Trauma Management in Orthopedics

K. Mohan Iyer
Editor

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Dedicated to my wife,
Nalini K. Mohan
And
Daughter, Dr. Deepa Iyer
M.B.B.S, MRCP(UK)
And
Son, Mr. Rohit Iyer, B.E

Foreword

Several decades ago I was fortunate to hear Dr. Iyer speak about a limited, posterior greater trochanteric osteotomy as an adjunct to a posterior approach to the hip. Since then I have used this method, as it allows easy access to the hip for joint replacement and then a secure posterior capsule and short external rotator muscle repair upon joint closure. Postoperative dislocations ceased to be an issue. As you might recognize, I have looked forward to additional contributions from Dr. Iyer, and here we have it – General Principles of Orthopedics and Trauma, Orthopedics of the Upper and Lower Limb and Trauma Management in Orthopedics (Springer).

What a huge task to organize such books: Deciding on the material to be included, writing multiple chapters, and asking for skilled contributors who will embrace the challenge and have the talents to write either a general or subspecialty chapter. The text is aimed at the newcomer to this field of medicine, and it will serve that purpose quite well. I have always felt the best approach to learning orthopedic surgery is to read, cover to cover, a text such as this, aggressively study anatomy, read about the problems in the patients under one's care, read subspecialty texts, and read at least the abstracts in selected journals. By doing these things one can be an educated person in the field – but it starts with the basic text!

In addition to the fundamentals, Dr. Iyer has added details about trauma and regional orthopedics. A cad has said only two types of doctors are necessary, and the others are optional. One of these is a physician who cares for broken bones. Details about fractures are essential to the field and to humanistic patient care. The regional chapters serve as a transition to the later reading about each anatomic region in detail, what will be required to become an orthopedic surgeon.

So there you have it. An editor who is an energetic, dedicated scholar and teacher. Plus, the type of textbook most needed to jump into the field of musculoskeletal medicine and surgery. Learning is a joy. Lucky readers, enjoy the intellectual journey.

Rochester, USA Robert H. Cofield, M.D.

Preface

This book is mainly an introduction to the principles of Orthopedics, which is written by different Orthopedic Surgeons who have specialized in, or are interested in, the subjects they have written in. This volume concentrates on Trauma in various regions, such as the upper limb, lower limb and spine.

I was an undergraduate and post-graduate teacher at the University of Liverpool, UK, and the University of London, UK, for the undergraduates and for the final FRCS candidates. On returning home to Bangalore, India, I was an undergraduate teacher at St. John's Hospital, Bangalore, India, and at M.S. Ramaiah Medical Teaching Hospital, Bangalore, India, and I am indebted to all my students for their constant desire to master Orthopedics at their young age. Above all, I would like to thank all my teachers who did not spare any effort to discuss with me topics of Orthopedic interest, both in the lecture hall and in their spare time.

I am deeply indebted to my dear friend, Mr. Magdi E. Greiss, M.D., M.Ch. (Orth), FRCS, Senior Consultant Orthopedic Surgeon North Cumbria University Hospitals, UK, Former President, BOFAS, UK, for his timely help in specially preparing the snaps that have been used in this book, despite him being extremely busy in setting up of a foot and ankle clinic for the World Orthopaedic Concern in developing countries.

I would express my sincere thanks to Mr. Adhish Avasthi, M.B.B.S., M.S. Orth., MRCS Registrar Orthopedics and Mr. Richard Hill, M.B. Ch.B., FRCS Ed, FRCS (Tr & Orth) Ed, Consultant Orthopedic Surgeon, Department of Trauma & Orthopedics, St Richard's Hospital, Chichester PO19 6SE,West Sussex, UK, for his comprehensive description on Common Sports Injuries, which is a subspeciality in vogue at the moment. I would also like to thank Dr. Suhas Namjoshi, Consultant Radiologist, Hillingdon Hospital, London, UK, M.B.B.S. (Bom), DMRE (BOM), DMRE(Liverpool), FRCR (UK), for his unique chapter on 'Role of Radiology and Imaging in Orthopedics', which is written up to give students an idea of the importance of Radiology and Imaging in Orthopedics. I would thank Dr. Geethan I, M.S. Orth., DNB (Orth), Orthopedic Surgeon, Fellow, Ortho One, Speciality Hospital, Coimbatore, India, and Dr. David V. Rajan, M.S. Orth., MNAMS, FRCS (G) Consultant Orthopedic Surgeon, Director, Ortho One, Coimbatore, India, and Past

President of the Indian Arthroscopy Society for their timely help on the chapter on 'Arthroscopy of the Knee Joint', which was specially written up for this book.

I would like to thank Sharad Goyal, D.Orth. (Gold Med), M.S. Orth., DNB Orth, M.Ch. Orth. (Liv), Orthopedic Surgeon, Department of Trauma & Orthopedics, St. Richard's Hospital, Chichester PO19 6SE, West Sussex, UK for his active interest and help in completing my book.

Finally, I would like to thank Dr. Robert H. Cofield, M.D., Emeritus Chairman, Department of Orthopedic Surgery, Mayo Clinic, Professor of Orthopedics, Mayo Clinic College of Medicine, Rochester, MN, for his ever encouraging foreword for this book of mine.

I would like to express my sincere thanks to Springer-Verlag for their kind permission to allow me to reproduce 35 snaps of my book entitled *Clinical Examination in Orthopedics* (Springer) for this book of mine.

Above all I would like to thank Mr. Steffan D. Clements, Editor, Clinical Medicine, Springer (London) for his untiring guidance in the preparation of this book.

I would like to express my sincere gratitude and thanks to all the Orthopedic Surgeons for their valuable contribution in their subspecialities. This textbook is mainly valuable and a must for the beginner who faces Orthopedics as he encounters in daily life, and, when combined with my book entitled *Clinical Examination in Orthopedics* (Springer), would make him complete in all aspects of Orthopedics, both clinical and theoretical.

I am very grateful to my son who has helped me in the tables, corrections, diagrams, charts and formatting of this book and its presentation.

(Dr. K. Mohan Iyer)

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Chapter 1
Polytrauma

Shaishav Bhagat and Bhavik M. Shah

The Multiply Injured Patient

The treatment of patients with multiple injuries changed considerably in the 1970s with the introduction of early fracture fixation. A number of studies showed the value of early femoral fracture fixation in particular, however, and surgeons quickly adopted the philosophy of early total care, fixing all major fractures as soon as possible after admission. This philosophy was challenged in the 1990s by surgeons who pointed out that early time-consuming surgery was not appropriate for all patients, particularly those who were very seriously injured or who presented with severe chest or head trauma. Thus, the concept of damage control surgery was initiated, and this philosophy is widely followed today.

There have been major advances in intensive care and in the understanding of the problems of systemic inflammatory response syndrome (SIRS), adult respiratory distress syndrome (ARDS), and multiple organ failure (MOF).

Epidemiology of Polytrauma

Polytrauma could be due to a number of different causes including gunshot injuries, explosions, airplane and train crashes, earthquakes, and other natural disasters. Commonly, we come across falls from a height and motor vehicle accidents.

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According to WHO 2002 report, road traffic accidents are the 11th most common cause of death. This situation is clearly changing, however, and it has been estimated that road traffic accidents will be the third commonest cause of death after heart disease and unipolar major depression by 2020 [1].

Structure of Trauma System

The objective of the system is to match the needs of patients to the most appropriate level of care. This has led to the development of level I, II, III, or IV, which in turn is dependent on the commitment and resources of the medical staff and administration to trauma care of a particular facility or hospital.

The configuration of the trauma team receiving patients is variable but includes accident and emergency physicians, nurses, allied health personnel, and the trauma surgeon as the team leader. Various subspecialists in general surgery, orthopedics, neurosurgery, cardiothoracic surgery, anesthesia, intensivist, and pediatrics are readily available at a level I center. The receiving facility should have a dedicated area for the resuscitation of trauma patients as well as a dedicated operating room available 24 h a day. A resuscitation room should be well equipped with devices for the warming of fluid, rapid infusers, blood bank, life-support systems, and appropriate surgical supplies for the performance of lifesaving procedures. Facilities for radiology services should be within the same premise. Staffing levels are maintained at optimum level with more experienced staff supporting the more junior trainees.

Following the acute phase of resuscitation and operative intervention, trauma victims need continuous monitoring. These patients are susceptible to complications such as sepsis, adult respiratory distress syndrome (ARDS), and multisystem organ failure. Subsequent care includes supervision of the patient, further rehabilitation, physiotherapy, assessment of nutritional status, assessment of physical and emotional health, and finally if any disability that may bring about lifestyle changes are evaluated. As the patient nears discharge, arrangements for home needs and potential placement are made by social services and case care coordinators. The availability of and relationships with rehabilitation centers and chronic nursing facilities are essential for injured patients.

Assessment of Trauma Victim

Different scoring systems are in use in different parts of world which attempt to assign a numerical value to the multiply injured. This allows more systemic evaluation and helps create a common language for communication between trauma facilities. Commonly used scoring systems are Glasgow coma scale for brain injury and injury severity score.

Glasgow coma scale

Parameter	Score
Eye opening	
Spontaneous	4
To voice	3
To pain	2
None	1
Verbal response	
Oriented	5
Confused	4
Inappropriate words	3
Incomprehensible sounds	2
None	1
Motor response	
Obeys command	6
Localized pain	5
Withdraws to pain	4
Flexion to pain	3
Extension to pain	2
None	1

The Glasgow coma scale is shown as above. It ranges from 3 to 15, with 15 being normal. There are three sections: eye opening, verbal response, and motor response, with increasing scores based on increasing patient response.

The injury severity score is based on the Abbreviated Injury Scale (AIS). The AIS gives a score of 1–6 for each body system: external, head and face, neck, thorax, abdomen and pelvic contents, spine and extremities, and bony pelvis. Score 1 represents a minor injury; 2, a moderate injury; 3, a severe but not life-threatening injury; 4, a severe life-threatening injury; 5, an injury where survival is uncertain, and 6, an unsurvivable injury. The ISS is computed by squaring the scores of the three most severely injured body systems and adding them together. Any patient with individual AIS of 6 is given an ISS of 75.

Example of AIS for musculoskeletal injuries

Injury	Score
Contusions/sprains	1
Interphalangeal dislocation	1
Digital fracture	1
Hind- or midfoot dislocation	1
Patellar tendon laceration	2
Hip dislocation	2
Calcaneus fracture	2
Medial malleolus fracture	2
Closed humeral fracture	2
Clavicle fracture	2
Open humeral fracture	3

(continued)

Injury	Score
Crushed elbow or shoulder	3
Severe degloving injury	3
Femoral fracture	3
Open tibial fracture	3
Above knee amputation	4
Severe pelvic fracture with blood loss ≤20 % by volume	4
Severe pelvic fracture with blood loss ≥20 % by volume	5

The Revised Trauma Score (RTS) is based on the Glasgow coma scale, the respiratory rate, and the systolic blood pressure. It is shown below [2]. The most sophisticated scoring system is the TRISS score, used to predict the probability of survival. This is calculated from the Revised Trauma Score and the injury severity score but also incorporates a number of coefficients (*b*0–*b*3) derived from multiple regression analysis of the Major Trauma Outcome Study (MTOS).

Revised trauma score

Result	Score
Respiratory rate (breaths/min)	
10–29	4
>29	3
6–9	2
1–5	1
0	0
Systolic blood pressure (mmHg)	
>89	4
76–89	3
50–75	2
1–49	1
0	0
Glasgow coma scale score	
13–15	4
9–12	3
6–8	2
4–5	1
3	0
RTS = 0.9368 GCS + 0.7326 SBP + 0.2908 RR	

Formulas and age indexes used to calculate the TRISS score

Probability of survival (P_s) = $1/(1+e^{-b})$		
$b = b0 + b1$ (RTS) + $b2$ (ISS) + $b3$ (age index)		
Age index = 0 if patient <55 years, 1 if patient ≥55 years		
	Blunt	Penetrating
*b*0	−0.4499	−2.5355
*b*1	0.8185	0.9934
*b*2	−0.0835	−0.0651
*b*3	−1.7430	−1.1360

The usefulness of scoring systems has been called in to question. In many parts of the world, there are variations from the original scores. The authors aim to highlight the basic components of such systems and their prognostic value linked to survival and overall outcome for our patients with polytrauma.

Resuscitation

Prehospital Management

The philosophy behind prehospital management is to allow on-scene evaluation and treatment of trauma patients. This varies considerably and depends on the level of training of the provider, local standards and protocols, and available resources. There are four levels of providers: first responder, emergency medical technician (EMT), paramedic, and prehospital critical care provider. On one end of the spectrum, the first responders are usually police or firefighters, and they are the first people to arrive at the scene, whereas on the other end, the prehospital critical care providers include critical care-trained paramedics, nurses, respiratory therapists, and physicians.

Most teams will do “scoop and run” by delivering the patient as quickly as possible to an appropriate hospital. Basic resuscitation with maintenance of the airway, breathing, and circulation is undertaken, but it is usually counterproductive to attempt more until the patient is in an appropriate hospital.

Hospital Resuscitation

Hospital resuscitation should be undertaken according to the basic principles laid down by the American College of Surgeons and demonstrated in their Advanced Trauma Life Support (ATLS) courses. In many countries, attendance at one of these courses, or an equivalent course, is mandatory during orthopedic training. A brief summary of AATLS protocol is given below.

Resuscitation/treatment protocol based on ATLS guidelines

1. Primary survey and resuscitation (patient stabilization)
   A Airway and cervical spine
   B Breathing and oxygenation
   C Circulation and hemorrhage
   D Dysfunction of the CNS
   E Exposure and environmental
2. Consider transfer to more appropriate hospital if indicated
3. Secondary survey
   A Allergies
   M Medicines

P Previous medical history/pregnancy
L Last meal
E Events leading to trauma
4. Definitive care
Early total care
Damage central surgery
5. Tertiary survey
Missed injuries

A detailed description of the ATLS guidelines and protocols is beyond the scope of this chapter, and the readers are encouraged to refer to the ATLS manual. Main principles can be summarized as below.

- The important initial steps are to check that the airway is clear and maintained using an oropharyngeal airway, nasopharyngeal airway, endotracheal tube, or a cricothyroidotomy as indicated.
- Breathing and oxygenation are maintained by examining for and treating a blocked airway, pneumothorax, tension pneumothorax, hemothorax, flail chest, or pericardial tamponade.
- It is vital to control hemorrhage and maintain circulation, remembering that bilateral femoral fractures and pelvic fractures may be associated with significant occult blood loss.
- Fluid resuscitation is achieved through two large-bore intravenous cannulas, one in each cubital fossa.
- An immediate crossmatch is undertaken, although O+ or type-specific blood may be required.
- A thorough examination of the abdomen, pelvis, and limbs is essential, looking for signs of abdominal and pelvic bleeding, pelvic instability, and hemorrhage and limb damage, particularly open fractures.
- A complete CNS examination is undertaken to check the patient's responsiveness and score on the Glasgow coma scale. In conscious patients, a neurological examination of the limbs is important.
- Radiographical examination of the chest and pelvis is mandatory, and radiographs of the head, neck, and spine are undertaken if clinically required.
- Once the patient is adequately stabilized, a secondary survey and appropriate investigations such as MRI scans are obtained.
- A management plan for definitive treatment is then decided, with life-threatening injuries treated first.
- It is important to carry out a tertiary survey within 24 h of admission after the initial treatment has been carried out.
- Studies have indicated that up to 65 % of injuries are initially missed, although these injuries are rarely life threatening.
  - The literature suggests that the number of missed injuries correlates with the ISS of the patient and over 50 % of missed injuries are musculoskeletal.
  - Analysis suggests that over 50 % of missed injuries are potentially avoidable.

General Principles of Fracture Treatment in Polytrauma Patients

Early Total Care

In the early 1980s, the concept of early total care of major skeletal injuries had become accepted. Several studies on femoral fracture fixation in particular showed reduced pulmonary complications and hospital stay. This concept was widely popularized and extended to include virtually all fracture types. A detailed analysis comparing early versus late fixation with regard to various factors was published by EAST practice management guidelines workgroup shown below [3].

An analysis of 1,227 patients who had early or late long-bone fixation (usually femoral)

	Improved results with early fixation (%)	No difference between early and late fixation (%)
Mortality	0	100
Multiple organ failure	0	100
Hospital costs	0	100
ARDS[a]	46.1	53.9
Pulmonary complications[a]	67.0	33.0
Pneumonia[a]	19.8	80.2
Ventilator days[a]	13.6	86.4
ICU days[a]	49.0	51.0
Hospital days[a]	42.6	57.4
Systemic infection[a]	52.9	47.1

[a]Showed improvement with early fixation

The problem with this approach was that it was applied to all patients without taking in to consideration the severity of the injury and coexisting chest trauma. Though reduction in morbidity was noticed, no benefit was observed with regard to reduction in MODS or subsequent mortality. This led to better understanding of the factors associated with adverse outcome in polytrauma patients. This also led to the birth of damage control surgery [4].

Factors Associated with Poor Outcome in Polytrauma

Unstable condition or difficult resuscitation
Coagulopathy (platelet count < 90,000)
Hypothermia (<32°C)
Shock and >25 units of blood
Bilateral lung contusions or initial chest radiographs
Multiple long bones plus truncal injury AIS ≥ 2
Probable operating time >6 h
Arterial injury and hemodynamic instability (RR < 90)
Exaggerated inflammatory response (I1–6 > 800 pg/mL)

The Concept of Damage Control Orthopedic Surgery (DCO)

“Damage control” is a US Navy shipboard doctrine developed to control fire and flooding in order to save the ship. Some of the situations that we come across in polytrauma patients have been compared to ship casualty; for example, flooding control (internal hemorrhage), fire suppression (inflammation), and shoring of bulkheads, decks, and frames to prevent structural collapse (fracture fixation) are simultaneously engaged to prevent sinking (death) of the vessel.

In medicine, the concept of damage control was first adopted by general surgeons, where the importance of the critical triad of hypothermia, coagulopathy, and acidosis was realized. This led to the emergence of short, focused early surgeries specifically aimed at preserving life.

The thinking behind DCO is that the clinical course following polytrauma is determined by three main factors: the initial degree of injury (the “first hit”), the patient’s biological response, and the type of treatment (the “second hit”).

Evidence indicates that early reamed femoral nailing is associated with significantly higher levels of interleukin-6 and elastase, where as primary external fixation and secondary nailing is associated with less blood loss, shorter operating times, and a lower incidence of multiple organ failure (MOF) and adult respiratory distress syndrome (ARDS) than primary intramedullary nailing. In a selected group of polytrauma patients, there is logic in delaying definitive surgery until the condition of the patient improves.

Multiply Injured Patients: Basic Physiology and the Inflammatory Process

The systemic metabolic response to injury is temporal and represented early by the *ebb phase*, which is dominated by cardiovascular instability, alterations in circulating blood volume, impairment in oxygen transport, and heightened autonomic activity. After resuscitation, the *flow phase* occurs. Hyperdynamic circulatory changes, fever, glucose intolerance, and muscle wasting are responses of this period.

Inflammatory Response

Inflammation plays a major role in determining the outcome and development of the major complications of trauma: adult respiratory distress syndrome and the multiple organ dysfunction syndrome and subsequently death.

The inflammatory response consists of two components: a proinflammatory process known as the systemic inflammatory response (SIR) and an anti-inflammatory response known as the counter-regulatory anti-inflammatory response (CAR). These two processes work in conjunction to assure that the inflammatory process is controlled and focused on improving the patient's condition. Should the balance be lost, significant complications can take place [5].

Patients with traumatic injuries may be in one of four categories [6]

1. No or little evidence of any systemic reaction. The recovery is determined by the severity of the injury, and no organ dysfunction results
2. A mild form of the systemic inflammatory response syndrome (SIRS) develops involving one or two organs but quickly resolves in several days
3. Massive SIRS develops rapidly after the initial trauma, and the patients may die rapidly
4. The initial course of SIRS is less severe but deteriorates markedly several days or more from the initial injury. This may occur after a secondary insult. The patients have organ failure and may die

Different theories exist regarding development of posttraumatic complications. The macrophage theory suggests adherence of neutrophils to endothelial lining. This has protective effect on toxic metabolites released from neutrophils. Toxins lead to breach in the integrity of the endothelial wall and allow exudation causing lung or organ failure [7].

One hit phenomenon has been linked to the intense inflammatory reaction, the capacity of which exceeds that of counter-regulatory anti-inflammatory response leading to MODS.

Second hit phenomenon is when the injury is less intense and the body can react with the appropriate counter–anti-inflammatory response. However, this finely balanced system can be thrown out of control by a second insult (further trauma, infection, prolonged operative procedure, etc.), causing SIRS to flourish, and this leads to MODS and death. *This is the situation that the concept of damage control orthopedics was devised to minimize*.

How to Decide, Which Patient for DCO? [5]

The idea of initial assessment during resuscitation is to determine whether the patient with multiple injuries can withstand early definitive surgical care without overwhelming the inflammatory response (avoiding second hit). It is important to obtain the patient's history from the injury scene, ambulance transport, and resuscitative course, as well as the injury patterns, based on which the patient may be classified into one of four groups.

The Stable Patient

No shock.
Minor-associated injuries may be multiple fractures.
Treat with the preferred method of care recommended for given fracture type.
The timing of surgery is usually in the first 24–36 h.

The Unstable Patient

Patient having continuous resuscitation.
Major non-lifesaving procedures must be avoided.
The initial treatment of the long-bone fracture can be with skeletal traction.
When clinical course becomes defined, definitive surgery can be performed.
If patient remains unstable, external fixation of the fractures should be considered.

The In Extremis Patient

Major insult and is never adequately resuscitated in the initial 24 h.
No major non-lifesaving surgical procedure in the short term.
External fixation of the long-bone fractures as a bridge to definitive internal fixation.
Temporary skeletal traction can be employed in the acute resuscitation period.
If the patient is in the OR for lifesaving surgery, external fixation of the long-bone fractures should be performed in concert with the lifesaving surgery.

The Borderline Patient

This patient is the most difficult to define.

Lower extremity long-bone fractures, especially of the femur and pelvic ring injury, associated with severe non-orthopedic injuries like head, chest, or abdominal genitourinary injuries.

The initial response to injury and treatment may compromise the patient's ability to withstand the second surgical hit necessary for the management of the orthopedic injuries. Therefore, the borderline patient has the propensity to deteriorate and develop major complications and die. So, these are the patients where some objective criteria are useful as mentioned in the literature.

Indications for Damage Control Surgery

Polytrauma + ISS > 20 and thoracic trauma (AIS > 2)
Polytrauma with severe abdominal/pelvic trauma and hemodynamic shock (BP < 90 mmHg)
ISS ≥40
Bilateral lung contusions
Initial mean pulmonary arterial pressure >24 mmHg
Pulmonary artery pressure increase >6 mmHg during long-bone intramedullary nailing

Summary

The goal of the management of polytrauma victim is the survival with normal cognitive function and minimum resultant disability. In the initial care of the MIP, orthopedic procedures and eventual musculoskeletal function are of little concern except within the context of the orthopedic intervention required to enhance the patient's immediate survival potential. The recognition that malunions, nonunions, limb length discrepancies, joint contractures, and chronic infection can be addressed by delayed reconstruction procedures allows the orthopedic trauma surgeon to focus on the overall immediate needs of the patient and not be distracted by concern over optimal fixation techniques for individual orthopedic injuries.

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Chapter 2
The Shoulder

K. Mohan Iyer

Fractures of the Clavicle

Most fractures of the clavicle are caused by a fall on the shoulder and some fractures are also caused by a fall on the outstretched hand.

The most common site of fracture of the clavicle is at the junction of its middle and outer thirds. When displaced, the outer fragment is downward.

Treatment

The most traditional way is by bracing the shoulder backward by a figure of eight bandage, with the aim of getting the two fragments together. This has been abandoned as it has the disadvantage that these bandages interfere with venous return of the upper limb. Many agree that only an arm support by a simple sling is enough for the relief of pain. The position of the fragment remains in perfect position, as moderate displacement will not interfere with union and the functions of the shoulder is not affected and hence should be accepted. The sling should be worn for 3 weeks, by which time the pain subsides, and active shoulder exercises should be started to regain normal shoulder mobility.

Fractures of the clavicle unite readily, and the only residual deformity is a palpable bump over the fracture, which in children, remodeling takes place very early to resume a normal contour of the shoulder. In adults, some thickening may persist

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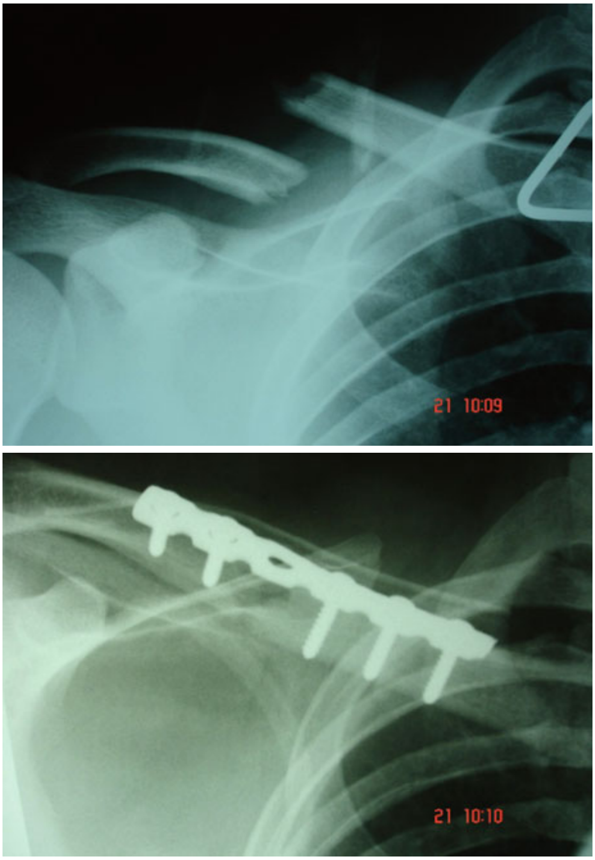


Figs. 2.1 and 2.2 Fracture of the clavicle. Treated by internal fixation (Courtesy of Dilip Malhotra, Bahrain)

permanently, and if the patient is seriously concerned about it, operative smoothening of the bony prominence may be undertaken. In young ladies who are extremely concerned about this cosmetic deformity, open reduction, and internal fixation (Figs. 2.1 and 2.2) of the fracture with an intramedullary pin or plate and screws may be considered. This operation is seldom advised, as the bony deformity is avoided at the expense of a scar.

The nonunion rate in a fracture clavicle is less then 1 %, and hence, the operative treatment is only reserved in cases where there is a widely displaced and severely comminuted clavicle.

Fractures of the Scapula

Fractures of the scapula usually occur with direct injuries.

Fractures of the Body of the Scapula: Though these fractures may be comminuted, there is no important displacement because they are held by muscle attachments both on the deep surface and on the superficial surface of the bone.

Treatment: The overall treatment is mainly directed toward restoration of shoulder function. Initially, a sling is used when there is pain initially, and when the pain begins to subside, intensive active and passive movements are carried out. The fracture usually extends from the scapular notch to the axillary border so that the part carrying the articular surface is detached in one piece from the body of the bone. The glenoid fragment is usually downward, but rarely, the displacement is not so severe because the soft tissues help it to retain this fragment in place.

Once the pain subsides, shoulder exercises are begun with active and passive movements and restoration of shoulder function.

Fracture of the Acromion Process: The fracture usually occurs at a variable distance from the tip of the acromion process, usually with any displacement, and it is comminuted and displaced downward.

If the fracture is just an undisplaced fracture or merely a crack, then shoulder exercises should be started once the initial pain settles down. If the acromion is severely comminuted, then an operative intervention to excise the acromion is indicated. Postoperatively, the arm is rested in a sling, whereafter exercises are started.

Fracture of the Coracoid Process: Fractures of this bone may range from an undisplaced crack to severely comminuted fractures, along with downward displacement of the coracoid process. In either cases, the fracture is disregarded and careful attention given to shoulder exercises when the initial pain settles down.

Dislocations of the Medial End of the Clavicle

This condition is extremely rare as the bone breaks easily and the ligaments supporting this articulation are strong; particularly, the rhomboid or the costoclavicular ligament is very strong and resists the tendency of the clavicle to slip upward, medially, and forward in line with the slope of the joint cavity. The dislocation is usually anterior and medially along with complete rupture of the costoclavicular ligament. Subluxation may also occur without breaking if the capsule and ligaments are stretched.

Posterior dislocation is very rare and is caused by direct violence, for this may injure the large vessels in the superior mediastinum.

Subluxation can be reduced by direct pressure over the clavicle, while the shoulder is simultaneously pulled upward and outward. This reduction is difficult to maintain and is usually held by a figure of eight bandage along with axillary pads for 6 weeks to allow the ligaments to heal.

In posterior dislocations, manipulation is usually ineffective, and hence reduction by an open operation is advocated.

Resection of the inner end of the clavicle is only used as a last resort for relief of symptoms and minimal residual disability.

Recurrent Dislocation of the Sternoclavicular Joint

In a very high proportion of cases, dislocation of the sternoclavicular joint may become recurrent, despite adequate and prompt treatment of the first episode. In this condition, the clavicle springs forwards when the shoulders are braced backward and clicks back into place when the shoulders are arched forwards.

Treatment: Usually, the disability is negligible and hence left alone. An operation is indicated when it becomes extremely troublesome with repeated dislocation, when the joint is stabilized by constructing a new ligament from a strip of fascia lata than the tendon of the subclavius.

Strain of the Sternoclavicular Joint

When the sternoclavicular joint is accompanied by pain and swelling, and the joint is tender on palpation, and the clavicle not displaced, a strain of the sternoclavicular joint is diagnosed and no special treatment is required for this condition.

Strain of the Acromioclavicular Joint

When the violence is sufficient to subluxate or dislocate the joint, a fall on the point of the shoulder may cause a strain of the joint capsule. The patient complains of pain, and there is tenderness on palpation. Pain is also aggravated by full abduction of the arm, when the acromioclavicular joint is also involved in this movement.

When painful, a sling may be worn, and the shoulder exercised after the pain settles down. Recovery is often spontaneous with time and use.

Recurrent Disclocation of the Acromioclavicular Joint

The clavicle may be dislocated upward or downward at the acromioclavicular joint, but upward dislocations are more common due to a blow on the back of the acromion or a fall on the tip of the shoulder.

In upward dislocations, the acromioclavicular ligament and the conoid and trapezoid ligaments which hold the clavicle down to the coracoid are ruptured, and hence the lateral end of the clavicle slides upward and projects.

As a result of this, the patient complains of severe deformity along with difficulty in some movements, such as lifting the arm.

If the reduction has occurred spontaneously, it can be secured firmly by a Robert-Jones strapping, when broad strips of sticking plaster is passed round the elbow and the shoulder, medial to the acromioclavicular joint.

Should these measures fail, then an operation is indicated. A lag screw is inserted down the clavicle to engage into the superior cortex of the coracoid process. An alternative operation may be excision of the lateral aspect of the clavicle for about 3 cm, till the trapezoid and conoid ligament, which is very helpful.

Subluxation and Dislocation of the Acromioclavicular Joint

Injuries of the acromioclavicular joint are more common than injuries of the sterno-clavicular joint because the joint has a weak capsule and is vulnerable in falls of the shoulder. The joint depends largely on the accessory extra-articular ligaments, namely, the conoid and the trapezoid ligaments. Injuries are common by falls onto the outer prominence of the shoulder, when the acromion is forced downward, such as rugby/football players.

Pathology

Subluxation: In this condition, the joint capsule is torn, and the acromion is slightly displaced downward from the lateral end of the clavicle. Severe displacement is prevented by the intact conoid and trapezoid ligaments, which anchor the clavicle to the coracoid process.

Dislocation: When the joint is dislocated, the mechanism is the same but with more violence, when the conoid and trapezoid ligaments are torn and the acromion is displaced medially and markedly downward.

Treatment

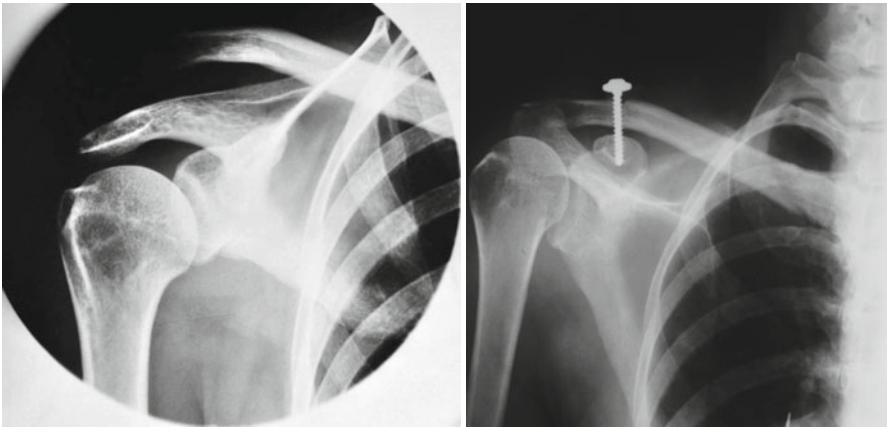
The strapping which is given from the midpoint of the clavicle round a flexed elbow is not recommended these days as it is ineffective and unnecessary in subluxation and inadequate for dislocation.

Subluxation: Any disability from subluxation of the acromioclavicular joint is normally insignificant and can be accepted. The only treatment is a sling for the first 2 weeks for pain, followed by intensive exercises to the shoulder girdle.

Dislocation: Because it is difficult to hold the joint in a reduced position by external splintage, an operation is usually considered.

A simple method of holding the clavicle in place is by a screw passed through the clavicle to engage into a pilot hole in the coracoid process (Figs. 2.3 and 2.4). Alternatively, a wire is passed horizontally from the tip of the acromion across the acromioclavicular joint into the clavicle. The screw or the wire is removed after 10–12 weeks, by which time the ligaments should have healed.

Late Reconstruction: In late and long-standing cases, a late reconstruction is indicated. The ideal technique is in which the coracoacromial ligament is detached from the acromion process and sutured to the stump of the clavicle after excision of its outer end, distal to the attachments of the conoid and trapezoid ligaments. After this operation, further stability is maintained by a screw to the coracoid process as described above.



Figs. 2.3 and 2.4 Dislocation of the acromioclavicular joint (Courtesy of Magdi E. Greiss, Whitehaven, Cumbria, UK)

Recurrent Dislocation of the Shoulder

See Chapter 1 in my book entitled ‘Orthopedics of the Upper and Lower Limb’ (Springer)

Rupture of the Tendinous Cuff of the Shoulder

See Chapter 1 in my book entitled ‘Orthopedics of the Upper and Lower Limb’ (Springer)

Fracture Neck of Humerus

Fracture neck of humerus is a common injury seen in the elderly, mainly women, due to rarefaction by osteoporosis. The fracture mainly results from a fall. Displacement is variable, and it may be ranging from none or there may be moderate to severe tilting of the head fragment so that the humeral shaft may be tilted and appears to be abducted or adducted in relation to it. A very common finding is that in majority of cases, the fragment is impacted so that the entire bone moves in one piece, and this feature is extremely important from the treatment point of view.

Diagnosis

The fracture may easily be overlooked, if it is impacted, since the patient can abduct his arm, without severe pain. The fracture should be suspected in an elderly lady with a history of fall and the marked bruising in the upper and middle part of the arm which accompanies it.

X-rays may not indicate for sure whether the fracture is impacted, and this is best judged by clinical examination, when the arm can be moved passively through a reasonable range without causing severe pain, and vice versa, when there is a fracture.

Treatment

It is very important to keep in mind that even severely displaced fractures can heal very well with restoration of function that is adequate for an elderly woman. Also that the shoulder is very prone to become stiff if it is immobilized for a long time, especially in the elderly.

Impacted Fractures: If the fracture is impacted, immobilization is not needed, and shoulder movements, both active and passive, should be started at the earliest to prevent stiffness.

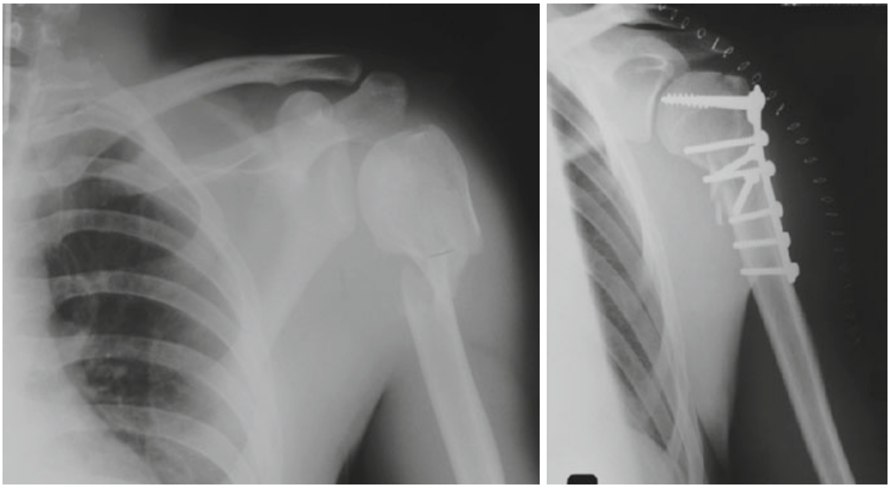
Unimpacted Fractures: If the fracture is not impacted, shoulder exercises should be prevented because any movement of the shoulder will cause pain. In these cases, the arm is supported by a sling along with a body bandage to hold the arm to the chest wall for the first week. Finger, wrist and elbow exercises should be started from the very start, and shoulder exercises started after 2 weeks. After this, intensive shoulder exercises may be carried out without any fear, as the fracture will have become gummy.

Alternative Method

There is an alternate method if there is considerable displacement as in young patients, reduction can be obtained by reduction of the fragment by manipulation, with the distal fragment being brought in line with the head fragment. To maintain the fracture, it may be necessary to place the limb in a shoulder spica or an abduction frame for 4 weeks.

Operative reduction is rarely justified if after manipulation, it is very difficult to hold the fragments together, especially in a "three part fracture," which is associated with a fracture greater tuberosity or a dislocation of the shoulder. Here, the choice rests between a plate and screws (Figs. 2.5 and 2.6) or an intramedullary nail, being inserted retrograde through the olecranon fossa.

In the more severe "four part fracture," there is always a risk of avascular necrosis or nonunion, and these cases are best treated with a replacement arthroplasty of the head of the humerus, with a long-stemmed prosthesis.



Figs. 2.5 and 2.6 Unstable fracture neck of humerus, treated by open reduction and internal fixation (Courtesy of Magdi E. Greiss, Whitehaven, Cumbria, UK)

Complications

1. Joint stiffness: In the elderly, patients are very prone to become stiff, and hence early mobilization is the encouraged as early as possible.
2. Arterial injury: There is a risk of arterial injury to the brachial artery by a sharp spike of bone, particulary when the shoulder is dislocated. This is an acute vascular emergency, or it may lead to a traumatic aneurysm along with vascular and neurological deficiency.
3. Nerve injury: Occasionally, a fracture of the neck of the humerus may be complicated by an injury to the axillary nerve, which is noted by the patient's inability to actively abduct the shoulder along with numbness or anesthesia over a small area at the outer side of the upper arm. Treatment is expectant, and there is gradual recovery in most cases.

   Very rarely there is damage to the brachial plexus either from direct injury to the nerves when the shoulder is dislocated or from progressive stretching of the nerves over a traumatic aneurysm of the brachial artery.
4. Dislocation of the shoulder: It is very rare for the fracture to be associated with a dislocation. The treatment is to reduce the dislocation first and then treat the fracture on its merits.

Juxta-Epiphyseal Fracture Separation

In children, this injury corresponds to a fracture of the neck of humerus, usually with detachment of a marginal piece from the shaft. If there is severe displacement, a reduction should be tried and, if it is not possible, then should accept the position because of the virtue of remodeling in children.

Fracture of the Greater Tuberosity of the Humerus

This is usually caused by a fall on to the shoulder in the elderly. Usually, there is not much of displacement, though it may be comminuted in many cases.
Treatment: The treatment mainly depends on the severity of displacement of the fragment.

When the fragment is not displaced, even any form of splintage is unnecessary, and shoulder exercises are mainly indicated to restore shoulder function and movements.

If the fragment is widely displaced, then an accurate reduction is very essential for the shoulder function and movements to return. It may be possible to replace the fragment by merely abducting the arm, which position is difficult to maintain without holding the limb in a plaster or splint. Hence, it is preferable to do an open reduction and fix the fragment with a screw, when early exercises may be given and shoulder movements can be restored adequately.

Complications

Painful Arc Syndrome: Thickening or irregularity of the greater tuberosity may interfere with free abduction because the thickened area may impinge on the acromion process or the acromioclavicular ligament, with resultant pain.

The majority of cases settle down nicely with treatment by exercises and very rarely do the symptoms not settle, when the need for excision of the acromion is indicated.

Scapular Disorders

For Sprengel's shoulder, winged scapula, or grating scapula, see Chapter 1 of my book entitled 'Orthopedics of the Upper and Lower Limb' (Springer).

Musculotendinous Cuff Lesions

For acute tendinitis, chronic tendinitis or painful arc syndrome, frozen shoulder or adhesive capsulitis, or supraspinatus tears, or lesions of the biceps tendon like bicipital tendinitis or rupture of the biceps tendon, see Chapter 1 of my book entitled 'Orthopedics of the Upper and Lower Limb' (Springer).

Chapter 3
The Arm

K. Mohan Iyer

Fracture of the Shaft of the Humerus

Fractures of the shaft of the humerus are rare in children, but they can occur at any age. It usually occurs in the midshaft region by a twisting force, when it is spiral or by a direct blow, when it may be transverse, short oblique or comminuted. Displacement may be variable ranging from no displacement to markedly displaced. In the proximal humerus, there is an increased incidence of carcinomatous metastases.

Treatment

The overall alignment should be satisfactory with an end to end contact of at least half or two-thirds the circumference of the humerus. The union should be adequate without the use of continued aplintage and the need for exercises to be started as early as possible.

When the fragments are displaced more than normal, a reduction is usually done and the arm immobilized in a "U"-shaped plaster encircling the fracture, from the shoulder to the elbow. Further support can be given by a broad arm sling, and exercises to the shoulder can be started off immediately. Once the fracture becomes sticky (3 weeks), the arm can be fitted with a well-molded brace of plastic or plaster that allows mobility of the elbow as well.

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Alternative Methods

When the fracture fragments are unstable or in cases of a pathological fracture, one method is to control rotation of the fragments by a shoulder spica, which encloses the full trunk and the whole of the upper limb, with the exception of the fingers and the shoulder kept semi-abducted, with the elbow flexed at a right angle. This method is cumbersome, and an operative method is usually preferred to this. Open reduction and internal fixation is by plate and screws (Figs. 3.1 and 3.2) or by a closed intramedullary locking nail when the fracture is in the midshaft. The nail can be inserted antegrade from the greater tuberosity, but it is preferably introduced retrograde from the olecranon fossa. It is important to remember that in closed intramedullary locking nailing, the distal locking screw is in an anteroposterior direction and not transversely like the proximal screw.

In cases of a comminuted or an infected fracture, even an external fixator may be considered as an optional method of treatment, by twin-threaded pins inserted percutaneously into each fragment, when these pins are held rigidly by the external metallic bar held by cement to the external fixator.

Complications

1. Nerve injury: Injury to the radial nerve is frequently seen because of its close proximity to the bone as it winds round the posterior aspect in the radial groove and is seen in about 10–15 % of the fractures. The nerve injury is usually no more than a contusion and rarely a complete division. The effects of paralysis in the extensor muscles of the wrist and fingers are commonly known as "wrist-drop." The only sensory deficit is a small area of anesthesia or blunting of sensibility on the radial side of the back of the hand.

   Treatment: In closed fractures, it is always presumed that the nerve is only contused, and hence, recovery is always awaited. In certain cases, the nerve may be explored, and the results are good. In neglected cases, or when repair of the nerve is not possible, adequate function can be restored by tendon transfers: The pronator teres is transferred to the extensor carpi radialis brevis to extend the wrist. The flexor carpi ulnaris or the flexor carpi radialis is transferred to the extensor digitorum and the extensor pollicis longus to extend the fingers and the thumb. The palmaris longus is transferred to the abductor pollicis longus to provide for abduction of the thumb away from the palm.
2. Nonunion: Though a majority of fractures of the humeral shaft unite quite readily, very rarely they are extremely difficult.

   Treatment: It is still doubtful whether they are not uniting with a bone grafting operation with or without internal fixation. Cancellous onlay grafts may be combined with a long intramedullary nail or by plate and screws. In very difficult cases, treatment by electrical stimulation may be considered.

Fig. 3.1 Comminuted fracture of the distal humerus (Courtesy of Dilip Malhotra, Bahrain)

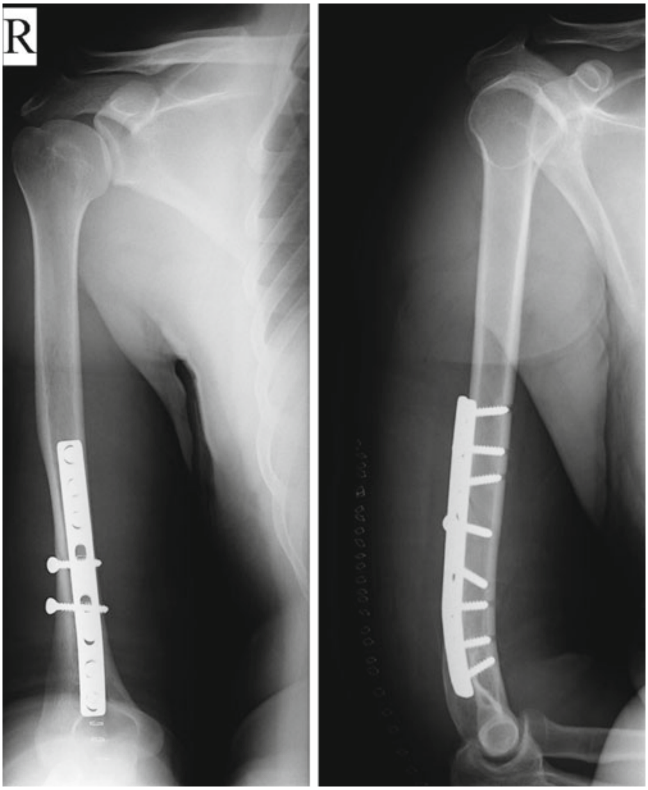

Fig. 3.2 Above fracture after ORIF with plate and screws (Courtesy of Dilip Malhotra, Bahrain)

Chapter 4
The Elbow Joint

K. Mohan Iyer

Dislocation of the Elbow

Dislocation of the elbow is a fairly common problem, which is caused by a fall on the outstretched hand and occurs in children and adults (Fig. 4.1).

