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Tendinopathy in the Workplace

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Introduction

Until relatively recently, little attention has been paid to the millions of workers who go to work each day and perform the same highly repetitive tasks for years at a time. An assembly line worker may repeat the same task 25,000 times per day [1]. Each exertion requires a specific movement of the upper or lower extremity, usually with the maintenance of a static posture of the trunk, head, and neck. Over time, the amount of physical effort required to accomplish such seemingly mundane tasks is extraordinary. With millions of people at computer keyboards each day, it is not surprising that overuse syndromes or repetitive strain injuries have come into media focus and attention.

Repetitive strain injuries are disruptions of muscles, tendons, bone, or nervous system precipitated or exacerbated by repeated forceful exertions, awkward posture sustained for a long time, surface contact stresses, vibration, or cold. Jobs that have multiple risk factors have a greater likelihood of causing or contributing to musculoskeletal disorders depending on the magnitude, duration, and frequency of the exposure to each risk factor [2].

Patients with upper extremity repetitive strain injuries present with pain, usually in the neck, shoulder, arm, or hand; fatigue, either generalized or localized; and weakness, paraesthesias, loss of dexterity, depression, and loss of sleep. Many patients relate this to the duration and intensity of their work. Symptoms may develop over weeks, months, or years, and patients commonly cannot pinpoint a specific time of onset. Symptoms may be poorly localized, nonspecific, and episodic, and the causes may be multifactorial. These patients may initially appear to suffer from simple fatigue. The difference between simple fatigue and repetitive strain is related to the duration and intensity of the symptoms. Fatigue can occur after a work shift and is short lived. With repetitive strain injuries (RSI), recovery between work shifts does not occur, and patients begin their day or week with pain [3].

The Occupational Safety and Health Administration (OSHA) has defined several conditions as "work-related musculoskeletal disorders" (WMSDs) caused by workplace stressors [4]. These include carpal tunnel syndrome, rotator cuff tendinopathy, de Quervain's disease, trigger finger, and lateral and medial epicondylitis.

The term tendinopathy denotes pain involving tendons or their surrounding structures, which at times can be inflamed, usually caused by repeated or forceful exertion by the affected part. Tendinopathy is usually made worse by performing an activity in an awkward position.

These conditions have now been recognized as the leading chronic work-related musculoskeletal disorders, and have served as the basis for the proposed ergonomic standard that will be discussed later. This chapter examines the epidemiology of these problems and the cost to society as a whole. Newer evidence for work relatedness and occupational tendon pathophysiology will be discussed, and we shall also discuss how ergonomics relates to the correction and prevention of these issues, focusing specifically on tendinopathy. There is much controversy about the cost-effectiveness of ergonomic programs. Follow-up evidence for cost effectiveness will be presented.

The Scope of the Problem—Epidemiology

Work-related musculoskeletal disorders account for nearly one-third of all occupational injuries reported in the US. In 1997, employees lost more than 600 000 workdays [5]. Between US $20 and $30 billion is spent each year on workers' compensation claims for repetitive strain injuries of the neck and upper extremity. Taken together, these represent more than 50% of the cost of all occupational injuries [6]. It is estimated that the total cost of treatment nationwide for carpal tunnel syndrome exceeds $3.5 billion. The average carpal tunnel release costs US $27,000, including the medical and legal costs, and intangible costs such as lost productivity [7].

Workers with severe symptoms can face permanent disability that prevents them from returning to gainful employment, and even everyday tasks can cause disabling pain.

The fundamental question is why so much attention is being paid to repetitive strain injury now, when workers have been toiling on assembly lines for nearly 100 years. The answer may lie with the dramatic rise in the reporting of such injuries, which has resulted in skyrocketing health costs in dealing with these patients. The Bureau of Labor Statistics reported in 1997 that in private industry alone there were 705,800 illness claims for repetitive strain, which represents a 2,700% increase since 1982. Of these, more than half were due to overexertion in lifting, 15% were due to overexertion in pushing and pulling objects, and 10% to holding, carrying, and turning objects. About 92,500 injuries were due to upper extremity repetitive motion. These include data entry and repetitive grasping [8].

Large epidemiological studies of cumulative trauma disorders indicate a wide variety of workers who are "high risk" for the development of these conditions. These include meat packers, cashiers, data entry clerks, musicians, construction workers, electricians, cake decorators, postal workers, assembly workers, punch press operators, and automobile workers [9]. The estimated probability that a worker will experience at least one work-related musculoskeletal disorder during a working lifetime of 45 years is 24 to 800 per 1,000 employees, depending on the industry sector [10].

The use of computers has dramatically risen during the past 15 years. With increased pressure to produce more in less time, many office tasks have been reduced to their simplest components, and individual workers may have to perform fewer tasks at ever increasing rates. The mechanics of computer use differ significantly from those of the typewriter. The typewriter by its nature demands the necessary steps in paper handling and adjustments. The computer user has no such break-time from repetitive keying. People who use computers for more than 4 hours at a time are at 3 times the risk for developing shoulder, arm, or hand pain. The odds are significantly higher for supermarket cashiers and assembly line meat packers.

