRI of the knee was able to predict the need for arthroscopic repair of a meniscal tear with high sensitivity and specificity [83].

There is little evidence to date linking disability or other functional outcomes to specific extremity MRI findings. As noted in the section on X–rays, there is a close association between the development of radiographic erosions and disability among populations of patients with RA. Because extremity MRI may be more sensitive in detecting erosions than radiographs, it is possible that this imaging approach could predict functional outcomes earlier and more accurately than radiographs. However, there are no published studies to support this concept. In addition, the presence of radiographic erosions correlates only roughly with functional outcomes in individual patients, and the significant false-positive rate of extremity MRI could offset the potential benefit of extremity MRI in predicting function outcomes.

Quinn et al. reported that patients with early arthritis treated with infliximab and methotrexate improved clinically and functionally compared with those taking methotrexate alone; high-field MRI evidence of synovitis mirrored these clinical and functional improvements [84]. Benton et al. studied patients with early RA and found that baseline total MRI score and the presence of bone edema by high-field MRI of the wrist

predicted the physical function part of SF36 (PF-SF36) at 6 years [85]. In fact, 16 % of the PF-SF36 score was explained by baseline total MRI score and 22 % of the PF-SF36 score was explained by the presence of bone edema. However, the results of HAQ at 6 years were not predicted by MRI results, and baseline Ritchie index and baseline HAQ predicted 6-year HAQ as well as MRI (20 % of 6-year HAQ was explained by these other baseline assessments). The authors noted that the best predictor of 6-year function was a regression model that included bone edema by MRI, CRP, DAS, HAQ, and modified Sharp score. This model predicted 23 % of the 6-year PF-SF36. Thus, although this study found correlations between certain functional outcomes and baseline high-field extremity MRI findings, the ability to predict outcomes was modest. In addition, it is unlikely that a clinician using extremity MRI in the office will utilize the radiographic and MRI scoring systems or the regression model described in this study. Importantly, this study was performed prior to the introduction of antitumor necrosis factor therapies.

To our knowledge, only one study has longitudinally evaluated low-field extremity MRI findings and the development of radiographic erosions [86]. The authors concluded that while extremity MRI could be used to predict which RA patients are more likely to progress to radiographic damage, the greatest advantage may be for patients without erosions or bone edema, in whom the likelihood of developing radiographic disease is low. Again, the lack of additional clinical information, such as RF and CCP status, limits the ability to understand the incremental value MRI provides to patient management [86].

In summary, limited data are available to answer the question whether MRI abnormalities are predictive of poor hand functional outcome. Radiographic erosions are considered a surrogate marker for poor functional outcome in long-standing RA, and findings on MRI could be considered a surrogate marker for radiographic erosions, making it a "surrogate marker for another surrogate marker." Whether MRI erosions in the absence of radiographic erosions are associated with poor hand functional capacity has not yet been evaluated. Large ongoing clinical trials utilizing MRI may provide such data [87].

Summary

Great progress has been made since the days when conventional radiographs were the only imaging modality available for assessing hand involvement in various arthritides, and they were hailed as the "gold standard." DXR and DXA assess hand bone density alone, but US and MRI have the ability to assess the soft tissues as well as other structures in the hand and are rapidly vying for the title of "gold standard" in these clinical situations. A lot of work still needs to be done to translate the data generated by these modern imaging modalities to hand functional outcomes in patients with inflammatory arthritis.

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Appendix 1: ABILHAND (Manual Ability Measure)

Answers to the questions
0 = Impossible
1 = Difficult
2 = Easy
N/A = Activities not attempted in last 3 months.