Pathology

The dislocation is mainly posterior or posterolateral, which means that the forearm is displaced backward or backward and laterally with respect to the humerus (Fig. 4.2). This may be associated with a fracture of the coronoid process of the ulna or the radial head or the capitulum or the medial epicondyle,and in most cases this associated fracture is a minor one.

Treatment

The dislocation can be reduced as early as possible by a steady pull on the elbow with the forearm and elbow semi-flexed, while pressure is applied behind on the olecranon. Check X-rays are always taken to confirm the reduction, with great care to examine the check X-rays for any associated fractures which may not be seen

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Fig. 4.1 Dislocation of the elbow in an adult (Courtesy of Dilip Malhotra, Bahrain)

clearly on the initial X-ray. The elbow is immobilized by an above-elbow back slab for 3 weeks, for rest to the injured elbow and thereafter for mobilization of the elbow, shoulder and hand exercises can be started intensively with a cuff-and-collar sling.

Complications

1. Vascular or nerve injury: Occasionally, the brachial artery or one of the major nerve trunks may be injured by this dislocation, which are then treated accordingly.
2. Joint stiffness: The elbow is very troublesome with stiffness after injury, especially after a dislocation, which is mainly caused by intra-articular and periarticular adhesions. This gradually responds to active exercises. Manipulation with passive stretching should be avoided, and the stiffness increases after this.

A less serious but more common complication is the development of myositis ossificans, when new bone is formed in the hematoma beneath the stripped periosteum

Fig. 4.2 Dislocation of the elbow in a child (Courtesy of Magdi E. Greiss, Whitehaven, Cumbria, UK)

and joint capsule. This is ideally treated by an operation where the elbow is approached by a bilateral incision and the myositis cleared completely. The elbow is then transfixed in 90° by a heavy pin/nail, which is removed after 3 weeks, and exercises are thereafter started both actively and passively.

Dislocation of the Head of the Radius

This rarely occus, when the head of the radius is dislocated forward, with any disturbance to the humero-ulnar relation or without any obvious associated fracture. This occurs due to a forced pronation, and similarly reduction of this condition is carried out with supinating the forearm by direct pressure over the radial head.

It must be noted that only dislocation of the head of the radius is an extremely rare injury and it usually occurs with fracture of the shaft of the ulna—Monteggia fracture. This is the main important reason why the whole forearm should be X-rayed to include the full length of the forearm showing both the elbow and the wrist in one film.

The head of the radius may be congenitally displaced, when it is globular and lacks the normal concavity on its upper articular surface. This deformity being congenital must be remembered as it is very often bilateral in nature.

Subluxation of the Head of the Radius (Pulled Elbow)

If a young child is lifted by the wrist, the head of the radius may be pulled out of the annular ligament, and this is very common and called as "pulled elbow." There is local pain along with limitation of movements of the elbow. The displacement can be easily reduced with pushing the forearm upward and rotating it alternately into supination and pronation, usually without anesthesia.

Contusion or Strain of the Elbow

In children, particularly, an injury of the elbow may cause severe pain with limitation of the movements, in the absence of any bony injury or displacement. This lesion is probably a strain on the capsule or a contusion of the articular cartilage or periosteum. The treatment for this condition is rest in a sling for 2 weeks, followed by intensive mobilization. Manipulation of the elbow is strongly contraindicated in these cases.

Supracondylar Fracture

This fracture is very rare in adults and very common and important in children. This fracture is also very dangerous because of injury to the brachial artery. It usually occurs due to a fall on the outstretched hand when the lower fragment is usually displaced backward or laterally.

Treatment

Undisplaced fractures in children require no more than 3 weeks in above elbow plaster back slab.

When the fragments are displaced, reduction and manipulation under anesthesia is carried out. The lower fragment is brought into alignment with the proximal fragment by longitudinal traction on the hand coupled with direct pressure on the olecranon to hold the elbow in 90° of flexion. A perfect anatomical reduction is not essential, and even a slight lateral tilt of the lower distal fragment is acceptable. After reduction, the elbow is immobilized in a above elbow back slab in 90° of flexion.

When the fracture is unstable, open reduction and internal fixation is done by two percutaneous wires inserted through the condyles. The first wire passes through the lateral condyle obliquely upward and medially to engage into the medial humeral cortex. The medial wire passes through the medial epicondyle obliquely upward and laterally, with the two wires crossing just above the olecranon fossa.

All throughout this procedure, a careful close watch is kept over the circulation in the hand and fingers, and the plaster should be cut away and left free on the radial side to feel the radial pulse.

Complications

1. Arterial occlusion: Injury to the brachial artery by the sharp end of the upper fragment leads to impairment of circulation in the hand and fingers. The artery may be severed or contused. If it is contused, the lumen can occluded by a thrombosis or even spasm of the vessel wall.

   The effects of arterial occlusion vary from case to case. In a small proportion of cases, the occlusion may be very severe that gangrene of the digits may be seen. Most often enough blood gets through the collateral circulation to the hand, and hence this phenomenon is rarely seen. Due to occlusion of the blood supply to the flexor muscle of the forearm and sometimes the nerve trunks may suffer irreparable ischemic damage. The affected muscles are replaced by fibrous tissue, when it contracts and draws wrist and fingers into flexion, to be called as Volkman's ischemic contracture. If the peripheral nerve trunks are also involved in the ischemia, then there will be motor and sensory paralysis in the forearm and hand, which may be temporary or permanent.

   Treatment: In the early stages, vascular occlusion is suggested by signs of impaired circulation in the digits and particularly by the patient's inability to extend the fingers fully, along with marked pain in the forearm when passive extension is attempted. This is the most important test which should always be carried out. A positive finding should immediately alert the surgeon of vascular occlusion. In the established stage, the diagnosis is obvious from the history and the characteristic flexion contracture of the wrist and fingers.

   In the early stages, all splints and external bandages which are causing some constriction are removed. Displacement of the fragments if already not done is carried out by gentle manipulation. Heat by hot water bottles is applied over the limbs to encourage vasodilatation.

   If the above measures fail to bring about adequate circulation in half an hour, then the brachial artery is explored. If the occlusion is due to kinking or spasm of the artery, an attempt is made to relieve it by freeing the vessel and applying papaverine. If this fails, the artery is distended by the injection of saline between clamps. As a last resort, the artery must be opened and the damaged intima removed, with repair being done by a vein patch or a bridging vein graft may be required. Any operative intervention for this serious complication should include decompression of the anterior fascial compartment of the forearm and whenever possible only by surgeons with vascular expertise.

In the established stage, when restoration to normal is impossible because of severe damage to important muscles, reconstructive surgery can only improve the functional end result and when the choice of treatment varies from case to case.

In the mild cases, acceptable function may be restored by intensive exercises guided and supervised by a physiotherapist. In the usual more severe cases, the muscle shortening may be counteracted by the detachment and distal displacement of the flexor muscle origin, which is popularly known as the muscle slide operation. In extremely severe cases when the muscles are severely damaged by infarction, a reasonable result can be achieved by excision of the dead muscles and subsequent transfer of the healthy muscle which are remaining. These muscle transfers can only be combined in selective cases, with arthrodesis of the wrist. When the median nerve is damaged irreparably by ischemia, a nerve grafting may also be considered.

2. Injury to the median nerve: The median nerve is occasionally damaged by the bony proximal fragment just like the brachial artery. At first the treatment is to wait and watch in the hope that the lesion is a neuropraxia.
3. Deformity from malunion: In children, one can expect a great deal of remodeling, but an alteration of alignment cannot be corrected spontaneously, and hence the most common permanent deformity is cubitus varus.

   When the deformity is minimal, it is usually accepted. But when it is marked and not acceptable, then a supracondylar corrective osteotomy of the humerus is very helpful.

Fractures of the Condyles of the Humerus

These fractures are very rare and, often troublesome, occur commonly in children, and the lateral condyle is fractured more commonly than the medial one (Fig. 4.3).

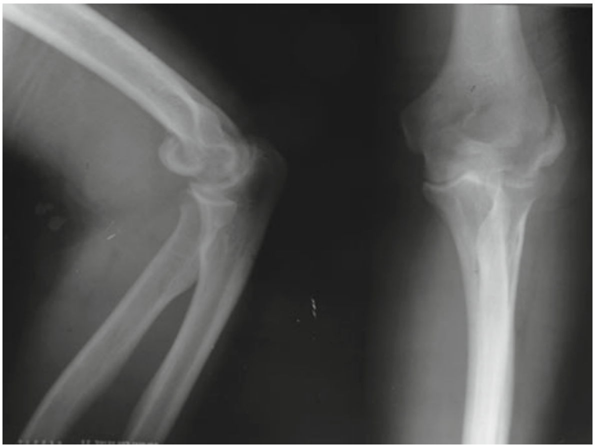

Fig. 4.3 Fracture of the lateral condyle of the humerus (Courtesy of Magdi E. Greiss, Whitehaven, Cumbria, UK)

The lateral condyle (fractured capitulum) extends obliquely upward and laterally from the capitular surface, and in children, the greater part of the detached fragment is cartilaginous, and hence the fragment appears smaller when seen radiologically. Displacement is not very severe, but even a moderate displacement should not be ignored as the fracture involves the articular joint surface.

Treatment: A simple undisplaced fracture is treated by a plaster for a few weeks followed by mobilization exercises to the elbow.

In case of displaced fractures, they should be regarded seriously because they have the potential to cause permanent disability. An attempt should be made for reduction by manipulation under anesthesia, and if successful, immobilization in a above elbow plaster with the elbow at 90° is accepted till the fractures unite.

If manipulation fails to give a perfect reduction, an open reduction with internal fixation is carried out with a small screw or "K" wire (Fig. 4.4).

Complications

1. Nonunion: Here, the fracture line remains visible on a radiograph, and the fragment consisting of a large part of the capitulum is slightly displaced upward.

   Treatment: An operation is considered, and the fracture surfaces are freshened and brought back into position, and the fragment is then fixed with a screw or a "K" wire.
2. Deformity at the elbow: The deformity is caused by persistent upward displacement of the fragment or by retardation of the growth at the lateral condyle, giving rise to cubitus valgus, where as deformity of the medial condyle causes cubitus varus.

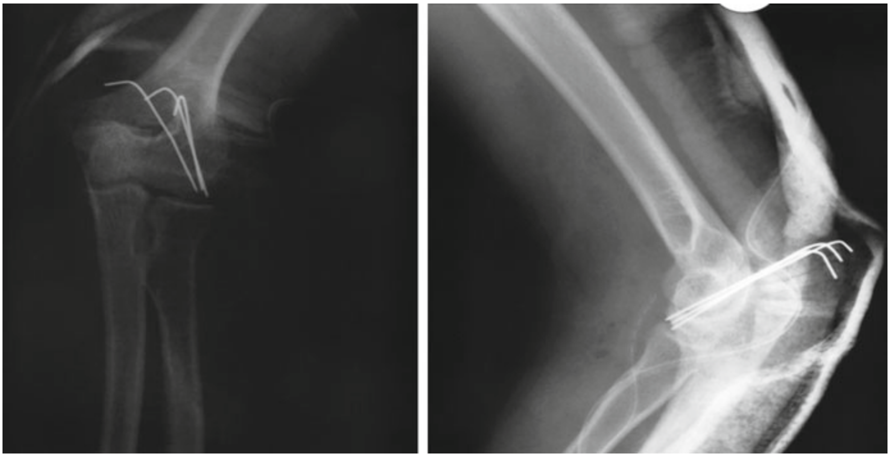

Fig. 4.4 Fracture of the lateral condyle of the humerus, treated by internal fixation (Courtesy of Magdi E. Greiss, Whitehaven, Cumbria, UK)

If the deformity is slight, it can be accepted, but if the deformity is considerable, then a corrective supracondylar osteotomy may be considered.

3. Ulnar neuritis: This is commonly seen because of frictional neuritis of the ulnar nerve behind the medial epicondyle, when if symptomatic, the ulnar nerve may be transposed anteriorly to the front of the elbow.
4. Osteoarthritis: This occurs when the displaced fragment leaves a permanent deformity at the articular surface. This occurs many years after the original injury when the elbow is subjected to heavy stress.

Fractures of the Epicondyles

This condition is more common in children, and here the medial epicondylar fractures are more common than the lateral epicondylar fractures. The injury more commonly occurs after a fall or by direct violence or it may be an avulsion injury which results in pulling off the flexor origin from the epicondyle.
Treatment: In uncomplicated cases, only symptomatic treatment is sufficient, as the displacement is never severe. The elbow is immobilized in a plaster cast for 3 weeks to relieve pain, and thereafter exercises are given to the elbow. In very rare cases is the displacement so severe to need an open reduction and internal fixation, when the fracture is held back to its place by sutures through the adjacent soft tissues.

Complications

1. Entrapment of the condyle into the joint: This occurs when the fragment is sucked into the joint, when it becomes jammed between the joint surfaces. The fragment is loose, but it retains its attachment to the flexor forearm muscles.

   Treatment: It is imperative that the fragment be removed from the joint with the patient anesthetized and the fragment extracted by fully extending the joint and by abduction of the joint, when the joint is widened on the medial side. If this maneuver fails, then an open operation is considered.
2. Traumatic ulnar neuritis: The ulnar nerve which is in close proximity to the medial epicondyle results in this condition. When it is troublesome and symptomatic, it is treated by anterior transposition to the front of the elbow.

Fracture of the Olecranon

This is usually caused by fall on to the elbow. This fracture occurs in three forms, namely, (1) a crack undisplaced variety, (2) a break with separation of the fragments, and the fracture line extends into the joint or (3) a comminuted fracture.

Treatment

1. Crack fracture: The elbow needs to be protected by an above elbow slab in a right angle for 3 weeks, after which it is removed and exercises begun to restore full movements at the elbow.
2. Clean fracture with separation: It will not be possible to reduce and hold the fragments because the triceps muscle acts to tilt and distract the fragments. Operative fixation is the best method in these cases. The fragments are exposed and fixed together, after curetting the fracture surfaces. Rigid fixation is obtained by a long coarse-threaded cancellous screw, or the fragments are fixed by a tension band wiring, which has the advantage of better fixation by axial compression of the fragment during flexion of the elbow. Postoperatively, the elbow is immobilized by an above elbow back slab with the elbow in 90° of flexion for 3 weeks, after which exercises are begun.
3. Comminuted fracture: Here, open reduction and internal fixation of the fragments do not give an acceptable apposition, and hence a contoured plate with screws is used in these cases. Another frequent treatment is to excise the fragments by dissecting them out of the triceps insertion and then secure the triceps to the end of the stump of the ulna by strong sutures passed through small drill holes in the bone. Postoperatively, the elbow is immobilized at a right angle for 3 weeks in an above elbow slab, after which the elbow is mobilized by exercises.

Complications

1. Nonunion: Olecranon fractures may fail to unite if here is a gap which persists between the two fragments, which is bridged by fibrous tissue. In the elderly patients, there may be slight weakness of the triceps, which does not cause sufficient disability. In young patients, it is preferable to excise the fibrous tissue, freshen the fracture ends, and internally fix the fracture with a long screw.
2. Malunion: This is described when the fracture fragments unite with a step or irregularity in the trochlear surface at the fracture site, which leads to the development of degenerative arthritis in later life. If the deformity is slight, the deformity is accepted, but in a young patient an operation is indicated in the form of an osteotomy or repositioning of the fragment and internal fixation with a screw or excision of the fragment if it is too small.
3. Osteoarthritis: Osteoarthritis of the elbow may develop later in life if there is a step or irregularity of the articular surface of the trochlea and it will not be severe enough to produce severe pain and stiffness unless the arm is used for heavy work.

The coronoid process is fractured unless it is with association with posterior dislocations of the elbow. Marked displacement is prevented by the strong aponeurotic fibers which are prolonged from the brachialis muscle to the bone. No special treatment is required other than that for dislocation of the elbow.

Fracture of the Head of the Radius

Fracture of the head of radius is one of the common fractures of the upper limb in young adults. It is caused by a fall onto the outstretched hand, the force being transmitted axially along the radius with impaction of the radial head against the capitulum. In majority of the cases, the fracture is no more than a vertical crack without displacement. In the rest, a segment of the disk-shaped radial head is broken away and depressed below the plane of the articular surface. At times, the radial head may be comminuted.

Diagnosis: Sometimes this fracture may be overlooked particularly if the fragments are impacted. Marked tenderness along with retricted painful movements of pronation-supination on elbow movement, particularly sharp pain on the lateral side of the joint in extreme rotation, may be indicative of a fracture of the radial head.

Treatment

1. Slight damage: If the radiographs suggest a slight damage and after union has occurred the articular surface will be smooth, conservative treatment is indicated with an above elbow plaster slab at a right angle and the forearm in a mid-prone position, for 3 weeks, after which exercises are begun.
2. Severe damage: If the radial head is severely comminuted with permanent distortion of the articular surface, then an operative excision of the radial head is considered. When the fracture is with dislocation of the elbow, this operation is deferred for 3 weeks because of the fear of development of myositis ossificans. Postoperatively, the elbow is immobilized in a plaster for 3 weeks, before active exercises are started.

There is also a recent trend toward operative reduction and internal fixation in order to prevent proximal migration of the radius, when fixation is achieved by a miniature plate and screw to the lateral aspect of the neck or a headless Herbert screw.

Replacement by a metallic or nonmetallic prosthesis may be an alternative to excision of the radius.

Fractures in Children: In children, the fracture is usually through the neck of the radius, with tilting of the head of the radius. Reduction is obtained by closed methods along with manipulation or if need be, by an operation. Excision of the head of the radius is never considered in children because of growth disturbances.

Complications

1. Joint stiffness: The range of flexion-extension and rotations at the elbow may be restricted for a long time after a badly comminuted fracture, though it has been

properly treated by excision of the radial head. In most cases, the stiffness yields gradually and slowly with active exercises carried out regularly. It must be remembered that the elbow is one joint where manipulation or forced passive movements are contraindicated.

2. Osteoarthritis: If the articular surface is left irregular and rough, wear and tear of the joint is quickened and osteoarthritis sets in. When arthritis has already set in, at that time excision of the head of the radius cannot bring relief as before the arthritis has set in.

Chapter 5
The Forearm

Naresh Shetty and K. Mohan Iyer

Simple fractures of the radius and ulna can occur at any level between the elbow and the wrist. These fractures are very unstable and are best treated by internal fixation of the both bones (Figs. 5.1 and 5.2). Closed reduction of fractures of these bones may appear satisfactory, but they have a tendency to redisplace (Figs. 5.3 and 5.4).

Isolated single bone fractures of the radius or the ulna have a high chance of nonunion (Fig. 5.5) and are best treated by internal fixation.

Monteggia Fracture

Fractures between the proximal third of the ulna and the base of the olecranon combined with an anterior dislocation of the proximal radioulnar joint were described by Monteggia in 1814. Bado coined the term Monteggia fracture in 1967 and described four different patterns of the Monteggia lesion.

Historical Background

Giovanni Batista Monteggia, a surgical pathologist and public health official in Milan, first described Monteggia fractures. In his monograph, Bado defined the

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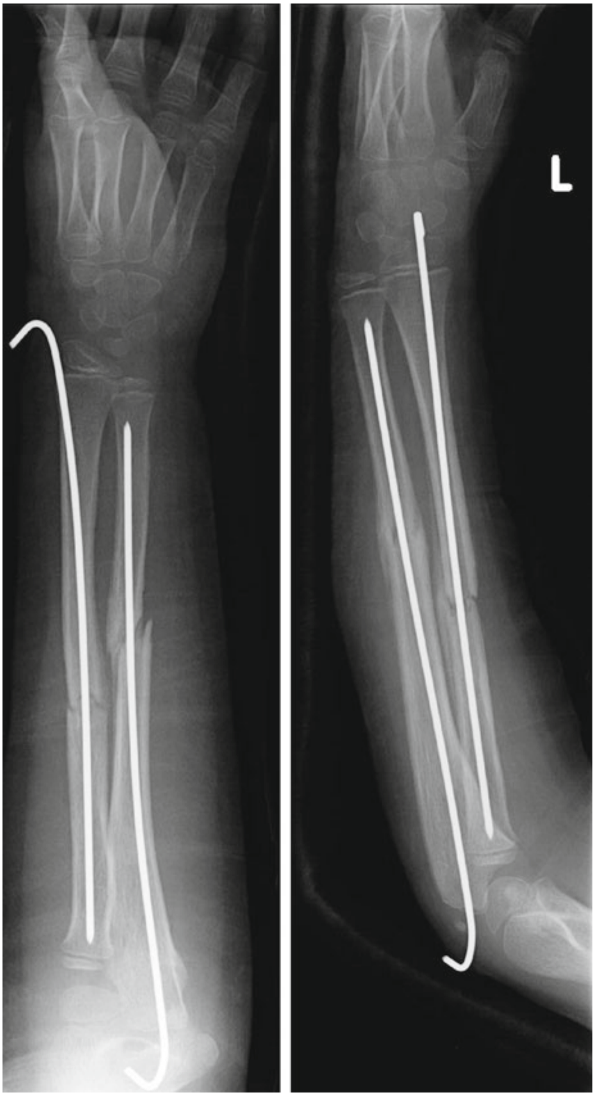

Fig. 5.1 Closed reduction and percutaneous pinning of the fractures of radius and ulna (Courtesy of Dilip Malhotra, Bahrain)

Monteggia lesion as an association of a radial head fracture or dislocation with a fracture of the middle or proximal ulna.

Classification

Bado's classification divides Monteggia fractures into four types of true Monteggia lesions and equivalent lesions

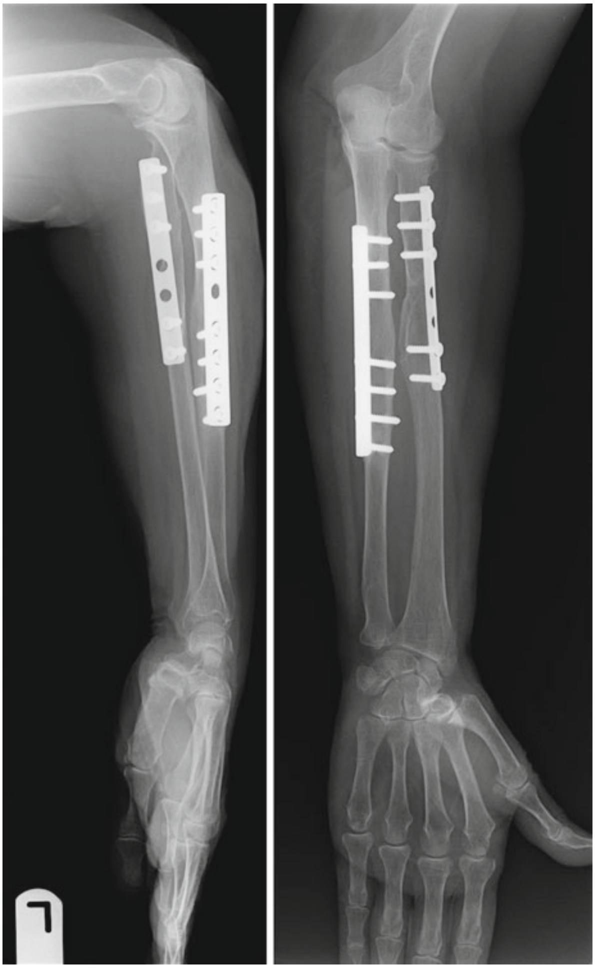

Fig. 5.2 Open reduction and internal fixation by plating of both bones of the forearm (Courtesy of Dilip Malhotra, Bahrain)

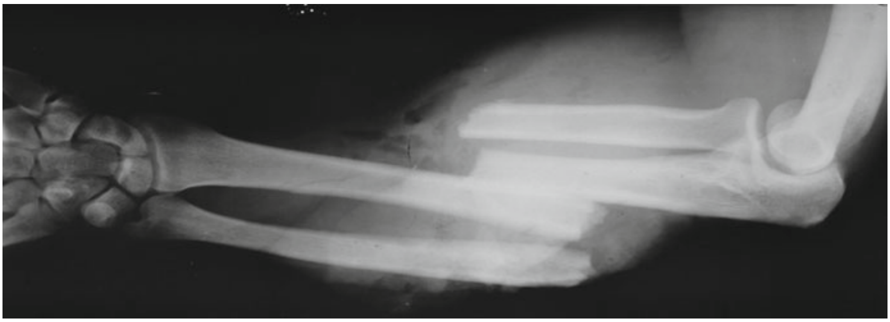

Fig. 5.3 Simple fracture of the mid-shaft of the radius and ulna (Courtesy of Magdi E. Griess, Whitehaven, Cumbria, UK)

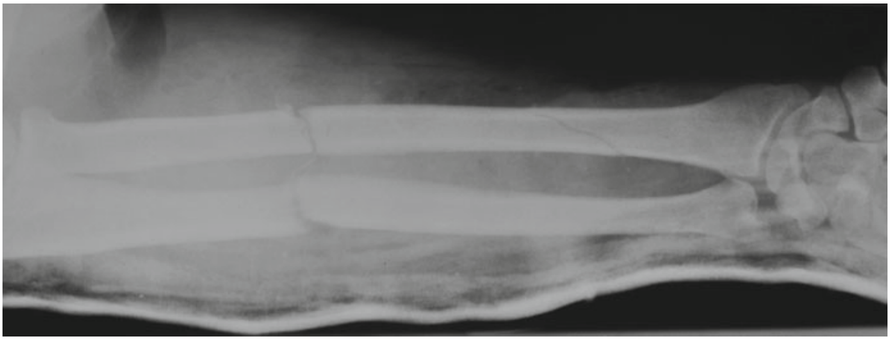

Fig. 5.4 Above fracture showing satisfactory reduction but with a tendency to redisplace (Courtesy of Magdi E, Greiss, Whitehaven, Cumbria, UK)

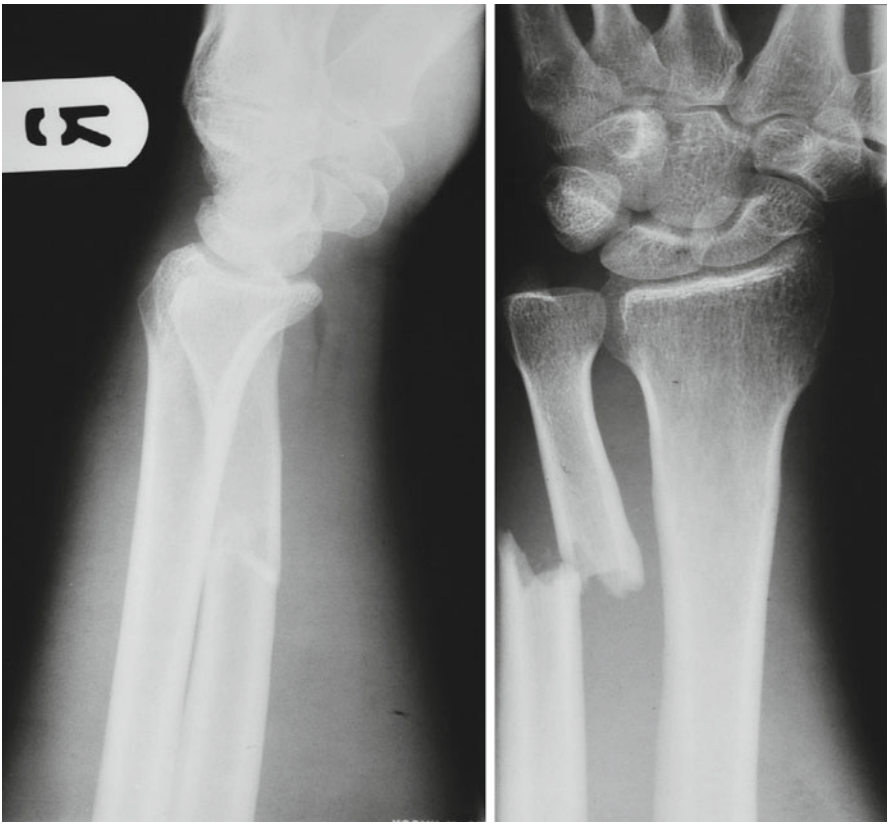

Fig. 5.5 Isolated fracture of the ulna with nonunion (Courtesy of Magdi E. Griess, Whitehaven, Cumbria, UK)

Bado's Classification

(a) Type I (anterior dislocation): the radial head is dislocated anteriorly and the ulna has a short oblique or greenstick fracture in the diaphyseal or proximal metaphyseal area.
(b) Type II (posterior dislocation): the radial head is posteriorly or posterolaterally dislocated; the ulna is usually fractured in the metaphysis in children.
(c) Type III (lateral dislocation): there is lateral dislocation of the radial head with a greenstick metaphyseal fracture of the ulna.
(d) Type IV (anterior dislocation with radius shaft fracture): the pattern of injury is the same as with a type I injury, with the inclusion of a radius shaft fracture below the level of the ulnar fracture.

Pediatric Monteggia Fracture Classification by Letts et al.

(a) Anterior dislocation of the radial head with plastic deformation of the ulna
(b) Anterior dislocation of the radial head with greenstick fracture of the ulna
(c) Complete fracture of the ulna with anterior dislocation of the radial head
(d) Posterior dislocation of the radial head with fracture of the ulnar metaphysis
(e) Lateral dislocation of the radial head and metaphyseal greenstick fracture of the ulna

Radiographic Evaluation

The standard evaluation of a Monteggia fracture includes anteroposterior (AP) and lateral x-rays of the forearm (Fig. 5.6).

Radiocapitellar Relation

Best defined by a true lateral view of the elbow: Line drawn through the center of the radial neck and head should extend directly through the center of the capitellum. This alignment should remain intact regardless of the degree of flexion or extension of the elbow

Composite drawing with the elbow in various degrees of flexion: A line drawn down the long axis of the radius bisects the capitellum of the humerus regardless of the degree of flexion or extension of the elbow.

Fig. 5.6 Monteggia fracture (Courtesy of Sharad Goyal, Chichester, West Sussex, UK)

Mechanism of Injury

Three separate mechanisms of type I lesions have been described: direct trauma, hyperpronation, and hyperextension.

Direct Blow Theory

The fracture dislocation is sustained by direct contact on the posterior aspect of the forearm, either by falling onto an object or by the object striking the forearm. The continued motion of the object forward dislocates the radial head after fracturing the ulna.

Hyperpronation Theory (Evans)

Rotation of the body externally forces the forearm into pronation. The ulnar shaft fractures with further rotation, forcibly dislocating the radial head.

Hyperextension Theory

(a) Hyperextension: forward momentum caused by a fall on an outstretched hand forces the elbow into extension.
(b) Radial head dislocation: the biceps contracts, forcibly dislocating the radial head.
(c) Ulnar fracture: forward momentum causes the ulna to fracture because of tension on the anterior surface.

Mechanism of Injury Type II

The mechanism proposed and experimentally demonstrated by Penrose was that type II lesions occur when the forearm is suddenly loaded in a longitudinal direction with the elbow flexed 60°.

Mechanism of Injury Type III

A forced varus stress causes a greenstick fracture of the proximal ulna and a true lateral or anterolateral radial head dislocation.

Mechanism of Injury Type IV

Bado proposed that a type IV lesion is caused by hyperpronation

Clinical Findings

- Marked pain and tenderness about the elbow. No flexion, extension, pronation, and supination. Paralysis of the interosseous nerve may occur.
  Type 1: head of radius felt anteriorly, anterior angulation
  Type 2: head of radius posterior, posterior angulation of ulna shortening of forearm
  Type 3: head of radius is lateral, lateral angulation
  Type 4: head of radius is anterior; deformity is at the fracture level

Treatment: In Children

Type 1: Closed reduction (if fails), open reduction of fracture ulna + closed reduction of head of radius.

If not reducible by closed methods, then one needs to go for open reduction of fracture ulna with open reduction of head of the radius.
Type 2: Closed reduction: if it fails, open reduction.
Type 3: Closed reduction.
Type 4: Closed reduction: if it fails, open reduction with plate and screw.

Treatment: In Adults

- Open reduction internal fixation of fracture ulna with plate and screws
- Closed reduction of head of radius if fails
- Open reduction head of radius + internal fixation of ulna
- If fracture more than 6 weeks excision head of radius is done.

Immobilization after reduction can be done in plaster cast for 3–6 weeks.

Complications

- Posterior interosseous nerve palsy
- Radial head instability
- Nonunion of fracture ulna
- Malunion of fracture ulna
- Myositis ossificans
- Missed Monteggia lesions/possible long-term sequelae

Progressive valgus

Proximal radial migration with disruption of normal forearm and distal radioulnar joint

Galeazzi Fractures

Fracture of distal one third radial shaft with dislocation of distal radioulnar joint is called Galeazzi fracture. Variants of Galeazzi fracture can occur anywhere along the radius or associated with fractures of both bones with DRUJ disruption. Is also called “the fracture of necessity” by Campbell.

Galeazzi fracture dislocations are relatively rare injuries in children.

Mechanism of Injury

The mechanism of injury is axial loading in combination with extremes of forearm rotation. In adults, the mechanism of injury usually is an axially loading fall with hyperpronation.

Clinical Features

Pain, swelling, and deformity of the lower end of the forearm. Pronation and supination are severely restricted. Neurovascular injury is rare.

Radiography

Standard full-length forearm with elbow and wrist AP and lateral to be taken.

Classification

Walsh and McLaren classified pediatric Galeazzi injuries by the direction of displacement of the distal radial fracture. Dorsal displacement (apex volar) fracture was more common than volar displacement (apex dorsal) fractures in their series.

Treatment

Galeazzi fractures are also called “the fracture of necessity.” Closed reduction has no role in treatment. Always requires open reduction, internal fixation with plate and screws. Sometimes require temporary pin fixation of DRUJ or repair of the ulnar styloid when fractured.

Postop if DRUJ stable start early motion. If DRUJ unstable, immobilize forearm in supination for 4–6 weeks in a long arm splint or cast. DRUJ pins are removed at 6–8 weeks.

Complications

1. Malunion leads to loss of supination and pronation.
   Treatment if it is persistent may require corrective osteotomy.
2. Nonunion. Treatment is bone grafting.
3. Compartment syndrome is rare

Galeazzi Equivalent

Radial shaft fracture with distal ulnar physeal injury instead of DRUJ injury.
Distal ulnar physeal injuries have a high incidence for growth arrest.

Chapter 6
The Wrist Joint

Naresh Shetty and K. Mohan Iyer

Distal Radius Fractures

Problems of Distal Radius Fractures

Distal radius fractures are common injury. This type of fractures has high potential for functional impairment and frequent complications. Risk factors include increasing age, decreased bone mineral density, female sex, white race, family history, and early menopause.

Distal radius fractures occur through the distal metaphysis of the radius, may involve articular surface, frequently involving the ulnar styloid, and most often result from a fall on the outstretched hand, forced extension of the carpus, and impact loading of the distal radius. Associated injuries may accompany distal radius fractures.

History

Pouteau of Lyon in 1780 was the first to distinguish impacted fractures of distal radius from dislocations. In France and other parts of the world, this fracture is called "Poteau's fracture."

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Fig. 6.1 Anteroposterior and lateral radiographs of the wrist showing a Colles' fracture (Courtesy of Dilip Malhotra, Bahrain; Reproduced with kind permission of Springer and Verlag)

In 1814, Abraham Colles (1773–1843), professor of anatomy and surgery at Trinity College in Dublin, clearly identified the fracture and today is named Colles' fracture (Fig. 6.1). He, as the single individual, is credited for directing the attention of his contemporaries to the underlying truth of these types of injuries. Abraham Colles (1814) used anterior and posterior tin splints to maintain reduction.

Cotton (1910) advised immobilization in position of extreme flexion and ulnar deviation at wrist.

Bohler in 1929 published his method of reduction of comminuted fracture by longitudinal traction and maintenance by skeletal pins incorporated in plaster cast.

Lambrinudi (1938) opined that Colles' fracture is a supination injury and hence immobilized in pronation after reduction.

Gartland et al. reported that the main reason or results in unstable distal end radius fractures were displaced inferior radioulnar joint.

Max Scheck in 1962 advised the use of Kirschner wires incorporated in the cast to prevent loss of reduction in comminuted Colles' fractures.

Roger Anderson's in 1979 devised an external fixator and was adopted in the treatment of fractures of the distal end of radius.

Barton, Smith, and Dupuytren were the other contributors.

Incidence

Children do well (10 %).

Middle age—high velocity injuries, high functional demands (60 %).

Old age—less functional demands (30 %).

Anatomy

- The distal radius is widest part of bone. It is biconcave, triangular, and covered with hyaline cartilage.
- It has five surfaces:
  1. Anterior surface.
  2. Posterior surface:
     - It has four grooves for ext. tendons.
     - Lister's tubercle can be palpable.
  3. Medial surface: has ulnar notch which articulates with ulna.
  4. Lateral surface: It is prolonged downward to styloid process.
  5. Inferior surface: It articulates with scaphoid laterally and lunate medially.
- Wrist joint: It is a biaxial type of joint, grouped under ellipsoid variety.

The bones taking part here are:

- Distal end of radius.
- Articular disc of scaphoid and lunate from above and triquetral bone from below, hence termed as midcarpal joint.
- A smooth AP ridge divides the articular surface of distal end radius into two facets:

  1. Triangular lateral facet articulates with the scaphoid
  2. Quadrilateral medial facet: articulates with the lunate

The medial surface of the distal radius forms a semicircular notch covered with hyaline cartilage, which articulates with the ulna head. This articulation enables the radius to swing around the ulna.

The lateral surface elongates into a prominent styloid process, which gives attachment to the brachioradialis muscle.

Radiological Anatomy

- Radiographic measurements have formed the foundation for evaluation of not only the injury but also the outcome of treatment.
- Standard x-ray views are anteroposterior, lateral, and oblique.
- The important radiographic determinations.
- Radial inclination or tilt (23°).
- Radial height (12 mm).
- Volar inclination or tilt (11°).
- Reduction of the distal radioulnar joint.
- Radial width (normally within 1 mm of that of the contralateral side).
    1. Normal distal radius tilt/inclination
    2. Volar tilt/inclination
    3. Radial length

Mechanism of Injury

The Avulsion Theory

The avulsion theory suggested by Linhart (1852) and analyzed by Lecomate (1861), it says that ulna is probably alone (because of intimate contact with humerus) absorbing the impact of fall on the hand; the force is being transmitted to radius via interosseous membrane and strong volar ligaments. Then, the fracture is produced by avulsion due to traction in the strong volar radiocarpal ligaments.
The injury produced depends on the position of the wrist, the magnitude, direction of force, and the physical properties of the bone.

A fall on the outstretched hand with the wrist in 40–90° of dorsiflexion produces a distal radius fracture with dorsal displacement.

The radius probably first fractures in tension on its palmar surface, followed by compression on the dorsal surface, resulting in dorsal comminution.

The lunate in particular can exert a compressive force on the distal radius, producing a so-called die-punch fracture.

The Bending Fracture Theory

When a person falls the kinetic energy causes the forward movement of the body to continue, the wrist becomes hyperextended and patient falls over the hand. This causes the volar ligaments and radius to be pressed against the carpal articular surface, the force being stopped by scaphoid and lunate bones; it is then transmitted to radius, which fractures at its weakest point. It says that the course of fracture is determined by three factors. These are the position of hand, surface of impact, and magnitude of force.

Radial styloid fractures result from an avulsion (tensile) force generated through the palmar radiocarpal ligaments.

The ulnar styloid fracture component of the Colles' fracture results from a force transmitted through an intact triangular fibrocartilage complex.

Classification of Distal Radius Fractures

Ideal system should describe type of injury, severity, evaluation, treatment, and prognosis.

Classifications of distal radius fractures are originally named after surgeons who described them:

Colles' fracture
Smith's fracture
Barton's fracture
Chaufeur's fracture

Smith's Fracture

- Fracture of the distal radius with volar displacement and angulation of the distal fragment (Fig. 6.2)
- Results from a fall on the back of the hand or a direct blow to the dorsum of the hand
- Often referred to as a reverse Colles' fracture

Barton's Fracture

- Fracture of dorsal margin of the distal radius extending into the radiocarpal articulation
- Reverse (or volar) Barton's fracture: when it involves the volar aspect of distal radius (Fig. 6.3)

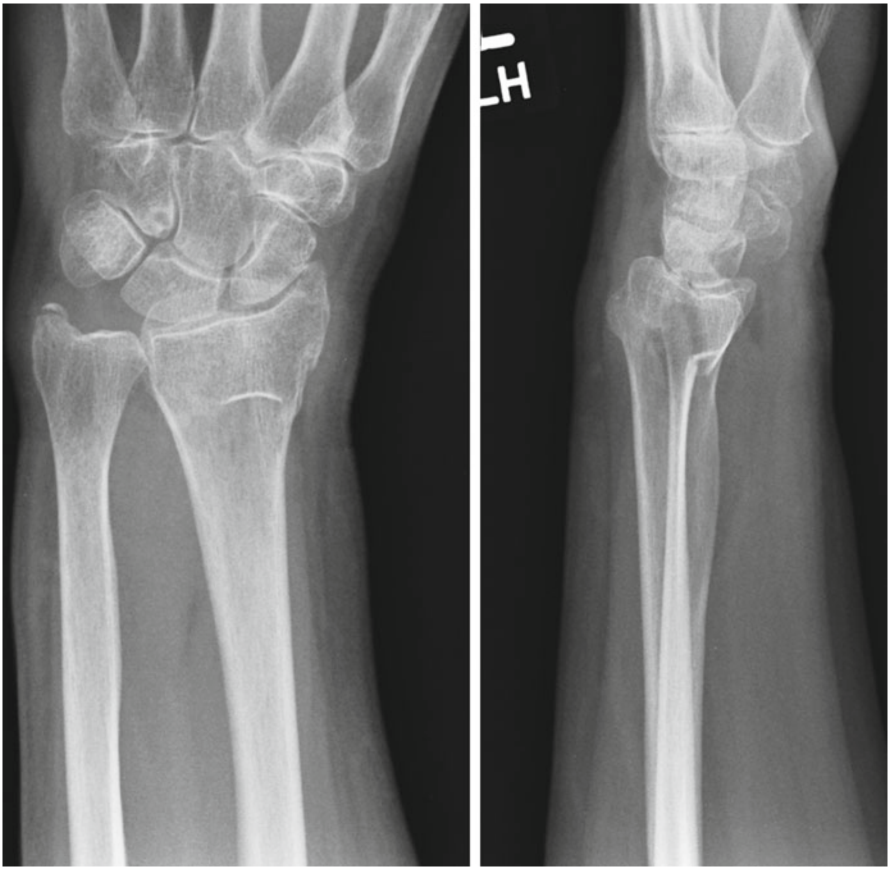

Fig. 6.2 Smith's fracture (Courtesy of Sharad Goyal, Chichester, West Sussex, UK)

Common Classifications Used Now

Gartland/Werley
Frykman
Melone
Column theory
Fernandez (mechanism)

Gartland and Werley

- Grp 1—Simple distal radius fracture with no involvement of radial articular surfaces
- Grp 2—Comminuted distal radius fractures with intra-articular extension without displacement

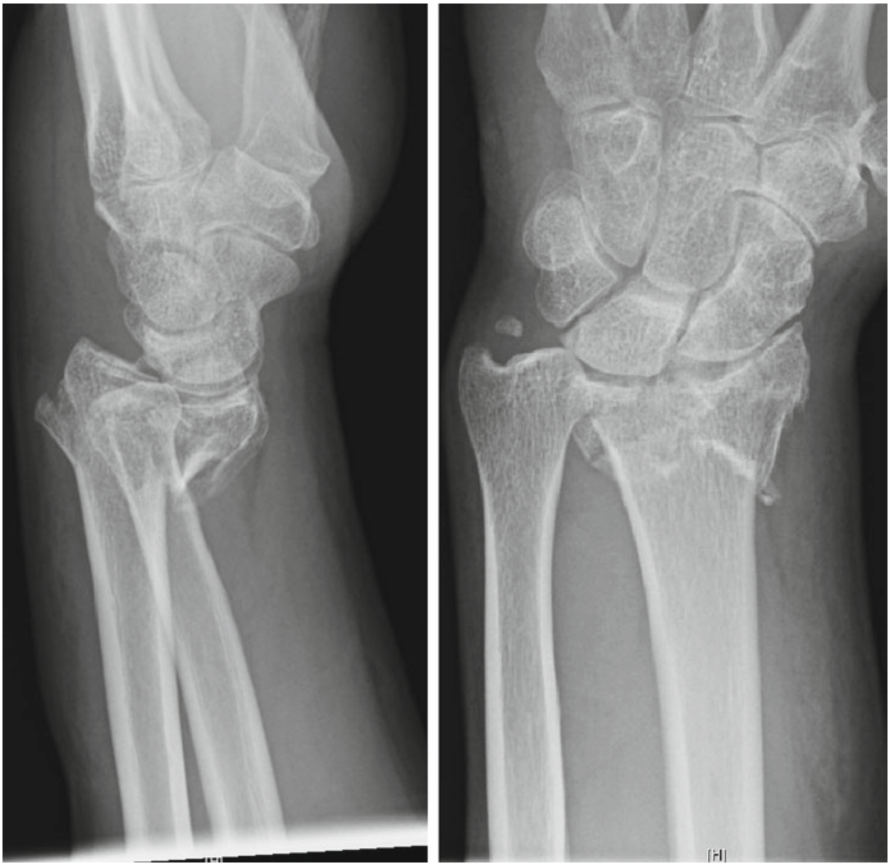

Fig. 6.3 Volar Barton's fracture (Courtesy of Sharad Goyal, Chichester, West Sussex, UK)

- Grp 3—Comminuted distal radius fracture with intra-articular extension with displacement
- Grp 4—Extra-articular, undisplaced

Frykman's Classification for Colle's Fractures

- Type I/II: Extra-articular
- Type III/IV: Intra-articular involving radiocarpal joint
- Type V/VI: Intra-articular involving distal radioulnar joint
- Type VII/VIII: Intra-articular involving radiocarpal joint and distal radioulnar joint

Melone Classification

- Type 1—stable fracture without displacement. This pattern has characteristic fragments of radial styloid and a palmar and dorsal lunate facet.
- Type 2—unstable "die punch" with displacement of the characteristic fragments and comminution of the anterior and posterior cortices.
- Type 2a is reducible.
- Type 2b is irreducible.
- Type 3—"spike fracture" unstable. Displacement of the articular surface and also of the proximal spike of the radius.
- Type 4—"split fracture" unstable medial complex that is severely comminuted with separation or rotation of the distal and palmar fragments.
- Type 5—explosion injury.

Fernandez (1997)

1. Bending metaphysis fails under tensile stress (Colles, Smith).
2. Shearing fractures of joint surface (Barton, radial styloid).
3. Compression intra-articular fracture with impaction of subchondral and metaphyseal bone (die punch).
4. Avulsion fractures of ligament attachments (ulna, radial styloid).
5. Combined/complex—high velocity injuries.