The Functional Anatomy of Tendons

A typical tendon extends from the myotendinous junction to the bone tendon junction. Tendons are composed of dense connective tissue with regularly arranged collagen fibers of great tensile strength. In general, tendons: 1) extend the reach of muscles and permit the muscle to pull through fibro-osseous tunnels; 2) enable the pull of a muscle to be focused onto a single or multiple sites; 3) eliminate the need for unnecessary length of muscle between the origin and insertion, allowing the length of the muscle belly to be appropriate to the amount of movement required. Thus, the longer the muscle belly, the greater the range of motion; 4) change the pull of a muscle by wrapping around bone pulleys; (5) reinforce the underlying joint capsule; (6) have elasticity so that energy is stored in the muscle-tendon units when the limb is passively stretched in the opposite direction of the tendon action; and 7) hold other tendons in position [11].

As a rule, tendons in the upper extremity are attached immediately distal to the joint that they move. Although this causes a mechanical disadvantage, it is compensated for by a greater speed of action and increased efficiency and excursion of the limb. Typically, the entheses are attachment points of tendon to the bone, and contain a high concentration of fibrocartilage [12]. These allow the transitional tissue to maintain high tensile strength in a relatively avascular environment. The tendon microstructure is modified where it changes direction and wraps around a bone pulley. At the pulley, both the tendon and the periosteum are fibrocartilaginous where compressive forces are maximal. Fibrocartilage is usually restricted to the side of the tendon facing the compressive structure [13]. This is particularly prominent in the fingers, where the tendons press against the fibrous pulleys and where the extensor tendons form the dorsal part of the finger joint capsule. The fibrocartilage may arise through metaplasia of the tendon cells [14].

Retaining Ligaments

Flexor and extensor retinacula in the wrist hold the tendons of the forearm and the muscles in position. Pulleys and fibrous sheaths in the fingers hold the flexor tendons in place and prevent them from moving out of line and bowstringing when flexing. These pulleys may be torn or avulsed by excessive load on the tendons. Pulleys may also be too small for the tendons, leading to constriction and development of a trigger finger. Retinacular and fibrous pulleys may contain fibrocartilage similar to the compressive fibrocartilage of tendons. Indeed, they may contain even more fibrocartilage than the tendons themselves. The fibrocartilage here may also change and respond to changes in mechanical stimuli.

Synovial Sheaths and Bursae

A tendon is held by a retaining ligament and must be able to glide freely beneath it. At such locations, the tendons are surrounded by synovial sheaths or by paratenon. These are closed sacs that contain a thin film of lubricating synovial fluid. These sheets often extend beyond the limits of the retaining ligament, so that the tendons can slide beneath them, and may surround a single tendon or a group of tendons. This synovial layer may also provide nutrition by diffusion to the tendon, especially in the avascular areas of the tendon. This may be a more important source of nutrients than blood vessels in general. Thus, the tendons are hydrodynamically lubricated. The friction caused by fast, repetitive motion of tendons within the sheath can result in tenosynovitis [15].

Physiology of Tendon Strain

The primary function of tendon is to transmit forces from the muscle to the bone. Accordingly, its principal injuries involve forces causing stretch deformation or inadequate recovery (i.e., return to resting length) on the one hand, and frictional damage due to shear and extrinsic compression on the other. The tendon is subject to both uniaxial tensile forces from muscles and transverse forces from anatomic pulleys, bursae, and extended range of motion. Tensile and transverse forces produce shear and influence tendon gliding. These forces across the tendons are increased during prolonged awkward or extreme positions at a joint such as the wrist [16].

As muscles contract, tendons are subject to mechanical loading and viscoelastic deformation. Tendons have excellent resistance to tensile loading, and their elastic properties enable them to move around turns, such as in the hand. When collagen bundles are placed under tension, they elongate without significant increase in stress. With increased tension, they become stiffer in response to loads. If the load on these structures exceeds the elastic limits of the tissue, permanent changes occur [17]. The ultimate tensile strength of normal tendons is about 50% that of cortical bone. If recovery time between contractions is too short, plastic deformation can result, along with permanent changes that decrease the tendon's ultimate strength.

Tendons also exhibit relaxation and creep. When a tendon is subjected to prolonged elongation and loading, the magnitude of tensile forces will gradually decrease, and the length of the tendon will gradually increase [18]. In repetitive loading, the tendon exhibits these properties and then recovers if there is sufficient recovery time. If the interval between loading does not permit restoration, then recovery can be incomplete, even if the elastic limit is not exceeded [19].

When tendons are subject to perpendicularly oriented compressive loading, as happens when they are sliding around fibrous or bony pulleys, friction is generated, causing a shearing force. This is seen commonly in the hand and wrist, especially in nonneutral wrist postures. For example, the compressive forces on A1 pulleys rise dramatically from neutral to full flexion of the wrist. Tendon friction is proportional to the axial tension of the tendon, the coefficient of friction between the tendon, and the adjacent surface of the angle of the tendon as it turns around the pulley. This may be the cause of surface degeneration in the tendon. Internal degeneration may result from friction-induced internal heat generation [20].