Questions: How difficult are the following activities?
1. Picking-up a can
2. Handling a stapler
3. Writing a sentence
4. Using a screwdriver
5. Screwing a nut on
6. Replacing a light bulb
7. Cutting meat
8. Peeling potatoes with a knife
9. Taking a coin out of the pocket
10. Sharpening a pencil
11. Filing one's nails
12. Handling a four-color ballpoint pen with one hand
13. Grasping a coin on a table
14. Wrapping up gifts
15. Turning a key in a keyhole
16. Peeling onions
17. Brushing one's hair
18. Tearing open a pack of chips
19. Turning off a tap
20. Fastening the zipper of a jacket
21. Opening a screw-topped jar
22. Hammering a nail
23. Fastening a snap (jacket, bag, …)
24. Threading a needle
25. Taking the cap off a bottle
26. Cutting one's nails
27. Combing one's hair

ABILHAND was originally developed using the Rasch measurement model. It allows ordinal scores to be converted into linear measures located on a unidimensional scale. The raw ordinal data is converted to linear measures expressed in logits (log-odds probability units). The higher the logit number, the greater the patient's perceived ability. Activities not commonly performed in the previous 3 months were not scored and were encoded as missing. It was validated in rheumatoid arthritis, systemic sclerosis, and chronic stroke.

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Appendix 2: Boston Questionnaire (Brigham and Women's Carpal Tunnel Questionnaire/The Carpal Tunnel Syndrome Instrument)

Questionnaire for Assessment of Severity of Symptoms and Functional Status

Symptom Severity Scale

The following questions refer to your symptoms for a typical 24-h period during the past 2 weeks (circle one answer to each question).

How severe is the hand or wrist pain that you have at night?

1. I do not have hand or wrist pain at night
2. Mild pain
3. Moderate pain
4. Severe pain
5. Very severe pain

How often did hand or wrist pain wake you up during a typical night in the past 2 weeks?

1. Never
2. Once
3. Two or three times
4. Four or five times
5. More than five times

Do you typically have pain in your hand or wrist during the daytime?

1. I never have pain during the day
2. I have mild pain during the day
3. I have moderate pain during the day
4. I have severe pain during the day
5. I have very severe pain during the day

How often do you have hand or wrist pain during the daytime?

1. Never
2. Once or twice a day
3. Three to five times a day
4. More than five times
5. The pain is constant

How long, on average, does an episode of pain last during the daytime?

1. I never get pain during the day
2. Less than 10 min
3. 10–60 min
4. Greater than 60 min
5. The pain is constant throughout the day

Do you have numbness (loss of sensation) in your hand?

1. No
2. I have mild numbness
3. I have moderate numbness
4. I have severe numbness
5. I have very severe numbness

Do you have weakness in your hand or wrist?

1. No weakness
2. Mild weakness

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3. Moderate weakness
4. Severe weakness
5. Very severe weakness

Do you have tingling sensations in your hand?
1. No tingling
2. Mild tingling
3. Moderate tingling
4. Severe tingling
5. Very severe tingling

How severe is numbness (loss of sensation) or tingling at night?
1. I have no numbness or tingling at night
2. Mild
3. Moderate
4. Severe
5. Very severe

How often did hand numbness or tingling wake you up during a typical night during the past 2 weeks?
1. Never
2. Once
3. Two or three times
4. Four or five times
5. More than five times

Do you have difficulty with the grasping and use of small objects such as keys or pens?
1. No difficulty
2. Mild difficulty
3. Moderate difficulty
4. Severe difficulty
5. Very severe difficulty

Functional Status Scale

On a typical day during the past 2 weeks have hand and wrist symptoms caused you to have any difficulty doing the activities listed below? Please circle one number that best describes your ability to do the activity.

The overall symptom-severity score is calculated as the mean of the scores for the 11 individual items and the overall score for function status is calculated as the mean of all eight items. The range of total scores is between 1 and 5. The high score indicates "most severe" or "bad function" for subscales (Symptom Severity Scale and Functional Status Scale). Item that is left unanswered or that is not applicable is not included in the calculation of the overall score.