Thomas Classification

- Type I: Transverse distal radial fracture with palmar and proximal displacement
- Type II: Palmar-lip fracture of the distal radius with dislocation of the carpus (palmar Barton's fracture)
- Type III: Oblique fracture of the distal radius, tilted palmarly

Options for Treatment

(a) Conservative: under GA, closed reduction, and POP cast in stable fracture
Casting: long arm vs. short arm
(b) Surgical Treatment
  - *External fixation*
    - Joint spanning
    - Non-bridging

- *Percutaneous pinning*
- *Internal fixation*
  - Dorsal plating
  - Volar plating
  - Combined dorsal/volar plating
  - Focal (fracture-specific) plating

Indications for Closed/Conservative Treatment

- Low-demand patient
- Low-energy fracture
- Medical comorbidities
- Minimal displacement—acceptable alignment
- *Match treatment to demands of the patient*

Depends on obtaining and then maintaining an acceptable reduction

Immobilization:

- Long arm cast
- Short arm adequate for elderly patients

Frequent follow-up necessary in order to diagnose re-displacement

Indications for Surgical Treatment

- High-energy injury
- Open injury
- Secondary loss of reduction
- Articular comminution, step off, or gap
- Metaphyseal comminution or bone loss
- Loss of volar buttress with displacement
- DRUJ incongruity

Evidence of High-Energy Injuries

- Irreducible fracture
- Unable to maintain reduction
- Significant initial displacement
- Comminution extending from dorsal to volar
- Significant soft tissue disruption

Chapter 7
The Hand and Fingers

Shabih Siddiqui

Scaphoid Fractures

This is the commonest carpal bone to be fractured and happens usually in younger or middle-aged population and commonly after sporting injuries (Fig. 7.1). This bean-shaped bone has a unique shape and anatomy, and quite often it may go undiagnosed and is many a time a case for successful litigation against orthopedic surgeons.

It may be accompanied with severe soft tissue injuries including swelling, ligamentous disruption, and neurovascular injuries.

What makes the scaphoid fracture unique and the subject of exam questions is the peculiar blood supply for which numerous studies have been done. There is no need to go in to microscopic detail, but some facts need to be known at the undergraduate level.

Anatomically, the scaphoid may be divided into proximal, middle (termed the waist), and distal thirds. Most of the blood supply to the scaphoid enters distally. The proximal part of the scaphoid has no blood vessels entering it, depending instead on vessels that pierce the midportion.

Fractures of the proximal third of the scaphoid account for 25 % of scaphoid fractures, those of the middle portion account for 60 %, and fractures of the distal part make up the remaining 15 %. Diminished blood flow to the proximal pole is noted in about one-third of fractures at the waist level.

This reduced blood supply may result in avascular necrosis of the proximal pole of the scaphoid.

Displaced scaphoid fractures have a nonunion rate of 55–90 %.

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Fig. 7.1 Radiograph of fracture of the scaphoid (Courtesy of Dilip Malhotra, Bahrain. Reproduced with kind permission of Springer and Verlag)

Mechanism of Injury

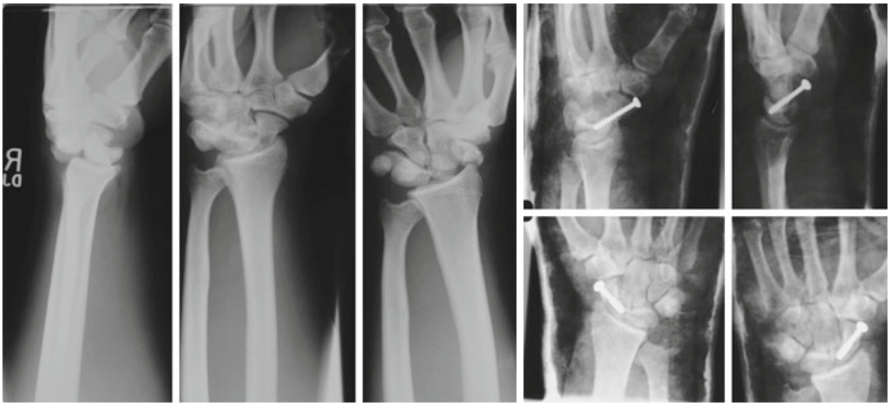
Fall on the outstretched hand is the commonest mechanism in which the wrist is dorsiflexed beyond 90–95°.

It is commonly taught that any snuff box tenderness must be investigated to rule out scaphoid fractures. If no fracture is seen initially, it is prudent to put the wrist in plaster and perform special scaphoid view X-rays in 2 weeks. The initial X-rays must include a lateral view to exclude carpal instability.

Radiographic classification suggested by Weber and Cooney is frequently used. Fractures with a gap of 1 mm and undisplaced have a periosteal hinge and usually go on to union. They are treated in a thumb spica scaphoid cast. These stable fractures are kept in cast for 8–10 weeks with good results.

Displaced fractures with gap of more than 1 mm are considered unstable fractures and may also have carpal instability. They have about 50 % chance of nonunion. Those that do go on to healing in this group by plaster treatment may take 14–16 weeks.

Diagnosis of scaphoid nonunions is pretty easy in the majority of cases but may need CT or MRI scans before surgical planning.



Figs. 7.2 and 7.3 Fractured scaphoid, treated by internal fixation (Courtesy of Magdi E. Greiss, Whitehaven, Cumbria, UK)

The overall prognosis of scaphoid fractures is thus dependent on two factors: the stability of the fracture and the anatomical location. Any fracture with a gap of more than 1 mm is usually associated with rotation and thus more at risk of nonunion.

Treatment is usually commenced with POP immobilization and regular X-rays. Fracture healing is usually established by elimination of snuff box tenderness, swelling, and radiological bridging trabeculae.

Contributory factors toward nonunion are late presentation, noncompliance, and irregular plaster treatment.

Indications for Open Reduction and Internal Fixation *(Figs. 7.2 and 7.3)*

Displacement more than 1 mm
Unstable fractures
Trans-scaphoid perilunate dislocations
Complete displacement of an avascular fragment
Polytrauma
Inability to tolerate POP for long duration

The approach is usually volar, but dorsal approaches have also been described.

Arthroscopic technique has been described in the hands of experts.

In any case, those who are familiar with the treatment and have a sound understanding of the anatomy and fixation devices should only undertake surgery for the scaphoid.

Established nonunions are treated with open reduction internal fixation and bone grafting. Vascularized bone grafting has also been described in the literature.

Untreated scaphoid unions can lead to osteoarthritis around the scaphoid or in the radio-scaphoid joint. Occasionally, one may see this radiological finding in

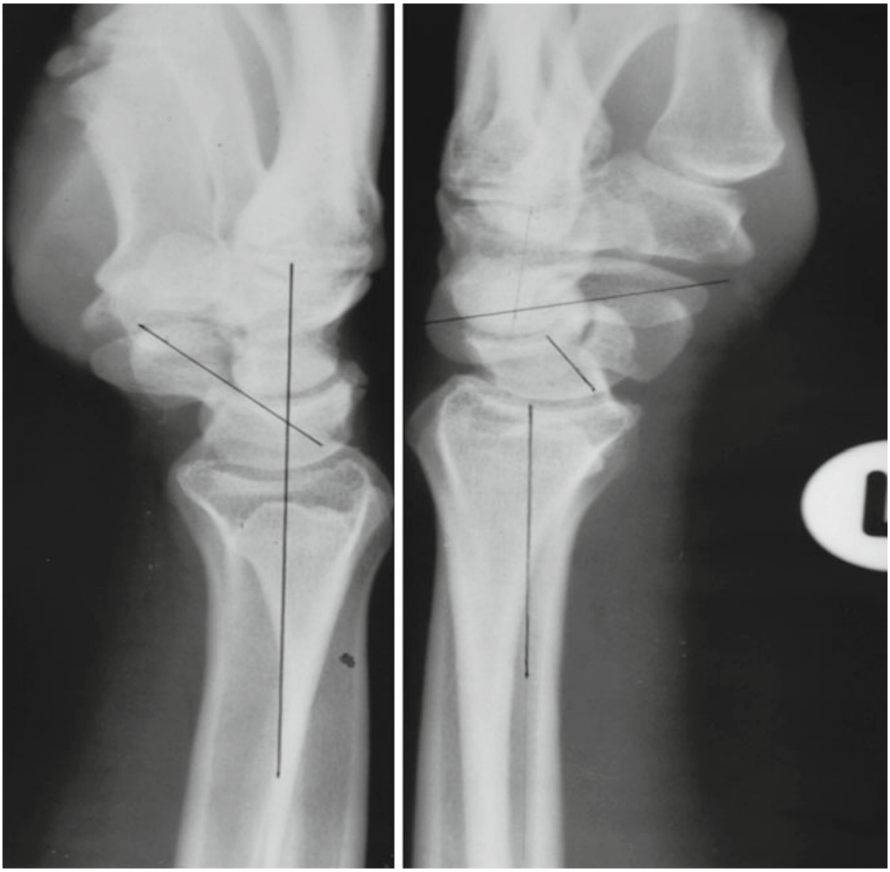


Fig. 7.4 Scapholunate angle—normal on the left side, while it is abnormal on the right side (Courtesy of Magdi E. Greiss, Whitehaven, Cumbria, UK)

those who have been asymptomatic and do not remember any previous episode of significant wrist trauma.

Lunate Dislocation

Lunate dislocations usually occur as part of a major injury such as a fall from a height or an automobile collision. When a lunate dislocation occurs, it usually dislocates volarly and may cause compression of the median nerve.

It can be associated with major injury to the wrist accompanied by displacement of other carpal bones as well (Fig. 7.4). The importance of this angle is very important in disruptions of the scaphoid or lunate.

The patient presents with severe pain and swelling in the wrist along with a boggy lump on the volar aspect of wrist.

The lunate dislocation is pretty easy to diagnose with plain radiographs. CT scans or MRI scans may be needed in difficult cases.

Reduction should be done acutely under anesthesia, and stabilization with K wires is often needed. Carpal tunnel release may also be needed. Often lunate dislocation is part of a complex injury called trans-scaphoid perilunate dislocation.

Trans-scaphoid Perilunate Dislocation

Without going into detail, it is worthwhile noting that in high-energy wrist trauma, one has to carefully go through wrist X-rays like a hawk. Undiagnosed or untreated it can lead to devastating complications and morbidity especially if it happens in the dominant hand.

The perilunate dislocation and the perilunate fracture dislocation are injuries that involve traumatic rupture of the radioscaphocapitate (RSC) ligament and the scapholunate interosseous ligament. Fractures of the radial styloid, the scaphoid, the trapezium, the capitate, and the triquetrum also may be associated with the dorsal or the volar perilunate dislocation.

The result of perilunate dislocation and of perilunate fracture dislocation is an extremely unstable wrist, potentially producing devastating complications.

Not only compression of median nerve but compartment syndrome can occur.

These patients need urgent closed or open reduction and repair of ligaments with stabilization of carpal bones under image intensifier. Patients must always be counseled about the severity of the injury and the high chance of developing stiffness, pain, and late arthrosis.

Fractures of Metacarpals

Approximately 30–40 % of hand fractures involve the metacarpals.

Fracture, displacement, angulation, and shortening of the index and middle finger metacarpal causes more disability than a similar injury to the other three metacarpals. Subsequent to the fracture the activity of the intrinsic muscles is a contributory factor to the angulation and rotation taking place at the fracture.

Bennett's Fracture

Intra-articular fracture of base of metacarpals is frequently seen at the base of thumb and the little finger. The former goes by the eponymous name of Bennett's fracture

Fig. 7.5 Anteroposterior and lateral radiographs of the fifth metacarpal with no rotational deformity (Courtesy of Dushyant H. Thakkar, London, UK; Reproduced with kind permission of Springer and Verlag)

or Bennett's fracture dislocation. Articular congruity must be reestablished like in any intra-articular fracture.

Closed reduction may be maintained by traction on the thumb metacarpal followed by radial abduction and applying pressure on the base of the thumb. If X-rays show an unsatisfactory position, then reduction under image intensifier and closed pinning may be needed.

Rolando's Fracture

This is a comminuted fracture of the base of the first metacarpal. These are usually immobilized in thumb spica cast with regular X-rays. Early mobilization in about 3 weeks is begun.

Those fractures, which have large displaced fragments, may be suitable for fixation with 2 or 2.7 mm screws or K wires.

Intra-articular fractures of base of little finger are dealt by reduction followed with pinning the fifth to the fourth metacarpal.

Untreated these intra-articular fractures may cause late arthritis needing arthrodesis or arthroplasty.

Extra-articular Metacarpal Fractures

Fractures of neck of metacarpals are very common in the fracture clinic setting quite often the result of punching injuries sustained on a Saturday night. With clenched fist injuries, it is vital to exclude human teeth injuries. Human bite infections can have disastrous results and needs aggressive surgical treatment.

With metacarpal neck fractures, one is often asked the difficult question as to how much angulation can be expected. For the index and middle metacarpal, 10–15° angulation can be accepted. However, for the ring and little finger, a lot more can be accepted in the range of 30–35°.

These fractures are treated by closed reduction and traction if indicated. Usually this can be done under local anesthesia. A removable metacarpal brace is worn for 3–4 weeks.

For unstable or irreducible fractures, various methods of pinning and K wiring exist, and one should do what one is familiar and confident of achieving. K wires should be retained for 3 weeks following which they are removed and replaced with buddy strapping.

Metacarpal Shaft Fractures

These fractures can occur subsequent to direct trauma, RTA's, and fist fights and in those employed in manual labor.

They may be angulated, rotated, or displaced. 10–12° angulation is accepted in the index and long metacarpal and approximately 15–20° in the little and ring finger (Fig. 7.5). Oblique or spiral fractures frequently displace leading to shortening or rotational deformities. These are frequently reducible and treated in thumb spica or may need closed pinning.

Oblique unstable fractures especially causing shortening of more than 3–4 mm may need open reduction and internal fixation with 2 mm screws or mini plates (Figs. 7.6 and 7.7).

Occasionally these fractures go into nonunion. One may often need another operation to remove the plates. The majority of metacarpal fractures can be treated with either watching closely or with pinning as this causes the least trauma to the soft tissues.

Fractures of the Phalanges: Usually they are treated by a companion strapping with the neighboring fingers, but very rarely do they require an open reduction with internal fixation by plates and screws or pinning (Figs. 7.8 and 7.9).

Tendon Injuries

An excellent treatise on this topic can be found in *Journal of American Academy of Orthopedic Surgery* entitled flexor tendon injuries by Strickland JW.

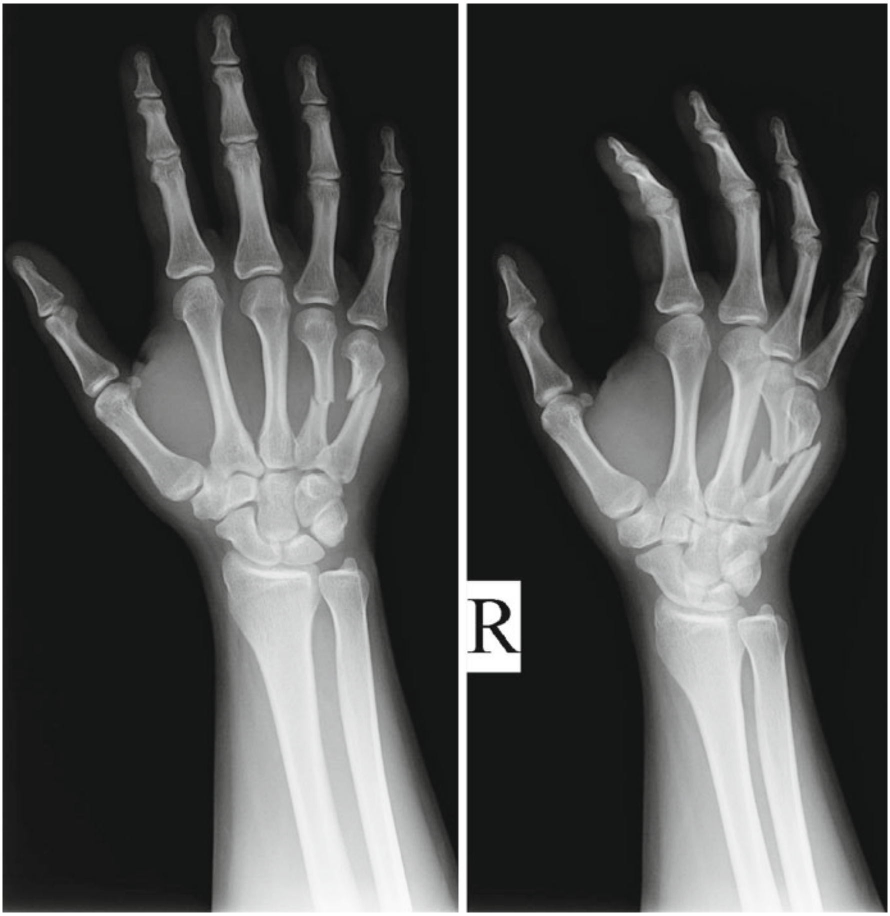


Fig. 7.6 Fracture of the fourth and fifth metacarpals (Courtesy of Dilip Malhotra, Bahrain)

Both extensor and flexor tendon injuries are quite common injuries to be seen in a busy casualty unit.

The surface of individual bundles of collagen of tendons is covered by a fine sheath, the endotenon. This surrounds the fascicles, blood vessels, and nerves. The tendons consist of fascicles of long, narrow, spiraling bundles of tendon cells called tenocytes and primary type I collagen fibers. A fine, smooth, outer layer of cellular tissue called the epitenon covers the tendons themselves.

Extensor Tendon Compartments in the Hand

At the wrist, the extensor tendons are enclosed in six compartments.

Starting Radially: The first compartment has abductor pollicis longus and extensor pollicis brevis.

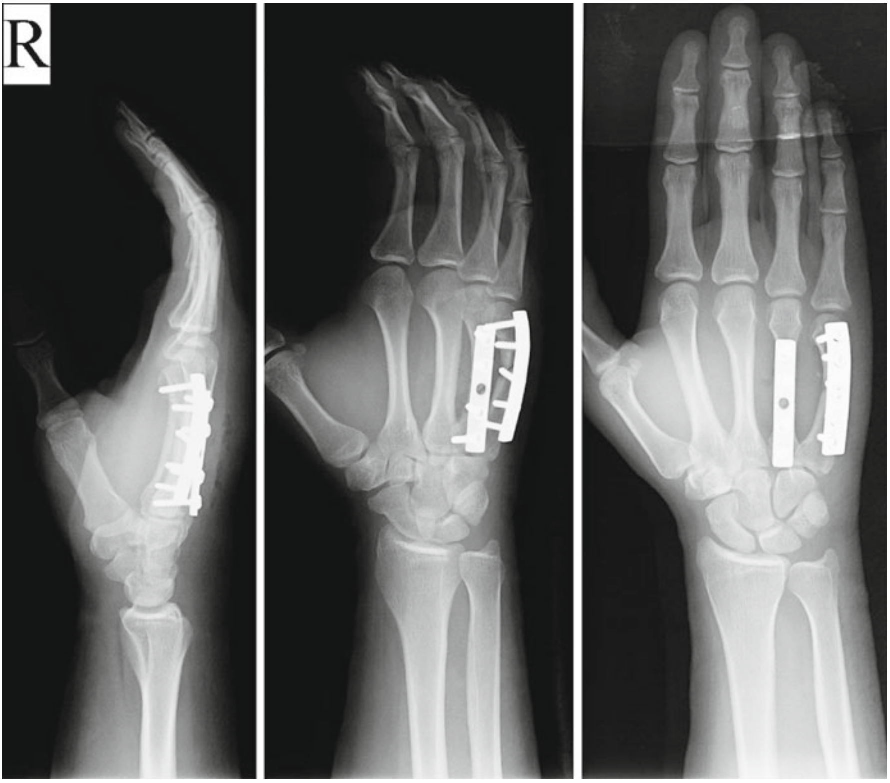


Fig. 7.7 Above fracture treated by ORIF with plating (Courtesy of Dilip Malhotra, Bahrain)

The second compartment has the extensor carpi longus and brevis.

The third compartment consists of extensor pollicis longus.

Fourth compartment has extensor indicis proprius and four tendons of extensor communis.

The tendon of extensor digiti quinti occupies the fifth compartment.

The last space has extensor carpi ulnaris.

The extensor tendons are attached together by intertendinous bands called *juncturae tendinum*. At the level of metacarpal heads, a complex extensor apparatus forms between the extrinsic extensor tendons and the intrinsic tendons which is called the extensor hood.

Flexor Tendons in the Hand

The common flexor tendon mass in the forearm produces the extrinsic tendons going into the hand. The most superficial layer consists of the flexor carpi radialis, palmaris longus, and the flexor carpi ulnaris. The flexor digitorum superficialis contributes to the middle layer, and the deepest layer consists of the flexor digitorum

Fig. 7.8 Fracture of the proximal phalanyx of the ring finger (Courtesy of Dilip Malhotra, Bahrain)

profundus and the flexor pollicis longus. On the volar aspect of the wrist, the nine long digital flexor tendons are enclosed with the median nerve in the carpal tunnel. The proximal edge of the carpal tunnel is also a common site of laceration to the wrist causing damage to the flexor tendons with or without damage to the median nerve. These flexor tendons are enveloped by thickening of the fibro-fascial sheaths on the volar aspect of the fingers to form a complex pulley system to facilitate in their glide to their most efficient mechanical advantage.

The nutrition of the tendons is to some extent supplied by the synovial sheath bathing the tendons. This also serves important lubricating functions. The nutrients are pumped into the tendon cells by a process called imbibition in which fluid is forced into and is aided by movement of flexion and extension. Early mobilization after tendon surgery may in some way be advantageous from their nutrition point of view in addition to preventing adhesions.

Fig. 7.9 Above fracture treated by ORIF with plating and screws (Courtesy of Dilip Malhotra, Bahrain)

The rich vascular architecture of the hand also provides several vessels to the tendons for the nutrition. These vessels enter through synovial reflections and long and short *vinculum*.

Management of Flexor Tendon Injuries

The diagnosis of these tendon injuries in the acute setting is pretty obvious especially with open wounds. Expertise is needed when more than one tendon is involved or when accompanied with neurovascular component. Whenever there is doubt, usually surgical exploration is advised. Once confirmed there is injury, repair is undertaken by competent hands as early as possible in a controlled and facilitated environment.

Traditionally flexor tendon injuries are divided into various zones on the basis of anatomical features. These are zones I–V in the fingers and I–III in the thumb.

Zone II is also called no man's land as results of surgery in this area are unrewarding.

The surgical principles with regard to repair of tendon surgery are:

Strength of suture material should be sufficiently strong enough to allow early mobilization.
Suture material should have sufficient glide properties.
Secure knot.
Sutures easily placed in the tendon.
Minimal gaping at the repair site.
Smooth junction of the tendon ends with minimal bulk.
Vascularity to be preserved as much as possible.

Kessler's repair has been used since 1973 with minor modifications. The other common repairs are Bunnells technique, Tajima stitch, and the Tsuge stitch. The details of these techniques are not required for the undergraduate.

In the past, repair of zone II injuries also called no man's land was not recommended for this difficult area, but current techniques allow for primary or delayed primary to be undertaken. In the past, repair of only the profundus tendon was advocated, but now many surgeons repair both the tendons in this challenging site. Early mobilization under expert supervision has paid dividends.

Primary repair in the palm and the wrist including carpal tunnel gives good results.

Management of Extensor Tendon Injuries

These are relatively simple to deal compared to the complicated repairs of flexor tendons. Nine zones are described.

Mallet Finger

The finger assumes a characteristic posture after injury to the extensor tendon at or proximal to the DIP joint (Fig. 7.10). Passively the finger can be extended. The injury can be closed or open, usually the former. This injury occurs after forceful flexion of the extended finger. The tendon may take with it a small flake of bone from the dorsal aspect of the distal phalanx.

Closed injuries are treated with a Mallet splint used for 6–8 weeks usually continuously for the first 4–6 weeks. K-wire fixation can be used if bony fragment is large. Open injuries are dealt with by debridement, direct repair with or without K-wire fixation.

Fig. 7.10 Mallet finger (Courtesy of Dilip Malhotra, Bahrain)

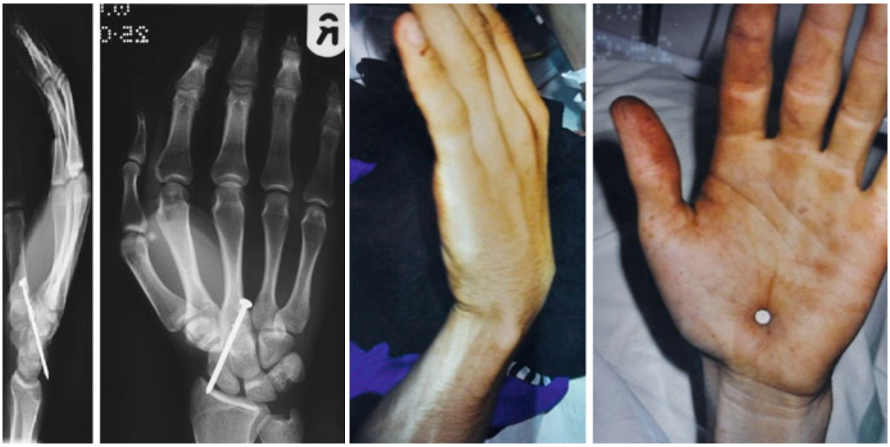
Transepiphyseal plate injuries of the distal phalanx produce mallet finger deformity in children. Usually closed reduction is stable.

Delayed Repair for Missed Flexor Tendon Injuries

After 4 weeks of injury, delayed primary repair is usually impossible. Free tendon grafting in which tendon of some muscle, which can be sacrificed, e.g., palmaris longus is used to substitute the damaged tendon. This is usually required for zone II injuries in which both the superficialis and the profundus tendon are damaged. The profundus tendon is usually reconstructed. The wound should have healed, and there should be good range of movement in the involved digit. There is always a risk of causing further damage and stiffness to the finger.

Staged Tendon Reconstruction

In difficult salvage situations especially in a heavily scarred finger or if there is severe damage to the sheath system, staged reconstruction in which a rubber tendon implant is put in temporarily. This surgery requires a very high degree of expertise.



Figs. 7.11 and 7.12 Nail gun injury (Courtesy of Magdi E. Greiss, Whitehaven, Cumbria, UK)

Rarely if all fails, the finger may need arthrodesis or amputation. If after primary or secondary repair the tendon appears to be stuck down to the bed, tenolysis which means freeing of the tendon may need to be employed. This is done when serial examination over 3 months has revealed no improvement.

A satisfactory outcome of flexor or extensor tendon injury needs liaison between surgeon, patient, and the hand therapist.

Crush Injuries of Hand

Industrialization has brought with it a considerable increase of severe crush injuries especially in the third world countries, but stricter adherence to legislation and health and safety issues has pari passu brought a decrease to such crippling and devastating injuries.

A crush injury takes place when a high-velocity compressive force is applied to the hand and forearm tissues. Open crush injuries and closed injuries may present obvious differences. Sharp machinery crush injuries will show obvious injuries to tendons and commonly neurovascular structures. Referral to reimplantantion center may be needed. Expertise is needed to preserve the amputated parts of hand till the final destination is reached.

In closed crush injuries, little may be apparent initially apart from bruising, ecchymosis, swelling, and pain.

This can happen in place of work (Figs. 7.11 and 7.12) when hand is crushed between two moving parts of machinery such as roller machine. It can also happen in road accidents in which limbs can get trapped under overturned vehicles or direct trauma. There may also be degloving injuries.

A high index of suspicion should be exercised when examining these cases. Of course, other life-threatening injuries will take precedence. Muscles, tendons, bones, nerves, and vessels including skin all may be involved. Continuing extravasation of fluid may cause compartment syndrome. Unrecognized it may have devastating results superimposed on the already damaged hand.

When dealing with crush injuries, a good history about the mechanism of injury is important. The extent of injuries needs to be documented in detail as quite a few go on to litigation. Tetanus toxoid status should also be noted.

A detailed examination is which state of skin, swelling, color, and feel is noted. Nerve examination along with vascularity should be noted. Radiographs should always be taken. The clinical examination should be repeated after 2–4 h to note difference. Pain out of proportion should alert one to impending compartment syndrome. Passive stretch test causing pain should also cause alarm.

Trained orthopedic surgeons or plastic surgeons in a hand unit best deal these injuries. Fractures and dislocations are treated. Minimal implant surgery and further dissection should be done to prevent stripping of already compromised blood supply. Thorough debridement and wash will be needed. Appropriate release incisions for compartment syndrome are required. Median nerve decompression in the carpal tunnel is usually done. Degloving of skin will need plastic surgery input.

Fasciotomy of forearm will need release of volar and dorsal compartment. There is a third dorsal mobile wad compartment, but this may not need be released. In the hand, multiple dorsal incisions are needed. On the palmar aspect, incisions to release the thenar and hypothenar compartment and additional incision for the carpal tunnel are needed. Fasciotomy of fingers will need mid-axial incisions.

These incisions are left open to be closed after 72 or more hours. Hand is appropriately splinted. After surgery, strict limb elevation, close monitoring of neurovascular status, antibiotic cover, intravenous drip, analgesia, and proper counseling of patient/relatives is needed.

Chapter 8
The Thumb

Sughran Banerjee

Thumb Fractures

Of all the fingers in the hand, thumb fractures are extremely important in terms of function and stabilization. Thumb is the most important functional component for grip and finer hand activities and occupies an area as large as any organ in the brain for its control. Thus, good management of thumb fractures is essential.

Bennett's Fracture

Bennett's fracture involves fracture of the base of the thumb metacarpal without comminution. It may be displaced or undisplaced. The displacement is typically due to the pull of the tendon of abductor pollicis longus (Fig. 8.1).

The fracture typically presents in patients with a fall on outstretched thumb. In undisplaced fracture, thumb spica is a preferred option, whereas in case of displaced fracture, as it is intra-articular fixation is the preferred option. Various methods of fixation have been described. Wagner described percutaneous closed K-wire fixation and open reduction with internal fixation. In percutaneous fixation, a K wire passed through the body of the first metacarpal to hold the trapezium is described; this will fix the displaced fragment once pushed in place. For open reduction, either K wire or internal fixation with plate is advised. Immobilization is generally for 6 weeks followed by physiotherapy.

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Fig. 8.1 Bennett's fracture (Courtesy of Sharad Goyal, Chichester, West Sussex, UK)

Rolando's Fracture

Fracture of the base of thumb metacarpal with comminution is known as Rolando's fracture. This is generally inherently unstable and because of intra-articular comminution should be fixed primarily. Various methods have been described; however, open reduction and internal fixation with mini plate is a preferred option. In severely comminuted fractures, distraction with mini external fixator often gives good results. The distraction may need to be maintained for 6–8 weeks if unstable. Plate fixation patients should have early mobilization to maximize the function.

Ulnar Collateral Ligament Tear

This lesion can cause chronic instability if left undiagnosed with significant morbidity and is often a cause of litigation. The lesion involves the rupture of metacarpal ulnar collateral ligament often with the apposition of adductor aponeurosis, in which case it is called a Stener lesion. The importance of the diagnosis lies in the fact that if conservative treatment with splinting is done initially, it may fail to heal because of the soft tissue apposition. In general, the diagnosis is clinical with evident instability of the thumb, but it need to be confirmed with stress views. Often an MRI scan will confirm the diagnosis. An open reduction is preferred in this setting, and the ligament may be fixed with suture anchor. Thumb spica must be applied thereafter for at least 4 weeks.

Chapter 9
The Pelvis

Sharad Goyal

Pelvic Fractures

Pelvis is made of several bones like sacrum, ilium, ischium, and pubis. These bones are connected altogether by various ligaments and forming a ring. It requires a high-energy trauma to break this ring. Fracture in one part of the ring can be associated with fracture in another part of the ring.

Pelvic fractures patients following high-energy trauma can bleed to death. It is an orthopedic emergency. The bleeding can be in the retroperitoneal space, or it can be intrapelvic bleed. Mortality following bleeding can be up to 15 %. Posterior pelvic fracture is more likely to be associated with injuries to the nerves or blood vessels which are in the close proximity to the sacrum. Lumbosacral plexus injuries are seen in 8–10 % of the cases. There is an incidence of almost 10 % of both bladder and urethral injuries.

Pelvic fractures are most commonly caused in elderly population following a fall, which is usually a low-energy trauma. This can be a fall on the ground while standing from a height of usually 1 m or less.

High-energy trauma causes more significant fractures. This can be as a result of motor vehicle accident, motorcycle injuries, and fall from height. There can be associated other injuries like urethral injuries (classical triad of blood at the meatus + distended bladder + inability to void), hematuria (partial urethral injury or bladder injury), rectal and gastrointestinal injury, injury to the genitals, and more importantly vascular injury.

In cases of associated urethral injury, a rectal examination can reveal high-riding prostate, and there can be associated scrotal hematoma, gross hematuria, or blood at the meatus. Blood on a rectal examination suggests that the fracture of the pelvis has perforated the rectum.

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Anterior pelvic injury is more likely to cause genito-urethral injuries.

In 75 % cases of the high-energy trauma, pelvic fractures can be associated with other musculoskeletal injuries. There can be associated head injury, abdominal injury, or an associated limb fracture. Pelvic trauma caused by lateral compression injury can be associated with brain injury, whereas anterior posterior compression can be associated with intra-abdominal or visceral injury.

Classification of Pelvic Fractures

Pelvic fractures have been classified by *Young and associates*, depending upon the mechanism of injury. This can be *anterioposterior compression*, *lateral compression*, or a *vertical sheer* or a *combination* of these forces.

Anterioposterior Compression (*APC*): This is of various subtypes:

- Grade I—associated widening (slight) of pubic symphysis or of the anterior sacroiliac (SI) joint, while sacrotuberous, sacrospinous, and posterior SI ligaments remain intact
- Grade II—associated widening of the anterior SI joint caused by disruption of the anterior SI, sacrotuberous, and sacrospinous ligaments; posterior SI ligaments remain intact
- Grade III (open book)—complete SI joint disruption with lateral displacement and disrupted anterior SI, sacrotuberous, sacrospinous, and posterior SI ligaments

Open Book Pelvic Fracture: Most commonly seen in a motorcyclist getting a head-on collision. The legs are separated wide apart on either side of the petrol tank, and the symphysis is usually placed next to the tank before and the driver meets a head-on collision. Petrol tanks hits the symphysis as the person is thrown forward, causing an open book fracture, and femur is externally rotated. This can cause injury to the blood vessels giving rise to internal bleeding and shock.

Lateral compression (LC) involves transverse fractures of the pubic rami, either ipsilateral or contralateral to a posterior injury.

- Grade I—associated sacral compression on side of impact
- Grade II—associated posterior iliac ("crescent") fracture on side of impact
- Grade III—associated contralateral sacroiliac joint injury

Injury to the side of the pelvis in a pedestrian hit by a car can cause fractures of the ilium, transverse fracture of the pubic ramus. Usually, these injuries are not life-threatening though there can be a situation where there has been telescoping of the pubic fracture at the time of injury causing a sharp spike of superior pubic ramus to impale a major blood vessel like femoral vessels causing vascular injury or even bladder injury.

Vertical shear (VS) injuries are of a result of fall from height causing one-half of the pelvis to move superiorly in relation to the other half, anteriorly symphyseal diastasis or vertical displacement and posteriorly through the SI joint, though occasionally through the iliac wing or sacrum.

Combination of Shear Forces: Most common is the combination of lateral compression and associated with vertical shear.

Marvin Tile has classified the pelvic ring fractures according to the increasing severity (Types A, B, C):

- Type A: pelvic ring is *stable*, posterior sacroiliac (SI) complex intact. Examples are avulsion fractures, isolated pubic rami fractures, and iliac wing fractures:
  - A1: Avulsion of innominate bone
  - A2: Stable iliac wing fracture or ring fracture
  - A3: Transverse fracture of sacrum and coccyx
- Type B: pelvic ring *partially stable*, partial disruption to SI complex. Pelvis is *rotationally unstable* but vertically stable. An examples is open book pelvic fracture:
  - B1: Open book injury
  - B2: Lateral compression injury
  - B3: Bilateral injury
- Type C: pelvic ring is *unstable*, *both rotationally and vertically*. Complete disruption to posterior SI complex. Examples are fall from height, motor vehicle accidents, and severe compression causing associated acetabular fractures:
  - C1: Unilateral
  - C2: Bilateral, one side B and one side C
  - C3: Bilateral C lesions

Assessment of Patient with Pelvic Injury

While the patient is being managed and stabilized along the ATLS guidelines a careful history to assess the mechanism of injury. Roadside smashed vehicle photographs often help to get in-depth idea of the amount of force and energy used to cause trauma and its severity. Time elapsed since injury.

Assess the patient age, so as to assess the quality of bone, physiological reserves, and hemodynamic response, any underlying medical conditions, and any medication history (anticoagulants, aspirin).

Any associated injury like head injury, spinal injury, long bone fractures, and injury to internal organs, blood vessels, and nerves is helpful as well as bruising of the pelvic area and bleeding from the genitourinary area, rectum. Assess the position of the lower limbs, shortened and externally rotated: vertical shear injury and externally rotated lower limbs: rotationally unstable injury.

Blood at the urethral meatus + distended bladder + inability to pass urine = injury to the urethra. Injury to vagina and bleeding may necessitate a gynecological review and assessment. Per-rectal (P/R) examination to assess perianal sensations, assessment of anal sphincter tone, and blood in the rectum (sacral fractures, rectum perforation). A high-riding prostate (urethral rupture), boggy feeling (hematoma), bony fragments (sacral fracture). Identify if any open fractures of pelvis.

Investigations and Imaging

Routine bloods for full blood count, group and save and crossmatch, clotting screen

Urine to assess for microscopic or gross hematuria, per rectal examination for any signs of bleeding

X-Rays: *Anterioposterior View* (*AP*) *of the Pelvis*. In a hemodynamically unstable patient, this x-ray is done as part of the ATLS protocol and suffices to assess initially any gross pelvic injury. Further views may be necessary like *pelvic inlet view of the pelvis* (beam-directed caudad), to assess any rotational displacement of the pelvis. It shows the posterior SI complex and anterior symphysis pubis. A disruption of 2.5 cm or more of the symphysis signifies a disruption to the anterior ligament complex. It also helps to see the ala of the sacrum. *Pelvic outlet view* (beam-directed cephalad) helps to assess any vertical displacement of the hemipelvis. *Judet view* of the pelvis may be necessary if there was an associated acetabular fracture.

While reviewing the x-rays, one should look for any break in one of the "rings" to avoid missing out any fractures of the pelvic ring: pelvic inlet ring, pelvic outlet ring, obturator foramens, sacral foramens, and finally also look at the acetabulum.

Look for any break in the bony lines: shenton lines, teardrop (injury to the quadrilateral plate-acetabular floor fracture), superior pubic ramus, inferior pubic ramus, ilioischeal line, and iliopectineal line.

Push-Pull X-Rays: These are necessary later in the treatment when the patient is stabilized and is taken to theater and anesthetized. They give information about the dynamic stability of the pelvis, which is useful to assess ligament stability in cases of vertical shear injuries.

CT scan is helpful to assess if there is any bleed in the retroperitoneal, intrapelvic, or intra-abdominal areas. Assess the posterior sacroiliac joint complex, any fractures of the acetabulum, fractures of the acetabular wall, and any intra-articular bony fragments. Contrast-enhanced CT is useful to assess abdominal injury before proceeding for laparotomy.

Ultrasound helps to assess intrapelvic bleed.

Emergency Arteriography: If the patient is hemodynamically unstable, despite resuscitative measures and any intraperitoneal bleeding is ruled out by CT scan, ultrasound, or peritoneal tap, then arteriography is indicated to locate site of arterial bleed. Embolization can be performed to control the bleed.

Urethrography and Cystography: Urethral injury is suspected in males, if there is blood on the external urethral meatus, prostate is riding high, and inability to void. Retrograde urethrography should be done prior to insertion of the catheter for the fear of converting an incomplete urethral tear to complete. In females, a vaginal tear can be associated with urethral injury. Cystography helps to assess any injury to the urinary bladder in cases where the urine is blood stained in absence of urethral injuries. This can be caused by pubic ramus fractures impaling on a full bladder following a high-energy lateral compression injury.

Neurological Assessment: This is done if there is any injury to the sciatic nerve affecting the lower limbs.

Management of Pelvic Fractures

Pelvic fractures which are as a result of low-energy trauma causing stable injuries can be treated nonoperatively. These injuries can include avulsion fractures and pubic ramus fractures. Treatment includes bed rest, analgesia, and mobilization as pain allows.

Treatment of high-energy trauma pelvic fractures which cause unstable pelvis needs active and more aggressive treatment. Treatment is started to resuscitate the patient per the ATLS guidelines.

Cases of open book pelvic fractures need stabilizing the pelvis. It is vital to decrease the pelvic volume by closing the book. This can be done in the resuscitation or trauma room firstly by keeping both the thighs, legs, and feet together. This helps to reduce the external rotation of the limbs and add to close the book and reduce the intrapelvic bleed. A rolled bedsheet can be passed under the pelvis and brought from the sides over the trochanters and crossed over in the front and pulled taut. This is secured taut with clamps or artery clips. This helps to reduce the book. Later, an external fixator can be applied at the anterior superior iliac spine (ASIS), and the book can be closed by bringing the symphysis together. Patient needs to be catheterized prior to closing the book to avoid squashing the urethra. A pelvic anti-shock clamp C-clamp can also be used to stabilize the pelvis anteriorly. If the clamp pins are placed posteriorly over the ilium, then it helps to stabilize the posterior SI complex. Other treatments to close the pelvis anteriorly include a reconstruction plate over the superior pubic ramus.

If there is vertical instability associated with rotational instability, then stabilization of the posterior SI complex would be necessary once the patient condition is stabilized. This can be done using plates or percutaneous screws. A push-pull x-ray film and assessment under anesthesia helps to identify vertical instability.

Stabilizing the pelvis helps to reduce the bleeding and also is convenient for transportation of the patient to a regional trauma center if necessary for the management of other injuries or fractures. It is always a good practice to contact the regional trauma center over the phone and take further advice about the pelvic injuries if in doubt.

In lateral compression injuries of the pelvis, the pelvis can be stabilized by using external fixator. In this situation, the external fixator is used as a distractor, distracting the pelvis and not compressing it so as to reduce the lateral compression.

A case of shortening and external rotation of the leg tends to reflect toward rotationally and vertically unstable pelvic injury (anterior pelvic injury associated with posterior SI complex injury), whereas external rotation of the legs is more in favor of rotationally unstable injury. It is not hard and fast rule but helps the orthopedic team to get some initial idea of the underlying injuries in suspected cases of pelvic fractures prior to the x-rays being taken in the resuscitation room. In multi-trauma patients to decrease the incidence of pulmonary embolism, one has to consider prophylactic placement of vena cava filter.

Arterial embolization may be necessary in patients who remain hemodynamically unstable after the pelvis has been reduced.

Complications

These can result from over compression of the pelvis by causing pressure areas over the trochanteric region by the bedsheet which is used to close the open book pelvis. They can be pin tract infection following external fixator or C-clamp application, loosening of the pins, and injury to the lateral femoral cutaneous nerve of the thigh. There is increased mortality with open pelvic fractures in the region of 30–50 %. Male patients can suffer from impotence. Sexual dysfunction can be seen in patients. Ten percent of the cases can have missed nerve injuries. There can be associated other abdominal injuries in 10–20 % of the cases. Limb-length discrepancy can happen as a result of vertically unstable injuries. Deep vein thrombosis should be prevented by appropriate DVT prophylaxis. There is a risk of pulmonary embolism.

Acetabular Fractures

Acetabular fractures are caused usually by blunt high-energy trauma, mostly road traffic accidents. They can be associated with pelvic fractures in 20 % of the cases and also with injuries to the internal organs, hip dislocations, and neurovascular injury. If acetabular fracture is not reduced and treated properly or if there is any intra-articular bony fragment in the hip joint, then it can lead to early secondary osteoarthritis of the hip joint. There can be various patterns of acetabular fracture depending upon the position of the femur/thigh at the time of the impact. If the hip was internally rotated, then it can cause posterior column fracture, whereas if the hip is externally rotated, then it can lead to anterior column fracture.

Judet and Letournel (1993) have classified acetabular fractures into five basic types and five subtypes according to the morphology of the fracture:

A: Posterior wall	B: Posterior column
C: Anterior wall	D: Anterior column
E: Transverse	
F: Posterior column + posterior wall	G: Transverse + posterior wall
H: T-fracture	I: Anterior column + posterior hemitransverse
J: Both columns fracture	

Anterior column: superior pubic ramus + pubic part of acetabulum.

Transverse fracture: a horizontal fracture line traversing through anterior column dividing the innominate bone into superior and inferior portions.

Posterior wall: posterior rim of acetabulum. It can be associated with the posterior dislocation of the hip.

Anterior wall: not so common, fracture of the anterior wall of acetabulum occurs mostly in association with anterior dislocation of the hip joint.

Imaging for Acetabular Fractures

Anterioposterior (AP) view of the pelvis: to assess if pelvic or acetabular fracture is present. (1) discontinuity of teardrop indicates a fracture of the quadrilateral plate; (2) discontinuity in the iliopectineal line indicates a break in the anterior column, and a discontinuity in the ilioischeal line indicates a break in the posterior column.

Judet views: this view is taken by turning/rolling the patient by 45° to the side. The x-ray beam is kept vertically down. There are two views: 45° *obturator oblique view* (to show the anterior column, posterior wall, and obturator foramen) and 45° *iliac view* (to show the posterior column, anterior acetabular wall)

CT scan: remains the mainstay for the evaluation of acetabular fractures. It helps in identifying fractures of the wall, any intra-articular bony fragment, and extent of the fractures. CT scan can help identify if the superior weight-bearing dome of the acetabulum is involved, amount of the displacement of the fracture fragments.

Treatment of Acetabular Fractures

Life-threatening conditions need to be treated primarily. Patient needs to be stabilized per the ATLS guidelines. Assess the skin condition locally.

Nonoperative Treatment: Cases which are not suitable for surgery due to systemic illness, osteoporotic bones, poor general health of the patient, multiorgan system failure, and localized infection are some of the indications for nonoperative treatment of acetabular fractures. A longitudinal skeletal traction is given. Fracture displacements of up to 2 mm can be treated by skeletal traction even if it involves the weight-bearing dome of the acetabulum.

Surgical Treatment: is challenging and requires great surgical skill and expertise and also good theater setup (for, e.g., cell saver) and a dedicated and experienced anesthetist. Aftercare in the high-dependency unit may sometimes be necessary due to other comorbidities. There is a learning curve associated with operating treatment and approaches, and the person doing them on a regular basis should do them, otherwise if there is any hesitation, then the patient, once stabilized, should be referred to the regional trauma center where pelvic and acetabular fracture treatment facilities are available.