Paratendinopathy (tenosynovitis) is mainly inflammation of the paratenon. Signs and symptoms include localized pain, swelling, warmth, and tenderness. Tendinopathy involves intratendinous degeneration with fiber disorientation, scattered vascular ingrowth, tissue necrosis, and calcification. Tendon nodularity may be noted, but swelling of the tendon sheath is absent. Paratendinopathy may be observed with tendinopathy. Paratendinosis, inflammation, and intratendinous nodularity are possible. Tendinopathy can range from a tear with inflammation and acute hemorrhage to chronic degeneration [21].

Clinically, tendon compression in the hand manifests as stenosing tenosynovitis initially. There is impaired motion, tenderness, and pain with resisted contraction of passive stretch, swelling, and crepitus. With time, the tendon swells and thickens from tendon fibril disruption, partial laceration, engorgement, and diffusion of metabolites. Ultimately, these limit the normal passage of the tendon through fibro-osseous canals, with triggering. The tendon becomes nodular with fusiform swelling, and fibrocartilaginous metaplasia or fraying of the tendon. When the tendon load is great or highly repetitive, there is insufficient recovery time between deformations for the tendon to return to its resting length, and viscous strain can exceed elastic strain, causing tendon deformation. A different injury mechanism occurs when tendons and tendon sheath are forced over hard, anatomic surfaces producing paratendinopathy, synovitis, or degeneration due to lack of blood flow at the site of compression. Impaired circulation, bony compression, and degenerative changes are typical of rotator cuff injuries where tendon insertions on the greater tuberosity can be compressed under the coracoacromial arch. Muscle tension itself can restrict circulation when the tendon's supply of arterial blood runs through the contracted muscle [22].

In de Quervain's syndrome, the retinaculum hypertrophies and traps the abductor pollicis longus and the extensor pollicis brevis in a narrowed first dorsal extensor compartment. Tendons and ligaments also undergo significant modification when they turn corners or insert into bone. The tendon matrix changes its microstructure in response to mechanical forces. Experimental studies suggest that mechanical loading and stresses can induce tissue injury and microstructural changes.

While working at a computer keyboard, the intrinsic and extrinsic muscles of the hand and forearm are moving and contracting dynamically, while the wrist, elbow, shoulder, and neck are in a static posture to support the moving joints. Although static loading of the trapezius reaches only 30% of maximal contraction, over long periods sustained contraction will result in fatigue. Microtears eventually develop in the affected muscles and tendons. Attempts at healing can be slowed down by repeated injury, with failed healing response, degeneration, and chronic pain. In computer users, the tendons of the wrist and fingers are subjected to traction and shear, according to the degree of muscle contraction, the velocity of tendon movement, and the friction between the tendons and adjacent retinacular tissues. After 500 submaximal work cycles in the wrist, the elastic strain on a tendon was equivalent to what would be accomplished by an 80% increase in load [19]. There is a fibrous thickening in the tendon sheaths and tenosynovium and an attempt repair with an aborted inflammatory reaction in the tendons themselves. Blood flow to the tendons is diminished, and intratendinous fatty degeneration occurs in the tendons. There is no vigorous inflammatory response because there has been no acute injury.

Work-Relatedness of Repetitive Strain Injury

At the center of the controversy around passage of the OSHA ergonomic initiative is whether the perceived explosion of the incidence of RSI is truly due to workplace conditions or to a multiplicity of other factors. In July 1997, the National Institute for Occupational Safety and Health published a monograph entitled "Musculoskeletal Disorders and Workplace Factors." This epidemiological meta-analysis examined the results of over 600 studies focusing on disorders of the neck and upper extremity, including tension neck syndrome, shoulder tendinopathy, tennis and golfer's elbow, hand and wrist tendinopathy, carpal tunnel syndrome, and vibration hand syndrome. The review focused on epidemiological studies based on recognized symptoms and standard methods of clinical evaluation. Studies that included measurement of psychosocial factors were included. The framework for evaluating causality was based on strength of association, consistency of the data, the dose-response relationship for exposure to a given hazard, and the coherence of the evidence.

This meta-analysis concluded that, for neck and shoulder pain and tendinopathy, there was evidence of work-relatedness and causality with a positive relationship among repetition, force, and symptoms. When posture was considered alone, a strong relationship was noted. For elbow tendinopathy, only high force was associated with symptoms repetition, and posture played a much lesser role. For hand and wrist tendinopathy, repetition, high force, and wrist posture play a role in the development of symptoms. But, when these factors are taken in combination, the association is strong. These consistently positive findings from this large sample provide strong evidence of work-relatedness. There are two fundamental weaknesses in this study. 1) There is no clear-cut evidence of a pure dose-response relationship of exposure and the development of symptoms, and there is, to date, no known minimum acceptable "dose" of a given occupational ergonomic hazard much as is seen with chemical hazards. 2) In all these workers, one cannot know for sure whether the ergonomic hazards described in the studies were the only hazards faced, or whether there were a myriad of unforeseen conditions or circumstances that may have contributed. These may include work performed at home or on another job by the worker. However, these studies are useful in that broad impressions can be formulated.