Activity	No difficulty	Mild difficulty	Moderate difficulty	Severe difficulty	Cannot do at all due to hand or wrist symptoms
Writing	1	2	3	4	5
Buttoning of clothes	1	2	3	4	5
Holding a book while reading	1	2	3	4	5
Gripping of a telephone handle	1	2	3	4	5
Opening of jars	1	2	3	4	5
Household chores	1	2	3	4	5
Carrying of grocery bags	1	2	3	4	5
Bathing and dressing	1	2	3	4	5

Reference

1. Levine DW, Simmons BP, Koris MJ, et al. A self-administered questionnaire for the assessment of severity of symptoms and functional status in crpal tunnel syndrome. J Bone Joint Surg Am. 1993; 75:1585–92.

Appendix 3: Duruöz Hand Index (DHI)

Duruöz Hand Index (DHI)

Answers to the questions:
0 = Yes, without difficulty,
1 = Yes, with a little difficulty,
2 = Yes, with some difficulty,
3 = Yes, with much difficulty,
4 = Nearly impossible to do,
5 = Impossible.

Answer the following questions regarding your ability without the help of any assistive device.

C1—In the kitchen.
1. Can you hold a bowl?
2. Can you seize a full bottle and raise it?
3. Can you hold a plate full of food?
4. Can you pour liquid from a bottle into a glass?
5. Can you unscrew the lid from a jar opened before?
6. Can you cut meat with a knife?
7. Can you prick things well with a fork?
8. Can you peel fruit?

C2—Dressing.
9. Can you button your shirt?
10. Can you open and close a zipper?

C3—Hygiene.
11. Can you squeeze a new tube of toothpaste?
12. Can you hold a toothbrush efficiently?

C4—In The Office.
13. Can you write a short sentence with a pencil or ordinary pen?
14. Can you write a letter with a pencil or ordinary pen?

C5—Other.
15. Can you turn a round door knob?
16. Can you cut a piece of paper with scissors?
17. Can you pick up coins from a table top?
18. Can you turn a key in a lock?

The raw scores of questions are added to get the total score of the scale. The range of total score is between 0 and 90, and high score indicates bad function. Duruöz Hand Index (DHI) was validated to assess hand function in several diseases and hand arthropathies such as rheumatoid arthritis, osteoarthritis, systemic sclerosis, psoriatic arthritis, tetraplegia, stroke, diabetes mellitus, flexor tendon injuries of hands, carpal tunnel syndrome, patient under hemodialysis, juvenile idiopathic arthritis, and geriatric persons.

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Appendix 4: Hand Mobility in Scleroderma (HAMIS) Test

Finger flexion
(All fingers must be tight to the object)
0-Can bend fingers 2–5 around a pencil (5 mm diam.)
1-Can bend fingers 2–5 around a piece of cutlery (15 mm diam.)
2-Can bend fingers 2–5 around handlebar (30 mm diam.)
3-Cannot manage the previous item

Finger extension
0-Can feel the table completely with digits 2–5
1-Can feel the pencil (5 mm diam.) with digits 2–5
2-Can feel the piece of cutlery (15 mm diam.) with digits 2–5
3-Cannot manage the previous item

Thumb abduction
0-Can grip around a coffee package (90 mm diam.)
1-Can grip around a milk parcel (70 mm diam.)
2-Can grip around a bottle (60 mm diam.)
3-Cannot manage the previous item

Pincer grip
0-Can form a round pincer grip
1-Can form a D-shaped pincer grip
2-Can form a long narrow pincer grip
3-Cannot manage the previous item

Finger abduction
0-Can spread the fingers and then fold the hands together to the bottom of the fingers
1-Can spread the fingers and then fold the hands together to the first phalanx
2-Can spread the fingers and then fold the hands together to the second phalanx
3-Cannot manage the previous item

Volar flexion
(The person stands with the arms alongside the body. The object is given from behind)
0-Can grasp a spool of thread with a slight flexion of MCP and extended PIP and DIP joints
1-Can grasp a spool of thread with a large flexion of MCP and extended PIP and DIP joints
2-Can grasp a spool of thread with a large flexion of MCP and flexion of PIP
3-Cannot manage the previous item

Dorsal extension
0-Can hold the palms together and put the wrists against the stomach
1-Can hold the palms together and put the thumbs against the throat
2-Can hold the palms together and put the thumbs up to the mouth
3-Cannot manage the previous item