Open reduction and internal fixation (ORIF) should be done once the patient general condition is stabilized; local soft tissues are favorable. Preferably, internal fixation should not be done later than 7–8 days. Indications are:

- Failure to maintain concentric reduction by closed methods.
- If there is a step of 2 mm or more of the articular surface.
- Thirty to forty percent involvement of the posterior wall.
- Sciatic nerve is involved.
- Vascular injury associated with acetabular fracture.
- Acetabular fractures with the roof arch measurements are less than 45°.

There are several surgical approaches used for ORIF of acetabular fractures. A particular approach is chosen per the portion of the acetabulum involvement:

1. *Kocher-Langenbeck approach*: this is used for:
   (a) Posterior wall fractures
   (b) Posterior column fractures

   It helps to also look at the sciatic nerve, if it is involved after the accident or post-relocation of the associated dislocated hip.
2. *Ilioinguinal approach*: this is indicated in:
   (a) Anterior column fractures
   (b) Quadrilateral plate injury
   (c) Superior pubic ramus fractures
   (d) Both column fractures
3. *Triradiate approach*: this is indicated if access is needed for the outer table of the pelvis.
4. Combined anterior and posterior approach.
5. *Extended iliofemoral approach*: similar to the triradiate approach but helps to give access to the bone above the sciatic notch.

   Implants Used

   Long cortical screws of 3.5 mm size of various lengths.

   3.5 mm reconstruction plates using 3.5 mm cortical screws are best suited for acetabular fractures as these can be contoured easily.

Aftercare

Care of the wound and avoiding any pressure sores.

Heterotropic calcification can be seen after acetabular fractures. It is best avoided by oral indomethacin for 6 weeks.

Care should be taken of deep vein thrombosis, pulmonary embolism by administration of appropriate anticoagulants (injectable low molecular weight Heparin LMWH or oral anticoagulants) till the patient is mobile. Sciatic nerve if involved, then appropriate splinting of the foot may be necessary.

Patient remains non-weight-bearing for 6–8 weeks after ORIF of acetabular fractures.

Regular physiotherapy and rehabilitation is necessary to get good functional outcome.

Complications

- *Infection*: the incidence is about 4–5 % in acetabular fractures. This can be treated with early thorough and aggressive debridement. In open book pelvic fractures with associated anterior column acetabular fractures requiring surgery, it is best to avoid external fixator for pelvic fractures (for primary stabilization) as it can compromise the surgical site for potential ilioinguinal approach (for acetabular fracture) due to possible pin tract infection. Under such situations, if an open book pelvic fracture has to be treated, preference should be internal fixation by a plate across the symphysis. Under these circumstances, if the patient has to be referred ultimately to a regional trauma center for management of acetabular fracture, it is best to discuss the case with the trauma/pelvis specialist before stabilization with external fixator. A definitive fixation of the acetabular fracture can then be done by ilioinguinal approach at the trauma center safely.
- *Bleeding*: this can take place from femoral vessels in cases of anterior column fractures.
- Sciatic nerve injury can be seen in about 30 % of the acetabular fractures. Care should be taken if using Kocher-Langenbeck approach, to explore the posterior wall of the acetabular, and sciatic nerve should be kept relaxed by bending the knee and keeping the hip extended.
- Lateral femoral cutaneous nerve can be injured during the ilioinguinal approach.
- Heterotropic ossification can be avoided by use of indomethacin 25 mg three times a day for a period of 6 weeks. Sometimes, low-dose irradiation is also helpful.
- Posttraumatic (secondary) osteoarthritis of the hip joint can take place if the acetabulum is not congruent. This can be managed by a future joint replacement if necessary.

Pelvic tenderness over the pubic symphysis, manual testing for assessing any clinical signs of pelvic instability by performing lateral compression.

Assess the sensations in lower limbs for any neurological involvement.

Chapter 10
The Hip Joint

Dipen K. Menon

Fractures and Dislocations of the Hip

Fractures of the Hip

Introduction

Hip fractures usually occur in osteoporotic bone and are classified as insufficiency fractures. These fractures usually occur in the elderly population. With people living increasingly longer, the incidence of these fractures is likely to increase in the future. Femoral neck fractures can occur in children and young adults. High energy is required to produce this fracture in young individuals with good bone quality. The complication rate (nonunion and avascular necrosis) is higher as a result of the higher energy imparted to the surrounding soft tissues in the latter group of patients. Current strategies are directed to the prevention of these fractures in the elderly. These include the prevention or reduction in the number of falls by medically managing the predisposing causes (e.g., treatment of arrhythmias and postural hypotension that predispose to syncopal attacks), reducing the severity of impact following a fall and treating osteoporosis. The combined management of these patients between orthopedic and orthogeriatric teams can result in better outcomes for these patients.

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Diagnosis

Patients who sustain these fractures can have multiple medical problems and can be on polypharmacy. Their previous level of mobility has to be determined. Patients may suffer from dementia. On reception in the emergency department, the diagnosis can be made based on the usual history of a fall and the inability to bear weight on the affected leg. Patients complain of pain in the groin, trochanteric area, or the buttock. The leg may be shortened and externally rotated, and the patient will find it difficult or more usually impossible to actively raise the fractured leg off the bed. Bruising may be visible in the trochanteric area (more commonly in intertrochanteric fractures). Palpation may reveal a tender spot in the groin. Any attempted movements of the hip (active or passive) will be painful.

Differential Diagnosis

Pelvic fracture (particularly stable fractures of the pubic rami in the elderly)
Acetabular fractures

Classification

1. Fractures of the femoral neck (intracapsular)
2. Intertrochanteric fractures (extracapsular)

This classification is important because these two fracture subtypes are associated with different problems. Fractures of the femoral neck can result in damage to the blood supply to the femoral head. This is because the predominant blood supply to the femoral head which comes from the retinacular vessels can be interrupted as result of the fracture. These blood vessels are predominantly posterior and run from the distal (lateral) aspect of the femoral neck proximally (medially). Disruption of these blood vessels can result in two potential problems (avascular necrosis and nonunion). Intertrochanteric fractures occur in a more vascular area of the femur and almost always unite (malunion being the more common end result). Generally, greater energy is required to produce an intertrochanteric fracture, and these fractures are associated with greater blood loss.

Investigations

An AP X-ray of the pelvis will show these fractures. It is essential to obtain a lateral view of the affected hip to avoid missing an undisplaced hip fracture. A bone scan, CT scan, or MR scan may very occasionally be required when the diagnosis cannot be made on the basis of clinical findings and an X-ray. Bone scans can be helpful in

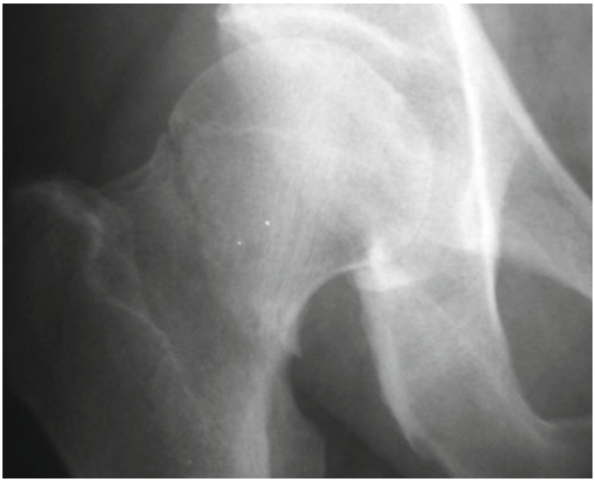

Fig. 10.1 Undisplaced intracapsular fracture of the hip (Courtesy of Dipen Menon, Kettering, UK)

diagnosing pathological fractures which usually result from metastatic bone disease. X rays can show fracture displacement.

Treatment

Analgesia should be administered to make the patient comfortable. Fluid management is critical. The vast majority of hip fractures are best treated operatively. This helps with nursing and results in more rapid recovery and rehabilitation. Patients should ideally be operated on within 24 h, medical condition permitting. Postponement of surgery beyond 24 h should ideally only be for optimizing the medical condition of the patient. Delaying surgery is associated with increased morbidity and mortality.

The factors that need to be taken into account in the treatment of intracapsular femoral neck fractures are the physiological age of the patient, level of mobility, fracture displacement, and hip osteoarthritis (usually associated with an intertrochanteric fracture). In young patients, every attempt should be made to internally fix the fracture aiming to preserve the femoral head. It is important to achieve as perfect a reduction as possible urgently. In about 20–30 % of these patients, secondary procedures may be required, which include removal of metalwork and treatment of complications (avascular necrosis and nonunion).

In older patients with undisplaced or minimally displaced fractures, internal fixation should be considered (Figs. 10.1 and 10.2).

Radiographs showing an intertrochanteric fracture treated initially by a Thomas' splint and later fixed by a DHS (Figs. 10.3, 10.4, and 10.5).

In displaced fractures in the elderly, a hemiarthroplasty would be the treatment of choice (Figs. 10.6 and 10.7). In patients with reasonable mobility (community ambulators), a cemented hemiarthroplasty (monoblock or bipolar) should be considered.

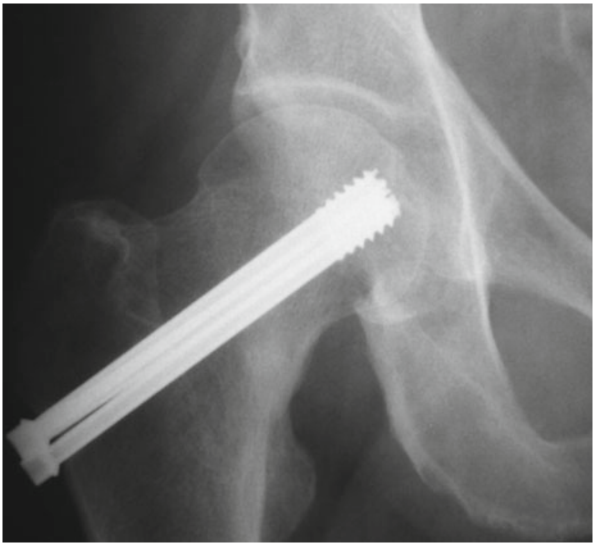

Fig. 10.2 Same fracture healed well with multiple Knowles' pins (Courtesy of Dipen Menon, Kettering, UK)

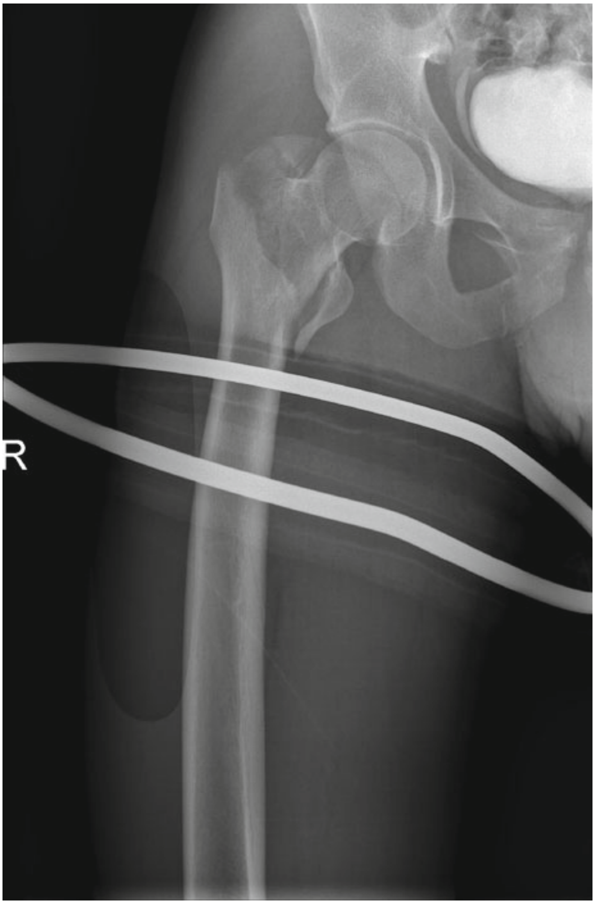

Fig. 10.3 Intertrochanteric extracapsular fracture treated initially by a Thomas' splint (Courtesy of Dilip Malhotra, Bahrain)

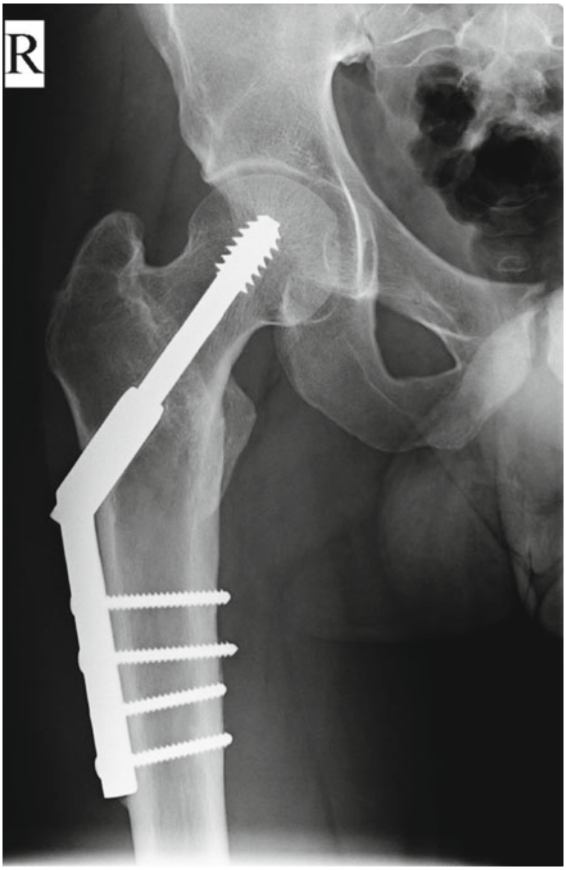

Fig. 10.4 Above fracture showing a healed intertrochanteric fracture which was treated by a DHS (Courtesy of Dilip Malhotra, Bahrain)

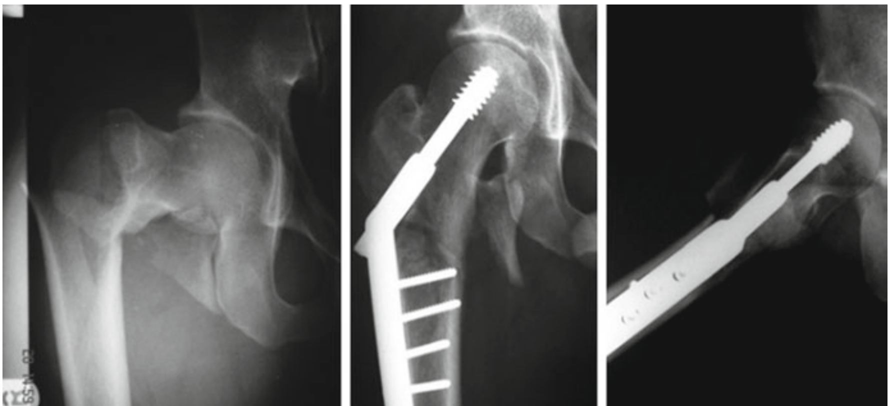

Fig. 10.5 Radiographs show an extracapsular (intertrochanteric) fracture of the right hip, which has been treated by a sliding dynamic compression hip screw and plate (Courtesy of Dilip Malhotra, Bahrain. Reproduced with kind permission of Springer Verlag)

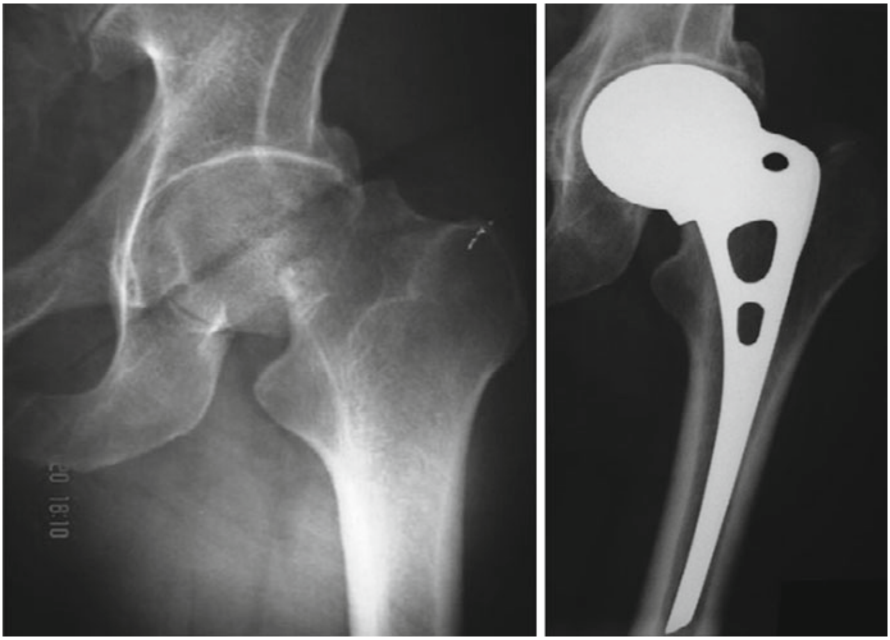

Fig. 10.6 Radiographs showing a displaced intracapsular fracture (transcervical) of the left hip which has been treated by an Austin Moore prosthesis (Courtesy of Dilip Malhotra, Bahrain. Reproduced with kind permission of Springer Verlag)

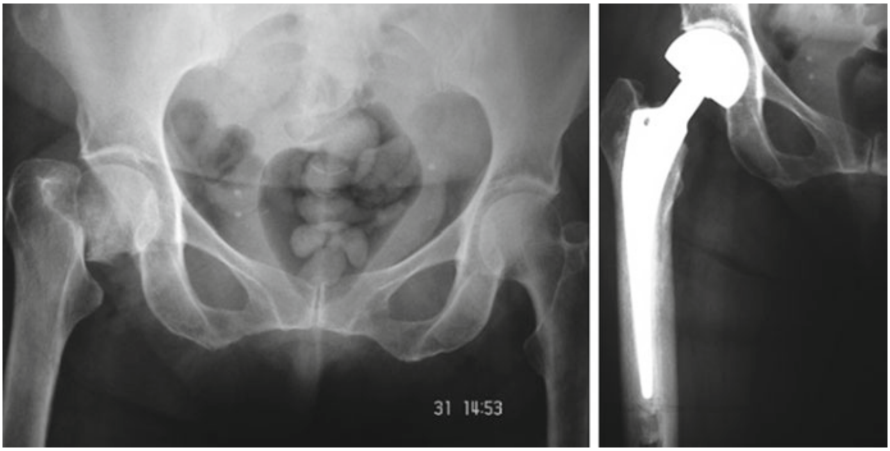

Fig. 10.7 Radiographs showing a displaced intracapsular fracture (transcervical) of the right hip treated by a cemented bipolar prosthesis (Courtesy of Dilip Malhotra, Bahrain. Reproduced with kind permission of Springer Verlag)

Fig. 10.8 Dislocation of the hip (Courtesy of Magdi E. Greiss, Whitehaven, Cumbria, UK)

In older patients with very poor mobility (household ambulators), a press-fit hemiarthroplasty is a procedure that can be performed expeditiously with minimum morbidity. In hips with advanced osteoarthritis or inflammatory arthritis, a total hip replacement would be the treatment of choice. This procedure is also reserved for the treatment of complications following internal fixation.

Intertrochanteric fractures require closed or open reduction with internal fixation. Fixation can be performed using a dynamic hip screw (DHS) that allows the controlled collapse of the healing fracture. Some of these fractures can be fixed with an intramedullary nail.

Traumatic Dislocation of the Hip

Hip dislocation is a surgical emergency. It is important to relocate the hip urgently to avoid circulatory compromise to the femoral head (Fig. 10.8).

The energy required to dislocate the native hip is significant and can be associated with soft tissue disruption and damage to the femoral head blood supply. This could result in avascular necrosis of the femoral head despite prompt reduction of the dislocation. The usual direction of dislocation is posterior although anterior dislocation can occasionally occur. In posterior dislocation, the limb is held in an attitude of flexion, adduction, and internal rotation with significant pain and muscle spasm. Reduction should always be attempted under GA with good muscle relaxation to avoid further damage to the surrounding soft tissues. Dislocation can be associated with fracture, and failure to concentrically reduce the hip would merit a CT scan to ascertain if there is any bone fragment in the hip, impeding reduction. With total hip replacements becoming more common, dislocation of a prosthetic hip

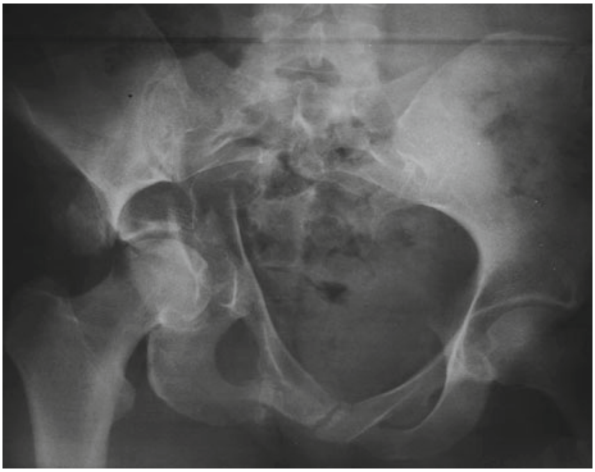

Fig. 10.9 Central fracture dislocation of the hip (Courtesy of Magdi E. Greiss, Whitehaven, Cumbria, UK)

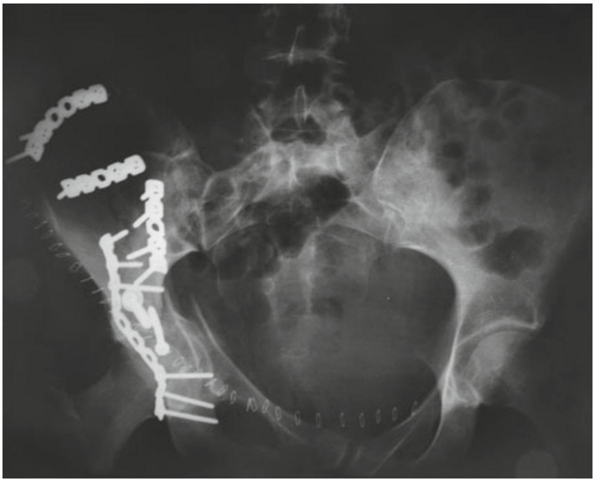

Fig. 10.10 Central fracture dislocation of the hip treated by internal fixation (Courtesy of Magdi E. Greiss, Whitehaven, Cumbria, UK)

is now much more common than dislocation of the native hip. Following reduction of a native hip dislocation, the patient can be initially kept on traction for about 2–3 weeks depending on the stability of the reduction. The patient can then be mobilized bearing weight progressively on the affected limb. Hip dislocations may occasionally be associated with fractures of the acetabular rim or floor, and these fractures would merit internal fixation (Figs. 10.9 and 10.10).

Chapter 11
The Thigh

K. Mohan Iyer

Fracture of the Shaft of Femur

Fractures of the shaft of femur occur at any age and are usually caused by a violent force. The pattern of the fracture is variable; it may be transverse, oblique, or spiral, and in children it may be of a greenstick type. The femur is also the common site of secondaries causing a pathological fracture. Blood loss in a fracture of the femur may be enormous, almost 1 L, though it is enveloped by numerous muscles.

Radiographs are always taken in the AP and lateral planes (Fig. 11.1), and great care should be taken to include the hip joint, as a dislocation of the hip joint can always be overlooked, which is coexisting with a fractured shaft of the femur.

Treatment

The most ideal method for conservative treatment is a sustained balanced traction in a Thomas' splint, which has now been replaced by the medullary nail with interlocking screws; the indications for this have widened over the years, with modern techniques which can be done closed with an image intensifier control with locking screws both proximally and distally. It must be noted here that an open reduction and nailing by the open method, a wide exposure of the fracture site, is required, and the complications like infection and knee stiffness are occasionally seen.

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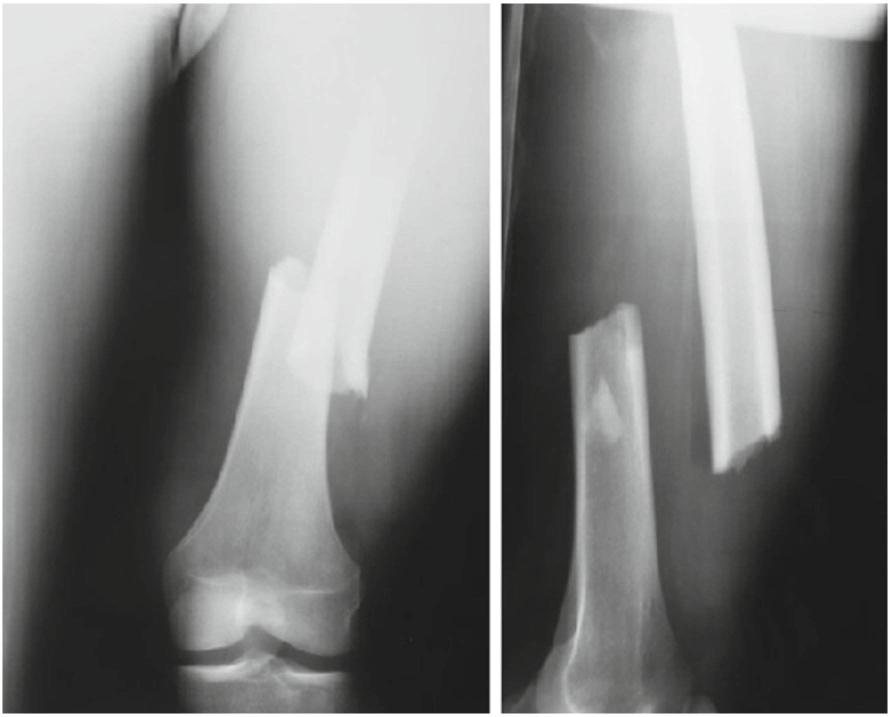

Fig. 11.1 Fracture of the shaft of femur (Courtesy of Magdi E. Greiss, Whitehaven, Cumbria, UK)

Conservative Treatment by Sustained Traction

The principles of the method are to reduce the fracture by manipulation and to support the limb in a Thomas' splint to maintain traction by means of a weight in order to preserve leg length, and rehabilitation exercises are also started early in treatment.

Reduction

An anesthetic is not always required. Traction is applied to the lower leg by an adhesive skin strapping or by a Steinmann pin passed through the upper end of the tibia. A Thomas' splint with a knee piece is then fitted on to the leg. This is normally done under an image intensifier with radiographic control to bring the fracture into correct apposition and alignment.

Splintage

When satisfactory reduction has been achieved, then canvas strips slung between the bars of a Thomas' splint are adjusted for tension when the splint with the contained limb is being suspended by an overhead beam by the balance weight, which is attached to the traction cord. The knee is flexed to 15–20° to permit control of rotation. Repeated serial check X-rays are taken every 2 weeks, and appropriate adjustments are made to the slings or weights as may be required.

Rehabilitation

Exercises for the foot and lower leg are necessary for preserving muscle tone and in preventing deformity especially equinus, which should be begun immediately. After about a week, when the pain due to the fracture is settling, active quadriceps and knee exercises are begun, and knee flexion till 60° is allowed so that active extension is far more important than flexion. These activities do not interfere with the union of the fracture.

The duration of the splintage varies from case to case. It may take anywhere between 12 and 16 weeks. When the stage of union is reached, the splint is then removed, and the patient is allowed to exercise freely in bed, before walking is begun. Thereafter, rehabilitation is confined to the gymnasium till full motion is restored.

Cast Bracing

In certain cases, when the femoral fracture is transverse or short oblique, plaster splint with cast bracing along with a hinge is helpful in reducing the time spent in convalescence. Once the fracture is sticky, in about 6–8 weeks, this functional brace can be substituted for the traction apparatus, with the aid of crutches. It is essential to check on the alignment of the fragments; angulation may occur leading to malunion.

Treatment by External Fixation

This method is extremely valuable for the treatment of open fractures by two stout threaded pins placed in both the fragments and rigidly anchored by an external steel bar by clamps or bone cement. This method holds the bony fragments rigidly in a reduced position.

Operative Treatment by Internal Fixation

Its indications are as follows:

1. When satisfactory reduction cannot be obtained or maintained by other means due sometimes to interposed muscle between the two fragments
2. In the elderly frail patients who respond unfavorably to a long period of rest in bed and are usually less mobile

3. In certain cases of multiple fractures in the lower limbs to facilitate the management of other injuries
4. In patients with pathological fractures from metastatic deposits to facilitate nursing
5. Closed intramedullary nailing when the fracture is suitable for nailing and when the advantages of early mobilization outweigh the risk of infection complicating the operation

Technique of Intramedullary Nailing for a Femoral Fracture

It is extremely essential to choose the length of the nail by measuring the normal side in the patient. It is important to give adequate bony traction and calcaneal traction for fractures of the tibia and fibula, upper tibial, or lower femoral in femoral fractures. The patient is anesthetized and placed on a fracture table, with both the legs well padded at the pressure points, such as the heels. The fracture fragments are then manipulated into the correct position and alignment by image intensifier control. A flexible guide wire is then inserted through the trochanteric fossa into the femur, and crossing the fracture site is very important. The initial guide wire is passed into the supracondylar area of the femur, and this is verified on the image intensifier. When the position of the guide wire is acceptable, powered cannulated reamers are then used to ream the medullary canal. When reaming till the adequate diameter is complete, the existing guide wire is replaced by the definitive guide wire. The selected nail is then passed over this guide wire. The entry point, the fracture site, and the distal placement of the nail are verified on the image intensifier, and the proximal locking screws are inserted into the proximal fragment. The distal locking screws are placed in a blind way in the distal fragment. This step requires expertise which is gained after doing a few cases by the interlocking technique in the tibia and the femur also. After the placement of the distal locking screws, further X-rays are taken on the image intensifier to reconfirm the exact position. If the fracture is separated by a small gap, this can be dynamized by the removal of one of the distal screws which helps in the closure the gap to promote union.

Postoperatively, the patient is left free without any splint or fracture. He is encouraged to exercise his knees and hips. If the fracture has been rigidly transfixed as in transverse cases, the patient may start mobilizing himself by graduated weight bearing 3 weeks from the operation.

Treatment in Children by Gallows Traction

This method of treatment is useful in children up to the age of 3 years. By means of adhesive skin strapping to the child's both legs, the child's both legs are suspended on an overhead beam. The cords are then tightened to just raise the child's buttocks off the mattress. The weight of the pelvis and trunk is sufficient to maintain traction and good alignment of the fracture, which is checked periodically by X-rays.

For caution in using this method, the child's knees are kept in slight flexion by crepe bandages to avoid a spasm of the major artery of the limb.

Complications

These have been documented, namely:

1. Simultaneous dislocation of the hip
2. Injury to a major artery
3. Injury to a nerve
4. Infection
5. Delayed union
6. Nonunion
7. Malunion
8. Stiffness of the knee

Simultaneous Dislocation of the Hip

Radiographs taken should always include the hip region in them.

Injury to a Major Artery

Very rarely, the sharp edge of the fractured bone may penetrate the soft tissues and the femoral artery. A constant watch must always be kept on the viability of the limb, and the continuity of the femoral artery may be restored by an immediate operation.

Injury to a Nerve

This may also be sometimes injured by a sharp fragment of the fractured bone. The severity of the damage can range from neuropraxia to complete severance of the nerve. The sciatic nerve is the nerve mostly likely to be injured in this way because it is broad. The management of these cases is the same as discussed in Chap. 8 of my book entitled 'General Principles of Orthopedics and Trauma'(Springer).

Infection

These may occur in compound fractures due to contamination in the initial injury. It must be emphasized that in the contamination of the wound, primary suture of the nerve is contraindicated.

Delayed Union

A fracture of the femur unites in an average of 4 months. Serial X-rays are indicative of how the fracture is progressing; delayed union must be considered if it is insufficient to allow unprotected weight bearing. A full length plaster spica or a cast brace may be considered in these cases. In certain cases, even a bone grafting may be considered if there is insufficient callus.

Nonunion

This can be recognized on serial X-rays if the fracture is not uniting or if the bone ends are rounded of and sclerotic. An operation wherein freshening of the bone ends along with bone grafting is considered. Closed intramedullary locked nailing or electromagnetic stimulation is considered in certain cases.

Malunion

This is can happen if the fracture is not supervised by serial check X-rays, such as in overlapping fragments uniting with shortening and lateral bowing. In cases where the malunion is slight, the fracture can be accepted with a shoe raise. If considerable, then an osteotomy and locking intramedullary nailing can be considered in certain severe cases of deformity.

Stiffness of the Knee

In most cases, stiffness is due to disturbance in the knee itself due to periarticular and intramuscular adhesions. Physiotherapy is satisfactory in many cases when they are carried out intensively and at an early stage. In certain cases, manipulation of the knee may be helpful, but passive stretching is strongly contraindicated. In very rare cases, when there is knee stiffness which is resistant to any form of treatment, then a quadricepsplasty may be considered to divide the adhesions.

Chapter 12
The Knee Joint

K. Mohan Iyer

Fractures of the Patella

Fractures of the patella are usually caused by:

1. Violent contraction of the quadriceps muscle
2. Fall or blow directly on the knee cap

Clinical Features

There is severe pain and hemarthrosis. Radiographs are very useful in all cases to note the nature of the fracture in AP and lateral views.
The fracture may be a crack fracture or a crack fracture with separation of the fragments or a comminuted fracture.

In crack undisplaced fractures of the patella, there is no fear of separation of the fragments because of the aponeurosis clothing the patella, which holds the patella in position. Treatment is mainly required for pain and preservation to restore function. An above-knee cylinder plaster cast is given from groin to the malleoli after aspirating the hemarthrosis. This plaster is given for 3–4 weeks after which the plaster is removed and physiotherapy given in the form of active and passive movements given along with quadriceps exercises to restore full movement.

In cases of crack displaced fracture of the patella, an operative treatment is the method of choice. The crack is usually a transverse fracture of the patella which is repaired by internal fixation (Fig. 12.1).The initial treatment is aspiration of the

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Fig. 12.1 Lateral radiograph of the knee joint showing a transverse fracture of the patella (Courtesy of Dilip Malhotra, Bahrain. Reproduced with kind permission of Springer Verlag)

hemarthrosis along with accurate reduction of the fragments. The internal fixation is usually performed by a tension band wiring or by a screw. The fracture is fixed after reduction in an anatomical position without any irregularity of its articular surface, which causes osteoarthritis in later life. This is then protected by a plaster cast for 3–4 weeks, after which physiotherapy is given in the form of active and passive exercises. Early walking is permitted on elbow crutches.

Comminuted Fracture

In comminuted fractures which are displaced and it is not possible to restore the patella to an anatomical configuration, excision of the patella is indicated. The patella is nowadays excised by a vertical incision rather than a transverse incision, as it makes a total knee replacement easier at a later date with a vertical incision. Postoperatively, the excision is protected by a plaster cast for 3 weeks, whereafter physiotherapy is started in order to restore function. This operation gives good results, though the knee may not be perfect, with slight discomfort in climbing or descending stairs.

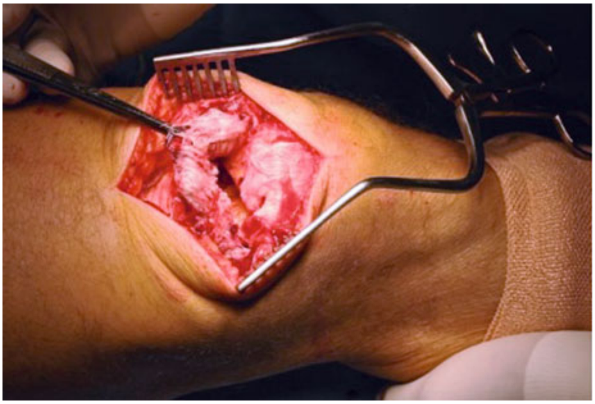


Fig. 12.2 Rupture of the quadriceps tendon (Courtesy of Dilip Malhotra, Bahrain)

Fracture of the Inferior or Distal Pole of the Patella

A small fracture of the inferior or distal pole of the patella is best treated by excision of the distal pole rather than trying to fix the fragment which is technically difficult.

Injuries of the Extensor Mechanism of the Knee

In injuries due a sudden violent muscular contraction of the quadriceps, the extensor apparatus of the knee may be ruptured in three places:

1. Superior pole of the patella: This is where the quadriceps gets inserted to the patella. In these cases which can happen in the elderly patient, the tendon is reattached to bone by stainless steel wires drilled through the bone followed by an above-knee pop cast (Fig. 12.2).
2. Fracture of the patella with interruption of the extensor mechanism: Here, the treatment is for a fracture of the patella along with aspiration of the hemarthrosis and immobilization.
3. Avulsion of the quadriceps from the tibial tuberosity: Here, treatment is toward fixation of the tibial tuberosity by a stainless steel wire or a screw fixation to restore the continuity of the extensor apparatus.

Injuries to the Ligaments of the Knee

See Chapter 10 in my book entitled ‘Orthopedics of the Upper and Lower Limb’ (Springer).

Tears of the Cruciate Ligaments

See Chapter 10 in my book entitled ‘Orthopedics of the Upper and Lower Limb’ (Springer).

Meniscal Injuries of the Knee

See Chapter 10 in my book entitled 'Orthopedics of the upper and Lower Limb' (Springer).

Traumatic Effusions of the Knee

The knee joint commonly becomes distended with fluid following injury. This fluid may be serous or blood or pus. A purulent effusion is readily diagnosed by constitutional symptoms like pyrexia and local signs of acute inflammation. The main problem arises in differentiating between a serous fluid and blood.

A serous effusion occurs after any injury that damages only the synovial membrane and does not tear any vascular structure. It regularly occurs after tears of menisci or after contusions of the capsule or ligaments. The characteristics of serous fluid are that it forms gradually over 24 h and rarely becomes tense.

A hemarthrosis is caused by an injury that tears the vascular structures, and it is also observed after complete rupture of the ligaments or capsule, fractures of the patella, or of the articular surfaces of the femur and tibia and after avulsion of the quadriceps tendon from the patella. The important characteristic features are that it forms rapidly, and the effusion is tense with the overlying skin warmer than normal, and it is usually accompanied by severe pain.

Treatment

Clear effusions are usually allowed to absorb spontaneously. Bloody effusions that are tense are aspirated and controlled thereafter by a compression bandage and immobilization.

Fractures of the Condyles of the Tibia

Fractures of the Lateral Tibial Condyle

The commonest injury is caused by a force that abducts the tibia on the femur with the foot fixed on the ground. This is usually the case when a car strikes the leg on the outside, and hence this fracture which is common in the elderly is called a "Bumper fracture." Most patients are women, and osteoporosis is an additional predisposing fracture.

The pattern of the fracture is mainly one of the three types, namely:

1. Comminuted compression fracture: This is the commonest type; when including its articular surface, it is crushed by the impact of the lateral femoral condyle and driven into it.
2. Depressed plateau type: This is less common than the comminuted type. A large part of the articular surface of the lateral condyle is depressed into shell of bone but remains intact as a single piece without severe comminution.
3. Oblique shearing fracture: This is the least common type, and a whole or part of the condyle is sheared off in one piece through an oblique fracture.

Treatment

The treatment is mainly dependent on the type of fracture that is seen radiologically. Plain radiographs may fail to show the true extent of the fracture, and in these cases a CT scan may be helpful in deciding whether an operation is indicated.

Comminuted Compression Type

This mainly forms the largest group. Since the articular surface is broken into many tiny pieces and many of these pieces may be crushed down into the underlying soft tissues, it is surgically impossible to reconstruct the articular surface into the original smooth surface. On the other hand, there is a tendency to cause further displacement, and the fracture which is through spongy bone will always unite rapidly. The best method is to accept the displacement, thereby avoid immobilization, and to encourage early movement of the knee joint. Initially, the patient is confined to the bed, and the hemarthrosis is aspirated when a removable plaster shell is constructed to protect the knee and prevent unguarded lateral movements of the knee, and active exercises may then be allowed under supervision of a physiotherapist. After 2–4 weeks, it is safe to allow walking with sticks, and further rehabilitation is carried out at the gymnasium.

Functional cast bracing is another method to avoid prolonged bed rest when the brace protects the knee to allow weight bearing within 2–3 weeks and at the same time allows knee movements with a hinge.

Depressed Plateau Fracture Without Fragmentation

In this group, every effort is made to restore the articular surface to normal. A window is cut in the anterolateral cortex of the tibia, and through this, the depressed fracture is pushed up from below by a broad punch until the articular cartilage is near to normal. The cavity in the lower part of the tibial condyle is then packed firmly with cancellous bone chips to hold the fragment in place. To prevent redisplacement of the reconstructed surface, the tibial condyle may be further buttressed by a broad plate fixed with transverse screws.

Oblique Shearing Fracture

This is best treated by an open reduction and fixation by a long screw. It is extremely important to make sure that there is no step in the articular surface.

It is interesting to note that the most common group, which includes the comminuted comminution group, do not give good results. On the other hand, the victims of this type are often elderly patients, where the results of conservative treatment are inadequate for their needs. Operation should normally be done on these cases, where they have a chance to obtain a near-normal articular surface.

Complications

Genu Valgum

A minor degree of genu valgum is unavoidable when there is some residual irremediable depression. In most cases, it is not so severe to warrant any treatment, and hence they are accepted.

Stiffness of the Knee

With early exercises along with physiotherapy, stiffness is not a serious problem. In selective cases, a manipulation under anesthesia may be helpful.

Osteoarthritis

This usually results from the damaged articular surface of the tibial condyle. When the articular damage is slight, it may take years for the arthritis to set in. In certain cases of painful posttraumatic osteoarthritis, an operation may be indicated by a corrective osteotomy or a total knee replacement or even arthrodesis.

Fracture of the Medial Tibial Condyle

This injury is rare and virtually a mirror image of the lateral condyle of the tibia.

Fractures of the Tibial Spine

Lesions of the tibial spine are relatively rare and often seen with other injuries like avulsion of the anterior cruciate ligament. There are mainly three groups of injuries:

1. Avulsion of the spine or its medial tubercle: This is produced by a mechanism similar to that of the anterior cruciate ligament tear when usually the ligament has remained intact and the brunt is borne by the bone process. The fragment is usually displaced in the direction of the anterior cruciate ligament, which is attached to the ligament.
2. Fracture of the lateral tubercle: The fracture in this case is usually due to direct contact with the inner margin of the lateral femoral condyle, and the fragment is usually pushed to the lateral side. The mechanism of injury is similar to that which results in lesions of the medial meniscus, extreme rotator violence.
3. Fracture of the spine in association with fractures of the tibial condyles: Here, the fracture is a crush fracture due to severe trauma in addition to the violent contact between the opposing articular surfaces when there is usually some forcible abduction or adduction strain leading to a fracture of either the medial or lateral condyle of the tibia. Hence, it may result from falls from a height or a heavy weight striking the thigh or a fixed knee joint.

Clinical Features

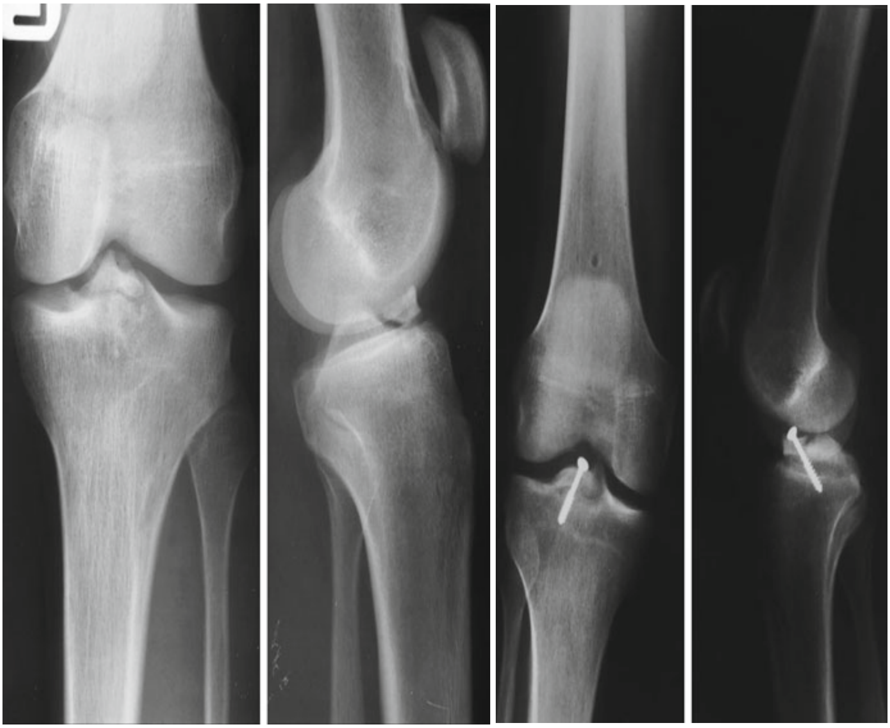
The diagnosis of tibial spine fractures is often masked by coincident lesions of the semilunar cartilage, the collateral ligaments, or the cruciates. In the first two types, there may be a history of locking, while in the third type, it may go unnoticed.

Treatment

Initial aspiration of the hemarthrosis or by pressure from a Jones' bandage is applied, and the patient mainly concentrates on exercises for the quadratus femoris.
In many cases, the bony block persists giving rise to considerable disability when the fragment is replaced by an operation (Figs. 12.3 and 12.4).

Supracondylar Fractures of the Femur

Typically, the fracture occurs just proximal to the knee joint, just proximal to the flare of the condyles. It may have a vertical extension giving the fracture



Figs. 12.3 and 12.4 Fracture of the medial tibial spine along with avulsion of the anterior cruciate ligament treated by replacement and fixation with a screw (Courtesy of Magdi E. Greiss, Whitehaven, Cumbria, UK)

a T-shaped configuration. The distal end is often titled anteriorly, with loss of end-to-end apposition.

Treatment

It is possible to treat a supracondylar fracture conservatively, but it is invariably tending to be treated increasingly by operative fixation with a condylar plate or nail plate.

Conservative Treatment

Most supracondylar fractures can be treated successfully in a Thomas' splint, with a knee flexion device attached to a continuous weight traction, as for fractures of the shaft of the femur. Closed reduction of a supracondylar fracture mainly depends on the forward tilting of the distal fragment, and knee flexion is an important part of holding a good reduction in place. The forward tilting of the distal fragment is corrected by increasing the angle of flexion, and the important position is determined by successive radiographs done during the first few days after injury.

In supracondylar fractures, unlike fractures of the femoral shaft, it is not advisable to start knee flexion exercises in the early days of treatment. For the first 3 weeks, active exercises are limited to the foot, ankle, and toe exercises along with static contractions of the quadriceps and gluteal muscles only. Knee movement can be started off when the fracture becomes stable in 3 week's time after injury.