Clinical Evaluation

The first step in developing a treatment plan is deciding whether the problem is indeed a manifestation of cumulative trauma or of other underlying pathology, such as an autoimmune or metabolic disease that affects nerves, tendons, or muscle. The clinician must also decide whether the disorder is work-caused or simply work-aggravated. To simply to call something "work-related" is insufficient. Although some RSIs are highly localized with a straightforward method of treatment, others may be poorly localized and present in an inconsistent and sporadic manner. A detailed medical and occupational history helps identify possible work-related risk factors. It is necessary to ascertain whether the risk factors have sufficient duration to cause or aggravate the problem and to find an association between the workplace and the onset of the symptoms. It may be impossible to tell whether the patient was asymptomatic before beginning the position. Because of the wide publicity given, RSI patients may have learned their presenting manifestations and may use their knowledge for secondary gains. It is important to get a sense of the social dynamics at the workplace. This may take several patient visits, and may even necessitate visiting the workplace. Social issues frequently confound the problem. Employees in a stressful or boring work environment may seek medical attention with an unstated goal of being transferred to another position, being removed from work, or being guaranteed continued medical coverage. The patient may have already had an evaluation by a physician employed by the workers' compensation insurance company, and therefore not objective.

Musculoskeletal disorders signs include decreased range of motion, limb deformity, decreased grip strength, and loss of function. Musculoskeletal disorders symptoms generally include numbness, burning, pain, tingling, cramping, and stiffness. These can appear gradually as muscle fatigue and pain at work and disappear at rest, but become more severe with increased exposure and continue after work. Symptoms may be localized or diffuse. Over time, symptoms become continuous and spread up the arm to the shoulder and the neck. In a typical case, an employee visits the company nurse and complains of musculoskeletal symptoms. The nurse refers the worker to the company physician, who advises the patient to take time off, wear a wrist splint, and take anti-inflammatory medication. When the employee returns to work, the symptoms return. The employee is referred to a specialist. Additional conservative measures follow. All too frequently, the patient ends up in the operating room. There is initial symptom relief, and the patient returns to light duty, then regular duty, and the symptoms recur. The worker is then viewed as a high-risk workers' compensation case, and some cause is found for laying the patient off. If the compensation claim is denied, an attorney becomes involved, and there is a court hearing. A rehabilitation nurse for the insurance company steps in for a permanent disability rating, and a second medical opinion is sought for a permanent disability payoff, which may take years. The process may literally consume the patient's life. There is a loss of self-esteem and income, causing home strife and depression. Patients see themselves as unemployable and end up as the taxpayers' burden. The longer the patient is out of work, the less the probability that the patient will ever get back.

Because the workers' compensation system was designed to deal with acute injuries, employers and workers' compensation carriers have great difficulty in dealing with workers suffering from RSI. An acute injury has a definite time of onset, an identifiable cause, a clear-cut plan for treatment, and a clearly defined time when the worker should be able to return to work. Workers with RSI pain have none of these conditions. The perception of malingering and secondary gain pervades. As productivity declines, the worker is laid off. Employers are unwilling to make accommodations, and will not allow return to work until the employee is 100% fit. Unions often get involved, OSHA investigates, litigation follows, and the costs of treatment escalate.

This scenario is played out tens of thousands of times across the United States on a yearly basis. This reflects the haphazard and reactive way in which RSI is typically treated. It has recently been realized that only with a proactive approach that begins in the workplace is this problem going to be addressed. Only then will significant inroads be made in reducing the national incidence of WMSDS.

A coordinated multidisciplinary approach is necessary. It involves workers and management working with occupational physicians, ergonomic engineers, industrial psychologists, and employee team coordinators. There needs to be a closer working relationship between industry and medicine. By employing ergonomics, work environments will be configured to fit employees' physical capabilities and reduce those hazards that rob employees and industries of their productivity.

For musculoskeletal disorders management, one requires a prompt response to musculoskeletal disorders when they occur. Employers need to determine the need for work restrictions. Employers must provide access to health care professionals, provide the health care professional with occupational information, and obtain written options from the heath care professional. This information includes description of musculoskeletal hazards, available work restrictions, and opportunity for heath care professionals to do a workplace walk-through. The program must be evaluated, and records must be kept. There is also increasing difficulty in performing the job. A musculoskeletal disorders symptom becomes significant when a health care professional is needed or if there is one or more days off of work, or there is a necessity for restricted work activity or transfer or retraining to another job.