Pronation
0-Can put the palms of the hands on the table (MCP 2–5 must touch the surface)
1-Can put the palms of the hands on the table (MCP 3–5 must touch the surface)
2-Can put the palms of the hands on the table (MCP 4–5 must touch the surface)
3-Cannot manage the previous item

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Supination

0-Can put the backs of the hands on the table (MCP 2–5 must touch the surface)

1-Can put the backs of the hands on the table (MCP 3–5 must touch the surface)

2-Can put the backs of the hands on the table (MCP 4–5 must touch the surface)

3-Cannot manage the previous item (MCP 4–5 must touch the surface

The test equipment consists of standardized cylinders for assessment of finger flexion, finger extension, and thumb abduction. Each hand is assessed separately. The raw scores are added to get the total score of HAMIS. It ranges for each hand between 0 and 27 points. High score represents a high degree of dysfunction.

Reference

1. Sandqvist G, Eklund M. Hand mobility in scleroderma (HAMIS) test: the reliability of a novel hand function test. Arthritis Care Res. 2000;13:369–74.

Appendix 5: Hand Functional Index (HFI)

Test items	Grading		Criteria
	Right	Left	
1. Tip of thumb touches hypothenar of 5th finger	0	0	Test performed fully and with no delay
	1	1	Test performed fully but with effort or delay or both
	2	2	Tip of thumb touches
			Proximal phalanx 3 and 4
	3	3	Neither realized
2. Bending of 2nd finger	0	0	Clutched normally
	1	1	Cannot be bent fully: tip reaches palm
	2	2	Fingertip does not reach palm
3–5. Bending of 3rd, 4th, 5th fingers	0	0	*As 2nd question*
	1	1	
	2	2	
6. Forearm held horizontal palmar surfaces pressed together point upward	1	1	Test performed fully and no delay
	2	2	Test performed fully with effort or delay, or both
	3	3	Volar and dorsal flexion of wrist 45°
7. Forearm held horizontal dorsal surfaces pressed together point downward	1	1	Fully; no delay
	2	2	Fully; with effort or delay, or both
	3	3	Palmar and ventral flexion of wrist 45°
8. Both backs of hands simultaneously on the table; elbows held rectangularly: ulnar margin of hand lifted	0	0	Performed fully
	1	1	Backs of hands on table; margin cannot lift
	2	2	Backs of hands not fully on table
9. Radial margins of hands simultaneously placed on table: thumb points downward before table edge: planes of hands inclined inward: no lateral bending of trunk	0	0	Performed fully
	1	1	Planes of hands perpendicular: cannot be inclined inward
	2	2	Planes of hand not vertical

Hand Functional Index (HFI) is the first of the nine questions [1] of Keitel Function Test (KFT) [2]
Raw scores of both hands are added to get the total score of HFI. It ranges between 4 and 42 points. The high score indicates bad function [1]

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Appendix 6: Michigan Hand Outcomes Questionnaire (MHQ)

Instructions: This survey asks for your views about your hands and your health. This information will help keep track of how you feel and how well you are able to do your usual activities.

Answer ***EVERY*** question by marking the answer as indicated. If you are unsure about how to answer a question, please give the best answer you can.

I. The following questions refer to the function of your hand(s)/wrist(s) ***during the past week***. (Please circle one answer for each question). Please answer ***EVERY*** question, even if you do not experience any problems with the hand and/or wrist.