Cast Bracing

Supracondylar fractures are best suited for functional cast bracing when the fracture shows signs of starting to unite, usually 4–6 weeks after injury. The cast brace allows for walking with partial weight bearing, and the knee hinge incorporated in the brace permits flexion/extension exercises.

Plaster Spica

Undisplaced supracondylar fractures can be treated by immobilizing the limb in a plaster hip spica for a longer time and at the same time encouraging the patient to walk with sticks or crutches. This method is ideal for children, and the plaster can be changed to a functional cast brace at the appropriate time.

Open Reduction and Fixation

This method is preferable when there is displacement at the fracture site or when the reduction cannot be maintained by conservative means. The ideal fixation device is probably a combined nail plate with a dynamic sliding screw or a reverse pin and plate. The nail or screw can be inserted horizontally across the lower fragment, and the plate contoured at right angles to the nail is screwed on the lateral side of the distal femur.

Treatment by a Long Intramedullary Nail

This has got a place in selected patients who are old with comminuted fractures which are unsuitable for a condylar screw plate. This is by an extra long nail intramedullary down the femur and transfixing the knee joint in this process into the upper aspect of the knee joint into the upper tibia. It affords the patient stability and resumes weight bearing at an early stage. When the fractures have united, the nail is removed to permit knee movements.

Complications

Most supracondylar fractures unite readily, and delayed union and nonunion are rarely seen in it. Otherwise, the complications are the same as for fractures of the femoral shaft, such as malunion and knee stiffness. Very rarely is a badly supracondylar fracture complicated by nerve or arterial injuries.

Fractures of the Femoral Condyles

Condylar fractures of the femur are rare, and when they occur, it is usually by direct violence in the region of the knee. There are two main types which are commonly seen, such as a crack fracture without displacement or fractures with marked separation of the fragments.

Treatment

Undisplaced Fractures

These may be treated in a long leg plaster for 6–8 weeks, and thereafter graduated weight bearing is permitted.

Displaced Fractures

Initially, reduction may be attempted by reduction and traction with manipulation, and if satisfactory, they can be further treated in a Thomas' splint with continuous weight traction or a long leg plaster.

If perfect reduction is difficult by the above method, then an open reduction and internal fixation can be undertaken. The method of fixation depends on the individual fracture, such as a long screw or by a dynamic condylar screw in T fractures of the femoral condyles. This device grips and compresses the fractures together, and the plate section may be located on the lateral surface of the femoral shaft.

Complications

Stiffness of the Knee

The treatment is mainly by exercises, and at times a gentle manipulation may be helpful in intra-articular adhesions, which can also be divided by an arthroscope.

Osteoarthritis of the Knee

This may develop after many years if the original fracture was not reduced anatomically.

Injury to Artery or Nerve

These may occur very rarely in violent injuries of the femoral condyles. A careful watch is kept over these rare complications, and the treatment of these is described in Chap. 2 of my book entitled ‘General Principles of Orthopedics and Trauma’ (Springer).

Fractures of the Tibial Condyles

The classification used in many centers today is by the classification given by Schatzker, who describes this classification in six stages:

1. This is the first stage which is caused by a bumper injury and mainly consists of a split lateral condylar with no depression. The fragment is neither depressed nor displaced. This is often caused by a valgus strain. The lateral meniscus is often involved in the injury, and it may even be trapped by the fracture. This injury is treated by lateral fixation only.
2. This fracture is the commonest variety of a lateral tibial condyle fracture, which has a split component and is also depressed. It is caused by a valgus strain or axial stress and is mainly in older patients with osteoporosis. This fracture is associated with lateral meniscus tears, medial meniscus tears, or medial ligament tears. This is basically treated by lateral fixation, and the depression is elevated by cancellous bone chips for support.
3. Here, the fracture only has pure depression. It is often seen in older patients with osteoporosis and can happen in patients with trivial injuries like a fall. If the depression is laterally and posteriorly, the joint may be unstable. If there is instability, the depressed fragments are elevated and supported and then fixed laterally.
4. Here, the medial tibial condyle is involved, and the split fracture is also depressed. It is usually caused by a varus stress with severe violence. It may be associated with a fracture of the tibial eminence, indicative of an anterior cruciate injury. There may also be an associated lateral ligament injury, a peroneal injury, or a popliteal artery injury. The fracture is usually treated by a medial plate fixation with screws.
5. This is usually with axial stress and severe trauma. It is bicondylar and involves both the medial and lateral condyles of the tibia (Fig. 12.5). The metaphysis maintains continuity with the diaphysis. It is commonly associated with ACL and meniscal injuries and may also show any type of neurovascular injury. The ideal treatment is fixation on both sides of the condyles.

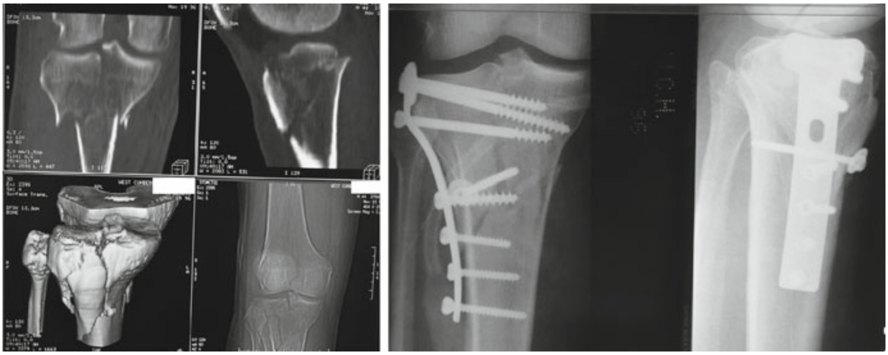


Fig. 12.5 Bicondylar fracture of both condyles of the tibia treated by internal fixation of both the condyles (Courtesy of Magdi E. Greiss, Whitehaven, Cumbria, UK)

6. This type is usually caused by high-energy trauma, where the metaphysis is separated from the articular surface by the diaphysis, and hence may involve both the surfaces, namely, medial, lateral, or both surfaces. It can be associated with neurovascular injuries and compartment syndrome, ACL tears, meniscal injuries, and both the collateral ligament injuries. It is treated by a medial and lateral fixation.

Chapter 13
The Leg

K. Mohan Iyer

Fracture of the Shaft of Tibia and Fibula

Mechanism and Displacement

Fractures of the shafts of the tibia and fibula occur either from an angulatory force or from a rotational force. Fractures from an angulatory force may be transverse or short oblique, and the fractures in both the bones are at the same level. Fractures from a rotational force are usually spiral and at different levels in both the bones. Often, the tibial fracture is at the junction of the middle and lower thirds, while the fibular fracture is near the junction of the middle and upper thirds. There is usually a considerable displacement of the fractures, though the undisplaced varieties occur mainly in children.

Because the tibia is very close to the surface and not well protected by muscles, it is usually of the compound type.

In Britain, motorcycle accidents are the most common cause of these fractures.

Treatment

In fresh fractures of the both bones, care and particular attention are given to only the tibia, and the fibula is disregarded as such because it unites readily and the bone is of secondary importance in that the actual position of the fragments is immaterial. In contrast, the tibial fracture requires constant supervision as its length and alignment matter a lot.

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Standard Method of Treatment

The most accepted method of treatment is closed reduction and an above-knee full-length plaster cast with the knee in slight flexion and the ankle at a right angle. This plaster may be later wedged if need be. Serial X-rays are taken every 2–3 weeks by which time the fracture is relatively stable because the soft tissue swelling will have settled down. For a transverse fracture, a walking heel can be given to help in mobilization. But if the fracture is slightly oblique, then there is a chance of redisplacement, and full unprotected weight bearing is deferred for 6–8 weeks. The same plaster is retained till the tibia shows signs of union on clinical and radiographic examination which is usually around 3–4 months. Thereafter, active exercises are carried out under the supervision of a physiotherapist.

Cast Bracing

In many cases, the period of immobilization of the knee and ankle can be reduced by a carefully applied functional cast brace, with hinges at the knee. In all cases, a check X-ray is always taken for any untoward angulation which may occur.

Operative Treatment, Internal Fixation

This line of treatment is usually considered when the fracture cannot be reduced adequately by manipulation, and the techniques are as follows:

1. Plate and screws
2. Intramedullary nail
3. Oblique fixation screws

Plate and Screws

Plate fixation is a nearly accepted and widely used method of fixation of a fracture of the tibial shaft. The plate is always of metal but even semirigid plates made up of acrylic compound and carbon fiber have been tried. Following plate fixation, additional support by a plaster is advisable till union is confirmed clinically and radiologically.

Intramedullary Nail

Closed intramedullary nailing with locked screws are gaining popularity in nearly most cases. It is only the severely comminuted fractures that one has to be careful of. Nailing is generally unsuitable for fractures close to the upper or lower articular surfaces. Above all, the main advantage of closed medullary interlocking nailing is to avoid infection, in addition to early weight bearing like the femur.

Initial traction is given through a calcaneal pin. Above all the exact size of the nail is measured in the opposite normal leg. The operation is carried out using general anesthesia and an image intensifier.

The skin incision is usually vertical longitudinally on the medial side of the tibial tuberosity when a guide wire is introduced about 1″ short of the lower articular surface of the tibia. Thereafter, the canal is reamed by flexible power reamers to about 12 mm when an appropriate length of the nail is taken. Then the guide wire is replaced by the definitive guide wire, and the chosen nail is driven over it. Then the proximal locking screws are first inserted into the tibia. The distal locking screws are drilled by the free-hand technique using an image intensifier. Finally, check X-rays are taken at the proximal end, the fracture site, and the distal end with the ankle joint.

Oblique Transfixion Screws

This is very useful in oblique fractures, which are difficult to hold in a plaster cast. This requires further additional support with a plaster cast also till union is achieved.

Treatment by External Fixation

This technique is particularly useful in open fracture or compound fractures where the chances of infection are quite high. Here, two or three pins are used on either side of the fracture, and their ends are connected outside by an external frame using clamps or bone cement.

Treatment by Continuous Traction

Should the patient be confined to bed because of other injuries, there is a place for continuous traction by a transfixion pin in the lower tibia when the leg is placed on a Braun frame.

Complications

The main complications are as follows:

1. Infection
2. Delayed union
3. Nonunion
4. Malunion
5. Impairment of vascular supply
6. Injury to a nerve

Infection

Established infection is indicated by persistent pyrexia and a suppurative odor over the wound. In that event, the plaster must be split and free drainage allowed. Later, the sequestra may have to be removed, and when the infection is overcome, healing may be hastened by the application of split-skin grafts to the granulating surface. In the event of serious infection, union of the fracture may be delayed or even there may be nonunion.

Delayed Union and Nonunion

Most tibial fractures unite quite readily, and bone grafting is indicated in most cases. The technique that is commonly used is when the fragments are in acceptable position and alignment. Usually slivers of bone are inserted beneath the periosteum, and the fracture is not disturbed. If it is necessary to adjust the fragments, then cancellous bone grafting may be combined with an intramedullary nail to provide rigidity. At times, it may be necessary to divide the fibula before the tibial fragments are brought into apposition. If persist infection make metallic internal fixation impossible, even an external fixation may be considered for stability while allowing for access to remove infected bone and soft tissues. Bone grafting should not be undertaken till the infection is cleared. In nonunion which does not heal by any method, an electrical stimulation may also be considered.

In most cases of delayed union of the tibia, the fibular fracture is soundly united. This may affect union of the tibia because the fibula is the longer bone and acts like a strut holding the tibial fragments apart. Should this be taken into consideration, then a simple operation of excising a minimal length of the fibula, 1″, should allow the tibial fragments to come together, and walking in a plaster may help the tibia to unite.

Malunion

This complication is very rarely seen in fractures of the tibia and fibula. In most cases, the disability is accepted when the deformity is minimal, but in severe cases, it is usually corrected by an osteotomy of the tibia and fibula.

Impairment of Vascular Supply

A displaced upper tibial fracture may damage a major branch of the popliteal artery with resultant obstruction of the blood flow or serious ischemia below the lesion. Another important cause of vascular impairment is the buildup of pressure due to edema occurring in a closed space within a closed fascial compartment.

This normally requires an emergency operation to prevent the development of a compartment syndrome. Constriction from tight dressings or a tightly given plaster may also cause such a similar situation.

Hence, it is of greatest importance to observe for the distal circulation periodically or for any injury to a peripheral nerve.

Injury to a Major Nerve

A displaced fracture of the tibia and fibula may damage a nerve trunk, particularly the common peroneal nerve or the lateral popliteal nerve below the knee and the tibial nerve in the lower quadrant of the tibia. The general management of nerve injuries is discussed in Chapter 8 of my book entitled ‘General Principles of Orthopedics and Trauma’ (Springer).

Fracture of One Bone Only

Fibula

Most spiral fractures of the fibula are associated with injuries of the knee or ankle, particularly high fractures of the ankle. Hence, a full-length X-ray of the affected leg is desirable on one film.

An isolated transverse fracture of the fibula may be due to stress or due to a direct blow. There is local tenderness, and the patient is unable to stand up and cannot move the knee and ankle. A crepe bandage is all that is needed for this.

Tibia

In children, a twisting injury may cause a spiral fracture of the tibia, without fracture of the fibula, and this is rare in adults. At any age, a direct blow such as a kick may result in a transverse or slightly oblique fracture of the tibia alone at the site of impact.

Clinically, there is local swelling along with bruising, but the knee and ankle movements are possible. Radiographs are very helpful in such cases.

Treatment

With displacement, a reduction should be attempted and a full-length above-knee plaster given. This is split at first, and this helps the swelling to subside down.

It takes around 8 weeks or even 12 weeks to consolidate when the plaster may be removed with intensive physiotherapy along with gait training begun.

Complications

With infection, the rate of union is slow. The isolated tibial fractures are slow to unite, and when there is displacement seen on serial X-rays, open reduction and internal fixation are considered.

Volkmann's Ischemic Contracture of the Leg

This is a condition seen in the forearm and may be seen very rarely in the leg also. Arterial spasm or obstruction or venous obstruction and myofascial or compartment pressure due to edema or hematoma of the musculature are the main components to give rise to this unpleasant condition following severe injuries of the lower extremity. Certain other factors causing it are unpadded plasters and tight plasters, which can result in a massive muscular infarction giving rise to this condition.

It is very important to recognize severe pain along with paraesthesia as preclinical features of this condition, which can be avoided by a shrewd observer. A breathing time of 6–8 h or 10–12 h exists to give chance for the surgeon to act to prevent this unfortunate complication after its recognition.

Though, performance of sympathetic blocks or an injection of Novocain into the injured vessel along with compartmental decompression in the various compartments of the leg has resulted in improvement.

It is worth noting that extension of the knee joint can significantly reduce the blood flow in the leg because the popliteal artery directly rests on the capsule of the knee joint.

Opening the deep fascia in the anterior and posterior compartments of the leg can reduce an impending Volkmann's ischemia. The outlook of impending Volkmann's ischemia is poor even with active early surgical intervention. Basically there are two types of vascular ischemia, namely:

1. When there is an injury to an artery and the effects are seen distally
2. When there is a direct injury to the artery, then there is ischemia to the artery at the site of injury. The important difference is because of the swelling of the soft tissues, there is an increase in the compartmental pressure, and this can be reversed by a timely fasciotomy which is well known.

Nervous tissue is most sensitive to ischemia, and the most important neurological sign is elicited in the nerves going through the tense compartment.

Wherever possible, the soft tissues should be palpated, whether they are tender or swollen and tense. If the diagnosis is in doubt, then the artery should be explored and the distal compartments generously decompressed immediately.

The cardinal features of a compartment syndrome are as follows:

1. Paraesthesia in the nerves traversing the compartment
2. Pain on passive stretching of the involved muscles
3. Pain on active flexion of the affected muscles
4. Tenderness over the affected compartment

Myoglobinuria may complicate this syndrome, and adequate fluids are a must to maintain urinary output.

In a young adult, the anterior tibial syndrome should be recognized, and vigorous contraction may lead to excessive metabolites which may cause swelling and increased tissue pressure leading to a rigid fascial compartment resulting in ischemia.

The patient is a young male, and he presents with pain over the anterior side of one or both the legs. There is tenderness and if allowed to persist may develop paralysis of the anterior tibial muscles, causing a foot drop. Passive motion of the involved muscles may be painful, and there is a sensory loss on the dorsum between the first and second toes.

It is now accepted that a high swelling and pressure in the soft tissues of the interfascial spaces after limb trauma may lead to progressive ischemic necrosis of the muscles and the corresponding nerve roots. At an advanced stage, these necrotic muscles may be replaced by fibrous tissues which may result in an ischemic contracture thereafter. Once the ischemic contracture sets in, it greatly impairs limb function.

Mild to moderate ischemic contracture can be misdiagnosed as a common peroneal injury due to foot drop clinically. Both the entities have paralysis and sensory loss, and this sensory loss in a common peroneal nerve injury is mainly on the lateral part of the dorsal surface, while in ischemic contracture of the leg, it is mainly over the sole of the foot and decreased in the active and passive activities at the ankle.

A wide prophylactic fasciotomy of the deep fascia is carried out on all patients requiring an arterial exploration. Special precaution is taken to avoid any pressure bandages or plasters. For interfascial spaces, a bilateral incision is preferable, one on the medial side and the other on the lateral side, and is helpful to decompress all the four compartments of the leg. The therapeutic outcome of severe ischemic contracture of the leg is generally unsatisfactory and hence prevention is better than treatment.

Chapter 14
The Ankle Joint

K. Mohan Iyer

Fractures of the Ankle

Mechanism

Usually the foot is anchored to the ground when a force pushes the body forward, such as stumbling over an object or fall from a height. This causes external rotation, abduction, and adduction.

The Ankle Mortise: An external rotation force causes a spiral fracture of the fibula. When the force continues, the medial malleolus is avulsed or fractured transversely. Further rotation leads to the avulsion of the posterior fragment of the tibia to which is attached the tibiofibular ligament.

An abduction force results in a fracture of the fibula transversely and may even avulse the medial malleolus.

Diastasis may occur in the above conditions. The tibiofibular ligament tears, with or without the avulsion of its tibial attachment. The ligament tears allowing the tibia and fibula to separate, with the talus being driven up between them.

An adduction force causes a near vertical fracture of the medial malleolus extending upward from the medial angle of the mortise, and the tip of the fibula may be avulsed.

An upward thrust may split the tibia vertically, and vertical fracture may also have another transverse extension about 2–3″ above the ankle joint. At times, the vertical force shears off the anterior or posterior corner of the tibia.

In adolescents, similar injuries occurring can cause fracture-separation of the lower tibial epiphysis.

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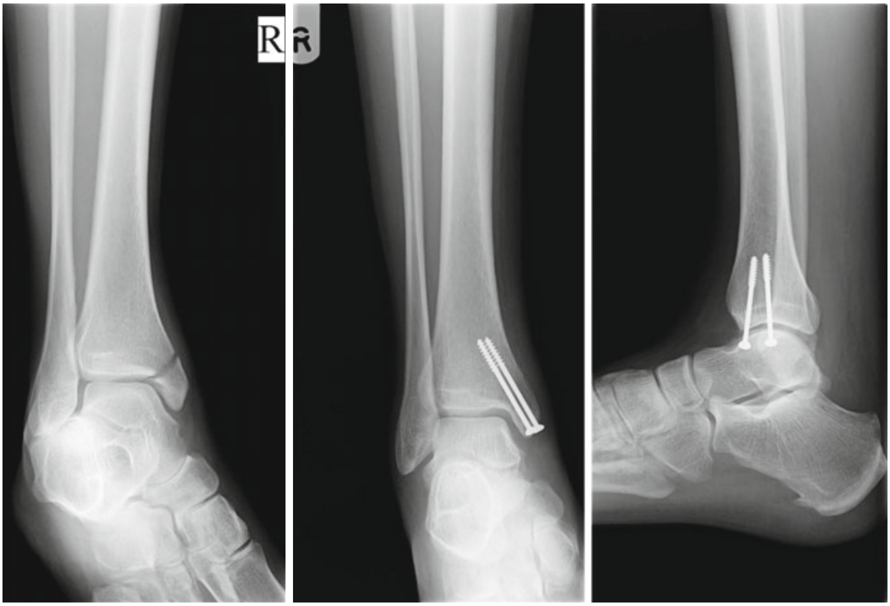


Figs. 14.1 and 14.2 Fracture of medial malleolus. Treated by internal fixation with two screws (Courtesy of Dilip Malhotra, Bahrain)

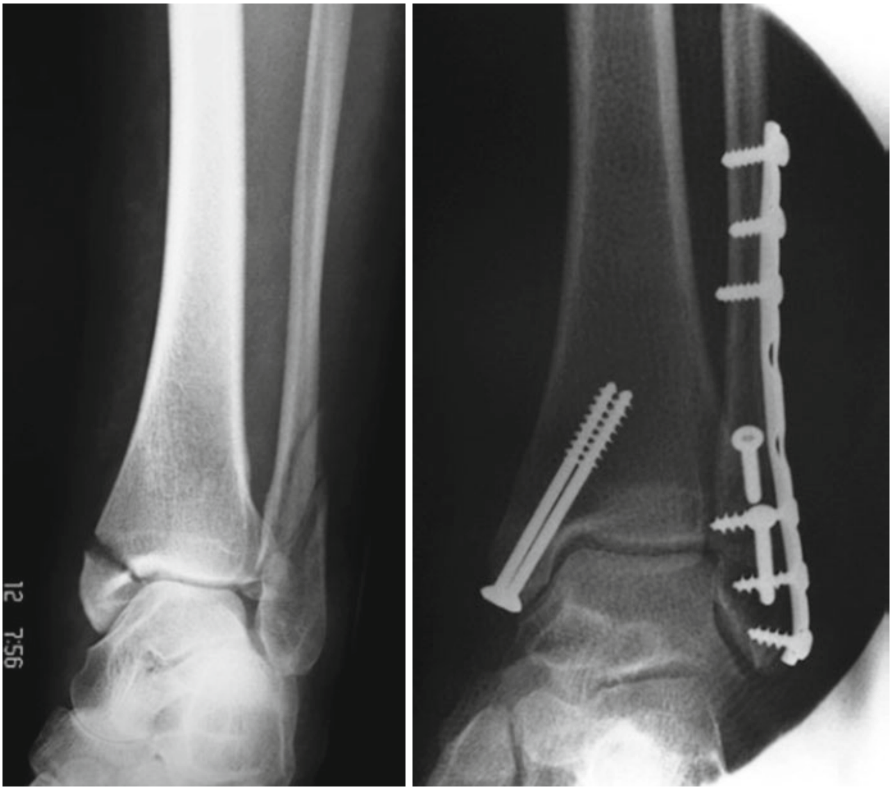
Treatment

It is extremely important to get and maintain a perfect reduction of the ankle, and there remains no doubt for internal fixation (Figs. 14.1 and 14.2) when other methods have not been successful.

Conservative Treatment

Ankle fractures which are undisplaced do not require a plaster and are well managed by only a crepe bandage.

Closed reduction by manual traction is applied in a reverse direction to the force that caused the initial injury. This enables the talus to be replaced into the ankle mortise correctly. A well-padded plaster is then applied to the leg from the knee to the toes, with the foot in plantar flexion and neither in valgus or varus position. The plaster is then split to the skin vertically, and check X-rays are then taken to note the position of reduction, which is kept for 6 weeks, if satisfactory reduction is obtained. In fracture caused by an external rotation force, 6 weeks are enough while in all other fractures, the plaster is kept for 12 weeks. The plaster is then fitted with a boot,



Figs. 14.3 and 14.4 Radiographs of the ankle joint showing a bimalleolar fracture which has been treated by open reduction and internal fixation to restore the congruity of the ankle joint (Courtesy of Dilip Malhotra, Bahrain. Reproduced with kind permission of Springer and Verlag)

and the patient is allowed to walk. After removal of the plaster, intensive ankle and foot exercises along with gait training are given with the ankle in a crepe bandage.

Operative Treatment

This is usually indicated (1) to ensure a perfect reduction, (2) to maintain reduction, and (3) to allow for early mobilization (Figs. 14.3 and 14.4).

The medial malleolus is internally fixed by a screw to ensure perfect reduction. Internal fixation of the medial malleolus alone is not sufficient to allow for walking, and regaining full movements is very necessary for this. The below-knee plaster is worn till the fracture is consolidated.

At times, the reduction is not perfect, and the talus does not fit into the ankle mortise perfectly since usually a flap of periosteum is interposed between the medial malleolus and the tibia or the peroneal tendons between the lateral malleolus and the shaft of the fibula.

Fractures with diastasis are extremely unstable, and they are held firmly by a diastasis screw which is inserted from the fibula to the tibia transversely to reach two-thirds way, but care is taken not to engage both the cortices of the tibia, and it just falls short of the opposite cortex of the tibia. It is preferable to remove the second screw after 3 months, and thereafter intensive ankle and foot exercises along with gait training are started.

Complications

Malunion

Incomplete reduction is common, and unless the talus is accurately seated back into the ankle mortise, degenerative arthritis eventually sets in. Early treatment of any residual deformity can be treated by a corrective osteotomy. Should degenerative arthritis have already set in, arthrodesis of the ankle is considered.

Nonunion

Nonunion of the medial malleolus is very rare and usually because of the periosteal flap interposed between it and the tibia. This should be prevented by operative reduction.

Joint Stiffness

Joint stiffness and swelling are due to the neglect of treatment of the soft tissues. The patient must walk correctly in the plaster, and gait training helps after its removal when a crepe bandage is usually sufficient till circulatory control is regained. Very rarely, a manipulation under anesthesia is considered.

Ligament Injuries

The usual mechanism is an inversion strain resulting in a partial rupture of the lateral ligament of the ankle when it is called as a strain. At times, the ligament is completely ruptured, and the talus tilts in inversion.

In inversion strains, there is tenderness and the ankle joint is swollen with painful movements. Radiographs are inconclusive with no bony fractures seen.

Treatment

Partial Tears

This is treated by a crepe bandage, and exercises are begun immediately. The patient is not allowed to hang the leg down, and the bandage is worn till the swelling has disappeared. Weight bearing is taught by gait training.

Complete Tears

A subluxation is treated by a below-knee plaster cast with the foot plantigrade, and no reduction is necessary. The plaster is worn till the ligament has completely healed, which is around 10 weeks. The patient is encouraged to have exercises to the ankle and foot along with gait training.

Complications

Adhesions

This is common after an ankle sprain and the patient complains of the ankle giving way. Usually, there is tenderness on the lateral side of the ankle and pain on inversion, which is not experienced on eversion. Active exercises along with paraffin wax baths are helpful in certain cases. A manipulation under an anesthetic is also considered in some cases.

Recurrent Subluxation

This condition is seen when complete tears of the lateral ligament are not treated. The history and symptoms are just similar to sprains, and the talus can be inverted further than a normal ankle. In doubtful cases, an examination under an anesthetic is carried out and inversion compared in both ankles to arrive at a diagnosis.

Treatment of Recurrent Subluxation

Initial treatment by raising the outer side of the heel and extending its lower surface laterally may benefit some patients.

Alternatively, an operative procedure is carried out by detaching the peroneus brevis at its attachment and rerouting it through a hole in the distal fibula, and suturing it back to itself and the peroneus longus, followed postoperatively by a plaster for 8 weeks.

Recurrent Dislocation of the Peroneal Tendons

Adhesions and recurrent subluxation are definite causes of giving way of the ankle. Recurrent dislocation of the peroneal tendons can also cause a feeling of giving way of the ankle. The patient can also demonstrate this phenomenon when the peroneal tendons dislocate forward over the fibula in certain positions. At operation, the superficial cortex of the lower fibula 5 cm is hinged backward and sutured over the peroneal tendons to hold them in their correct place.

Fracture of One Bone Only

Fibula

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An isolated transverse fracture of the fibula may be due to stress or due to a direct blow. There is local tenderness, and the patient is unable to stand up and cannot move the knee and ankle. A crepe bandage is all that is needed for this.

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Clinically, there is local swelling along with bruising, but the knee and ankle movements are possible. Radiographs are very helpful in such cases.

Treatment

With displacement, a reduction should be attempted and a full-length above-knee plaster given. This is split at first and this helps the swelling subside down.

It takes around 8 weeks or even 12 weeks to consolidate when the plaster may be removed with intensive physiotherapy along with gait training begun.

Complications

With infection the rate of union is slow. The isolated tibial fractures are slow to unite, and when there is displacement seen on serial X-rays, open reduction and internal fixation are considered.

Chapter 15
The Foot and Toes

Shaisshav Bhagat and Bhavik M. Shah

Fractures of Foot

Foot trauma is often the result of motor vehicle crashes, industrial accidents, or a fall from a height. In recent years, there has been an increased awareness of biomechanics of foot along with renewed interest in surgical treatment due to advances in CT and MRI scans. Foot fractures account for approximately 12 % of all fractures. There is approximately equal gender distribution. Fractures of metatarsals and phalanges are commonest of all foot fractures. Calcaneal fractures account for approximately 10 % of all foot fractures. Fracture dislocations of tarsometatarsal and subtalar joints are associated with significant morbidity.

Important Points in Examination of a Patient with an Acute Foot Injury

History, obtained from the patient or paramedic, may give an indication of suspected foot trauma.

Both feet and ankles should always be completely exposed to facilitate examination.

Skin is checked for puncture wounds, abrasions, blisters, skin tenting, lacerations, erythema, and swelling, including the plantar aspect of the feet, posterior aspect of the heels, and webspaces.

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A well-documented neurovascular exam of the foot should include:

1. Dorsalis pedis and posterior tibialis pulses with performance of an ankle brachial index and comparison to the opposite side if necessary
2. Capillary refill of the toes
3. Proprioceptive status
4. Sensation of all five nerves (deep peroneal, superficial peroneal, tibial, saphenous, and sural) with a light touch examination using a paper clip or alternative instrument
5. Motor function of all muscle groups in both the foot and leg

The compartments of the foot and leg must be carefully examined and compared with those on the other side.

Examination of more proximal aspects of extremity, pelvis, and entire spine is essential.

In spite of the several advances in the understanding of foot biomechanics, imaging modalities like 3-D reformatted CT scans, approaches and instrumentation for fracture fixation, there are several controversies in the management of following injuries. The foot is unable to withstand even minor degrees of malalignment or instability, and subsequent disability can ensue if appropriate measures are not taken. The following is a list of burning questions in the management of foot and ankle trauma. The aim here is to discuss the basics of fracture management and dealing with issues highlighted below which one would come across in routine trauma practice. Only important anatomy will be discussed, and for further details on surgical anatomy and approaches, the readers are encouraged to refer to other relevant sections of the anatomy textbook. The aim of the authors in this chapter is to cover the basic patterns of injuries, recent advances, and current controversies in the management of such injuries.

Current Controversies in the Treatment of Foot and Ankle Fractures

How should talar body fractures be treated?
How successful is their treatment?
What are the long-term effects of lateral process fractures of the talus?
Is nonoperative or operative treatment preferable for intra-articular calcaneal fractures?
How should calcaneal fractures be fixed?
Is bone graft required for calcaneal fractures?
How should extra-articular calcaneal fractures be managed?
How common are midfoot fractures?

How should they be treated?
How should Lisfranc fracture–dislocations be treated?
How common are stress fractures of the metatarsus?
How should Jones fractures be treated?

Fractures of the Talus

Talar fractures account for approximately 1 % of all fractures and are frequently the result of high-energy trauma such as falling from a height or a motor vehicle accident. Fifteen to twenty percent of talar fractures are open and associated with other injuries.

Surgical Anatomy

Talus is the second largest tarsal bone with two thirds of the surface being covered by the articular cartilage. The osseous anatomy can be divided into body, neck, head, and peripheral processes. The superior articular surface is pulley shaped and wider anteriorly. The medial wall is straight, and lateral wall has a gentle slope. They articulate with the medial and lateral malleoli respectively. On the inferior surface of the talar body are three articular facets that articulate with the calcaneus.

The body has a wedge-shaped lateral process. The lateral process is almost completely covered with articular cartilage, contributing to the talofibular as well as the talocalcaneal articular surface and serves as an attachment site for multiple lateral stabilizing ligaments of both ankle and subtalar joint, including the lateral talocalcaneal ligament.

The posterior process is composed of medial and lateral tubercles that are separated by a groove for the tendon of flexor hallucis longus. The larger posterolateral tubercle forms part of the subtalar joint. The posterolateral tubercle can exist as an oversized trigonal process called the Stieda's process or as a separate accessory bone called the os trigonum found in 3–8 % of the population [1].

The neck extends anteroinferiorly from the body. The talar neck is angled at a mean of 24° medially (range, 10–44°) and plantarly (range, 5–50°) and is one of the few areas not covered by articular cartilage [2]. The neck provides attachment to the strong interosseous talocalcaneal ligament, a major stabilizer of the subtalar joint. Immediately anterior to this ligament is a transverse groove that forms the tarsal canal in conjunction with a corresponding groove on the superior surface of the calcaneus, and laterally, the groove becomes wide and called sinus tarsi.

The talar head is rotated an average of 45° lateral side from a longitudinal line of the talar body. It is covered by cartilage and articulates with the navicular to form the TN joint and provides attachment to the spring ligament (inferior calcaneonavicular ligament) and the anterior facet of the subtalar joint.

The blood supply to the talus comes from three main arteries and their branches. The main blood supply is from the posterior tibial artery, which gives off a branch to the tarsal canal running between the posterior and middle facets. This supplies most of the body. The head and neck are supplied by the dorsalis pedis artery and the artery of the tarsal sinus, a branch of the perforating peroneal artery. The posterior part of the talus is supplied by branches of the posterior tibial artery that enter through the posterior process.

Imaging and Special Views

Standard radiographs for evaluation of any foot and ankle injury should include AP, lateral, and oblique views of the foot and AP, lateral, and mortise views of ankle. Specialized radiographs for the talus are the Canale and Broden's views.

The Canale view is a true AP projection of the talar neck and particularly useful in assessing talar varus malignment. The Canale view is obtained by:

1. Maximally plantar flexing the ankle
2. Pronating the foot 15° to eliminate superimposition of the talus and calcaneus
3. Angling the imaging tube 75° cephalad from horizontal

The Broden view is obtained by:

1. Internally rotating the foot 45°
2. Sequentially angling the imaging beam between 10° and 40° until an accurate image of the posterior, middle, or both facets is obtained [3].

MRI is indicated when there is suspicion of (1) occult cartilage injury, (2) associated soft tissue injuries, and (3) assessing talar AVN versus revascularization following talar injury.

Classifications of Talus Fractures

The two main classification systems include the:

1. Hawkins (1970) classification [4] of talar neck fractures, with later modification by Canale and Kelly [5]
2. Sneppen (1977) classification of talar body fractures

Hawkins separated talar neck fractures into three types:

Type I fractures are undisplaced fractures that exit between the middle and posterior facets. Risk of AVN is 10–14 %.
Type II fractures are similar, but there is subluxation or dislocation of the subtalar joint. Risk of AVN is 20–50 %.
Type III fractures include dislocation of the body of the talus from both subtalar and ankle joints. Risk of AVN is 75–100 %.
Canale and Kelly added a type IV fracture, where the talar head is dislocated from the navicular. Hawkins had included these fractures in his type III group. Risk of AVN is 100 % [5].

Sneppen divided talar body fractures into six basic types [6]:

Type A fractures are osteochondral fractures.
Type B fractures are sagittal shear fractures.
Type C fractures are coronal shear fractures.
Type D fractures contain the posterior process fractures.
Type E includes lateral process fractures.
Type F fractures are crush fractures.

The classification does not include all variants of talar shear fractures. Boyd and Knight (1942) described the comparatively unusual transverse shear fracture and also pointed out that the sheared fragments could displace and become dislocated from the ankle and subtalar joints in the same way as a type III talar neck fracture [7].

Clinical Evaluation and Associated Injuries

- Most talar fractures follow high-energy injuries. The lateral process fractures may be caused by sports such as snowboarding and axial loading.
- The clinical presentation is with a swollen painful hindfoot associated with deformity if there is subtalar or ankle dislocation.
- Careful assessment of local swelling, deformity, and the state of the soft tissues must be made with any open wounds carefully examined.
- If there is an associated dislocation, the vascularity of the overlying skin and the foot must be carefully assessed.
- Examination of the spine, pelvis, ipsilateral, and contralateral extremities is important as there is 58–86 % reported incidence of remote fractures [8]. The most commonly associated injury is a fracture of the medial malleolus (up to 25 %) [9]. Fourteen to twenty-seven percent of all talar neck fractures and over 50 % of Hawkins' type III talar neck fractures are open. These injuries need aggressive irrigation and débridement, as infection rates are reported as high as 40 % and can have disastrous consequences particularly in the setting of AVN.

Treatment of Talar Neck Fractures

Nonoperative

Restricted to Hawkins type 1 undisplaced talar neck fractures. The treatment protocol in most centers involve non-weight-bearing immobilization in a short leg cast maintained for 4–6 weeks, followed by progressive, protected weight bearing for another 4–6 weeks until both radiographic and clinical evidence of bony union are seen. In general, closed treatment of talar neck fractures today is best reserved for cases in which reduction is anatomic as even minimal talar fracture displacement may substantially alter subtalar contact mechanics and hindfoot motion, factors associated with development of posttraumatic subtalar arthrosis.

Operative Treatment

Percutaneous Fixation

Indications
- Undisplaced fracture like type 1
- Anatomically reduced type 2 or 3 fractures
- No comminution

Technique: Percutaneous fixation performed from an anterior approach typically requires that the patient be supine; percutaneous fixation via a posterior approach may be performed with the patient in a prone or lateral decubitus position.

In biomechanical testing, a posterior-to-anterior screw trajectory provides the most rigid fixation of talar neck fractures. Disadvantages of the posterior approach in a prone patient are an inability to directly visualize the fracture site and a limited access to the subtalar joint. Lateral positioning of the patient enables the surgeon to externally rotate the leg to perform a simultaneous anterior exposure for direct fracture visualization and subtalar joint débridement when required.

A minimally invasive posterolateral approach between peroneal and Achilles tendon with FHL retracted medially and protecting sural nerve can be used to identify posterior process of talus. Cortical screws should be used in a countersunk fashion with size 2.7–4.0 mm (Figs. 15.1 and 15.2). Lag principle should be applied to achieve good compression. Penetrating superior and inferior surfaces should be avoided. Alternatively, 3.5- or 4.0-mm cannulated screws may be utilized. Although cannulated systems may permit a less-invasive approach, they typically do not provide equal fixation strength afforded by solid-core screws of comparable size.

For anterior approach, small medial and lateral stab incisions just distal to the talar head are used. One screw placed on each side of the anterior talus is preferred, but two parallel screws on only one side may be considered. Screws should be placed perpendicular to the fracture plane to avoid gapping of the fracture on the side opposite the screw being tightened in compression. The screw heads must also be countersunk in the subchondral bone of the talar head to avoid interference with

Figs. 15.1 and 15.2 Talar neck fracture, treated by open reduction and internal fixation (Courtesy of Magdi E.Greiss, Whitehaven, Cumbria, UK)

the talonavicular joint. Excessive countersinking is to be avoided since it may result in reduced screw fixation. Headless screw fixation is an option, provided the screws are not excessively countersunk. An advantage to the anterior over the posterior approach in percutaneous fixation of talar neck fractures is that the surgeon can readily convert to an open approach that provides direct visualization of the fracture should displacement or comminution be encountered.

Open Reduction and Fixation

Most displaced fractures of talus will require ORIF. Timing of operation and development of AVN although remain controversial, most authors now believe that AVN, union rates, and overall outcome are perhaps more related to the severity of the injury, as expressed by displacement, comminution, soft tissue damage (open fractures), and quality of surgical reduction.

Talar neck fractures are orthopedic emergencies when associated with (1) irreducible dislocation, (2) unresolvable tented soft tissue envelope or impending skin necrosis, (3) compartment syndrome, (4) neurovascular compromise, or (5) open wounds. Emergent treatment consists of reduction of dislocations, pressure relief of surrounding soft tissues, débridement of open wounds, and fasciotomies if compartment syndrome is a concern.

The surgical approach is determined both by fracture pattern and soft tissue status. In general, four working approaches are used: the medial utility approach (with or without a medial malleolar osteotomy), the anterolateral approach, the posteromedial approach, and a combined approach. Rarely, a fibular osteotomy or window, as described by Hansen, can be used if access to the posterolateral talar body is required.

Surgical Tips and Technique

After the talar body is exposed, a temporary 2.0- to 2.5-mm K-wire or 4.0-mm Schanz pin may be used like a joystick to manipulate the fracture fragments in anatomical position.

With minimal comminution, the talus can then be definitively fixed with several lag screws. These can be placed through any combination of incisions but, ideally, should not cross at the fracture site. With comminution, this technique is usually best avoided because of the tendency to “overcompress” the fracture site, which tilts the talar neck into extension and varus.

In cases where there is comminution, a low-profile, rigid, blade, straight, or T-plates can be used to maintain length, height, and correct rotation on both or either medial or lateral sides.

Intraoperative X-ray control should include Canale view besides standard AP and lateral views to avoid varus positioning of talar neck.

For type 3 and 4 injuries, stability of subtalar, tibiotalar, and talonavicular joints should be checked, and if necessary, temporary stabilization with K-wires or ex-fix can be done.

If primary closure is limited by excessive tension at the wound margins or if the skin is severely traumatized, delayed primary closure or skin grafting after 5–7 days minimizes the risk of wound problems and subsequent infection. Temporary wound management is accomplished with an antibiotic bead pouch or vacuum-assisted closure (VAC) device prior to delayed closure.

Postoperative Care

A period of approximately 2–3 weeks of strict non-weight-bearing with a splint followed by early assisted exercises and protected weight bearing for further 3 weeks is generally recommended. The weight-bearing status is advanced in line with the evidence of early healing on both X-rays and clinically. This will also coincide with the potential first radiographic indicator of talar revascularization. Hawkins sign, disuse osteoporosis of the subchondral bone beneath the superior talar dome noted on the mortise view of the ankle, suggests talar revascularization and represents a favorable prognostic sign with respect to AVN.

Complications and Outcomes

Results of treatment of talar neck fractures[a]

Result/ complication	Overall (%)		Type I (%)		Type II (%)		Type III[b] (%)	
	Range	Average	Range	Average	Range	Average	Range	Average
Excellent/good	45–96.4	72.7	50–100	87.3	25.6–91.6	45.5	14.2–66.6	60
Open	10–24.7	18.1						
Infection	0–10	3.3						
Avascular necrosis	13–53.2	28.1	0–15.4	3.9	13.6–66.6	25.6	27.2–92.5	69.8
Nonunion	0–6.1	3.9	0–7.7	1.3	0–5.7	2.6	5–13	10.5
Osteoarthritis								
Ankle	30.9–32.9	31.7	15	15	36	36	69	69
Subtalar	36–47.1	45.5	24	24	66	66	63	63

Vallier et al. [10]

[a]Most type I fractures have been treated nonoperatively, with types II and III fractures treated operatively

[b]Type IV fractures are included with the type III fractures

AVN: In 1970 and 1978, Hawkins and Canale and Kelly reported a 53 and 52 % incidence of AVN respectively in their initial series. The rate was as high as for displaced fractures only. However, more than half of the fractures (including Hawkins' type II and III injuries) were treated nonoperatively in these papers. More recent series note much lower rates of AVN, ranging from 6.6 to 16.6 %, possibly as a direct result of rigid fixation techniques. The rate of osteonecrosis rises to about 30–35 % when considering displaced fractures. Most series consider three variables leading to development of talar osteonecrosis: fracture comminution, displacement, and open wounds.

Radiologically, AVN will manifest as sclerosis with or without subchondral collapse of talar body with anterolateral aspect of talar dome commonly affected.

Hawkins' sign is the classic early indicator of talar body revascularization best seen on the AP and mortise views. It has appearance of patchy subchondral osteoporosis, manifesting as a zone of relative radiolucency. Although this sign has proven a reliable indicator of vascular integrity of the talar body following talar neck fracture, not all cases lacking a Hawkins' sign at 6–8 weeks go on to AVN.

Treatment includes reconstruction with either autogenous iliac crest graft or allograft, tibiotalar arthrodesis, or pantalar arthrodesis. Ankle arthroplasty is contraindicated.

Talar Body Fractures

Fractures of the talar body are less common than those involving the talar neck, accounting for 7–38 % of all fractures of the talus. Radiographically, talar body and neck fractures are distinguished by the primary fracture line passing anteriorly or posteriorly to the lateral talar process, respectively. Most common mechanism of injury is fall from height leading to axial loading with shear or crush type of fractures.

Overview of Management of Talar Body Fractures

CT scans should be used to check for displacement of shear fractures.

Undisplaced fractures should be treated nonoperatively with 10–12 weeks in a non-weight-bearing cast or brace.

Displaced fractures should be reduced and fixed with interfragmentary screws/low-profile plates as necessary.

Crush fractures should also be reconstructed with interfragmentary screws if possible, otherwise primary arthrodesis of the ankle and/or subtalar joints is recommended.

Talar Head Fractures

Account for less than 10 % of all talus fractures and usually are associated with complex fractures of body and neck. Involvement of talonavicular joint with or without subluxation and subtalar joint with extension in to middle facet is possible.

Usually results from violent dorsiflexion and inversion at midfoot with damage to articular surface.

When evaluating talar head fractures, lateral column injuries must also be considered; the injury pattern may extend into the lateral column to involve the CC joint or cuboid.

Undisplaced shear fractures can be treated nonoperatively with 6 weeks in a cast or brace.

Displaced shear fractures should be treated by open reduction and internal fixation with interfragmentary screws.

Impacted fractures are likely to lead to talonavicular osteoarthritis, and if the impaction is severe, a primary talonavicular arthrodesis may be undertaken.

Fractures of Posterior Process of Talus

Fractures of the posterior process may involve the whole posterior process or the medial or lateral tubercles.

Most are undisplaced or minimally displaced, and nonoperative management is indicated.

A below-knee weight-bearing cast or brace should be used for 4–6 weeks.

Nonunion of either the medial or lateral tuberosity may occur, and symptomatic nonunions are best treated by surgical excision.

Fractures of the whole posterior process are less common.

Undisplaced fractures should be treated nonoperatively, but displaced fractures require open reduction and internal fixation with interfragmentary screws.

Missed posterior talar process injuries present with chronic posterior ankle pain. This is also known as "posterior impingement syndrome of the ankle." The pain is likely due to a variety of factors like (1) soft tissue impingement, (2) inflammation causing increased volume, (3) micromotion at the nonunion site, (4) bone bruising, and (5) flexor hallucis longus irritation or stenosing tenosynovitis. Treatment includes debridement and excision of ununited fragment.