The Necessity for an Ergonomic Program

People work best and more productively and safely in a proper physical environment. People have attempted to adapt to a fixed work environment, but these have resulted in the development of musculoskeletal disorders. Ergonomic designs change the workplace physical environment, the size and arrangement of workspaces, the physical demands of manual tasks involving the upper extremity, and the design of hand tools. The fundamental goal of ergonomic designs is to improve people's ability to produce and to work, reduce lost work time, and thereby lower work error or accident, which would decrease productivity. Studying the human and machine interface is the essence of ergonomic redesign. Ergonomics is an applied science that coordinates the physical features, devices, and working conditions within a selected job along with the capacities of the people working within that environment. When a new production process or equipment change is being considered, the following needs to be taken into account: The working heights, the reaches, the distances one must reach, the necessity to move, to push, to pull, and to lift while standing or sitting, the weights of the materials an employee must move horizontally or vertically during the given operation, the hand motions needed to grasp or pinch materials, the tools used for each process, and other physical capabilities required by the arm and hand. In addition, the path of workflow during manual handling of materials is critical, as are the required speed and frequency of manual activities that are demanded of an employee. Locating work surfaces, tools, and raw materials in awkward reaches causes the individual to adopt body postures that can overstress the neck, shoulders, elbows, wrists, and hands.

Reaching for products requires the shoulder to be used. Shoulders tend to fatigue when the employee raises the arms above shoulder height or behind the neck. The supraspinatus muscle accomplishes abduction of the glenohumeral joint in the shoulder. The supraspinatus tendon also functions as a humeral head depressor, thus widening the subacromial space between the rotator cuff tendons and the overarching acromion. With heavy, repetitive overuse in shoulder abduction, overhead lifting, or prolonged forward flexion, the rotator cuff tendon becomes worn and allows the humerus to ride upward under the acromion, creating an impingement lesion with pain with shoulder abduction as the humeral head impinges on the lateral aspect of the acromion, further entrapping the supraspinatus tendon, with wear on the supraspinatus tendon and in the subacromial bursa, with subsequent inflammation and pain. If the arm is held elevated, shoulder muscle fatigue and biceps tendinopathy result [23].

This has been identified as a major concern in the workplace, especially for older workers who have reduced joint mobility. Sustained elevated arm work, especially supporting a load, must be minimized to avoid shoulder muscle and tendon fatigue and tendinopathy. Fatigue and tendinopathy will develop if the relative load of the muscles is over 40% of the maximum voluntary contraction, and the rest periods between contractions are shorter than 10 times the contractile period. Short duty cycles, less than twenty per minute, with low loads less than 0.4 kg, with no more than 35 degrees above shoulder level are acceptable, provided that work activity is not maintained for long periods [24]. Even without a hand load, any elevation of the arm in abduction or forward flexion above 90 degrees greatly increases the stress on the rotator cuff. Acute tendinopathy of the shoulder can be induced by high-velocity arm movements such as tossing materials. Such motions can result in sudden and excessive strain on specific tendons as particular muscles contract to provide the acceleration and deceleration necessary to execute gross motion while maintaining joint integrity. When reaching forward, the shoulder joint is flexed and the elbow becomes extended. If a load is held in the hands, the load moments at the elbow and the shoulder can become large relative to the flexor tendon moments required at both joints. Thus, even small loads cannot be supported for sustained periods, especially if the arm or forearm is elevated and pushed forward. Thus, power tools used during a workday for sustained periods should be suspended from an overhead tool balancer designed to minimize the weight effect. Also, workpieces or assembly should not have to be supported by one hand while the other one performs the required operation. Good workplace design provides adjustable fixtures that support the workpiece in proper orientation for the operator, taking into account both visual and manual task requirements.

The shoulder is assisted by the posture and motion of the elbow. When the elbow is bent, it assists in shoulder flexion motions during manual handling of products. In addition, the elbow assists in bringing the hand to the face. Epicondylitis of the elbow (lateral most common) has been reported with constant use of a hammer, repeated supination or pronation, repeated forceful wrist extension, and supination of the gripping hand with wrist extension [25].

Additionally, forearm postures are not only dictated by the location of the hand, but also by hand orientation around the longitudinal axis of the forearm. If the hand is supinated, then the arm will be adducted and close to the torso. If the task requires the hand to be pronated, then the arm will be more abducted and elevated. If the hand is located in a position that already requires the arm to be elevated, then using the prone hand posture will further require arm elevation. If a screw must be turned in a clockwise direction, with supination of the forearm, it is important that the elbow be flexed to 90 degrees, running good mechanical advantage for the biceps brachii. If the elbow is extended, the short forearm supinators, which fatigue much more easily than the biceps brachii, accomplish supination. The mechanical advantage of the biceps disappears with elbow extension [26]. When attempting to push or pull with one hand while sitting, the resulting strength exerted depends on shoulder and elbow angles. When the elbow is straight or locked in extension, push and pull forces can become quite high. As a general rule, each employee should have the elbows postured at midrange, at 90 degrees of flexion. When keeping the elbows close to the body, at no further than 30 degrees of shoulder abduction, and working within arm's length, one must minimize forearm rotation and maintain a pistol grip so that hand strength is maximized [27].