A. The following questions refer to your ***right*** hand/wrist.

	Very good	Good	Fair	Poor	Very poor
1. Overall, how well did your ***right*** hand work?	1	2	3	4	5
2. How well did your ***right*** fingers move?	1	2	3	4	5
3. How well did your ***right*** wrist move?	1	2	3	4	5
4. How was the strength in your ***right*** hand?	1	2	3	4	5
5. How was the sensation (feeling) in your ***right*** hand?	1	2	3	4	5

B. The following questions refer to your ***left*** hand/wrist.

	Very good	Good	Fair	Poor	Very poor
1. Overall, how well did your ***left*** hand work?	1	2	3	4	5
2. How well did your ***left*** fingers move?	1	2	3	4	5
3. How well did your ***left*** wrist move?	1	2	3	4	5
4. How was the strength in your ***left*** hand?	1	2	3	4	5
5. How was the sensation (feeling) in your ***left*** hand?	1	2	3	4	5

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II. The following questions refer to the ability of your hand(s) to do certain tasks ***during the past week***. (Please circle one answer for each question). If you do not do a certain task, please estimate the difficulty with which you would have in performing it.

A. How difficult was it for you to perform the following activities using your ***right hand***?

	Not at all difficult	A little difficult	Somewhat difficult	Moderately difficult	Very difficult
1. Turn a door knob	1	2	3	4	5
2. Pick up a coin	1	2	3	4	5
3. Hold a glass of water	1	2	3	4	5
4. Turn a key in a lock	1	2	3	4	5
5. Hold a frying pan?	1	2	3	4	5

B. How difficult was it for you to perform the following activities using your ***left hand***?

	Not at all difficult	A little difficult	Somewhat difficult	Moderately difficult	Very difficult
1. Turn a door knob	1	2	3	4	5
2. Pick up a coin	1	2	3	4	5
3. Hold a glass of water	1	2	3	4	5
4. Turn a key in a lock	1	2	3	4	5
5. Hold a frying pan?	1	2	3	4	5

C. How difficult was it for you to perform the following activities using ***both of your hands***?

	Not at all difficult	A little difficult	Somewhat difficult	Moderately difficult	Very difficult
1. Open a jar	1	2	3	4	5
2. Button a shirt/blouse	1	2	3	4	5
3. Eat with a knife/fork	1	2	3	4	5
4. Carry a grocery bag	1	2	3	4	5
5. Wash dishes	1	2	3	4	5
6. Wash your hair	1	2	3	4	5
7. Tie shoe laces/knots	1	2	3	4	5

III. The following questions refer to how you did in your ***normal work*** (including both housework and school work) during the ***past 4 weeks***. (Please circle one answer for each question).

	Always	Often	Sometimes	Rarely	Never
1. How often were you unable to do your work because of problems with your hand(s)/wrist(s)?	1	2	3	4	5
2. How often did you have to shorten your work day because of problems with your hand(s)/wrist(s)?	1	2	3	4	5
3. How often did you have to take it easy at your work because of problems with your hand(s)/wrist(s)?	1	2	3	4	5
4. How often did you accomplish less in your work because of problems with your hand(s)/wrist(s)?	1	2	3	4	5
5. How often did you take longer to do the tasks in your work because of problems with your hand(s)/wrist(s)?	1	2	3	4	5

IV. The following questions refer to how much ***pain*** you had in your hand(s)/wrist(s) ***during the past week***. (Please circle one answer for each question).

A. The following questions refer to ***pain*** in your ***right*** hand/wrist.

1. How often did you have pain in your ***right*** hand(s)/wrist(s)?
   1. Always
   2. Often
   3. Sometimes
   4. Rarely
   5. Never

If you answered **never** to **question IV-A1** above, please skip the following questions and go to the next page.

2. Please describe the pain you had in your ***right*** hand(s)/wrist(s).
   1. Very mild
   2. Mild
   3. Moderate
   4. Severe
   5. Very severe

	Always	Often	Sometimes	Rarely	Never
3. How often did the pain in your ***right*** hand(s)/wrist(s) interfere with your sleep?	1	2	3	4	5
4. How often did the pain in your ***right*** hand(s)/wrist(s) interfere with your daily activities (such as eating or bathing)?	1	2	3	4	5
5. How often did the pain in your ***right*** hand(s)/wrist(s) make you unhappy?	1	2	3	4	5

B. The following questions refer to **pain** in your ***left*** hand/wrist.

1. How often did you have pain in your ***left*** hand(s)/wrist(s)?
   1. Always
   2. Often
   3. Sometimes
   4. Rarely
   5. Never

If you answered **never** to **question IV-B1** above, please skip the following questions and go to the next page.