Lateral Process Fractures

Mechanism of injury involves axial loading on an everted foot and usually follow a fall, motor vehicle accident, or sports injury. They may be associated with significant subtalar damage caused by the axial load and may lead to late onset of pain due to nonunion and subtalar osteoarthritis.

Treatment is nonoperative for undisplaced fractures, or if there are small displaced fragments, with 4–6 weeks in a weight-bearing cast or brace. Larger fragments should be fixed with an interfragmentary screw. If there is symptomatic subtalar osteoarthritis, an arthrodesis is indicated. Symptomatic nonunion of small bony fragments should be treated by excision, and larger fragments should be fixed with an interfragmentary screw.

Osteochondral Fractures

The true incidence of osteochondral talar fractures is difficult to define because a number occur as a result of ankle or plafond injuries.

The classification of Berndt and Hardy (1959) is generally accepted [11].

Stage I lesions consist of subchondral trabecular compression with intact overlying cartilage.
Stage II lesions show an incomplete separation of the fragment.
Stage III lesions are separate but undisplaced, and in stage IV lesions, the fragment has become separate.

Some surgeons include subchondral cysts as a IIa lesion, but although these may predispose to fracture, there is debate about whether they are traumatic in origin.

Osteochondral fractures occur anterolaterally and posteromedially on the dome on the talus.

Treatment

Stage I lesions are treated nonoperatively with cast or brace immobilization for 6 weeks.
Early stage II lesions should be similarly treated, but persistently painful lesions should be treated by drilling the subchondral bone.
Stage III lesions are best treated nonoperatively unless symptoms persist, in which case debridement of the fragment and subchondral drilling should be undertaken.
Stage IV lesions are usually treated by excision with debridement of the subchondral bone. Larger lesions should be replaced if an accurate reduction can be achieved.

Talar Dislocations

Subtalar Dislocation

- Subtalar dislocations are rare.
- They involve the talocalcaneal and talonavicular joints and may, at times, be associated with a hindfoot fracture, particularly a talar neck fracture.
- About 50–65 % of subtalar dislocations are associated with other fractures of the foot and ankle.
- Most subtalar dislocations are the result of high-energy injuries such as motor vehicle accidents or falls from a height, but 20–25 % follow low-energy injuries such as sports injuries.
  - They are caused by rotational forces applied to the hindfoot.
- About 80 % of subtalar dislocations are medial, 15 % are lateral, and the remainder are either anterior or posterior, although they usually have a component of medial or lateral rotation as well.

- Patients with subtalar dislocation present with deformity of the hindfoot:
  - There is tenting of the skin over the prominent talar head, and between 10 % and 40 % of the injuries are open.
  - The diagnosis is usually obvious, but care must be taken to check for other foot injuries.
  - Standard anteroposterior, lateral, and oblique X-rays of the foot are required.
  - CT scans show osteochondral fractures and the presence of other occult fractures in the foot.
- Treatment is by closed reduction if possible.
- Open wounds must be treated according to earlier discussion.
- Approximately 10–15 % of subtalar dislocations are irreducible by closed means and require open reduction:
  - This is usually caused by the head of the talus buttonholing adjacent soft tissues. In lateral subtalar dislocations, the tendon of tibialis posterior may prevent reduction.
- An impaction fracture occasionally may lock the talonavicular joint, preventing reduction.
- After reduction, the hindfoot should be immobilized in a weight-bearing cast for 4–6 weeks.
- The results are generally poor, with only about 25 % of patients having excellent or good results.
- The results are worse in open injuries and in lateral dislocations.
- Complications include reflex sympathetic dystrophy, hindfoot stiffness, posttraumatic osteoarthritis, and occasionally avascular necrosis of the talus.

Total Talar Dislocation

- Total talar dislocation or extrusion of the talus is very rare.
- The talus can dislocate medially or laterally, and it is caused by continuation of the forces that cause subtalar dislocation.
- Virtually all of these dislocations are open, and the prognosis is poor.
- Treatment is by open reduction of the talus with a thorough debridement of all devitalized and contaminated tissues.
- Casts should be applied and maintained for 6–8 weeks.
- Complications include infection, avascular necrosis, and posttraumatic osteoarthritis, which may necessitate tibiotalar, subtalar, or pantalar arthrodeses.

In the largest series reported, Smith et al. (2005) showed that in 27 patients who presented with an extruded talus, 70.4 % had associated fractures of the talar neck, body, or lateral process, and 78 % had other associated fractures. There was a 7.4 % incidence of infection [12].

Fractures of the Calcaneum

Calcaneum is the largest of tarsal bones. The fractures of the calcaneum account for 2 % of all fractures and approximately 60 % of all tarsal fractures [13].

Calcaneal fractures are more common in young patients. Usual mechanisms of injury include motor vehicle accidents and fall from height with associated spinal injuries. The fractures of calcaneum can be considered as intra-articular or extra-articular.

Anatomical Considerations

Calcaneum has complex three-dimensional anatomy. It provides major support during weight bearing and helps to transfer the loads through the calf. The superior surface has three facets: anterior, middle, and posterior. All of them articulate with corresponding facets on the undersurface of the talus. The posterior facet is convex and saddle-shaped, sloping posteromedially in its support of the talar body. In contrast, the anterior and middle facets are flatter and support the talar neck and head. Although smaller, the anterior and middle facets bear more weight per unit area than the larger posterior facet. A small, oblique, nonarticular groove divides the region between the posterior facet and the anterior and middle facets. The groove provides attachment to the interosseous ligament, the inferior extensor retinaculum, and the joint capsule of the posterior facet.

On medial side, sustentaculum tali, which is a dense plate of bone, provides support to middle facet and a groove for passage of FHL. Dorsal to sustentaculum, there are tendons and neurovascular bundle, so one needs to be careful while drilling screws from lateral to medial side.

On lateral side, there is opening of the tarsal canal as the sinus tarsi. Peroneal tubercle provides a groove for the passage of peroneal tendons which pass under cover of retinacula. Peroneus brevis is superior and longus is inferior separated by tubercle. Posttraumatic impingement results from broadening or malunion of tubercle. The sural nerve is 3 cm above the tip of lateral malleolus.

Anterior aspect has anterior process articulating with cuboid, and posterior aspect receives the insertion of tendo achilles on the calcaneal tuberosity. Posterior tuberosity also provides origin to abductor hallucis, flexor digitorum brevis, and part of abductor digiti minimi, lateral head of flexor accessories, and the plantar fascia.

Initial Management and Imaging

One should follow the principles of management of acute foot injury as set out earlier in the chapter.

Imaging for calcaneal fractures should include three standard foot radiographs (anteroposterior, lateral, and oblique) and an axial (Harris) view of the calcaneus of both feet. The comparison views are useful in identifying any occult contralateral injuries and in providing guidance in restoring normal anatomy. Harris view is performed with the foot in maximal dorsiflexion and the X-ray beam angled 45° cephalad.

CT scan with 3-D reconstruction is essential. Also, the axial, coronal, and sagittal sections should be 2–3 mm in thickness or less.

The Importance of Radiographic Examination

The idea of the management of such fractures is restoration of orientation all three facets. This can be evaluated on plain lateral X-rays by looking at two important angles. Böhler's angle (A) is the angle formed by the intersection of a line joining the tip of the posterior tuber with the posterior facet and one joining the tip of the posterior facet to the tip of the anterior process. Typically, the Böhler's angle is 25–40°. In the injured calcaneus, Böhler's angle provides an assessment of loss of calcaneal inclination (height) and joint depression. The critical angle of Gissane (B) is the angle formed by the intersection of a line drawn along the dorsal aspect of the anterior process of the calcaneus and a line drawn along the dorsal slope of the posterior facet. The normal value of Gissane's angle is 120–145°. In the injured calcaneus, alteration of Gissane's angle is indicative of an alteration in the relationship among the anterior, middle, and posterior facets.

The AP X-ray of the foot suggests injury to medial or lateral column of the foot including talonavicular, calcaneocuboid joints, and lateral wall. The axial Harris view shows varus malposition or widening of the heel, step-off in the posterior facet, and the relationship between the posterior facet and the sustentacular fragment. The oblique view is to delineate any displacement of fracture and cuboid injuries.

Fracture Patterns and Mechanism of Injury

During axial loading, the talus with its lateral process acts like a wedge and is driven in to the middle and posterior facets of calcaneum where Gissane angle is formed. Although the fracture pattern may be variable, two major fragments have been recognized.

The posterolateral fragment comprises the calcaneal tuberosity, the lateral wall, and part of the posterior facet. The anteromedial fragment consists of the anterior and middle facets, the sustentaculum, and the residual posterior facet. The anteromedial fragment maintains the position due to relationship with talus and foot by strong ligaments whereas posterolateral fragment displaces laterally by the pull of TA.

Carr and colleagues demonstrated two primary fracture lines reinforcing the Essex-Lopresti (1952) explanation of fracture fragments. The first fracture line starts at the angle of Gissane and extends to the medial calcaneal cortex. The second fracture line divides the calcaneus into medial and lateral portions and exits variably through the anterior facet or the CC joint [14, 15].

Classification

Calcaneus fractures can be divided into two broad categories: intra-articular and extra-articular. Thirty percent of calcaneus fractures are extra-articular. Anterior process fractures represent 10–15 % of these extra-articular injuries and are more common in women. Intra-articular fractures comprise 70 % of all calcaneus fractures.

Essex-Lopresti classified intra-articular calcaneus fractures in 1952 into two broad types: tongue type and joint depression. In "joint depression" injuries, the posterior facet is dissociated from the remaining posterior tuber by a secondary fracture line and will usually require ORIF. In tongue-type injuries, some continuity of the posterior facet with the tube remains, and they can be treated by percutaneous pin and plaster technique described as Essex-Lopresti maneuver [15].

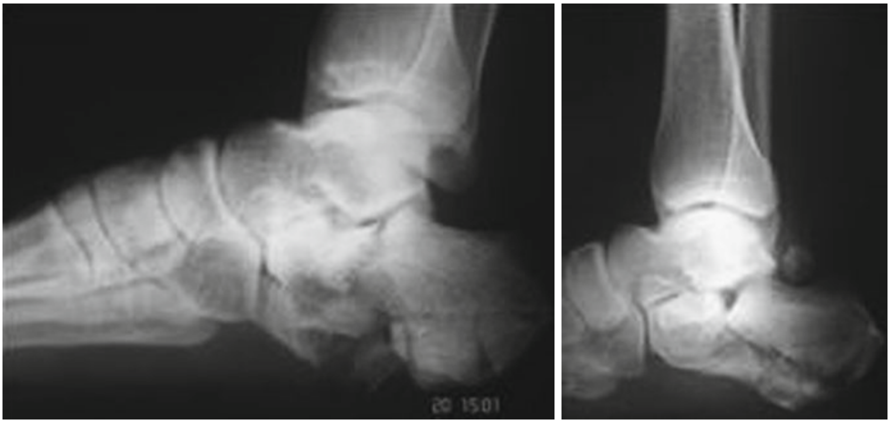
The Sanders classification method is based on the fracture pattern through the widest portion of the posterior facet as seen on coronal CT. Type I fractures are nondisplaced. Type II fractures are two-part fractures of the posterior facet. Type III fractures are three-part fractures of the posterior facet. Type IV fractures are highly comminuted with four or more fragments to the posterior facet. Type II and type III fractures are further classified based on the location of the fracture lines [16].

The Sanders CT classification is unique in that it is prognostic as well as descriptive. In general, as the comminution of the posterior facet worsens, the prognosis also worsens.

Treatment of Calcaneal Fractures

Calcaneum has important function as it acts as a lever arm through the tendo achilles for the propulsive gait. It provides a dynamically stable foundation for carrying the body weight forward. Even a minimal disturbance as little as 2 mm in the congruity of the subtalar joint can compromise the function of the hindfoot and ability to adapt to the uneven grounds.

Although treatment of the intra-articular calcaneal fractures remains controversial (Figs. 15.3 and 15.4), there is some support in the literature for the operative management. It is important to carefully consider patients for operative treatment. The factors to take in to account before offering the surgery include age, mental



Figs. 15.3 and 15.4 Fracture of the calcaneum (Courtesy of Dilip Malhotra, Bahrain)

capacity, gender, smoking history, medical comorbidities, worker's compensation status, and the severity of the fracture.

Although considered as a relative contraindication by some authors, advanced age has not been cited as a contraindication to surgery by others. One's ability to comply with postoperative rehabilitation and medical comorbidities is far more important considerations, and so patients with drug-alcohol addiction, mental incapacity due to organic brain disorders, heavy smokers, manual workers, diabetics with peripheral vascular diseases, and those with neuromuscular foot disorders will have poor outcomes.

A Brief of Review of Literature Comparing Operative to Nonoperative Treatment

A Cochrane review analysis [17] summarized results of RCT and noted no difference between patients treated operatively (24/40) or nonoperatively (24/42) (odds ratio [OR] 0.9; 95 % confidence interval [CI] 0.34–2.36). However, when compared with the nonoperative group, a significantly greater number of patients treated operatively were able to return to the same work (OR 0.3; 95 % CI 0.13–0.71) and were able to wear the same shoes as before the injury (OR 0.37; 95 % CI 0.17–0.84). Randle and coworkers performed a meta-analysis examining the results of several trials of nonoperative versus operative treatment of calcaneus fractures [18]. Their results suggested that operative treatments provide a better outcome than nonoperative treatment, although their results did not reach statistical significance.

Buckley and associates in their largest randomized study reported good outcome in women, younger patients, patients not receiving worker's compensation, and those with Bohler's angle of 0–14. Some of the recent studies have shown a satisfactory outcome at early follow-up with safer compromise between extensile exposures and nonoperative management, minimally invasive or percutaneous techniques, and external fixation methods.

Nonoperative Management

This should be limited to undisplaced Sanders type 1 fractures. After initial evaluation and exclusion of other injuries, the management should include rest, ice, elevation, and removable posterior plaster splint to prevent equines contracture as well as pain relief. Some of the cases may not require immobilization, and most cases do not require beyond 2 weeks as it will lead to stiffness. At 2–3 weeks, range of motion exercises are started, radiographs are obtained at 4 weeks interval, and at approximately 8 weeks, progressive weight bearing can be started.

The Essex-Lopresti technique involves lifting the tongue fragment with pin to maintain the height of the posterior facet and holding it with a well-molded cast.

Operative Management

Preoperatively, the condition of the soft tissues determines the timing of the surgery. A positive wrinkle test has been recommended by Sanders. According to this, when the ankle is dorsiflexed and the foot everted, skin over the lateral aspect of the calcaneus should wrinkle and be free of pitting edema. So a positive test suggests that intervention should be safe.

Surgical Approaches to Calcaneum

Suggested treatment of intra-articular calcaneal fractures

Injury	Treatment
Sanders 1 fracture	Nonoperative management
	Non-weight-bearing cast or brace for 6–8 weeks
Sanders 2 and 3 fracture	Lateral calcaneal plate
	Bone grafting not required
Sanders 4 fracture	Primary arthrodesis

Lateral approach is commonly used. This approach offers adequate access for directly reducing the posterior facet, the posterolateral fragment, and any separate anterolateral fragments. However, indirect fracture reduction is required to restore the anatomic relationship of these fragments to the anteromedial sustentacular ("constant") fragment (Figs. 15.3 and 15.4). An L-shaped skin incision is made along the lateral border of the heel. The proximal limb of the incision is located immediately anterior to the Achilles tendon. The plantar limb of the incision is located at the junction of skin of the foot and the sole.

Medial approach is useful for sustentacular fractures where FHL tendon may be entrapped in the fracture. Also, this allows direct reduction of both anteromedial and posterolateral fragment.

Complications

Wound Infection

- Wound complications are relatively common after calcaneal fracture surgery.
- These are more common in diabetics, smokers, and obese patients.
- They also tend to be associated with more severe fractures and with delay between the fracture and surgery.
- An incidence of 50 % wound complications has been reported if surgery is delayed by more than 2 weeks.
- Many surgeons believe surgery should be delayed to allow the soft tissues to improve, but no good evidence in the literature supports this belief.

Osteomyelitis

- Osteomyelitis is relatively unusual but more common in open fractures.
- The management of calcaneal osteomyelitis is very difficult to treat.
- Debridement with excision of devitalized and infected bone followed by flap cover should be undertaken, but there is a relatively high incidence of below-knee amputation.

Subtalar Stiffness

- Few patients achieve normal subtalar movement after an intra-articular calcaneal fracture, possibly only 3–5 %.
- On average, 70–75 % of subtalar motion is regained, but this varies with the severity of the fracture.

Arthrodesis

- The requirement for subtalar arthrodesis correlates with the severity of injury, with Sanders 4 fractures 5.5 times more likely to require arthrodesis than Sanders 2 fractures.
- Nonoperative treatment is six times more likely to result in arthrodesis than operative treatment, and patients on social support are three times more likely to have a subtalar arthrodesis.

- Calcaneocuboid arthrodesis may be required if there is incongruency of this joint.
- Presumably the factors that determine the likelihood of the requirement for calcaneocuboid arthrodesis are similar to those that determine subtalar arthrodesis, but the literature contains little information.

Compartment Syndrome

- This has been reported to vary between 1 % and 10 %.
- It should always be considered in intra-articular calcaneal fracture.

Nerve Damage

- Sural nerve damage has been reported to occur in about 3 % of cases, but the incidence may well be higher.
- It is avoided by identifying and safeguarding the nerve during dissection.
- Damage to the medial and lateral plantar nerves and to calcaneal branches of the tibial nerve can be caused by screw, wire, or drill insertions or by impingement from an exostosis.

Tendon Impingement

- There are two main causes of tendon impingement.
- In nonoperatively managed fractures, the diminution in heel height combined with the displacement of the lateral calcaneal wall means the peroneal tendons may be trapped between the lateral wall and the distal fibula:
  - Treatment is by decompression by lateral wall ostectomy.
- Tendon impingement may occur after plate fixation due to the presence of the plate and screws:
  - This has been reported to occur in as many as 18 % of patients.
  - Treatment is by removal of the plate.

Heel Pain

- Heel pain may occur as a result of damage to the heel pad, plantar fasciitis, or the development of calcaneal exostoses.
- It is best treated by the use of orthoses, and the literature suggests about 30 % of patients require heel cups, insoles, and other orthotics.

Types of calcaneal malunion and their treatment

Type	Description	Treatment
I	Large lateral exostosis with or without lateral subtalar osteoarthritis	Lateral exostectomy and peroneal tenolysis
II	Lateral exostosis and subtalar osteoarthritis	Subtalar arthrodesis and lateral exostectomy
III	Subtalar osteoarthritis with varus or valgus angulation	Subtalar arthrodesis, peroneal tenolysis, calcaneal exostectomy, and calcaneal osteotomy

Special Situations

Calcaneal Fractures in Adolescents

- The literature suggests about 80 % of calcaneal fractures in young adults are intra-articular.
- They are usually Sanders 2 in severity, and the results of surgical treatment are unquestionably better than in older patients.
- About 75 % excellent or good results can be expected, with about 60 % return of full subtalar movement.
- Care should be taken to avoid the calcaneal physis when plating the fracture.

Open Fractures

- Open calcaneal fractures are uncommon but associated with significant soft tissue damage.
- Treatment is the same as for closed calcaneal fractures, but the incidence of deep infection is higher.
- The literature quotes the incidence of osteomyelitis as 19–31 %, but recent studies have suggested an incidence of 8–10 %.
- The management of open fractures is discussed in detail in Chapter 4 of my book entitled 'General Principles of Orthopedics and Trauma'(Springer).

Primary Arthrodesis

- Most authorities agree that Sanders 2 and 3 fractures should be treated by open reduction and internal fixation, and Sanders 4 fractures are best treated by primary arthrodesis.
- This should be done by restoring the heel height and width as far as possible by open reduction and internal fixation using a lateral calcaneal plate and then undertaking a standard subtalar arthrodesis.
- Analysis of the results has indicated 80 % excellent or good results in experienced hands.

Fractures in the Elderly

- It seems likely that the incidence of calcaneal fractures in the elderly will increase, and surgeons will be faced with the problems associated with treating osteopenic calcaneal fractures.
- About 18 % of calcaneal fractures occur in patients aged 65 or more, and most are caused by simple falls, falls down stairs, or falls from a low height.
- The literature suggests that good results can be obtained.

Extra-articular Calcaneus Fractures

Extra-articular calcaneus fractures are defined as those that do not involve the subtalar joint; they account for approximately 25 % of all calcaneus fractures. These injuries generally occur by low-energy mechanisms and are the result of twisting or avulsive forces on the foot. Extra-articular calcaneus fractures can involve the anterior process, the tuberosity, the body, or the medial sustentaculum.

Fracture of Anterior Process

The inferior aspect of the anterior process articulates with the cuboid. Both the bifurcate ligament and the EDB attach to the anterior process. The bifurcate ligament connects the cuboid and the navicular with the anterior process of the calcaneus.

The mechanism of injury that leads to such fractures involves plantar flexion and inversion which create stress at the bifurcate ligament insertion. Consequently, a fragment of bone is avulsed from the anterior process. It is important to note that ankle sprains may occur by the same mechanism (plantar flexion and inversion); therefore, the surgeon should always suspect an anterior process calcaneus fracture, particularly in the patient with a chronic ankle sprain.

Anterior process fractures are best visualized on a lateral or oblique view of the foot as a small avulsion. These fractures should be distinguished from the os calcaneus secondarium—a small accessory bone that can be seen in this proximity and has all the hallmarks of a secondary ossification center as opposed to a fracture. If the X-rays are inconclusive but a high index of suspicion remains, MRI, CT, or bone scan can aid in definitive diagnosis.

Degan and colleagues proposed a classification scheme for anterior process fractures of the calcaneus that is based on displacement and involvement of the CC joint [19]. Type 1 fractures are nondisplaced avulsions of the tip of the process. Type II fractures are displaced but do not involve the CC joint. Type III fractures are displaced and involve the CC articulation.

In an acute setting, most type III fractures will require ORIF through Ollier's approach and mini-fragment fixation, where as type II and I can be treated in a cast or boot, subsequent radiological examination, and progressive weight bearing. In a chronic setting, either open or arthroscopic excision may be required.

Posterior Tuberosity of the Calcaneus

This may involve superior or inferior portion of the tuberosity. Superior part fractures are avulsion-type fractures common in elderly, osteoporotic, and diabetics. Undisplaced fractures may be treated with slightly plantar-flexed short leg cast for a period of 6 weeks. Displaced fractures are typically described as parrot beak fractures and usually associated with skin problems. They will require open reduction and internal fixation. A posterolateral or posteromedial approach, 3.5- or 4-mm screws in a lag fashion, and occasionally gastrosoleus recession may be required where muscle is pathological and does not allow reduction.

When the inferior part of tuberosity is fractured, it typically involves the proximal medial weight-bearing portion of the calcaneus where the abductor hallucis, plantar fascia, and flexor digitorum brevis (FDB) originate. It is rarely significantly displaced, and most of these injuries can be treated nonoperatively.

Body Fractures

These are usually undisplaced with a fracture that exits on the superior surface of the calcaneus close to but not involving the posterior facet:

- Undisplaced fractures are treated nonoperatively with 4–6 weeks in a weight-bearing cast or brace, but displaced fractures should be reduced and fixed with a lateral plate.
- It is wise to obtain a CT scan to examine the posterior facet:
  - Even if the facet is intact, there may well be chondral damage, and late subtalar arthrodesis may be required if pain persists.

Medial Sustantacular Fractures of the Calcaneus

Although sustentacular fractures are included in this section, the majority of these fractures do extend into the subtalar joint. Isolated fractures of the sustentaculum are unusual and typically occur as a result of a direct impact on an inverted foot. Nondisplaced or minimally displaced fractures can be immobilized in a short leg cast for 6 weeks, followed by early mobilization and progressive weight bearing and physical therapy. Large sustentacular fragments with displacement greater than 2 mm should be considered an indication for operative treatment.

Calcaneal Dislocations

Very few cases of dislocation of the subtalar and calcaneocuboid joints, without an associated calcaneal fracture, have been reported. These are treated by closed reduction and the use of a walking cast or brace for 6–8 weeks.

Calcaneal fracture–dislocations occur when the calcaneal fracture is associated with rupture of the calcaneofibular ligament. Here, the posterolateral calcaneal fragment moves laterally, and the anteromedial fragment and the attached talus move downward so the talus is beside the posterolateral calcaneal fragment. This requires ORIF.

Fractures of the Midfoot

Anatomy

The bones of the midfoot are navicular, cuboid, and cuneiforms. They articulate proximally with the talus and calcaneus, forming Chopart's joint. Distally, the cuneiforms and the cuboid form part of Lisfranc's tarsometatarsal joint. The midfoot bones are tightly bound together by interosseous ligaments that also join the midfoot to the hindfoot and forefoot. The midfoot and forefoot are divided into medial and lateral columns with the medial two metatarsals and the adjacent midfoot bones forming the medial column and the lateral three metatarsals and their adjacent midfoot bones forming the lateral column.

Two important ligaments are the bifurcate ligament, which arises from the anterior process of the calcaneus and inserts into the navicular, and the cuboid, although the cuboid component of the ligament is often absent or weak. The spring ligament joins the sustentaculum tali to the navicular.

Tibialis posterior is attached to navicular and sends slips to the sustentaculum tali, all three cuneiforms, the cuboid, and the bases of the second, third, and fourth metatarsals. The flexor hallucis brevis arises from the undersurface of the cuboid and all three cuneiforms.

Classification

Sangeorzan et al. introduced a classification for navicular fractures that has been adapted to apply to all midfoot bones [20].

There are four basic types. Type I fractures are avulsion fractures; type II fractures are shear fractures, which may be coronal (IIA) or sagittal (IIB). Type III fractures are uniarticular impaction fractures, and type IV fractures are biarticular impaction fractures.

Treatment

The treatment of midfoot fractures is essentially the same no matter which bone or bones are involved.

Avulsion fractures rarely need internal fixation, although a displaced avulsed fragment of the navicular tuberosity may require open reduction and internal fixation with an interfragmentary screw. Also, one needs to be aware of the possibility of an os naviculare or secondary navicular ossification center that may mimic a fracture.

Undisplaced shear fractures can be treated nonoperatively with a below-knee weight-bearing cast or brace worn for 6–8 weeks.

Displaced shear fractures should be fixed with interfragmentary screws.

The more difficult decision is how to treat comminuted fractures:

- It is important to maintain the length of the medial and lateral columns of the foot, which nonoperative management will not achieve in the presence of extensive comminution.
- If only one articular surface is damaged, nonoperative management may be adequate with late fusion reserved for persistent pain.
- If the comminution is extensive and the length of medial or lateral column is affected, a primary arthrodesis is indicated with a plate spanning the affected bone with or without bone graft.

Suggested treatment of midfoot fractures

Fracture	Treatment
Type I (avulsion)	Symptomatic treatment Cast or brace if required Interfragmentary screw for large displaced navicular tuberosity fragment
Type II (shear)	
Undisplaced	Cast or brace
Displaced	Interfragmentary screw(s)
Type III (uniarticular)	
Minor impaction	Cast or brace. Late arthrodesis if required
Major impaction	Primary arthrodesis
Type IV (biarticular)	Primary arthrodesis. Preservation of column length

Midfoot Dislocations

Calcaneocuboid and talonavicular dislocations are very rare. It is likely that spontaneously reducing subluxations are more common, but their incidence is unknown. They are associated with fractures of the anterior process of the calcaneus and avulsion fractures of the calcaneus, navicular, and cuboid. Dislocations of both the calcaneocuboid and talonavicular joints have been reported but are very rare. They are caused by high-energy injuries and treated by closed or open reduction followed by the use of a walking cast for 6–8 weeks. Instability after reduction is treated by stabilization with K-wires, which can be removed after 6 weeks.

Lisfranc's Dislocation

Lisfranc's joint consists of the three cuneiform and two cuboid metatarsal articulations. The stability of the joint is gained from the strong interosseous ligaments and the fact that the second metatarsal articulates with the middle cuneiform proximal to the articulation of the medial and lateral cuneiforms with the first and third metatarsals. Thus, the base of the second metatarsal is recessed into the midfoot, providing stability. As a result, most tarsometatarsal dislocations involve a fracture of the base of the second metatarsal (Fig. 15.5). The strongest ligament in the TMT complex is the Lisfranc ligament, coursing from the lateral surface of the medial cuneiform to the plantar medial second metatarsal base.

Consequently, there are no ligamentous connections between the first and second metatarsal bases. The first TMT joint articulation is further stabilized by the insertions of the peroneus longus and tibialis anterior muscles. Indirectly, the plantar fascia and the intrinsic musculature of the foot also add to the stability of the TMT complex.

While medial three TMT articulations stabilize the midfoot, the lateral two TMT joints are highly mobile so as to allow for accommodative gait.

The first intermetatarsal branch of the dorsalis pedis artery crosses the midfoot close to the second TMT articulation. This branch is prone to disruption during Lisfranc's injuries and may be associated with the onset of compartment syndrome. The deep peroneal nerve travels just lateral to this artery and is also prone to injury.

The mechanism of injury could be high energy resulting from injury to plantar flexed ankle and foot that occurs in rapid deceleration in both MVAs and falls. Violent twisting and abduction of the forefoot are a likely mechanism in motorcycle accidents. Poor clinical outcome is frequently associated with high-energy Lisfranc's joint complex injuries. Low-energy injuries are encountered during sports.

Napoleon's surgeon, Lisfranc, encountered these injuries when troops were thrown from their horses while their feet remained anchored in the stirrup. Similar injuries have been described in windsurfers.

Clinically, the foot may appear to be grossly malaligned in abduction and prominence of medial cuneiform. Patients are frequently unable to bear weight on the swollen, injured forefoot and present with variable dorsal midfoot swelling and ecchymosis. Plantar ecchymosis may correlate with disruption of the Lisfranc ligament.

Stress maneuvers like dorsiflexion and abduction across the TMT joint may elicit a "chandelier" or "apprehension" sign. The contralateral foot and proximal extremity should also be examined.

Fig. 15.5 Radiograph of both feet, showing a Lisfranc injury to the left foot (Courtesy of Dilip Malhotra, Bahrain)

Radiographic Examination: Surgeons should be aware of certain normal radiographic parameters. Standard X-rays should be AP, lateral, and 30° oblique views.

On the AP view, the medial bases of the medial aspects of the first and second metatarsal bases are congruent with their respective cuneiforms.

Fig. 15.6 AP Radiographs of both feet showing a Lisfranc injury (Courtesy of Dilip Malhotra, Bahrain)

On the 30° oblique view, the medial third metatarsal aligns with the medial border of the lateral cuneiform, and the fourth metatarsal is congruent with the medial cuboid.

On the lateral view, there should be no dorsal step-off in the TMT joint alignment.

There is variation in the distance between the first and second metatarsal bases on the AP radiograph, with up to 3 mm considered normal.

A "fleck sign" on the AP foot film or avulsion of the Lisfranc ligament from the second metatarsal base suggests a TMT joint complex injury (Fig. 15.6).

On a lateral weight-bearing view, Meary's line (a line drawn through the longitudinal axis of the talus should be congruent to a line drawn through the longitudinal axis of the first metatarsal) should be intact.

For subtle injuries, CT is more sensitive in detecting small fractures or displacements (<2 mm).

Classification

A useful classification of TMT injuries, however, is difficult to devise because so many fracture combinations are possible. The amount of displacement in a TMT disruption can vary from a subtle pure dislocation to severe displacement with associated fractures in the metatarsal bases, the cuneiforms, or the distal metatarsals.

In general, three major patterns of disruption have been described, defined by metatarsal subluxation or dislocation in varying number and direction:

1. Isolated (unidirectional displacement of at least one but not all the metatarsals, typically the first or second rays)
2. Homolateral (uniform medial or lateral subluxation or dislocation of all the metatarsals)
3. Divergent (separation of any combination of metatarsals in different directions or in more than one plane)

This system was modified by Hardcastle and associates in 1982, who categorized the injuries by the congruity of the TMT joint: (1) partially congruent, (2) totally incongruent, and (3) divergent.

Treatment

Initial assessment followed by reduction of dislocations and fracture–dislocations to protect the soft tissues from sustained tension. The maneuver for closed reduction requires exaggeration of the deformity (abduction and plantar flexion), followed by reversal (adduction and dorsiflexion). The surgeon's thumb may be placed on the medial cuneiform to act as a fulcrum, and the foot is placed in a well-padded, loosely applied splint maintaining the ankle in neutral dorsiflexion.

Dislocation may partially occlude the forefoot's arterial and venous circulation, so early restoration of circulation is critical. Disruption of the first intermetatarsal branch off the dorsalis pedis located in the first intermetatarsal space is common in these Lisfranc's injuries and can be the cause of a foot compartment syndrome. Despite successful reduction, carefully monitoring for compartment syndrome is essential in the immediate postinjury or postoperative period.

Close reduction and percutaneous fixation should be undertaken with caution as neurovascular damage is possible, so appropriately placed small incisions and blunt dissection down to bone should be used.

For open reduction, one of the three surgical approaches can be used:

1. Two parallel dorsal (medial and lateral) incisions, with intervening skin flap of 7 cm and maintained at full thickness
2. The utilitarian single longitudinal "Hannover" incision starting at the second webspace and extending to proximally to the extensor retinaculum
3. A transverse incision over TMT joints that may be extended into a T-shaped incision if application of a medial plate is required

Technique of Reduction and Fixation

ORIF should progress from medial to lateral column. Ideally, second TMT joint should be reduced first. The first, second, and third TMT joints must be cleared of interposed bony fragments or soft tissue. A small drill hole is placed in the lateral aspect of the second metatarsal base to support one end of a pointed reduction forceps. The forceps is then applied across the medial cuneiform/second metatarsal articulation and used to maintain reduction. Reduction is held with K-wire. Now, first TMTJ is reduced and reduction is held with K-wire. Attention is turned toward the third and lateral TMTJ, and different views are taken to ensure anatomic reduction. This should result in indirect reduction of fourth and fifth TMTJ.

Definitive Fixation

For medial column, use of cortical screws or a bridge plate in case of comminuted fractures is useful to maintain length. Isolated fixation of medial column is associated with high rates of failure. Definitive fixation may begin either with the first TMT joint or the medial cuneiform/second metatarsal articulation.

The medial cuneiform/second metatarsal articulation is stabilized with the Lisfranc's screw, which mimics the direction and function of the disrupted Lisfranc's ligament. Through a medial stab incision, a 4.0-, 3.5-, or 2.7-mm screw is inserted through the medial base of the medial cuneiform and directed obliquely into both cortices of the second metatarsal base. The second metatarsal should be predrilled and held reduced to the medial cuneiform. The screw enters the base of the second metatarsal at the proximal medial corner and penetrates the lateral cortex at an angle of approximately 45°. A longer screw may be extended into the base of the third metatarsal for greater stability.

The size of the screw to be used for the first TMT joint depends on the diameter of the bone; a 4.0- or 3.5-mm cortical screw is used in large bone, whereas a 2.7-mm cortical screw is used in smaller bone. In placing a retrograde cortical screw across the first TMT joint, a trough is made in the dorsal cortex of the first metatarsal approximately 2 cm distal to the joint using a 3-mm bur. This maneuver countersinks the screw and prevents the screw head from striking the metatarsal's inclined surface and splitting the dorsal cortex.

The third metatarsal is then stabilized with a retrograde screw placed through the lateral incision. The angle of entry is different from that used in the first and second TMT joints because the transverse arch in the third and fourth TMT joints slopes downward, plantarward, and laterally.

For lateral column, if the lateral TMT joints are reduced, they may be stabilized with percutaneous K-wire fixation; otherwise, open reduction and internal fixation with K-wires should be done. The K-wires should penetrate the lateral cortices of the fourth and fifth metatarsals and should end up in the lateral cuneiform (fourth) or cuboid (fifth), respectively. Cadaveric biomechanical studies have not shown any difference in the stiffness of the construct with either K-wires or screws for lateral column [21].

Complications: Compartment syndrome, foot pain, posttraumatic osteoarthritis, vascular impairment, and reflex sympathetic dystrophy. Missed or neglected cases may need to be treated by limited arthrodesis.

Metatarsal Fractures

These are the most common fractures in the foot. They are usually low-velocity injuries, although they can occur from a variety of different causes. Stress fractures also occur, particularly in military recruits, athletes, or ballet dancers. Treatment is usually nonoperative although the Jones fracture of the proximal fifth metatarsal is associated with a high incidence of nonunion. Metatarsal fractures may be isolated or multiple.

Anatomy

The medial two metatarsals form part of the medial longitudinal arch of the foot, with the lateral three metatarsals forming part of the lateral longitudinal arch. The metatarsals are also arranged in a transverse arch, with the medial side of the transverse arch higher than the lateral side. Slips of tibialis posterior insert into the bases of the second, third, and fourth metatarsals. The vascular supply to the area is from branches of the dorsalis pedis artery on the dorsum and branches of the medial and lateral plantar arteries on the sole of the foot. The main nerve supply to the muscles is from the lateral and medial plantar nerves.

Classification

Metatarsal fractures are classified by anatomical location: base, shaft, neck, and head.

Treatment

Although treatment is mainly nonoperative, certain authors have suggested surgical treatment in the following circumstances:

1. More than 10° of angulation
2. More than 3–4 mm of displacement
3. Rotational abnormality of the toes
4. Shortening that alters the distal "parabolic" relationships of the metatarsal heads

If surgery is required, either K-wires or plates can be used, although most surgeons favor K-wires for the second to fifth metatarsals and plating for the first metatarsal (Figs. 15.7, 15.8, 15.9, and 15.10).

Fifth Metatarsal Fractures

- About 75 % of fractures occur in the fifth metatarsal, and they are generally low-energy injuries.
- The distribution of fifth metatarsal fractures is shown below:
  - About 66 % of these fractures occur in zone 1 and are avulsion fractures (Fig. 15.11).
  - A further 15 % are Jones fractures occurring in zone 2.
  - Zone 3 fractures account for about 14 % of fifth metatarsal fractures.
- These may be caused by a simple fall or twist, but they also may occur in athletes and present as a stress fracture.
- Fractures of the neck of the fifth metatarsal are relatively uncommon, accounting for about 5 % of fifth metatarsal fractures.

Zone 1 Fractures

- Avulsion fractures to the proximal fifth metatarsal are treated nonoperatively.
- They are low-energy injuries, and late displacement is extremely rare.
- Symptomatic nonunion is very uncommon. They should be treated by a supportive strapping or a cast or brace depending on the patient's symptoms.
- Weight bearing is allowed.

Zone 2 (Jones) Fractures

- The true Jones fracture is not a stress fracture as has been postulated in the literature.
- It is caused by adduction and axial loading on a plantar-flexed foot.
- It is relatively uncommon, and analysis shows that about 50 % are caused by inversion injuries, 15 % by simple falls, and 17.5 % by sports injuries.

Figs. 15.7, 15.8, 15.9, and 15.10 Radiograph showing fractures of the second ,third ,fourth metatarsal necks with fracture of the base of the first metatarsal; treated by open reduction and internal fixation; 3 months postoperatively (Courtesy of Dilip Malhotra, Bahrain)

- The presentation is with a painful forefoot, and radiographs show a transverse fracture in zone 2.
- The debate is between nonoperative and operative management because of the incidence of nonunion (Fig. 15.12), which has been reported in up to 30–35 % of patients:
  - It is reasonable to employ nonoperative management initially in the form of a walking cast or brace for 6 weeks, but if there is no indication of union at 6 weeks, open reduction and internal fixation should be offered to the patient.

Fig. 15.11 Radiograph showing a fracture of the base of the fifth metatarsal (Courtesy of Dilip Malhotra, Bahrain)

- In athletes, primary open reduction and internal fixation may be selected to reduce the rehabilitation time.
- Surgical treatment is usually with an intramedullary screw or a small plate.

Zone 3 and 4 Fractures

- These may present as stress fractures in athletes or following a twisting injury or fall. They are treated symptomatically with strapping or a cast or brace depending on the patient's symptoms.

Stress Fractures

- Stress fractures of the metatarsals are often referred to as march fractures.
- They are reported as common, but the reports come from specialized centers, and they are relatively uncommon in the overall population.

Fig. 15.12 Radiograph showing nonunion of the tuberosity of the fifth metatarsal (Courtesy of Dilip Malhotra, Bahrain)

- Patients present with a painful forefoot usually with no history of trauma.
- There is often a history of unaccustomed exercise such as running or marching.
- Treatment is symptomatic, and union can be expected.
- Open reduction and internal fixation should be reserved for nonunions.

Sesamoid Fractures

Fractures of the sesamoid bones are very rare. The sesamoid bones are situated in the tendons of flexor hallucis brevis. They cushion the hallux metatarsal head and help protect flexor hallucis longus, which runs between them. Patients who present with pain in the area of the hallux metatarsal phalangeal joint may have a fractured sesamoid, but the surgeon must be careful not to confuse a fractured sesamoid with a bipartite sesamoid, which occurs in 19–31 % of the population:

- Sesamoid fractures are usually caused by a direct blow to the undersurface of the forefoot, and they are classically seen in dancers and runners, with the latter occasionally presenting with stress fractures of the sesamoid. Diagnosis is often difficult because of the frequency of bipartite sesamoids, but a bone scan or MRI scan may be helpful. Treatment should be nonoperative unless symptoms persist. Treatment alternatives are excision of the sesamoid or bone grafting of the non-union. The latter should be attempted but sesamoidectomy undertaken if symptoms persist. Sesamoidectomy is not without its complications, however, and hallux deformities and persistent pain have been reported.

Phalangeal Fractures

- Phalangeal fractures are relatively common. It is difficult to estimate their true incidence because many patients do not present to emergency departments or to orthopedic surgeons. They rarely require operative treatment.

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Chapter 16
The Cervical Spine

Shibu P. Krishnan

Injuries to the Cervical Spine

Epidemiology

Cervical spine injuries usually follow high-energy injuries – motor vehicle accident (45 %) and falls from a height (20 %).

Forty percent of patients with cervical spine fractures have neurological injury.

Radiographs reveal no obvious evidence of bony abnormality in 10 % of traumatic cord injuries.

Spinal cord damage more frequently occurs in lower rather than upper cervical spine injuries.

Five percent of head injury patients have an associated spinal injury while 25 % of spinal injury patients have head injury.

Ten percent of patients with a C-spine fracture have a second associated noncontiguous vertebral column fracture, and vice versa.

Relevant Anatomy

The cervical spine is divided into two parts: upper (C1 or atlas and C2 or axis) and lower (C3–C7) cervical spine.

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The Atlas

It has no vertebral body. Two large lateral masses provide the only two weight-bearing articulations between the skull and the vertebral column.

The tectorial membrane (proximal extension of the posterior longitudinal ligament) and the alar ligaments are the key to providing normal craniocervical stability.

The anterior tubercle is held adjacent to the odontoid process of C2 by the transverse atlantal ligament.

Fifty percent of total neck flexion and extension occurs at the occiput–C1 junction.

The vertebral artery emerges from the foramen transversarium and passes between C1 and the occiput, traversing a depression on the superior aspect of the C1 ring. Fractures are common in this location.

The Axis

Its body is the largest among the cervical vertebrae. The transverse atlantal ligament provides primary support for the atlantoaxial joint.

The alar ligaments are the secondary stabilizers of the atlantoaxial joint.

The facet joint capsules at occiput–C1 and C1–C2 provide little support.

Fifty percent of the total neck rotation occurs at the C1–C2 junction.

Neuroanatomy of the Cervical Spine

The lateral dimension of the spinal cord measures 13–14 mm, while the anterior–posterior extent measures 7 mm. An additional 1 mm is necessary for the cerebrospinal fluid anteriorly and posteriorly, as well as 1 mm for the dura mater.

Exiting at each vertebral level is the spinal nerve root, which is the result of the union of the anterior and posterior nerve root. Interconnections are present between the sympathetic nervous system and the nerve root proper.

Since the numbering of the cervical roots commences above the atlas, 8 cervical roots exist, with C8 exiting between the seventh cervical vertebra and the first thoracic level.

Vascular anatomy consists of a larger anterior spinal artery located in the central sulcus of the cord and paired posterior spinal arteries located on the dorsum of the cord. The anterior two-thirds of the cord is supplied by the anterior spinal artery, and the posterior one-third is supplied by the posterior arteries.

Pathophysiology

Conceptually, the cervical spine may be viewed as being composed of two columns. An anterior load-bearing structure consists of all structures anterior to and including the posterior longitudinal ligament. The posterior column includes the pedicles, laminae, facet joints, spinous processes, and the posterior ligament complexes (ligamentum flavum, interspinous ligaments, and supraspinous ligaments). Tension is resisted by the posterior column, which fails under extreme flexion or distraction and which may be associated with concomitant injury to the anterior column.

Allen and colleagues introduced a comprehensive classification system of injuries. This classification system includes three common mechanisms: compression–flexion, distraction–flexion, and compression–extension. Vertical compression injury results in the burst-type injury with anterior column failure. Less common modes of insult are the distraction–extension and lateral flexion subtypes. These are classified further into stages of progressive injury.

Specific Types of Cervical Spine Injuries

Injuries to the Occiput–C1–C2 Complex (Craniocervical Region)

Highly susceptible to injury because of the large lever arm created cranially by the skull and the relative freedom of movement of the craniocervical junction, which relies disproportionally on ligamentous structures rather than on intrinsic bone stability.

Occipital Condyle Fractures

Mechanism of Injury: compression and lateral bending causes compression fracture of the condyle as it presses against the superior facet of C1 or avulsion of the alar ligament with extremes of atlantooccipital rotation.

CT Scan: investigation of choice.

Associated with C1 fractures and cranial nerve palsies.

Classification

Anderson and Montesano classification of occipital condyle fractures

Type I: impaction of condyle, usually stable
Type II: associated with basilar or skull fractures, potentially unstable
Type III: condylar avulsion, unstable

Treatment

Rigid cervical collar immobilization for 8 weeks for stable injuries.

Halo immobilization or occipital cervical fusion for unstable injuries.

Occipitocervical Dissociation (Occipitoatlantal Dislocation)

Twice common in children because of the inclination of the condyles.

Mechanism: high-energy injury with a combination of hyperextension, distraction, and rotation at the craniocervical junction.

The diagnosis could be made on lateral C-spine radiograph:

- The tip of odontoid should be in line with the basion (midpoint on the anterior margin of foramen magnum).
- The odontoid–basion distance is 4–5 mm in adults and up to 10 mm in children.
- Translation of the odontoid on the basion is never greater than 1 mm in flexion/extension views.
- Power ratio (basion–posterior arch/opisthion–anterior arch) should be <1. (Power ratio >1 indicates instability of the atlantoaxial junction.) (Opisthion is the midpoint on the posterior margin of foramen magnum.)
- Widening of the pre-vertebral soft tissue shadow in the upper neck.

Associations

Submental lacerations, mandibular fractures, posterior pharyngeal wall lacerations, cranial nerve and vertebral artery injuries, and cervicomedullary syndromes (include cruciate paralysis and hemiplegia cruciata).