Cumulative trauma to tendons, tenosynovitis, tendinopathy, de Quervain's syndrome, and paratendinopathy can occur as a result of repetitive motion about the wrist. Awkward posturing exacerbates this. Examples of this include ulnar deviation of the wrist with a fixed thumb, rapid finger flexion, grasping in radial deviation, violent pulling, wrenching grip, twisting with forearm pronation and supination, or pinch followed by quick pronation. Excessive flexion and extension of the digits against resistance, and overuse of index finger with pistol-type air tools can cause trigger finger.

Force

The force with which an employee must lift a grip is associated with cumulative prominent disorders of the upper extremity. The greater the force exerted, the greater the potential for these disorders. External loads on the musculoskeletal system induce high muscle, tendon, and joint forces. Because these activities are under precise motor control during work, peak tissue stress is usually well within the physiologic capacity of the tissues, provided that the forces are of short duration and rest periods are adequate. Overexertion or very frequent exertions can result in diminished functional capacity. This can cause in the tendon a reaction to a mechanical strain of the tissues when there is not adequate rest to allow physiologic recovery and adaptation [28]. With further exertion, tendon collagen fibers become separated. At the point of greatest stress where tendons pass around adjacent bone or ligament structures, the collagen fibers can be shredded, leaving debris-containing calcium salts. These calcium salts and circulatory fluids within injured tendons produce further swelling and pain [29]. If the harmful work activity is continued, degeneration will involve surrounding tendon synovia and bursae. This is particularly present when the weight of the object being held or lifted is substantial. Other factors, such as the shape and configuration of objects may make lifting difficult as may poorly fitting gloves [30].

In the workplace, force can be reduced by adding a better gripping surface such as rubber slips to tool handles, reducing the weight held by workers through the use of gigs or balancers to keep hand forces to the minimum, aligning the object's center of gravity to the hand and body center of gravity, reducing rotating movements caused either by the tool or work design, and reducing tool power speeds and torque.

Repetition

Repetitiveness is often cited as a risk factor for cumulative trauma disorder of the upper limbs [40]. Although the relationship between this exposure factor and cumulative trauma disorders has been established, the acceptable dose-relationship or tolerance ratios have not. Engineers and managers use the term repetition to indicate task cycles and standard task completion times. Other factors such as selected job methods or length of time spent on a given task will vary the repetitiveness of the job.

Workplace Controls (Modifying the Workplace to Prevent Tendinopathy)

To control repetitiveness, an administrative control is recommended. Such controls include job method change, relief of workers, job enhancements, and change of production pace. Sometimes engineering controls will create less manual work for employees and reduce the repetitiveness of job tasks. Examples of workplace controls include reducing the weight of objects handled, rotating the job functions, varying the job tasks, allowing short breaks, using sit/stand workstations, using antifatigue mats, providing footrests, and providing cushion insoles. In such a way, static postures can be alleviated. To relieve excessive force, one uses balanced power tools and provides lift assists. For sitting for an extended period of time, one implements standing breaks, lumbar supports, appropriate seats with padding on the seat with good lumbar support, and seat height adjustments that are correct.

- For workstation or edges that press hard into muscles or tendons, one has to provide round edges and large handles, and pad the surfaces of handles.
- For using hands or body as a clamp to hold objects while performing tasks, one implements fixture, clasps and jigs, uses job rotation, and pads work surfaces.
- For objects that are too heavy, one needs to lighten the load, use lift assists, use lift tables, and allow two people to lift as a team.
- For horizontal and vertical reaches that are too long or too high or low, one needs to readjust the workstation so these problems are alleviated.
- For tasks that involve moving objects significant distances, one needs to use mechanical conveyors, such as forklifts, hand dollies, and carts. For conveyor belts, objects should have appropriate handles to make things easier to lift without assuming awkward positions or high contact stresses.

A simple reach triggers a complex action of the arm and hand. The type of motion, the amount of motion, and the duration of the motion determine the level of body stress. Reducing stress requires proper position of the body parts. Work surfaces and seats must be adjustable in heights and reaches. Proper positioning is tied closely to the measurement of body size and anthropometry. Through anthropometry, proper positioning is often achieved. However, this alone will not eliminate ergonomic posture stresses if work motions or applied force are needed to complete a job.

Hand Tool Shape and Size Considerations

Many of these workplace hazards are directly related to the design of hand tools and the methods employed when using these tools. As forceful hand grip relies on muscle contractions of the forearm, with force being transferred to the bones and the joints of the fingers via the long flexor and extensor tendons, the level of muscle and tendon exertion largely depends on grip configuration and, to a lesser extent, on hand and wrist anthropometry. Furthermore, biomechanical studies disclose that the angle of the wrist directly affects grip strength. It is proposed that the wrist be kept relatively straight during forceful gripping to avoid wrist strain [31]. Failure to do so can result in tendinopathy and synovitis, with later entrapment of the median nerve within the carpal tunnel. Thus, the shape and size of a hand tool can have a direct effect on the worker's performance ability, grip strength, and arm comfort.