2. Please describe the pain you had in your ***left*** hand(s)/wrist(s).
   1. Very mild
   2. Mild
   3. Moderate
   4. Severe
   5. Very severe

	Always	Often	Sometimes	Rarely	Never
3. How often did the pain in your ***left*** hand(s)/wrist(s) interfere with your sleep?	1	2	3	4	5
4. How often did the pain in your ***left*** hand(s)/wrist(s) interfere with your daily activities (such as eating or bathing)?	1	2	3	4	5
5. How often did the pain in your ***left*** hand(s)/wrist(s) make you unhappy?	1	2	3	4	5

V. A. The following questions refer to the appearance (look) of your ***right*** hand **during the past week**. (Please circle one answer for each question).

	Strongly agree	Agree	Neither agree *nor* disagree	Disagree	Strongly disagree
1. I am satisfied with the appearance (look) of my ***right*** hand	1	2	3	4	5
2. The appearance (look) of my ***right*** hand sometimes made me uncomfortable in public	1	2	3	4	5
3. The appearance (look) of my ***right*** hand made me depressed	1	2	3	4	5
4. The appearance (look) of my ***right*** hand interfered with my normal social activities	1	2	3	4	5

B. The following questions refer to the appearance (look) of your ***left*** hand **during the past week**. (Please circle one answer for each question).

	Strongly agree	Agree	Neither agree *nor* disagree	Disagree	Strongly disagree
1. I am satisfied with the appearance (look) of my ***left*** hand	1	2	3	4	5
2. The appearance (look) of my ***left*** hand sometimes made me uncomfortable in public	1	2	3	4	5
3. The appearance (look) of my ***left*** hand made me depressed	1	2	3	4	5
4. The appearance (look) of my ***left*** hand interfered with my normal social activities	1	2	3	4	5

VI. A. The following questions refer to your satisfaction with your ***right*** hand/wrist **during the past week**. (Please circle one answer for each question).

	Very satisfied	Somewhat satisfied	Neither satisfied *nor* dissatisfied	Somewhat dissatisfied	Very dissatisfied
1. Overall function of your ***right*** hand	1	2	3	4	5
2. Motion of the fingers in your ***right*** hand	1	2	3	4	5
3. Motion of your ***right*** wrist	1	2	3	4	5
4. Strength of your ***right*** hand	1	2	3	4	5
5. Pain level of your ***right*** hand	1	2	3	4	5
6. Sensation (feeling) of your ***right*** hand	1	2	3	4	5

B. The following questions refer to your satisfaction with your ***left*** hand/wrist **during the past week**. (Please circle one answer for each question).

	Very satisfied	Somewhat satisfied	Neither satisfied *nor* dissatisfied	Somewhat dissatisfied	Very dissatisfied
1. Overall function of your ***left*** hand	1	2	3	4	5
2. Motion of the fingers in your ***left*** hand	1	2	3	4	5
3. Motion of your ***left*** wrist	1	2	3	4	5
4. Strength of your ***left*** hand	1	2	3	4	5
5. Pain level of your ***left*** hand	1	2	3	4	5
6. Sensation (feeling) of your ***left*** hand	1	2	3	4	5

Raw scores are converted to a scale from 0 to100 according to a scoring algorithm [1]. Ranges for subscales are the following: hand function (5–25), unilateral ADL (5–25), bilateral ADL (7–35), work (5–25), pain (0–24), aesthetics (4–20), and satisfaction (6–30). Higher scores indicate better hand performance in all domains except pain. In the pain scale, high scores indicate more severe pain.

If 50 % or more of the items in a scale are missing, then that particular scale cannot be scored. An overall MHQ score can be obtained by summing the scores for all 6 scales and divide by 6. If scores for more than two scales are missing, an overall MHQ score cannot be computed.