Investigations

Fine-cut CT scan.

MRI: indicated if there are associated spinal cord injuries.

Classification (Harborview)

Stage I: MRI shows hemorrhage or edema at the craniocervical junction.
Craniocervical alignment is normal by Harris lines.
No distraction on traction test with 25 lb of traction.
Stage II: MRI shows hemorrhage or edema at the craniocervical junction.
Craniocervical alignment is normal by Harris lines.
Traction at weights less than 25 lb shows sufficient distraction to meet craniocervical dissociation threshold established by the Harris measurements.
Stage III: Static imaging studies show distraction beyond thresholds of Harris measurements.

Treatment

Immediate: halo vest application with strict avoidance of traction.

Surgical Treatment: occipitocervical fusion.

Indications: stage II or III injuries or any injury with associated neurological deficit.

Atlas Fractures

Mechanism of Injury

Axial compression with elements of hyperextension and asymmetric loading of condyles.

Instability equates to the presence of transverse atlantal ligament insufficiency, which can be diagnosed by identifying bony avulsion on CT scan or ligament rupture on MRI or indirectly by identifying widening of the lateral masses.

Associations

Other cervical spine fractures (50 % incidence) especially odontoid fracture and spondylolisthesis of the axis, cranial nerve lesions of VI to XII, neurapraxia of the suboccipital and greater occipital nerves, and vertebral artery injuries.

Classification (Levine)

A. Isolated bony apophysis fracture
B. Isolated posterior arch fracture
C. Isolated anterior arch fracture
D. Comminuted lateral mass fracture
E. Burst fracture, three or more fragments

Treatment

Most C1 fractures are treated by nonoperative methods.

Rigid Cervical Orthosis: for stable fractures (posterior arch or non-displaced fractures involving the anterior and posterior portions of the ring).

Halo Immobilization: less stable configurations (asymmetric lateral mass fracture with "floating" lateral mass, burst fractures).

Operative Management

When there is loss of transverse atlantal ligament integrity, as suggested by a combined lateral mass displacement of 7 mm or more.

Transverse atlantal ligament disruption introduces the potential for progressive lateral mass separation, C1–C2 instability, and pseudarthrosis. Halo immobilization alone may be insufficient to maintain acceptable alignment in these patients.

If upright x-rays in a halo show further lateral mass displacement or an anterior atlanto-dens interval (ADI) of >3 mm, patients must be treated either with prolonged recumbency in cranial tong traction or with operative stabilization, generally with posterior C1–C2 or occiput–C2 fixation.

Traumatic Atlanto-Axial Instability (Transverse Ligament Rupture)

Mechanism of Injury

Forced flexion.

Presentation

Rare, usually fatal injury, seen mostly in older age groups. The clinical picture ranges from severe neck pain to complete neurological compromise.

Diagnosis

Rupture of the transverse ligament may be determined by:

1. ADI > 3 mm in adults (ADI > 5 mm in adults implies rupture of the alar ligaments).
2. Atlantoaxial offset >6.9 mm on an odontoid radiograph.
3. Visualizing the avulsed lateral mass fragment on CT scan.
4. Direct visualization of the rupture on MRI scan.

Treatment

- Halo traction or immobilization.
- If bony avulsion, halo immobilization is continued until osseous healing (transverse ligament competency) is confirmed on flexion extension views.
- *Atlantoaxial Fusion*: if mid-substance tear or chronic instability or pain.

Atlanto-Axial Rotary Subluxation and Dislocation

Mechanism of Injury

Flexion/extension injury with a rotational component. Some present with no history of trauma.

Presentation

Neck pain, occipital neuralgia, symptoms of vertebrobasilar insufficiency, torticollis, etc.

Diagnosis

Odontoid radiographs – asymmetry of C1 lateral masses with unilateral facet joint narrowing or overlap (wink sign).

AP Radiograph

C2 spinous process rotated from the midline.

Dynamic CT scans demonstrate subluxation.

Classification (Fielding)

Type I: simple rotatory displacement without anterior shift. Odontoid acts as a pivot point; transverse ligament intact.

Type II: rotatory displacement with anterior displacement of <5 mm. Opposite facet acts as a pivot; transverse ligament insufficient.

Type III: rotatory displacement with anterior displacement >5 mm; both joints anteriorly subluxed; transverse and alar ligaments incompetent.

Type IV: rare; both joints posteriorly subluxed.

Type V: (Levine and Edwards) frank dislocation; extremely rare.

Treatment

All symptomatic subluxations should be reduced – cervical halter traction in supine position and active range of motion exercises for 24–48 h initially and followed by ambulatory orthotic immobilization with active range of motion exercises until free motion returns.

After reduction, if transverse ligament insufficient, do C1–C2 posterior fusion (types II, III, and IV).

Odontoid (Dens) Fractures

Mechanism of Injury

High-energy injuries include motor vehicle accident or falls with avulsion of the apex of the dens by the alar ligament or lateral/oblique forces that cause fracture through the body and base of the dens.

Classification (Anderson and D'Alonzo)

Type I: oblique avulsion fracture of apex (5 %).
Type II: fracture at the junction of the body and the neck, high nonunion rate (60 %) (Fig. 16.1).
Type IIA: highly unstable comminuted fracture extending from the waist of the odontoid into the body of the axis (Figs. 16.2 and 16.3).
Type III: fracture extends into the body of C2 and may involve the lateral facets (30 %).

Treatment

Type I: immobilize in a cervical orthosis.
Type II: controversial. High incidence of nonunion (36 %) due to lack of periosteum and cancellous bone and presence in watershed area.
Surgical Stabilization: for irreducible fractures, fractures with distractive patterns of displacement, or fractures with associated spinal cord injury. Relative indications include multiply injured patients, associated closed head injury, initial displacement of 4 mm or more, angulation greater than 10°, delayed presentation (>2 weeks), multiple risk factors for nonunion, inability to treat with a halo due to advanced age, associated cranial or thoracoabdominal injury or other medical factors, and presence of associated upper cervical fractures.
Anterior Odontoid Screw Fixation: for non-comminuted fractures in patients with favorable bone quality and appropriate body habitus. Allows preservation of some atlantoaxial motion.
Posterior Atlantoaxial Arthrodesis or Segmental C1–C2 Fixation: in patients with extensive fracture comminution, compromised bone quality, or in whom achieving the requisite anterior odontoid screw trajectory is not feasible due to body habitus or the neck position required to maintain reduction.
Odontoid screw fixation beyond 3 weeks carries a substantially increased risk of nonunion and thus is not a preferred treatment.
Type III: rarely requires surgical stabilization. High likelihood of union with halo immobilization owing to the cancellous bed of the fracture site.

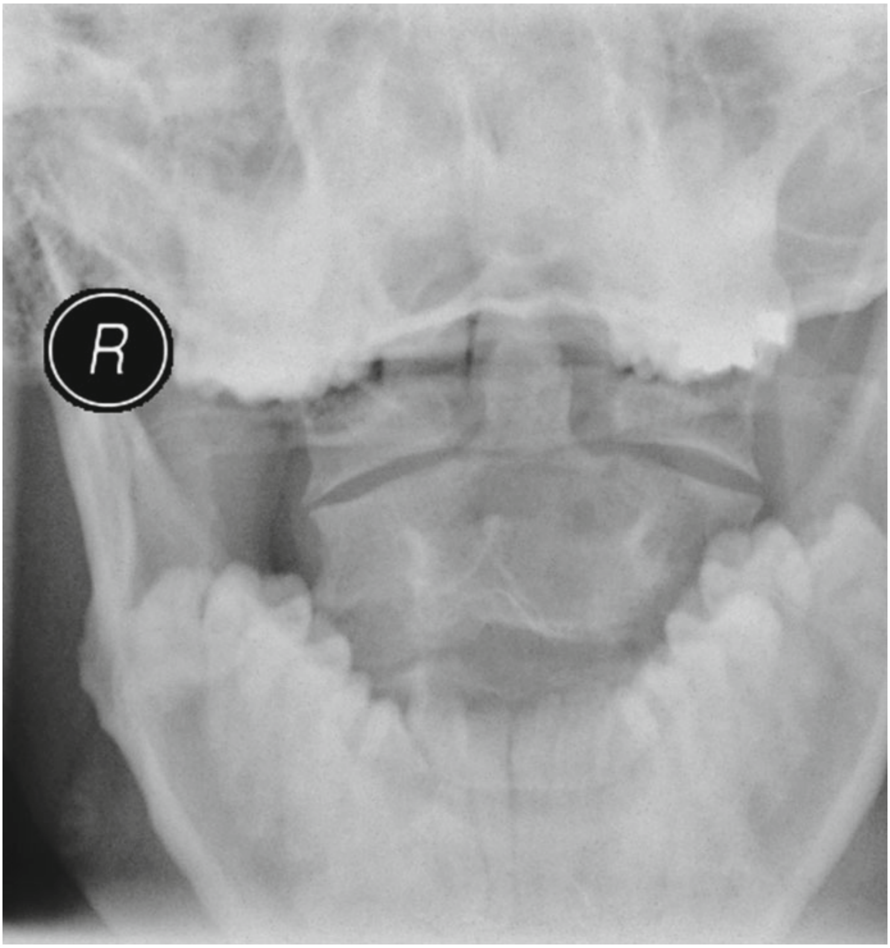

Fig. 16.1 Open-mouth radiograph demonstrating an Anderson and D'Alonzo type II odontoid fracture (Courtesy of Shibu P. Krishnan, London, UK)

Operative stabilization is indicated in fractures with associated spinal cord injury or distractive instability patterns. Posterior C1–C2 arthrodesis is the surgical treatment method of choice, since anterior odontoid screw fixation has a high failure rate with these injury types. Relative indications include highly displaced irreducible fractures, patients with displaced injuries who cannot be treated with a halo, and fractures with initial displacement of 5 mm or more, which have a high potential for nonunion, particularly in the elderly population. Results may be less predictable than is generally recognized, however, with delayed unions or pseudarthroses reported in up to 54 % of nonoperatively treated patients.

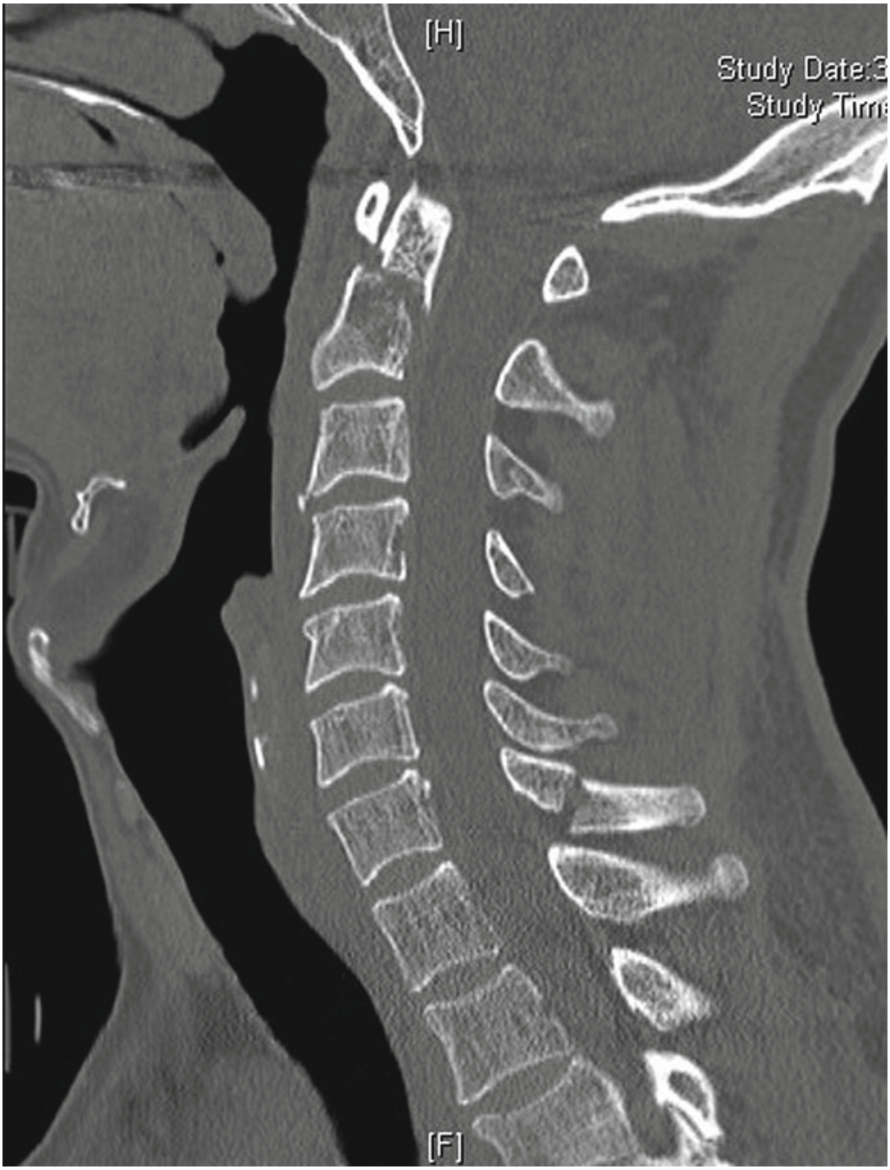

Fig. 16.2 Sagittal CT section showing an Anderson and D'Alonzo type IIA odontoid fracture (Courtesy of Shibu P. Krishnan, London, UK)

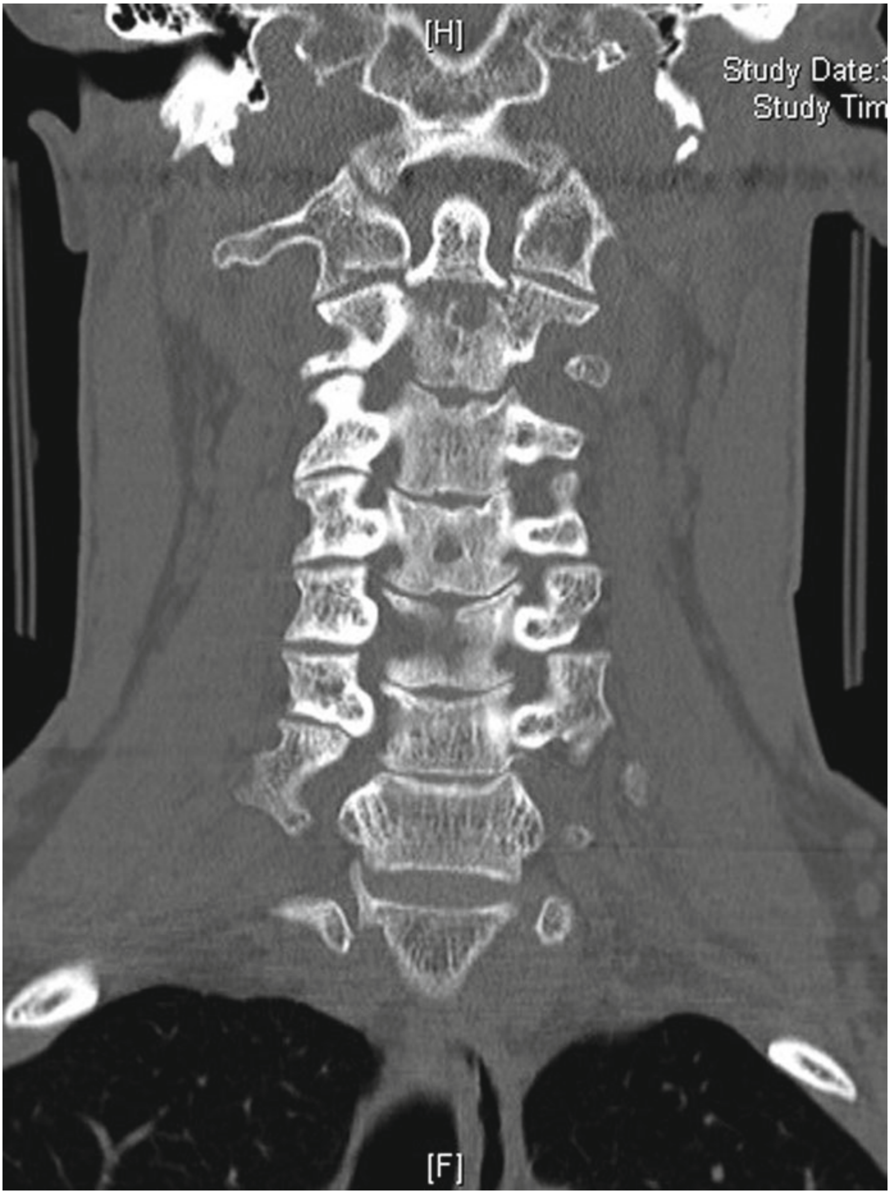

Fig. 16.3 Coronal plane view of the fracture in Fig. 16.1 (Courtesy of Shibu P. Krishnan, London, UK)

C2 Lateral Mass Fractures

Presentation: neck pain, reduced range of motion, and no neurological injury.

Mechanism of Injury: axial compression and lateral bending.

Diagnosis: CT scan – depression fracture of the C2 articular surface.

Treatment: collar cervical immobilization or late fusion for chronic pain.

Traumatic Spondylolisthesis of the Axis (Hangman's Fracture)

Second most common type of C2 fracture (38 %). This is associated with 30 % incidence of concomitant cervical spine fractures. There may be associated cranial nerve, vertebral artery, and craniofacial injuries.

Mechanism of Injury

Road traffic accidents and falls with flexion, extension, and axial loads. Associated with varying degrees of intervertebral disc disruption. Hanging mechanisms involve hyperextension and distraction injury with bilateral pedicle fractures and complete disruption of disc and ligaments between C2 and C3. The incidence of spinal cord injury is low with type I and II injuries and high with type III injuries.

Classification (by Effendi and Subsequently Modified by Levine and Star)

Type I: minimally displaced, relatively stable fracture of the pars interarticularis; translation <3 mm, no angulation, C2–C3 disc intact.

Type IA: atypical unstable lateral bending fractures that are obliquely displaced and usually involve only one pars interarticularis, extending anterior to the pars and into the body on the contralateral side. The oblique plane of these fractures makes them less obvious on lateral x-rays, giving the appearance of an elongated pars.

Type II: significant angulation at C2–C3; translation >3 mm; unstable; C2–C3 disc disrupted (56 %); most common injury pattern; subclassified into flexion, extension, and listhetic types.

Displacement results when a flexion force follows the initial hyperextension and axial loading insult. Type II injuries may appear similar to type I injuries on supine x-rays but will displace on upright x-rays. Physician-supervised flexion–extension x-rays of type I injuries have also been advocated to differentiate them from spontaneously reduced type II injuries.

Type IIA: results from a flexion–distraction mechanism; avulsion of the entire C2–C3 disc in flexion with injury to posterior longitudinal ligament; anterior longitudinal ligament intact; results in severe angulation (kyphosis); no translation; traction contraindicated.

Type III: rare, highly unstable injuries; results from initial anterior facet dislocation of C2 on C3 followed by extension injury fracturing the pars interarticularis fractures; results in severe angulation and translation with unilateral or bilateral C2–C3 facet dislocation, which is not generally reducible by nonoperative means; most commonly associated with spinal cord injury.

Treatment

Type I: rigid cervical orthosis for 6 weeks.

Type II: based on stability; usually requires halo traction/immobilization with serial radiographs to confirm reduction for at least 6 weeks.

Type IIA: halo immobilization.

Type III: initial halo traction followed by open reduction and posterior fusion of C2–C3, with possible anterior fusion.

Injuries to Lower Cervical Spine (C3–C7)

The most common and potentially most devastating injuries involving the axial skeleton. Assume a cervical spine injury is present until proven otherwise in patients presenting to an emergency facility with a history of a high-speed motor vehicle accident, significant head or facial trauma, a neurologic deficit, or neck pain.

The age distribution of patients presenting with lower cervical spine and spinal cord injuries is bimodal. Injuries in persons aged 15–24 years are usually the result of high-energy trauma, such as motor vehicle accidents, accidents resulting from sporting activities, or acts of violence. Injuries in persons older than 55 years usually result from low-energy trauma, such as falls from the standing position. The age-associated cervical spondylosis narrows the spinal canal and predisposes the cervical cord to injury at this level.

Relevant Anatomy

C3–C7 can be conceptualized as a three-column system (Dennis).

Anterior Column: The anterior vertebral body and the intervertebral disc resist compressive loads; the anterior longitudinal ligament and annulus fibrosis are the most important checkreins to distractive forces (extension).

Middle Column: The posterior vertebral body and uncovertebral joints resist compression; the posterior longitudinal ligament and annulus fibrosis limit distraction.

Posterior Column: The facet joints and lateral masses resist compressive forces; the facet joint capsules, interspinous ligaments, and the supraspinous ligaments counteract distractive forces.

The vertebral artery bypasses the empty foramen transversarium of C7 to enter the vertebral foramina of C6–C1. Injuries to the vertebral arteries are uncommon because of the redundancy of the vessel.

Articulations include the disc–vertebral body, uncovertebral joints, and zygapophyseal joints. The disc is thicker anteriorly, contributing to the normal cervical lordosis, and the uncovertebral joints located in the posterior aspect of the body define the lateral extent of most surgical exposures. The zygapophyseal or facet joints are oriented 45° to the axial plane, allowing a sliding motion, as the joint capsule is weakest posteriorly. Supporting ligamentum flavum, posterior and interspinous ligaments also strengthen the posterior column.

Radiographic Evaluation

AP, lateral, and odontoid views of the cervical spine.

Flexion/Extension View: if instability is suspected in a conscious and cooperative patient without neurological compromise.

A "Stretch" Test (*Panjabi and White*): performed with longitudinal cervical traction. More than 1.7-mm interspace widening or a >7.5° change between vertebrae is abnormal.

CT Scan with Reconstruction: to delineate the fracture pattern and the degree of canal compromise.

MRI: delineates the spinal cord, disc, and canal compromise.

Classification (Allen–Ferguson)

1. Compressive Flexion (Shear Mechanism Resulting in "Teardrop" Fractures)
   Stage I: blunting of anterior body; posterior elements intact.
   Stage II: "beaking" of the anterior body; loss of anterior vertebral height.
   Stage III: fracture line passing from the anterior body through the inferior subchondral plate.
   Stage IV: inferoposterior margin displaced <3 mm into the neural canal.
   Stage V: "teardrop" fracture; inferoposterior margin >3 mm into the neural canal; failure of the posterior ligaments and the posterior longitudinal ligament.

2. Vertical Compression (Burst Fractures)
   Stage I: fracture through superior or inferior end plate with no displacement.
   Stage II: fracture through both end plates with minimal displacement.
   Stage III: burst fracture; displacement of fragments peripherally and into the neural canal.

3. Distractive Flexion (Dislocations)
   Stage I: failure of the posterior ligaments, divergence of the spinous processes, and facet subluxation.
   Stage II: unilateral facet dislocation, translation always <50 %.
   Stage III: bilateral facet dislocation, translation of 50 %, and "perched" facets.
   Stage IV: bilateral facet dislocation with 100 % translation.

4. Compressive Extension
   Stage I: unilateral vertebral arch fracture.
   Stage II: bilateral laminar fracture without other tissue failure.
   Stage III, IV: theoretic continuum of stages II and V.
   Stage V: bilateral vertebral arch fracture with full vertebral body displacement anteriorly; ligamentous failure at the posterosuperior and anteroinferior margins.

5. Distractive Extension
   Stage I: failure of anterior ligamentous complex or transverse fracture of the body, widening of the disc space, and no posterior displacement.
   Stage II: failure of posterior ligament complex and superior displacement of the body into the canal.

6. Lateral Flexion
   Stage I: asymmetric, unilateral compression fracture of the vertebral body plus a vertebral arch fracture on the ipsilateral side without displacement.
   Stage II: displacement of the arch on the AP view or failure of the ligaments on the contralateral side with articular process separation.

7. Miscellaneous Cervical Spine Fractures
   Sentinal Fracture: Fracture occurs through the lamina on either side of the spinous process. A loose posterior element may impinge on the cord. Treatment is often symptomatic unless there is spinal cord compromise.
   "*Clay Shoveler*'*s*" *Fracture*: avulsion of the spinous processes of the lower cervical and upper thoracic vertebrae. Historically, this resulted from muscular avulsion during shoveling in unyielding clay with force transmission through the contracted shoulder girdle. Treatment is often symptomatic.
   Ankylosing Spondylitis: This may cause calcification and ossification of the ligamentous structures of the spine, producing "chalk stick" fractures after trivial injuries and are very unstable fractures with high risk for nonunion (Fig. 16.4). Treatment includes traction with minimal weight in flexion, with aggressive immobilization with either halo vest or open stabilization.
   Gunshot Injuries: This may cause high-velocity fragmentation with associated gross instability and complete spinal cord injury. Surgical extraction of the missile fragment is often unnecessary in the absence of canal compromise. Missiles that traverse the esophagus or pharynx should be removed, with aggressive exposure and debridement of the missile tract to prevent abscess formation, osteomyelitis, and mediastinitis.

Fig. 16.4 Lateral radiograph of a patient with ankylosing spondylitis and C5 vertebral body fracture treated in halo vest (Courtesy of Shibu P. Krishnan, London, UK)

Spinal Cord Syndromes

Central Cord Syndrome

- Most common incomplete cord lesion.
- Frequently associated with extension injury to osteoarthritic spine (cervical spondylosis) in middle-aged person who sustains hyperextension injury.
- Cord is injured in central gray matter and results in proportionally greater loss of motor function to upper extremities than lower extremities with variable sensory sparing, clinical picture of greater upper-extremity involvement than lower-extremity motor deficits.
- Majority will achieve functional walking with progressive return of motor and sensory power to the lower extremities and trunk (gait may be spastic).
- Tend to have poor recovery of hand function owing to irreversible central gray matter destruction.
- Likely to regain bowel and bladder function.

Brown–Séquard Syndrome

- Hemisection of the spinal cord, with loss of ipsilateral motor function below the level of involvement, contralateral pain, and temperature loss.
- Seen with penetrating injuries, such as gunshot wounds.
- Good prognosis for recovery.
- More than 90 % of patients regain bladder and bowel control and ability to walk.
- Most patients will regain some strength in lower extremities and most will regain functional walking ability.

Anterior Cord Syndrome

- Damage is primarily in the anterior 2/3 of the cord and is related to vascular insufficiency.
- There is sparing of the posterior columns (position sense, proprioception, and vibratory sensation).
- Complete motor paralysis (corticospinal function) and sensory anesthesia (spinothalamic function).
- Patient demonstrates greater motor loss in the legs than arms.
- Worst prognosis among all cord syndromes.
- Only 10–15 % of patients demonstrate functional recovery.

Facetal Dislocation

Posterior injury may result in unilateral or bilateral facet fracture, dislocation, or both (Fig. 16.5). Isolated spinous process injury is usually a stable injury and does not require surgical attention. Unilateral facet dislocations may be the most difficult to reduce by closed means, and open reduction and stabilization are often necessary. Radiculopathies with or without cord damage may be seen with the unilateral facet injury. Bilateral facet dislocations have the highest incidence of spinal cord injury, with both incomplete and complete syndromes appearing.

Management of Cervical Spine Injuries

Pre-hospital Care and Transfer

Suspect fractures or dislocations in any patient involved in a high-velocity injury. Successful treatment starts with appropriate transportation of the patient from the scene of the accident to the trauma center. Airway with cervical spine immobilization, breathing, and circulation should always be the highest priority. Immobilization of the cervical spine with sandbags or a cervical collar and placement of the patient on a long spine board help to prevent secondary injury. Transfers and intubation should be accomplished under strict spine precautions.

Assessment in the Emergency Department

1. Assess and resuscitate according to ATLS protocol including in-line immobilization of the cervical spine.

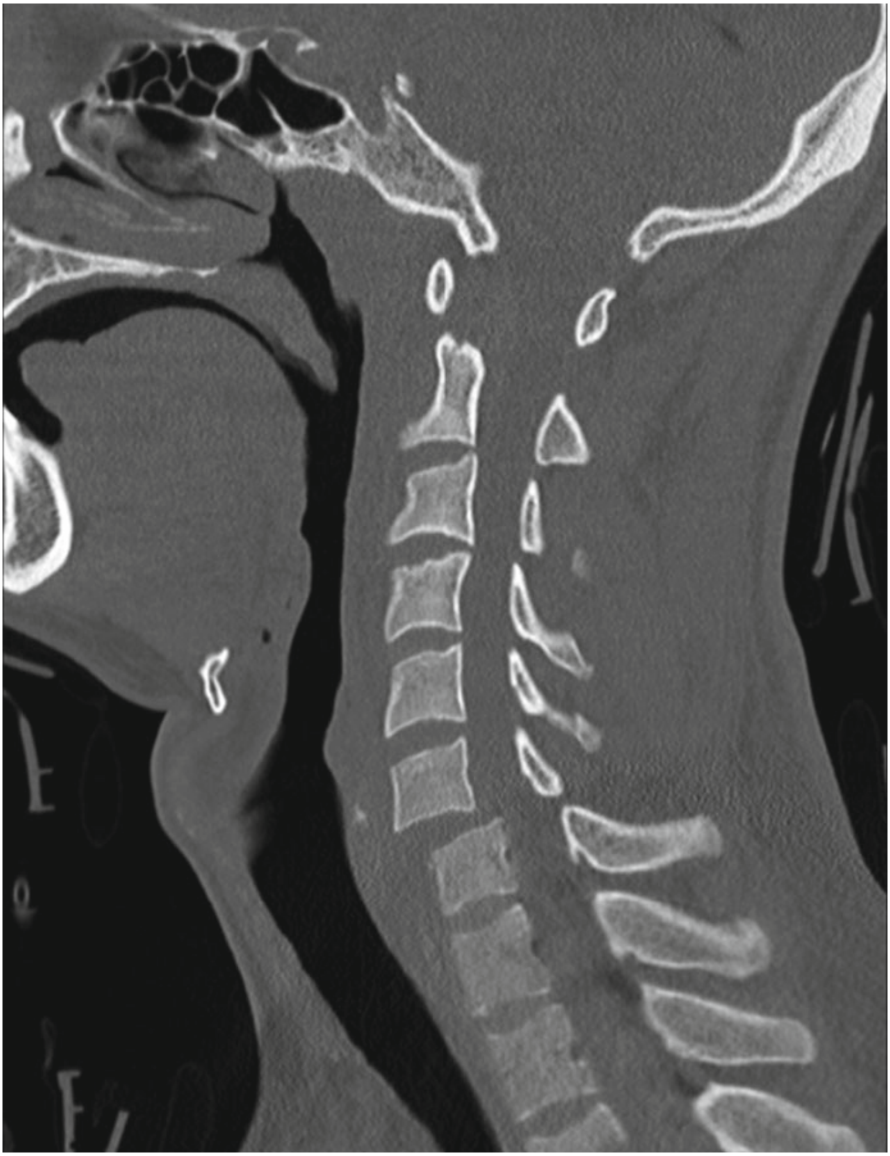

Fig. 16.5 Sagittal CT scan demonstrating bi-facetal dislocation of C6 vertebra over C7 (Courtesy of Shibu P. Krishnan, London, UK)

2. Address life-threatening injuries.
3. Movements caused during tracheal intubation risk displacing unstable cervical fractures or dislocations. Manual in-line stabilization should be maintained throughout the intubation process. Alternatively, mask ventilation can be continued until fiber-optic or nasotracheal intubation can be safely performed. If an

unstable spine is highly suspected, a cricothyroidotomy may be the safest alternative for airway control.

4. Exclude head injury.
5. *Ascertain the patient's history*: mechanism of injury, witnessed head trauma, movement of extremities/any history of loss of consciousness following trauma, retrograde amnesia, etc.
6. A thorough neurologic examination should be performed as soon as possible to detect any evidence of cord damage. It is useful to use a validated tool such as the ASIA (American Spinal Injury Association) scoring system for communication and monitoring purposes. This is based on examination of essential minimal elements of neurologic assessment which includes motor strength assessment of ten muscles on each side of the body and pinprick and light touch assessment at 28 specific sensory locations on each side.

Examination of the sacral roots and reflexes are important since detection of sacral sparing indicates an incomplete spinal cord injury, and a return of the sacral reflexes indicates the passing of spinal shock. Anal sphincter tone and perianal sensation are good tests of sacral root function. The bulbocavernosus reflex and anal wink are good tests of the sacral reflex arc.

Serial examinations are important to detect the end of spinal shock (usually occurs in 24 h) and to determine whether an incomplete lesion is improving or worsening. This better helps to define the best treatment pathway.

Investigations

Lateral Radiograph of Cervical Spine: The base of the skull, all seven cervical vertebrae, and the first thoracic vertebra must be visualized or else a swimmer's view of the lower cervical and upper thoracic area must be obtained. This combination of radiographs would detect 85 % of cervical spine injuries.

To assess the upper cervical spine adequately, an open-mouth odontoid view of the odontoid process and the C1–C2 articulations should be obtained. An anteroposterior radiograph of the C-spine may assist in the identification of a unilateral facet dislocation injury in instances where there is little or no dislocation identified on the lateral radiographs. The combination of lateral, AP, and open-mouth radiographs increases the sensitivity for identification of a fracture to approximately 92 %.

Reading the C-Spine Lateral Radiograph: Look for adequacy, alignment, bony abnormalities, base of skull abnormalities, contours (acute kyphosis or loss of lordosis), disc space, and soft tissue swelling (ABCDS). For assessing alignment, look for continuity of the radiographic lines: anterior vertebral line, posterior vertebral line, facet joint line, and spinous process line. Radiographic markers of C-spine instability include:

Compression fractures with >25 % height loss
Angular displacements >11° between adjacent vertebrae

Translation > 3.5 mm
Intervertebral disc space separation >1.7 mm
CT scan may be valuable to assess the upper cervical spine or the cervicothoracic junction, especially if it is inadequately visualized by plain radiography.
MRI scan is useful in detecting traumatic disc herniation, epidural hematoma, spinal cord edema or compression, and posterior ligamentous disruption. Patients with incomplete neurological deficits or who are neurologically intact with uni/bilateral facetal dislocations require MRI before reduction via traction to evaluate for a herniated disc, especially if a patient is not awake and alert and able to cooperate with serial examinations during reduction.

Flexion–extension lateral radiographs are rarely indicated if instability is suspected. It should be performed in an awake and alert patient only. In a patient with neck pain, they are best delayed until spasm has subsided, which can mask instability.

Treatment

Orthoses

The majority of cervical spine fractures can be treated nonoperatively including the use of a cervical orthosis.

Soft Cervical Orthosis: This produces no significant immobilization but gives support for minor injuries.

Rigid Cervical Orthosis (*e.g.*, *Philadelphia Collar*): Effectively controls flexion and extension; however, it provides little rotational or lateral bending stability.

Cervicothoracic Orthoses: Effective in flexion and extension and rotational control but limited control of lateral bending.

Halo Device: Provides the most rigid immobilization in all planes.

Gardner–Wells Tongs: Applied one finger's breadth above the pinna of the ear in line with the external auditory canal. Slight anterior displacement will apply an extension force while posterior placement will apply a flexion force.

Halo Application: Apply the halo ring 1 cm above the ears. Anterior pin sites should be placed below the equator of the skull above the supraorbital ridge, anterior to the temporalis muscle, and over the lateral two-thirds of the orbit. Posterior sites are variable and are placed to maintain horizontal orientation of the halo. Pin pressure should be 6–8 lb in the adult and should be tightened at 48 h and monthly thereafter. Pin care is essential.

Surgery

The primary indications for surgical intervention in subaxial (C3–C7) cervical injuries include malalignment of the spine, with or without neurologic deficits, and

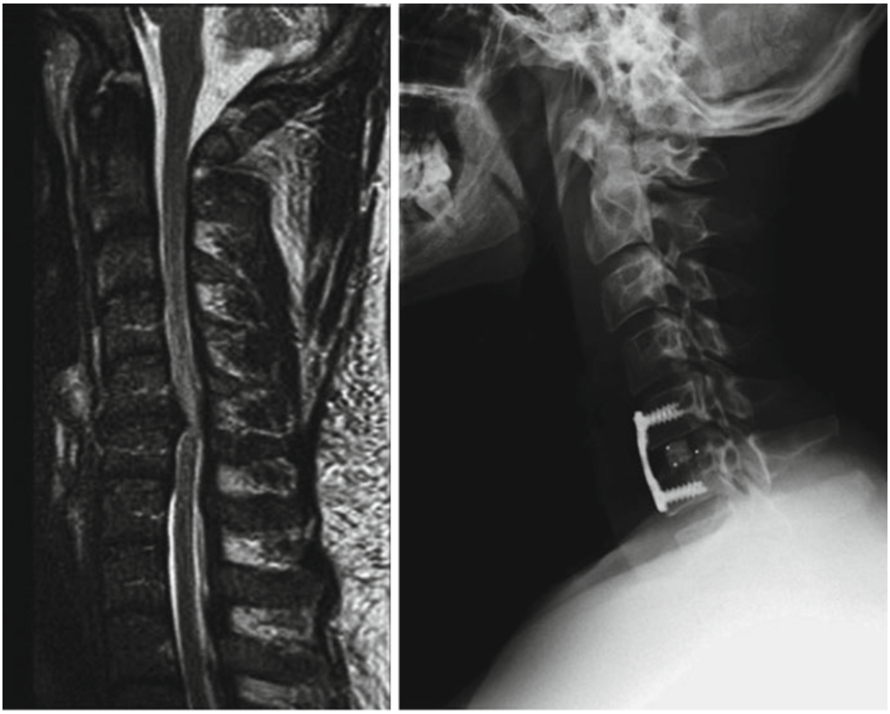

Fig. 16.6 Radiographs showing C5/C6 disc prolapse treated by C5/C6 curettage and fusion (Courtesy of Dilip Malhotra, Bahrain. Reproduced with kind permission of Springer Verlag)

progressive neurologic deterioration in the face of persistent compression from bone or disc fragments.

While malalignment can be managed initially with cervical tong traction, definitive surgical stabilization, with or without decompression, generally is required.

Stabilization options include posterior decompression and fusion, anterior decompression and fusion (Fig. 16.6), or bilateral lateral mass plating.

Fifty percent of flexion/extension and 50 % of rotation are evenly distributed between each of the facetal articulations. Fusion of each level therefore decreases motion to a proportionate amount.

Chapter 17
The Dorsolumbar Spine

Shibu P. Krishnan

Relevant Anatomy

Twelve thoracic vertebrae and five lumbar vertebrae.

The normal thoracic kyphotic curve ranges from 18° to 51°.

The thoracic vertebral bodies are wedge-shaped, being larger posteriorly than anteriorly. The kyphosis of the thoracic spine results in a center of gravity anterior to the apical T7 vertebra, resulting in compression anteriorly and tension posteriorly in the resting state.

Thoracic spine is much stiffer than the lumbar spine in flexion-extension and lateral bending. T1–T6 flexes 4°, and T6–T7 to T12–L1 gradually increases to 5–12°. Lateral bending is approximately 6° per level from T1–T10 and approximately 8° at the thoracolumbar junction.

Axial rotation is greater in the thoracic spine with a maximum at T8–T9, due to the coronal orientation of the facets in the thoracic spine. The rotation arc is approximately 75° for the thoracic spine and only 10° for the lumbar spine where the facets are sagittally oriented.

The thoracolumbar junction is more prone to injury because of the (1) transition zone between the thoracic and lumbar spine with increased stress concentration, (2) lack of rib restraint, and (3) changes in disc size and shape that occur at this level.

In the corticospinal tract, the cervical fibers are distributed centrally and the sacral fibers peripherally.

The conus medullaris (terminal portion of the spinal cord) normally begins at the T11 level. It ends at the L1–2 disc space in males and slightly more proximally in

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females. The cauda equina starts from this region and extends distally into the lumbosacral spine with each peripheral nerve root exiting at its corresponding neural foramen. The cauda equina is more resistant to injury and has a greater potential for recovery than the spinal cord.

The ratio of the spinal canal dimensions to the spinal cord dimensions is smallest in the T2–T10 region, which makes this area prone to neurologic injury after trauma. T2–T10 region is a circulatory watershed area, deriving its blood supply from antegrade vessels in the upper thoracic spine and distally from retrograde flow from the artery of Adamkiewicz.

The lumbar vertebrae are particularly large and heavy compared to the cervical and thoracic vertebrae. The bodies are wider and have shorter and heavier pedicles, and the transverse processes project somewhat more laterally and ventrally than other spinal segments.

The laminae are shorter vertically than are the bodies and are bridged by strong ligaments. The spinous processes of lumbar spine are broader and stronger than are those in the thoracic and cervical spine.

The intervertebral discs consist of two components, the annulus fibrosus and the nucleus pulposus. The annulus is a dense fibrous ring located at the periphery of the disc that has strong attachments to the vertebrae and serves to confine the nucleus pulposus.

Mechanism of Injury

Several different mechanisms of injury can occur within the thoracolumbar spine. Most commonly, a combination of one or two mechanisms accounts for the injury.

Axial Compression

This type of injury results in a purely compressive load. Endplate failure occurs, followed by vertebral body compression. With higher energy, a centripetal displacement occurs, resulting in a burst fracture. In severe burst fractures, discs become fragmented and the posterior elements are disrupted. Radiographically, this mechanism can manifest as a widened interpedicular distance.

Flexion

This mechanism results in compression anteriorly. Disruption of posterior elements with flexion often results in instability of the involved area. If anterior compression exceeds 40–50 %, the posterior ligamentous structures are often disrupted. Instability ultimately can result in progressive deformity and neurologic deficit if not appropriately stabilized.

Lateral Compression

This mechanism usually results in a stable injury unless disruption of posterior structures or associated axial compression occurs.

Flexion-Rotation

With a flexion-rotation injury, posterior ligamentous structures commonly fail. Oblique disruption of the anterior vertebral body and disc failure occur. This type of injury can result in a "slice fracture." With fractures of the facets and concomitant disruption of posterior elements, thoracic spine dislocation can occur.

Shear

Shear injuries often result in severe ligamentous disruption and subsequent anterior, posterior, or lateral listhesis. Anterolisthesis is the most common of the 3, with complete spinal cord injury. However, occasionally, concomitant fractures through the pars interarticularis result in autolaminectomy, with resultant neural sparing.

Flexion Distraction

This injury is more commonly referred to as the seat belt injury. The axis of flexion is anterior to the vertebral column. Osseous, disc, and ligamentous structures are disrupted either alone or in combination. Combined osteoligamentous or purely ligamentous injuries can be present, and this injury occurs most commonly at the thoracolumbar junction. Bilateral facet dislocation can occur.

Extension

Tension is placed on the anterior longitudinal ligament, with compression occurring posteriorly. Facet, laminar, and spinous process fractures often occur. Most of these injuries are stable, provided that significant retrolisthesis does not occur.

Clinical Evaluation

Resuscitate the patient as per the ATLS protocol while maintaining spine immobilization.

Watch for neurogenic shock (hypotension and bradycardia).

An extensive physical examination should be performed, and neurologic status should be documented upon initial presentation.

Use a standardized scoring system (e.g., ASIA scoring system) to document neurology, and this should be repeated on a regular interval.

Thoracic and lumbar spine injury can be ruled out on clinical examination, in the alert and cooperative patient, based on the absence of pain or tenderness or distraction mechanism of injury and a normal neurological examination. Otherwise, imaging will be indicated.

Investigations

Radiographic evidence of a fracture at any level of the spine necessitates further radiographic analysis of the entire spine.

Anteroposterior (AP) and Lateral Radiographs

Used for initial assessment of injuries. Analysis of plain radiographs should proceed in an organized sequence, beginning with the alignment on both AP and lateral radiographs, with identification of the margins of the vertebral bodies, spinolaminar line, articular facet joints, interspinous distance, and the position of the transverse processes.

Oblique radiographs are useful in examining for pars interarticularis fractures and facet subluxation. Disruption of the posterior margin of the vertebral body line and widening of the interpedicular distance are important signs of vertebral disruption. Narrowing of a disc space usually accompanies a flexion injury and is seen at the level above the fractured vertebra. Widening of the facet joint or complete baring of the facets indicates a severe posterior ligamentous injury. These findings usually are associated with widening of the interspinous distance.

CT Scan

Provides information regarding the extent of injury to the osseous structures and the posterior elements. The scan should include one full vertebra above and one full vertebra below the level of the fracture, with 3- to 5-mm thickness. Both bone and soft tissue windows should be imaged and coronal and sagittal reconstructions obtained.

Fractures oriented in a horizontal plane, such as Chance fractures, may not be well visualized with axial CT scans. Coronal reconstructions facilitate the evaluation of complex spinal fractures. Three-dimensional reconstructions are useful to define the extent of canal compromise and posterior element fractures.

MRI

Useful in evaluating soft tissue injury to the ligaments, discs, and epidural spaces (Fig. 17.1). Most useful when traumatic disc herniation, epidural hematoma, or spinal cord injury is suspected.

Its disadvantage includes a need for special nonmagnetic mechanical ventilators and other life-support monitors. Some patients who are hemodynamically unstable may not be candidates for MRI scanning. In addition, patients with multiple traumatic injuries frequently pelvic fractures stabilized with external fixators, which may produce significant metallic artifact. MRI is contraindicated in patients with implanted pacemakers, dorsal column spinal cord stimulators, vagal nerve stimulators, or other metallic mechanical implants.

Urodynamic Studies

Patients with spinal fractures can develop urinary retention. Urodynamic testing provides valuable information for the evaluation and subsequent treatment of neurourological dysfunction.

Methods of objectively testing the behavior of the lower urinary tract during filling, storage, and micturition include uroflowmetry, cystometry, sphincteric electromyography, and combined studies.

Evoked Potentials

Somatosensory evoked potentials and nerve action potentials may be employed to both illustrate preoperative dysfunction and confirm postoperative improvement.

Classification

Holdsworth Two-Column Theory of Spinal Stability

The vertebra is divided into an anterior and posterior column. The anterior column consists of the vertebral body, intervertebral disc, anterior longitudinal ligament, and the posterior longitudinal ligament. The posterior column comprises the facets,

Fig. 17.1 MRI image showing anterior wedge compression fracture of T8 vertebra with cord damage (Courtesy of Shibu P. Krishnan, London, UK)

neural arch, and interspinous ligaments. Disruption of one or more columns implies instability of the involved segment.

Denis Three-Column Concept

The vertebra is divided into three columns: anterior, middle, and posterior. The anterior column comprises the anterior half of the vertebral body along with the anterior longitudinal ligament and the anterior portion of the annulus fibrosis. The middle column is made up of the posterior annulus fibrosus along with the posterior half of the vertebral body and the posterior longitudinal ligament. The posterior column consists of the posterior ligamentous complex and the posterior bony elements. When two of the three columns are disrupted, the fracture is considered unstable.