Tool Shape to Avoid Wrist Tendinopathy

Allowing the hand and wrist to remain in alignment during forceful grip exertions necessitates specific tool handle configurations. For example:

Cylindrical Versus Pistol-Shaped Tools

Based on biomechanical considerations, the handles of powered drivers such as drills should sometimes be pistol-gripped when drilling into a vertical surface. Some horizontal surfaces that are low down can be drilled with pistol-grip tools as well, while other surfaces higher up require a cylindrical grip. Usually, the driving torque of a tool creates the tendency for the tool to rotate in the worker's hand unless firmly gripped. Generated forces near maximal strength are not uncommon in such activities. If the wrist is forced into deviation during such exertions, there is an increased risk of cumulative trauma [32]. Occasionally, the cylindrical grip tool may need to be suspended from a balance beam in the ceiling.

Bent-Pliers Design

In a comparative study between two different types of pliers used by 80 employees, over 60% of those using the common straight-handled pliers developed wrist and related disorders at the end of 12 weeks, while only 10% of those using the new bent-handled design were affected [33].

Bent-Knife Handle Design

In a similar situation, in poultry processing operations, with a common straight-handled knife that required extreme wrist flexion and ulnar deviation, the cumulative trauma incidence rate was 17 per 100 workers a year, 50% higher than the plant average. A pistol-grip-handled knife reduced the need to continually grip because knives sometimes get slippery between cuts. By relaxing the hand between cuts, muscle fatigue incidents were reduced [34].

Bent-Hammer Handle Design

The curve in the handle has resulted in less muscle fatigue as measured by decreased grip strength than was the case when using a straight-handled hammer to pound 20 nails. The optimum curvature is believed to be between 5 and 10 degrees [35].

Tool Shape to Avoid Shoulder Abduction

If the shape of a tool requires extreme wrist deviation, a person will often raise the arm to reduce the stress on the wrist. A small amount of arm abduction at the shoulder up to 20 degrees from the vertical will not normally create an excessive load moment on the shoulder. Greater abduction, however, rapidly increased shoulder load moment. If a heavy tool is involved, abduction of the arm simply compounds the moment requirement of the shoulder, since its weight acts at the end of the upper extremity. In general, if shoulder abduction angle was about 30 degrees, the time to reach significant muscle fatigue was over 3 times than when abducted 60 degrees, and 6 times than when at 90 degrees of abduction. Bending tools such as a soldering iron can and will reduce the requirement for wrist ulnar deviation and shoulder abduction [36].

Tool Shape to Assist Grip

Any tool that may require a person to exert a pushing or pulling force across the palm should be designed with a flared handle, which will guard against the hand slipping. The use of long-padded handles distributes the force on the fingers and palmar tissue, avoiding stress concentrations in sensitive areas. In general, any tool that must be squeezed forcibly should be designed with handles that avoid concentrating grip forces in the center of the palm, as it is poorly designed to withstand direct force application due to the presence of the median nerve, radial and ulnar arteries, and finger flexor tendon synovium in this location. The length of a tool handle should be sufficient to distribute compressive forces across the palm and across all the digits. The force area must be at least 9 cm long to assure that handles are supported on both the thenar and hypothenar muscles [37]. Reverse curvature on pliers and shears reduces the forces across the palm. The compressive forces acting across the palm are significantly higher with triangular or rectangular-shaped handles than with circular or square handles. Pulling a handle toward the body, a T-shaped handle is superior to a straight cylinder. When low continuous torque is required, a cylinder that could be grasped easily is preferred to other shapes [38].

Size of a Tool Handle to Facilitate Grip

Upper strength and resulting stress on finger flexor tendons vary with the size of the object being grasped. If the handle force is applied to the distal segment of the fingers, as is the case when grasping a large tool, the counterforces can be 2 to 3 times higher than when a comparable force is applied to more proximal finger segments [39]. Conversely, if an object is very small, the fingers cannot effectively apply force to it, partially because finger flexor tendons become extremely shortened. This is especially true when attempting to forcibly grasp a small object or tool handle with a flexed wrist, as this action further shortens the finger flexor muscles. Maximum grip strength is achieved when the handle begins to close for about 8 cm. In general, women demonstrate approximately half the grip strength of men. When grip strength exceeds 40 Newtons and is repeated often, the odds of developing carpal tunnel syndrome are 15 times higher than if workers exerted less than 10 Newtons infrequently [40]. Thus, force and magnitude grip frequency play a role in the development of RSI.

Employee Exercise Programs

RSIs occur more frequently in people who do not follow a regular exercise program. Looking at the computer workplace, mini exercise breaks throughout the workday not only diminish the incidence of RSI but actually increase worker productivity and prevent productivity “drop-off” that frequently occurs at the end of the day [41]. There are many published “mini break” exercise programs that allow workers to stretch the neck, shoulders, forearms, hand, and wrists at the workstation. There are also “maxi break” exercises that workers can do twice daily [41]. Other options include job rotation, introduction of other tasks into the work cycle, and limitation of work hours. Many companies have included in-house fitness facilities where stretching, relaxation, and strengthening exercises are taught. Pictorial handouts and poster displays throughout the workplace may also be useful. Many software companies have developed exercise programs that flash reminders on the screen that instruct the worker to stop work, and start exercise.