MHQ Scoring Algorithm[1]

Scale	Recode[a]	RawScoreRange[b]	Normalization[c]
Overall hand function	None	5–25	$[-(\text{rawscore}-25)/20]\times 100$
Activities of daily living	None	5–25 1 handed	$=[-(\text{rawscore}-25)/20]\times 100$
		7–35 2 handed	$=[-(\text{rawscore}-35)/28]\times 100$
		Overall ADL	$=(1\text{ handed}+2\text{ handed})/2$
Work	None	5–25	$[(\text{rawscore}-5)/20]\times 100$
Pain	Question 2: (1 = 5) (2 = 4) (4 = 2) (5 = 1)	5–25	if question 1 = 5, then pain score = 0
			if question $1 \neq 5$, then $[-(\text{rawscore}-25)/20]\times 100$
Aesthetics	Question 1: (1 = 5) (2 = 4) (4 = 2) (5 = 1)	4–16	$[(\text{rawscore}-4)/16]\times 100$
Satisfaction	None	6–30	$=[-(\text{rawscore}-30)/24]\times 100$

[1]The scoring algorithm is available from the authors is SAS program.
[a]The response categories for some of the questions are reversed and are recoded
[b]Sum of the responses for each scale
[c]Fort he pain scale, higher scores indicate more pain. Fort he other 5 scales, higher scores indicate better hand performance. The scores are normalized to a range of 0–100

Reference

1. Chung KC, Pillsbury MS, Walters MR, et al. Reliability and validity testing of the Michigan hand outcomes questionnaire. J Hand Surg Am. 1998;23: 575–87.

Appendix 7: Quick-DASH (The Disabilities of the Arm, Shoulder and Hand)

INSTRUCTIONS. This questionnaire asks about your symptoms as well as your ability to perform certain activities. Please answer *every question*, based on your condition in the last week, by circling the appropriate number. If you did not have the opportunity to perform an activity in the past week, please make your *best estimate* of which response would be the most accurate.

Answers to the Questions

Questions 1–6, 11	Question 7	Question 8	Questions 9–10
1 = No difficulty,	1 = Not at all	1 = Not limited at all	1 = None
2 = Mild difficulty,	2 = Slightly	2 = Slightly limited	2 = Mild
3 = Moderate difficulty,	3 = Moderately	3 = Moderately limited	3 = Moderate
4 = Severe difficulty	4 = Quite a bit	4 = Very limited	4 = Severe
5 = Unable. **(Q = 1–6)**	5 = Extremely	5 = Unable	5 = Extreme
… = So much difficulty that I can't sleep **(Q = 11)**			

Please rate your ability to do the following activities in the last week.

1. Open a tight or new jar.
2. Do heavy household chores (e.g., wash walls, wash floors).
3. Carry a shopping bag or briefcase.
4. Wash your back.
5. Use a knife to cut food.
6. Recreational activities in which you take some force or impact through your arm, shoulder, or hand (e.g., golf, hammering, and tennis).
7. During the past week, *to what extent* has your arm, shoulder, or hand problem interfered with your normal social activities with family, friends, neighbours, or groups?
8. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder, or hand problem?

Please rate the severity of the following symptoms in the last week.

9. Arm, shoulder, or hand pain.
10. Tingling (pins and needles) in your arm, shoulder, or hand.
11. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder, or hand?

The sum of the responses produces a score, which then is transformed to obtain the Ouick-DASH score. The final score ranges between 0 (no disability) and 100 (the greatest possible disability). Only one missing item can be tolerated, and, if two or more items are missing, the score cannot be calculated.

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$$\text{QuickDASH Disability / Symptom Score} = \left[\left(\frac{\text{Sum of n responses}}{\text{n}}\right) - 1\right] \times 25$$

where *n* is equal to the number of completed responses.

Reference

1. Beaton D, Wright J, Katz J, The Upper Extremity Collaborative Group. Development of the QuickDASH: comparison of three-item reduction approaches. J Bone Joint Surg Am. 2005;87:1038–46.

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