Efficacy of Ergonomic Programs

OSHA’s estimate of the overall effectiveness of ergonomic programs is expressed in the mean reduction of musculoskeletal disease injury rates for all musculoskeletal disorders. OSHA’s case study reported at a meeting 96% reduction in injury rates. The median and mean reduction of the lost workdays was 82%. Although the effectiveness of individual ergonomic programs can vary, most interventions achieved at least a 30% reduction in injury rates [42]. Also, 70% of the case studies reduced musculoskeletal disease rates by half [43]. A quantitative study found a statistically significant higher number of back injuries than would be expected in manual handling jobs that required an exertion beyond the physical capabilities of more than 25% of the working population [44]. Back injuries could be reduced by 66% in jobs with a level of physical exertion such that 75% or more of the working population can perform it without overexertion [44].

For jobs that involve exposure to multiple risk factors, the risk of work-related musculoskeletal disorders can be reduced by either reducing or eliminating exposure to one of the aforementioned risk factors or reducing duration of exposure to the risk factors. Armstrong and Silverstein examined the prevalence of carpal tunnel syndrome and tendinopathy among populations exposed to various combinations of risk factors, including low force–low repetition, high force-low repetition, low force–high repetition, and high force–high repetition [39]. The high force and high repetition population was exposed to 2 or more risk factors, and the prevalence of carpal tunnel was statistically significantly elevated among workers exposed to high repetition alone, or to both risk factors. Odds ratios for hand and wrist tendinopathy were elevated for all 3 groups of exposed workers, but were statistically significant only among workers exposed to both high force and high repetition [41]. Based on implementing ergonomic conditions that reduce employee exposures from 2 risk factors to one, a reduction of injuries of 83% for carpal tunnel syndrome and 89% for tendinitis could be expected. Punnet, in a cross-sectional study in an automobile stamping plant, assessed exposures to workplace risk factors that reflected intensity and duration of exposures to any of several risk factors, and he found a positive, statistically significant relationship between risk factor exposure and prevalence of upper extremity disorders [45]. Data from this study indicate that the prevalence of employee-reported symptoms of upper extremity disorders and the prevalence of physician-confirmed musculoskeletal disease could be reduced more than 50% if the exposure was reduced by at least half [45]. The median estimated effectiveness of ergonomic programs and interventions ranges from about 28% to 43% in multiple OSHA studies. If all work-related risk factors were eliminated, the median effectiveness would range from 56% to 86% [46]. Overall, OSHA believes that the incidence of musculoskeletal disorders would be reduced by a half or two-thirds as a result of implementing ergonomic programs. These risk factors include forceful lifting, pushing, pulling, repeated bending, twisting, repetitive arm or hand motions, static and awkward postures, contact stresses, and whole-body and localized vibration.

OSHA’s evidence consists of 92 case studies that document reductions in musculoskeletal injury rates that have resulted after ergonomic programs and employers have implemented interventions. Several epidemiology studies have shown quantitative relationships between the intensity of duration of exposure to workplace risk factors and the risk of musculoskeletal diseases. This provides direct evidence that reducing exposures will reduce musculoskeletal disease incidence [48]. From these studies, OSHA estimates that ergonomic programs and interventions will reduce the incidence of musculoskeletal disorders and lost workdays by a mean of 76%.

Tadano demonstrated a dramatic decrease in the incidence of repetitive strain injury in a company that used only employee monitoring and job rotation [47]. Schierhout and coworkers also showed a reduction in RSIs simply with surveillance and ergonomic education [48]. Schneider showed that, when one insurance company with 800 workers improved its workstation design, it decreased absenteeism from 4.4% to 1.6%, increased efficiency in processing claims by 137%, and saw a 9% decrease in errors [49].

Controversies

There is still international controversy about the true nature of RSIs and whether they should be considered work-related. This is due in part to the lack of outcome-based prospective controlled studies to determine treatment effectiveness. There is no defined "dose" of ergonomic hazard that can be determined to cause RSI in a given population. Several states (notably Virginia) have followed the Australian model, which claims that RSI is not work-related, and that it might not even have an organic basis at all [50]. In Australia, workers with RSI do not receive workers' compensation benefits. This presupposes that this condition is purely psychosocial. That view is supported by the fact that many clinical presentations of RSI have no neurological or physical findings, although the patients complain of pain, numbness, or weakness. Objective tests are often negative as well. The lack of definitive findings may be due in part to the lack of definitive tools to make the diagnosis objectively. RSI often occurs in workers with low pain tolerance who work in repetitive, monotonous jobs, and have many personal problems unrelated to their occupation [51]. Although this may be true for some patients, there is no scientific evidence to date to suggest that this is true in the majority of patients.

Repetitive strain injury is a broad, multifaceted condition. Sweeping it under the legislative carpet will not lower the incidence of employee pain or increase worker productivity. It will merely silence the complaints or shift medical coverage for the problems to the private sector. These problems must be addressed directly and primarily in the workplace rather than in the clinic. Through prevention, the biggest impact of intervention will be felt.

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