Denis Classification

Based on the three-column concept and the following three modes of failure:

1. Compression
2. Distraction
3. Rotation shear

Injuries divided into the following category types:

Minor spinal injuries

- Articular process fractures
- Transverse process fractures
- Spinous process fractures
- Pars interarticularis fractures

Major spinal injuries

- Compression fractures
- Burst fractures
- Fracture-dislocations
- Seat belt-type injuries

McAfee Classification

Based on three modes of failure of the middle column–axial compression, axial distraction, and translation within the transverse plane. This led to six injury patterns as follows:

1. Wedge compression fracture
2. Stable burst fracture

3. Unstable burst fracture
4. Chance fracture
5. Flexion-distraction injury
6. Translational injury

Wedge Compression Fractures

- Result from compressive failure of the anterior column due to an axial load applied in flexion.
- Fifty to seventy percent of all thoracolumbar spine fractures.
- Simple wedge compression fractures demonstrate anterior compression of the vertebral body without any disruption of the posterior cortex.
- Simple wedge fractures have less than 10 % compression with no neurologic impairment since the middle column remains intact.
- Simple wedge fractures are stable, since pure flexion injuries do not disrupt the middle column and an additional rotational force is necessary to cause an unstable fracture pattern. However, if there is severe compression (>50 %), kyphosis greater than 20°, multilevel compression fractures, or a rotational component to the injury, then the middle column may fail resulting in spinal instability.
- Integrity of the posterior cortex is the key feature that distinguishes the wedge compression fracture from an unstable burst fracture. CT scan should be performed when in doubt.

Burst Fractures

- Result from a compressive force causing a fracture of the endplate, pressure of the nucleus pulposus on the vertebral body, and bone fragments being retropulsed into the spinal canal.
- Those with posterior element involvement are at higher risk for neurologic deficits.
- All burst fractures should be considered unstable, since standard radiographs miss a significant number of posterior element fractures and neurologic deficits are seen in 42–58 % of these patients.
- On lateral radiographs, a burst fracture demonstrates a loss of anterior and posterior vertebral height.
- On the AP view, there may be widening of the interpedicular distance (greater than 1-mm difference between the vertebrae above and below).
- Since retropulsed bone fragments often occur at the level of the pedicles, burst fractures may be difficult to visualize by plain radiography. Unstable burst fractures are therefore often misdiagnosed as stable anterior wedge fractures.
- CT imaging is recommended if a burst fracture is suspected.

- No direct relationship exists between the percentage of canal compromise and the degree of neurological injury.

Chance Fractures

- Result primarily from a mechanism of distraction, although there may be a minor component of flexion.
- The axis of flexion is anterior to the nucleus pulposus and the anterior longitudinal ligament. If the distraction forces are great enough, both the middle and posterior columns may be disrupted.
- Usually seen with seat belt injuries.
- Best seen on a lateral radiograph, which demonstrates a horizontal disruption through the spinous process, laminae, transverse process, pedicles, and the vertebral body. The height of the vertebral body is increased, and the distance between the spinous processes above and below the injury may appear to be widened. The AP view may demonstrate an increased interspinous distance and a break in the transverse processes. Routine axial CT scans of the spine frequently miss these fractures, since the image cuts are parallel to the level of the injury. Thus, sagittal reconstruction of CT images is recommended if a Chance fracture is suspected.
- Commonly associated with intra-abdominal injuries, such as intestinal perforations, hematomas, and contusions.
- Neurologic deficits occur in less than 5 %.

Flexion-Distraction Injuries

- The forceful flexion component of the injury causes compressive failure of the anterior and middle columns and a tear in the posterior longitudinal ligament. Since both middle and posterior columns are disrupted, this fracture pattern is unstable.
- Pure ligamentous disruptions also occur and account for 10–25 % of flexion-distraction injuries.
- Also associated with seat belt injuries and intra-abdominal injuries.
- Radiographs show anterior impaction with compression fractures of the vertebral body and increased posterior interspinous spaces caused by distraction. The hallmark finding is an increased length of the vertebral segment as a result of a distractive force. Because there is no significant rotational or translational component, displacement is unusual.
- As with Chance fractures, flexion-distraction injuries are frequently missed on routine axial CT scans since the disruption is oriented in the horizontal plane. Therefore, obtain sagittal reconstructions of CT images if a flexion-distraction injury is suspected.

Translational Injuries

- Result in failure of all three columns from massive direct trauma to the back causing several injury patterns, including the "slice" fracture, rotational fracture-dislocations, shear injuries, and pure dislocations.
- Most common at thoracolumbar junction (T10–L2).
- Examination findings include tenderness at the fracture site, kyphosis, and a widening of the spinous processes at the level of the dislocation. Those with shear fractures in the lumbar region may present with large contusions in the lumbosacral area due to direct trauma. Patients with a complete vertebral dislocation usually have neurologic deficits.
- Those with paraplegia usually have a fracture-dislocation injury. Sixty to eighty percent of these injuries result in permanent neurologic deficits, and most patients also sustain serious trauma to other organ systems. Shear fractures and pure dislocations also result in severe neurologic sequelae, with complete paraplegia occurring in nearly all patients.
- On plain radiographs, the classic "slice" fracture is best seen on the lateral view and appears as the superior segment being anteriorly subluxed on the inferior segment with a slice through the upper portion of the vertebral body below it. The spinous processes will appear widened due to posterior ligament rupture. If there is also a rotational component, the alignment of the spinous processes will be distorted.
- Pure dislocations are generally not subtle and appear as a complete displacement of the superior vertebrae on the one below it.
- CT scan should be done to assess the fracture pattern and the extent of spinal canal compromise.

Spinal Instability

A spinal injury is considered unstable if normal physiological loads cause further neurological damage, chronic pain, and unacceptable deformity.
White and Panjabi first described the concept of spinal instability, which they defined as the inability of the spine to maintain the anatomical relationships between vertebrae necessary to prevent neurologic injury or compromise.

Treatment

Initial management of lumbar spine injury begins in the field. Any patient in whom a spinal injury is suspected should be placed on a board in a neutral supine position and immobilized in a neck collar for expeditious transportation to a trauma center.

In the emergency department, all patients should be treated as though they have a spinal injury until spinal injury can be ruled out. The Advanced Trauma Life Support (ATLS) guidelines of the American College of Surgeons should be followed.

Surgery Versus Nonoperative Management

The primary goals of treatment for thoracolumbar spine fractures include protecting the neural elements and preventing deformity and instability. In general, stable fracture patterns in a neurologically intact patient can be treated nonoperatively.

The ultimate decision to operate is based on many factors, including fracture morphology, presence of neurological deficit, potential for deformity, associated injuries, and patient-related factors and expectations.

The effect of kyphosis on long-term results is uncertain. Kyphosis greater than 30° may be associated with poorer long-term results and therefore is a relative indication for surgery. A compression of more than 40 % of the anterior vertebral wall or a kyphotic deformity of more than 25° is often associated with posterior ligamentous injury. If the kyphotic angulation is less than 25° and the anterior body compression is less than 40 % of the vertebral height, the injury can be treated nonoperatively.

The presence of other injuries also may affect the choice between operative and nonoperative treatment. The most predictable benefit of surgery is more rapid mobilization, which can be an important consideration in the patient who has experienced multiple traumatic injuries.

Timing of surgery is also an important issue in the treatment of thoracolumbar spine fractures. Progressive neurologic deficit in the presence of continued canal compromise is an accepted indication for immediate decompression and stabilization. Some studies suggest that patients with thoracic spine fractures treated within 72 h, irrespective of concomitant injuries, do much better physiologically postoperatively than those in whom stabilization is delayed. Early fixation results in less time in the intensive care unit, less ventilator support, decreased rate of pulmonary complications, and less overall time in the hospital.

The treatment of burst fractures of the thoracic spine and the thoracolumbar junction is an area of debate. In burst fractures, it is important to analyze the percentage of canal compromise, the degree of angulation, and the neurologic status of the patient. If the canal compromise is less than 40 %, the patient may require a TLSO brace worn for at least 3 months. Standing lateral radiographs should be obtained on a regular basis to document any interval increase in spinal deformity. If the canal compromise is more than 40 %, the kyphotic deformity is more than 25°, or the patient develops neurologic changes, surgical intervention may be required.

In general, most fracture-dislocation injuries require surgical treatment. If a patient with a fracture-dislocation has normal neurologic examination findings, the spine must be stabilized to prevent a spinal cord, cauda equina, or nerve root injury. When the patient has an incomplete spinal cord injury from a fracture-dislocation, the spinal canal should be decompressed and the spine stabilized to prevent neurologic deterioration. Stabilization of the spine in patients with a complete neurologic deficit from a fracture-dislocation may prevent progressive kyphotic deformation, allowing early mobilization and rehabilitation, thereby minimizing the hospital length of stay.

In general, decompressive surgery is not indicated for patients with complete deficit lasting more than 48 h and is advocated for patients with partial cord or cauda equina injuries.

Studies have failed to show a significant difference in results in patients without neurologic injury who undergo surgery as long as significant posterior column injury is not present. Significant remodeling of the spinal canal has been shown to occur within the first year in burst fractures treated nonoperatively. Residual kyphosis is also seen, but the degree of kyphosis present does not correlate with the patient's pain or functional abilities.

Additional studies have been performed that reveal similar or even more beneficial results with nonoperative versus operative treatment of thoracic spine fractures, both with and without neurologic deficit. No correlation has been shown between neurologic deficit and the extent of canal compromise or, more importantly, between the resolution of the deficit and surgical decompression. In addition, the risk of postoperative infection is eliminated with nonoperative treatment, which ranges from 7 to 15 % in various studies.

High-Dose Steroids for Patients with Spinal Cord Injury

Currently there is no level evidence to justify its use although it is used in some centers.

Nonoperative Treatment

Use of the 3-column rule can be helpful in determining brace types. Single-column injuries, such as compression fractures involving only the anterior column, are generally stable injuries and can be treated with a simple extension orthosis to limit flexion. Isolated posterior element fractures are usually stable, and conservative treatment with mobilization is appropriate for these injuries. Light bracing can be used with these injuries for comfort and to hasten mobilization.

More severe injuries with 2-column involvement require more rigid immobilization. Standard thoracolumbosacral orthoses (TLSO), such as the Boston brace, provide good immobilization but only of the lower thoracic spine. The usefulness of TLSO is limited to injuries from about T7 distally. Extension of the brace to the cervical spine (cervical thoracolumbosacral orthoses [CTLSO]) can allow for immobilization of upper thoracic segments; however, these braces are very poorly tolerated by patients. Upper thoracic spine injuries are more difficult to treat with bracing, and if nonoperative immobilization of the upper thoracic spine is chosen, a halo with extended vest generally should be used.

The patient is placed in a rigid orthosis with restriction of activities. After 3–4 months, flexion-extension radiographs should be obtained. If no motion is present

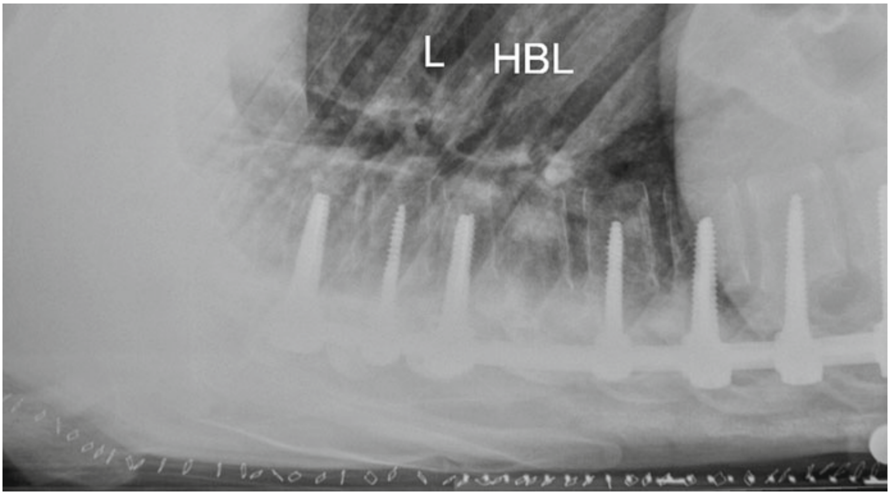

Fig. 17.2 Posterior instrumented fusion from T4 to T11 vertebrae for patient shown in Fig. 17.1 (Courtesy of Shibu P. Krishnan, London, UK)

and the deformity has not progressed, the patient can be weaned from the orthosis over several weeks and can start physiotherapy for muscle strengthening. If abnormal motion is present, the deformity has progressed, or severe pain persists, surgical stabilization may be required.

Surgical Treatment

Surgical approach is determined based on fracture morphology, associated ligamentous injuries, neurologic status, age and medical condition of the patient, and associated injuries. Patients with complete neurologic deficit who are no longer in spinal shock have very little chance of significant neurologic recovery. The primary goal of surgery in this group is realignment and stabilization, typically through a posterior approach.

The relationship between the timing of surgical decompression and neurologic outcome has been widely debated. Some evidence in the literature suggests that acute surgical therapy decreases the length of hospitalization and related costs, facilitating rehabilitation in many patients with spine injury.

When partial neurological deficit is present, improving residual canal compromise is also a goal of surgery. This situation most typically occurs with burst fractures. If performed early enough (generally within 72 h), posterior instrumentation allows for distraction and correction of sagittal alignment and successful indirect decompression of the spinal canal (Fig. 17.2). Laminectomy with transpedicular decompression also can improve the canal clearance achieved through a posterior approach.

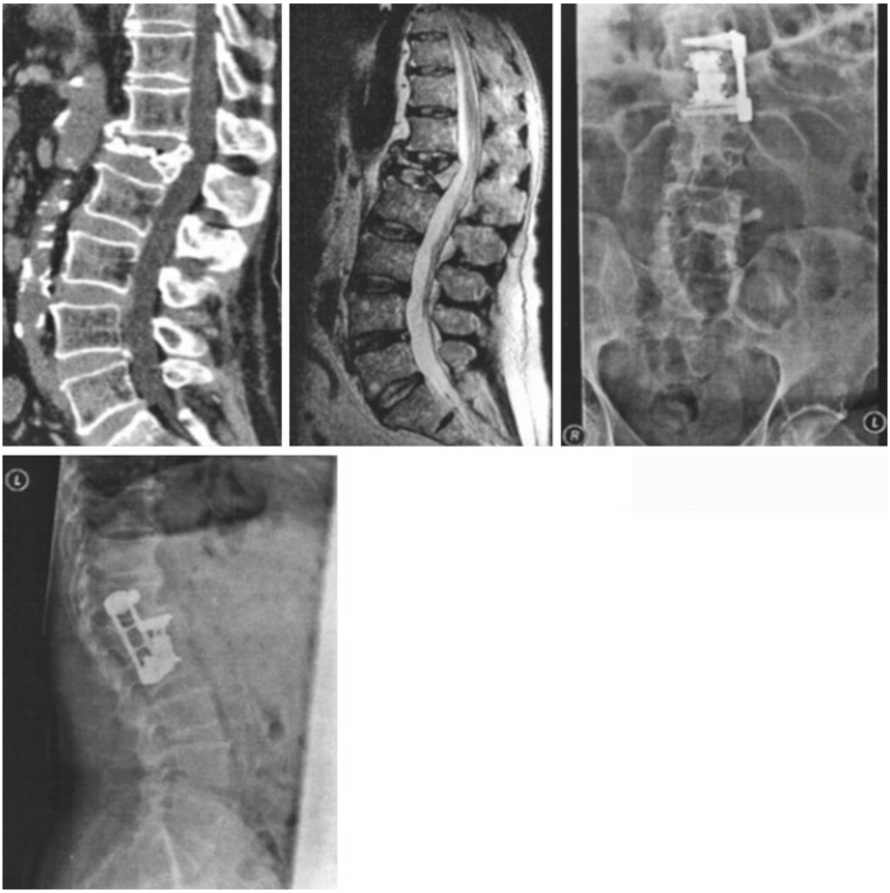

Fig. 17.3 Magnetic resonance imaging showing an unstable fracture of L1 with an internal gibbus, treated by internal fixation with correction of the internal gibbus (Courtesy of Dushyant H. Thakkar, London, UK. Reproduced with kind permission of Springer Verlag)

Another option is anterior decompression and fusion with instrumentation.

Surgeon preference often plays a role, as does fracture morphology (Fig. 17.3). Concomitant lamina fractures with posterior canal compromise generally necessitate beginning with a posterior approach due to possible neural entrapment and dural tears.

Flexion-distraction injuries result in disruption of the posterior and middle columns in tension. Very often, the anterior column remains intact, acting as a hinge. Surgical intervention for these fractures typically involves a posterior approach. Anterior approaches are not routinely used in these injuries, to preserve the intact anterior column.

Fracture-dislocation injuries result in disruption of all three columns and, as a result, carry a high incidence of complete spinal cord injury. Therefore, the main objective of surgical intervention is solely to provide posterior stabilization facilitating early mobilization and rehabilitation. Anterior decompression and stabilization is performed following posterior surgical realignment of the fracture in rare instances in which partial neurologic deficit exists in the presence of significant anterior neural compression.

Methods for Surgical Stabilization

Harrington Rods

Less popular technique since it involves several motion segments. It requires spanning two to three levels above and below the injured segment, thus creating a large moment arm conferring a high degree of stability to the construct.

They perform relatively poorly in 3-column injuries due to predisposition to over distraction and the relatively high incidence of rod breakage and hook cut out (7–10 %).

Hybrid Constructs

Consist of spinous process and sublaminar or Luque wires provide segmental fixation with improved results. A disadvantage of this mode of fixation is the risk of neurologic injury with sublaminar wire passage. Due to this potential complication, sublaminar wires are not routinely used in patients with incomplete neurologic injuries or normal neurologic status.

Pedicle Screw Fixation

This allows for rigid bony purchase through all three columns (Figs. 17.4 and 17.5). Because of this increased rigidity, often fewer segments are necessary for stable fixation, allowing the preservation of more motion segments. Fractured or absent laminae are not a contraindication for this fixation.

The osseous structures are fused concomitantly with posterior instrumentation. With modern segmental fixation, fewer segments need to be instrumented to provide stability, and generally, the entire instrumented region is fused.

Individual anatomic factors, such as the presence of lamina fractures, often dictate choice of anchors. In the thoracic spine, it is not uncommon for pedicles to be too small to allow screw placement. Depending on the injury, generally two to three segments of fixation above and below the level of injury are required if hooks alone are used. With pedicle screws, this often can be limited to one to two segments.

The condition of the anterior column also can affect instrumentation choices. If severe comminution or kyphosis is present anteriorly, extending the length of the posterior instrumentation or improving anterior support should be considered. This

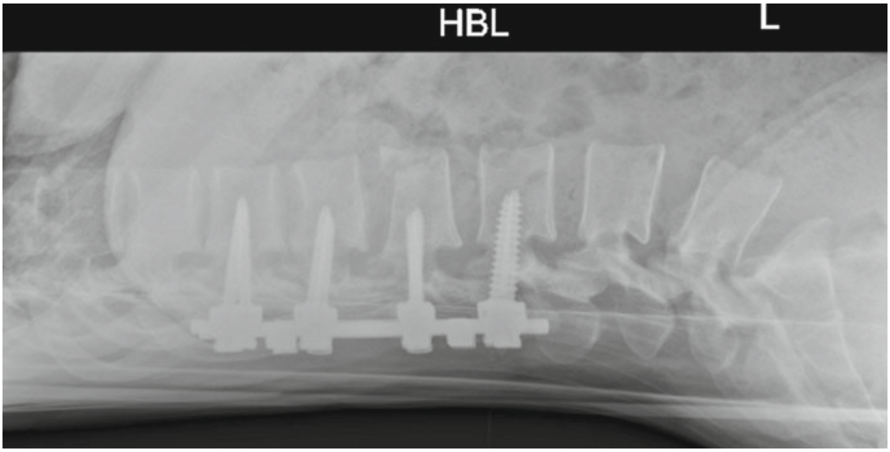

Fig. 17.4 Lateral and anteroposterior radiographs demonstrating the use of pedicle screws for posterior instrumented fusion (Courtesy of Shibu P. Krishnan, London, UK)

is often an issue with burst fractures, and anterior interbody fusion (concomitant or staged) may contribute to the stability of the fixation.

Use of anterior systems often requires reconstruction of the anterior column with strut grafting, cages, or both. Older anterior instrumentation required the concomitant use of posterior instrumentation due to the lack of stability. However, newer constructs provide enough structural stability to be used alone and have been shown to provide greater torsional stiffness than the intact spine. Biomechanical studies have shown that this type of fixation can be equal in strength to a 2-above and 2-below pedicle screw construct.

Reported fusion rates and clinical success with anterior interbody techniques are widely variable. Differences probably are related to surgical technique, source of donor bone, patient selection, and method by which determination of fusion was evaluated.

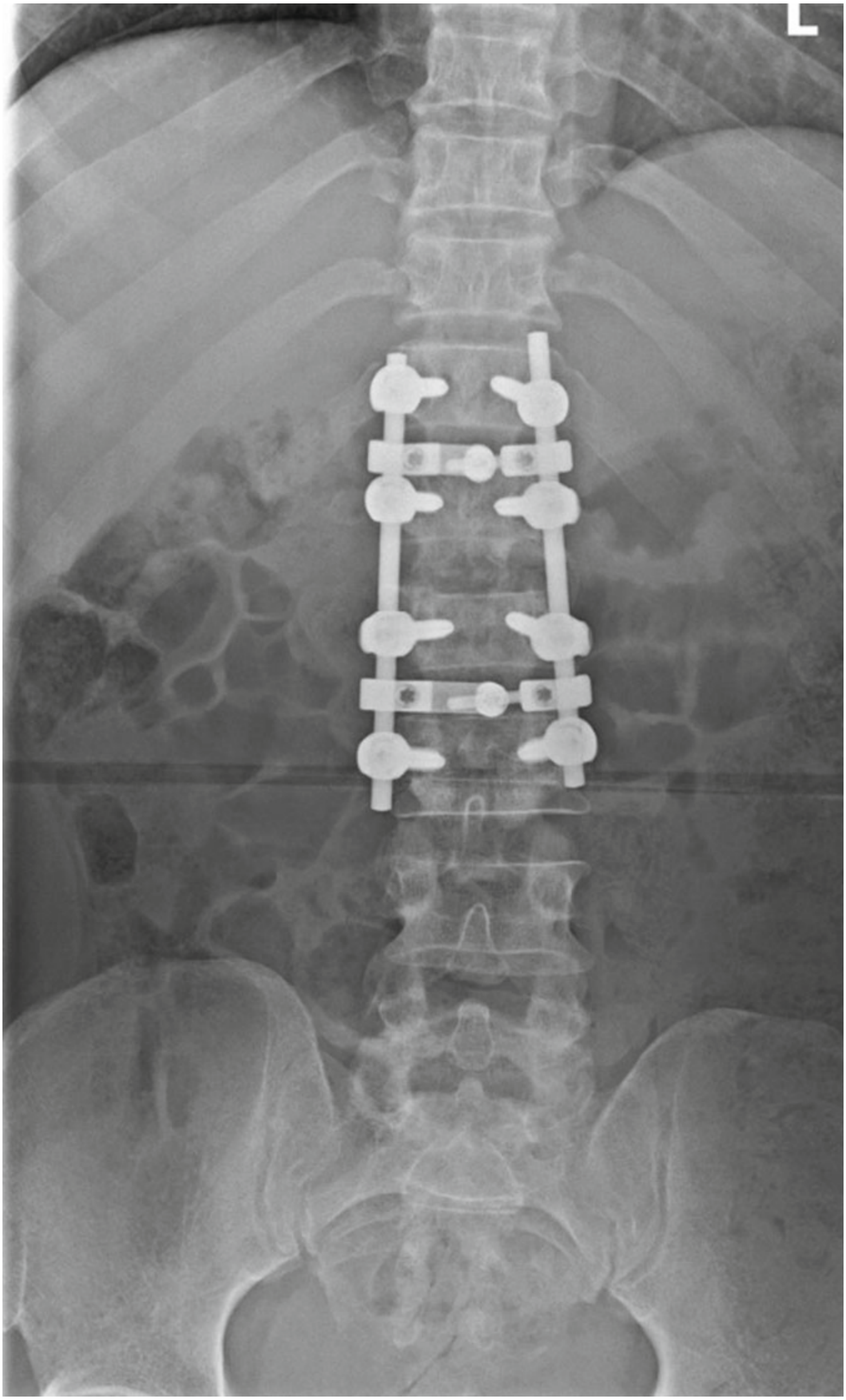

Fig. 17.5 AP radiographs showing anterior instrumentation systems (Courtesy of Shibu P. Krishnan, London, UK)

Chapter 18
The Sacrum and Coccyx

Shibu P. Krishnan

Sacral Fractures and Lumbosacral Dislocation (Fig. 18.1)

- One percent of all spinal fractures.
- Frequently associated with pelvic fractures and often are overlooked.
- Mechanism of injury: Indirect (more common) or direct trauma; motor vehicle accidents, falls, and gunshot injuries.
- Direct, severe, blunt trauma results in a comminuted sacral fracture. Sacral nerve root injuries are common in this injury.
- More than 90 % are associated with pelvic fractures. Twenty-five to fifty percent of these fractures have neurological deficit.
- Examine for sacral root dysfunction, suggested by decreased perianal sensation and rectal sphincter disturbance, decreased ankle jerk reflexes, and absence of a bulbocavernosus reflex.

Classification (Dennis)

Dennis's zones	Description of zone involved	Incidence of neurological deficit (%)
I	The region of ala	5.9
II	The region of sacral foramina (Fig. 18.2)	28
III	The region of the central sacral canal	87

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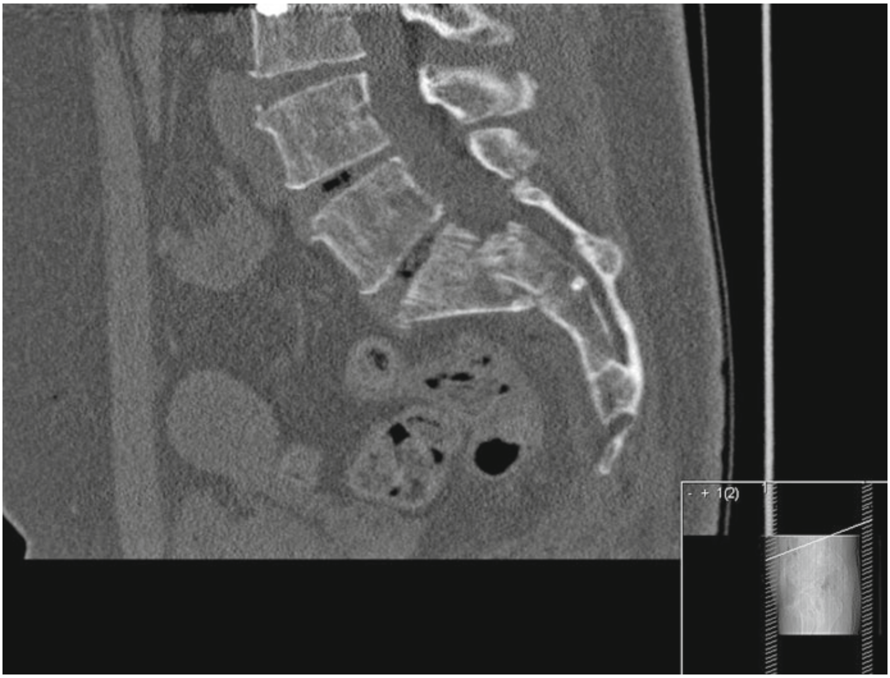


Fig. 18.1 Multilevel comminuted sacral fracture with impaction of S2 segment to the posterior aspect of S1 (Courtesy of Shibu P. Krishnan, London, UK)

Treatment

Non-operative treatment is the mainstay and includes bed rest for 8–12 weeks.

Surgery may be indicated for patients with associated unstable pelvic ring fractures, neurological injury, confirmed neural compression from fracture fragments, or sacral deformity and rarely chronic pain.

Sacral laminectomy allows exploration of the lower lumbar and upper sacral nerve roots. The prognosis for return of bowel and bladder function and sexual function is uncertain, and recovery depends on whether the deficits are from direct root compression, stretching, or laceration.

Coccydynia (Coccygodynia)

Definition

Pain in the region of coccyx.

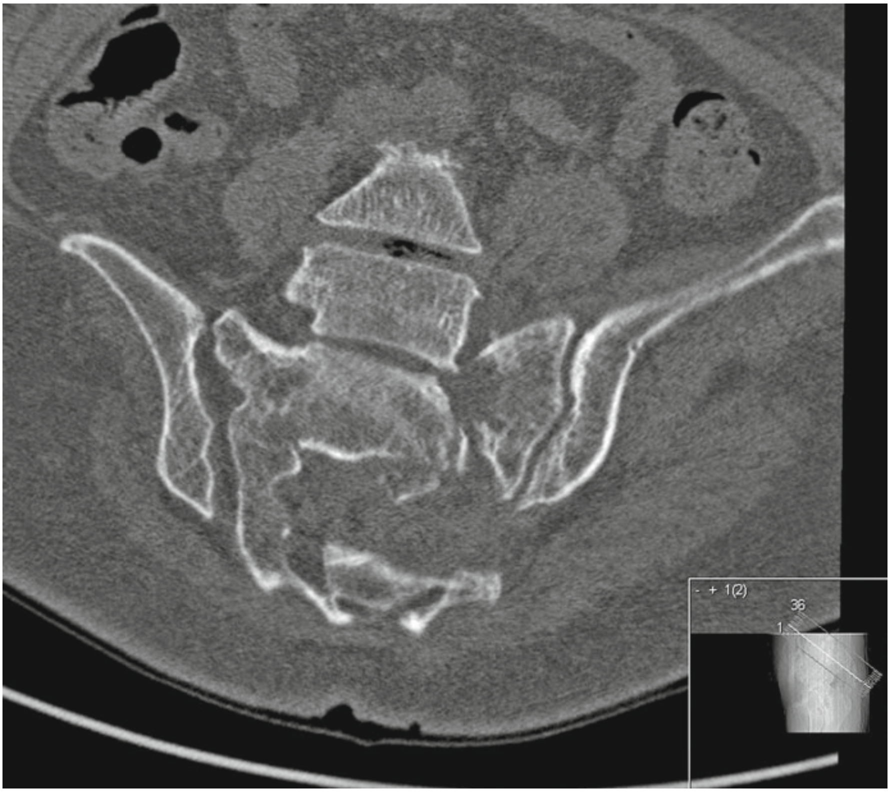


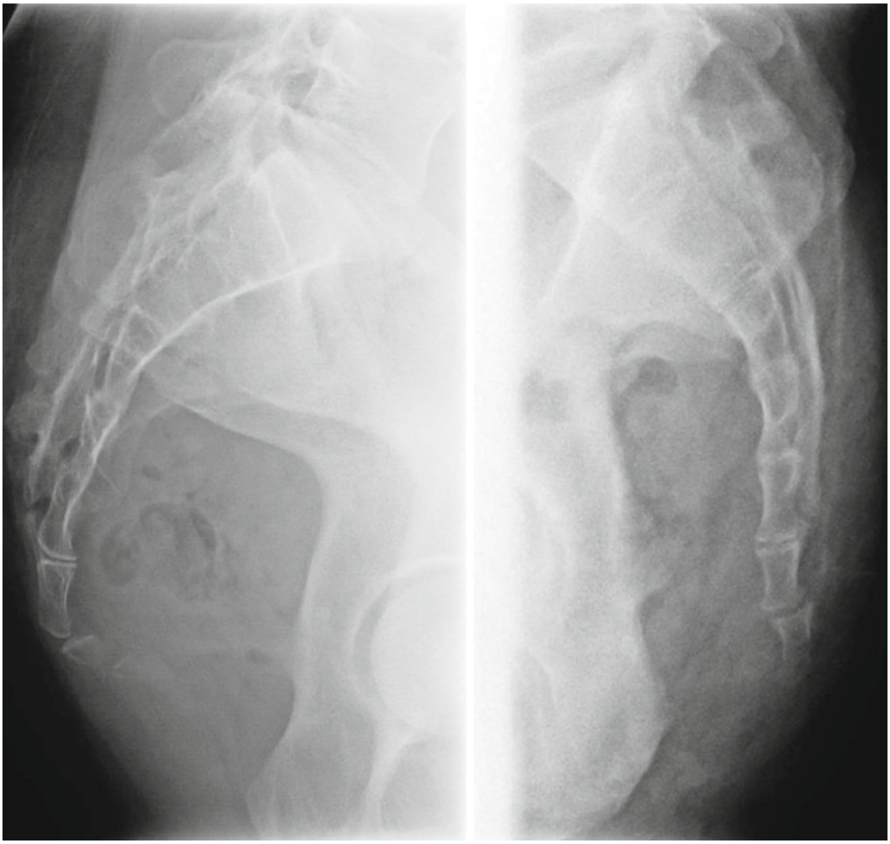
Fig. 18.2 Coronal CT slice showing Dennis type II sacral fracture (Courtesy of Shibu P. Krishnan, London, UK)

Incidence

Rare. Less than 1 % of all back pain conditions. Five times more common in women.

Anatomy

The coccyx is formed of four (3–5) rudimentary vertebrae. The borders of the coccyx are narrow and give attachment on either side to the sacrotuberous and sacrospinous ligaments, to the coccygeus in front of the ligaments, and to the gluteus maximus behind them. All these structures can be involved in sacrococcygeal dysfunction.



Figs. 18.3 and 18.4 Forward and backward subluxation of the coccyx (Courtesy of Dilip Malhotra, Bahrain)

Aetiology

1. Direct injury to the sacrococcygeal synchondrosis – most common (Figs. 18.3 and 18.4). The result is an injury to the sacrococcygeal junction that causes abnormal movement of the coccyx, especially when sitting pressure is applied to this region. Resulting pain can involve the levator ani muscle and the anococcygeal, sacrotuberal, and sacrospinal ligaments, as well as the gluteus maximus muscles.
2. Injury during childbirth. At the end of the third trimester, hormonal changes enable the synchondrosis between the sacrum and the coccyx to become more mobile. This increased mobility may result in stretching and a permanent change in the resting tension of the ligaments and muscles that surround and attach to the coccyx. Unlike fractures, which can remodel, injuries to this region can result in this synchondrosis being repeatedly forced out of its normal position, causing inflammation of the tissues surrounding the coccyx.

3. Idiopathic: One-third of cases.
4. Miscellaneous causes: Piriformis pain pudendal nerve injury or neuropathic pain secondary to repeated damage to nerves (e.g., in bike riders), pilonidal cyst formation, so-called Tarlov cysts or meningeal cysts, obesity (due to excess pressure on the coccyx when sitting), and a bursitis-like condition that can arise in slim patients who have little buttocks fat padding, allowing the tip of the coccyx to rub against the subcutaneous tissues, causing friction.

Clinical Findings

Direct palpation of the coccyx for tenderness
A rectal and pelvic examination to exclude other causes for pain

Treatment

Non-surgical: Donut pillow, NSAIDs and local steroid injection
Surgical: Coccygectomy – complete or partial
Indications for surgery:

Failure to respond to conservative management
Worsening symptoms in a well-screened patient

Chapter 19
Scoliosis

Shibu P. Krishnan

Definition

Any lateral curvature of the spine.

A triplanar deformity comprising lateral curvature with rotation and sagittal plane deformity (usually lordosis or hypokyphosis). A Cobb angle of at least 10° is essential for diagnosing scoliosis.

Types

1. Idiopathic
   - Infantile – below 3 years
   - Juvenile – 3–10 years
   - Adolescent – 10 years to skeletal maturity
2. Secondary
   - Congenital
   - Neuromuscular
   - Degenerative
   - Post-trauma/tumor/infection
   - Postural

Other subtypes:

- Right or Left: sidedness defined by the side of convexity of the curve, cervical, cervicothoracic, thoracic, thoracolumbar, and lumbar

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- Single vs. Compound: single has one-sided spinal deviation, whereas compound has both right and left spinal deviations
- Primary vs. Secondary (compensatory)
- Major vs. Minor: major curve denotes the greatest curve which is often accompanied by a minor curve, usually a compensatory curve(s) in the other direction above and below the major curve. Sometimes, the compensatory curve is as large as the major curve, in which case, this is called a double major curve.
- Non-structural vs. Structural: non-structural curve will be corrected with lateral bending toward the convex side. In structural scoliosis, the curve remains with side bending.

Evaluation

A. History

1. Chronological age.
2. Age at recognition of deformity: The longer the muscle imbalance, the more the distortion.
3. Impression of the rate of progression.
4. Associated symptoms: Pain, fatigue, and cardiopulmonary symptoms. History of night pain resolved with non-steroidals is suggestive of osteoid osteoma. Back pain in young children can be due to spondylosis or spondylolisthesis and disc herniation.
5. Developmental factors: Menarche status – peak growth velocity for 2 years around menarche. Highest rate of progression in this time. Progression usually halts or is much slower at skeletal maturity.
6. Genetic factors: Family history?

B. Physical examination

Side of convexity
Balanced? Is occiput over sacrum – drop plumb line
Flexible or fixed
Rib hump and chest wall asymmetry
Leg lengths
Neurology includes abdominal reflexes - syringomyelia
Neurocutaneous stigmata

C. Radiological evaluation

Standing PA radiograph taken from occiput to sacrum: In general, young patients with mild scoliosis can be safely monitored and radiographs done every 6–9 months. For faster progressive curves, do 3 monthly radiographs. In adolescents, a progression of 1°/month is normal, whereas a significant progression is 3–5°/month.

Radiographic imaging may not be needed in children with very mild curves detected on routine school screening examination (Fig. 19.1).

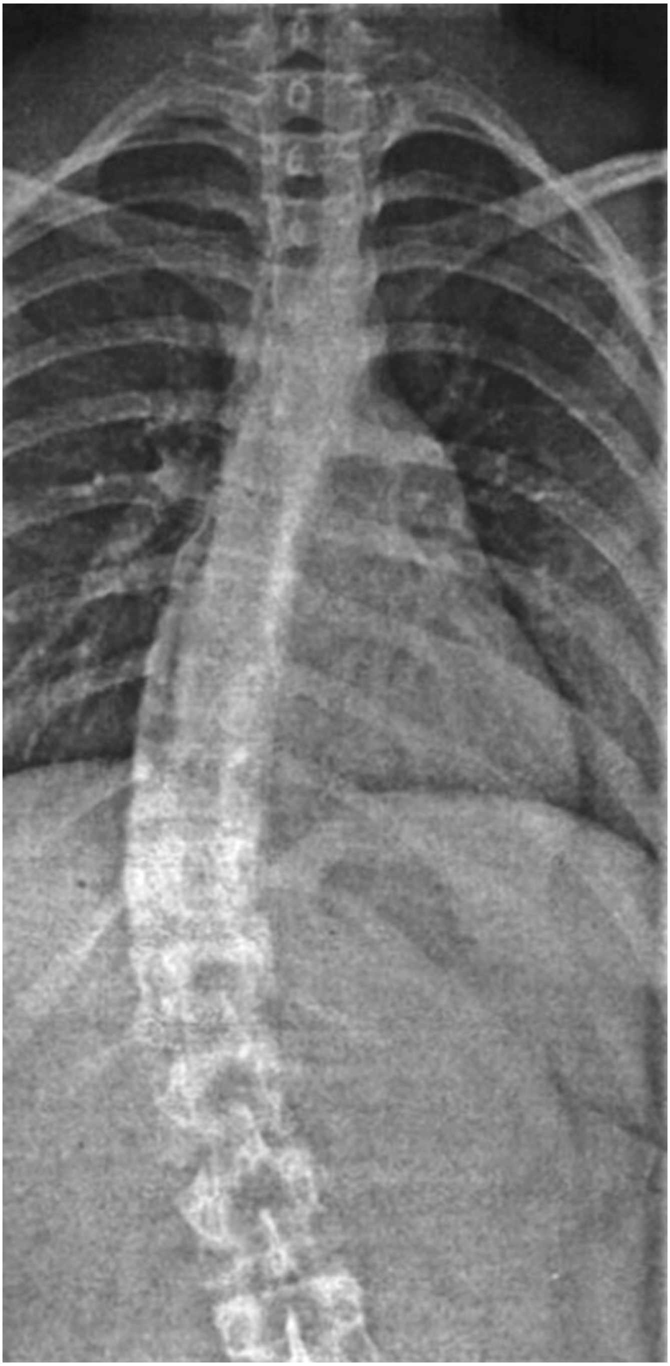


Fig. 19.1 Full-length weight-bearing anteroposterior radiograph of a 15-year-old girl during school screening (Courtesy of Dushyant H. Thakkar, London, UK. Reproduced with kind permission of Springer Verlag)

These children can be followed by physical examination with scoliometer. If there is a significant change over the previous 6 months or if there is a severe rib rotation, radiograph is then warranted.

Lateral radiograph: To assess for spondylolisthesis and spondylosis which can occur in 3,035 % of children with Scheuermann's disease (occurs in 5 % of idiopathic scoliosis which is the same as that of the general population).

Side bending radiographs: To determine the rigidity of scoliosis which is an important consideration for surgical planning. It will also help to delineate structural from non-structural scoliosis (non-structural curves will uncoil with bending to the convex side).

MRI: Not used routinely.

Indications:

Pre-op
Painful
Boys
Neurological abnormality, congenital, neuromuscular, etc.
Rapid progression
Left convex

Curve measurement:

Cobb method: This method relies on the accuracy of identifying the vertebra at the upper and lower end of the curve. These end vertebrae are those with maximal tilt toward the concave side. Horizontal lines are then drawn at the superior border of the superior end vertebrae and at the inferior border of the inferior end vertebrae. Perpendicular lines to these two horizontal lines will intersect. The angle formed is the Cobb angle, the degree of scoliosis.

Skeletal maturity:

Scoliosis progression slows significantly at skeletal maturity. It is therefore essential to know when skeletal growth is complete to plan treatment, follow-up frequency and cessation of therapy.

In general, girls mature at about 16 ½ years old and boys about age of 18. Reviewing the radiographs can reasonably predict skeletal maturity.

Risser stage: Ossification of the iliac crest starts laterally and meets with the SI junction as well as fuses with the ilium at full maturity. Once ossification starts in the apophysis, a prediction could be made that an average growth of 2 years remains for the patient:

Risser 0 – no apophysis visible
Risser 1 – 25 % of the apophysis ossified
Risser 2 – 50 % of the apophysis ossified
Risser 3 – 75 % of the apophysis ossified
Risser 4 – 100 % of the apophysis ossified
Risser 5 – completely fused, no apophysis visible

- Left hand and wrist films for comparison with Greulich and Pyle atlas.
- Growth plate of the vertebra forms a solid union at full maturation. At 6–8 years of age in girls (7–9 years old in boys), a calcific ring develops at the superior and inferior aspect of the vertebra. This ring gradually fuses with the vertebral body at the age of 14–15. Complete fusion occurs at age 21–25.

Idiopathic Scoliosis

Etiology

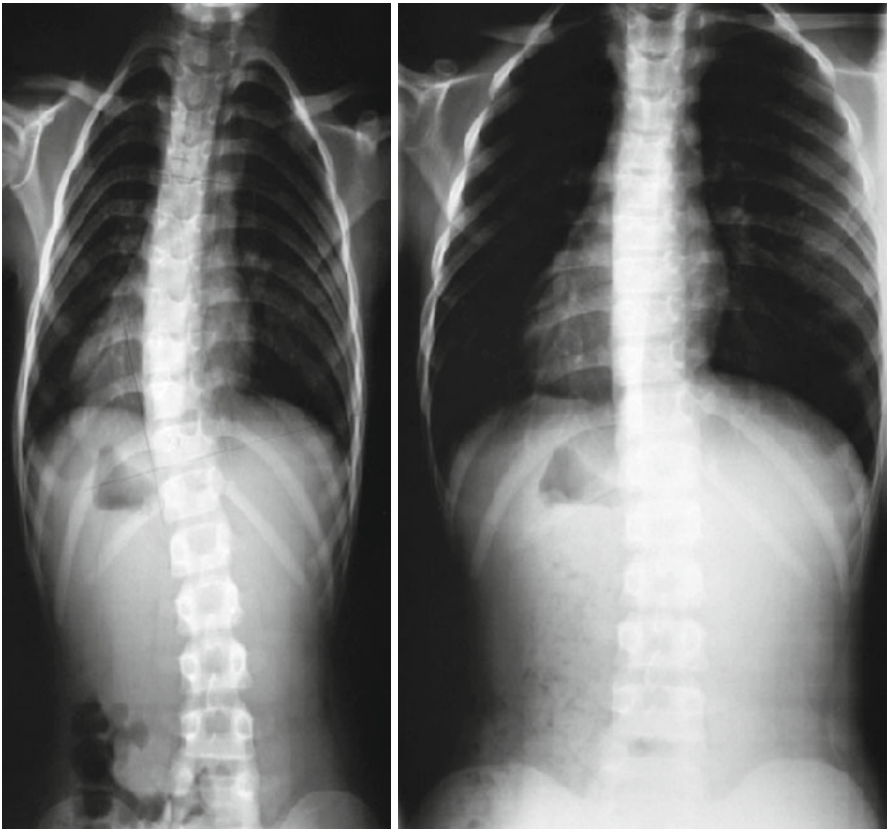
Still unknown. Many theories suggested
Multifactorial
Strong genetic predisposition
Abnormalities in platelet calmodulin levels suggested
Melatonin synthesis and metabolism implicated

Biomechanics

Overgrowth of anterior column leads to buckling and rotation of the vertebral column. Spinous process deviates into concavity.
Heuter-Volkmann law states that pressure on epiphysis retards growth whilst distraction increases growth (consider Blount's). This is thought to explain curve progression.
Characteristic deformities – lateral curvature, rotation, lordosis, and wedged vertebrae.

Infantile Idiopathic (Figs. 19.2 and 19.3)

More common in males
Convex to left
Not present at birth
Associated hip dysplasia and plagiocephaly
Must exclude – neuromuscular, congenital, myelodysplasia, and intradural pathology
Assess with plain radiographs – curve magnitude and pattern
MRI? Underlying abnormality



Figs. 19.2 and 19.3 Infantile idiopathic scoliosis (Courtesy of Magdi E. Greiss, Whitehaven, Cumbria, UK)

Rib-Vertebrae Angle Difference (RVAD)

This is measured by (1) drawing a line perpendicular to the middle of the upper or lower border of the apical vertebrae of the curve and then (2) measuring the angle this line makes with medial extension of another line drawn from the midpoint of the head to the midpoint of the neck of the rib, just medial to the beginning of the shaft of the rib. The difference between the right and the left side (the concave and the convex side) is the RVAD.

If >20° – high risk of progression.

Treatment

If Cobb angle <25°, RVAD <20° is observed. May resolve spontaneously.

If more than this – serial casting and bracing.

Surgery – for failed bracing or rapid progression.
Options – instrumentation without fusion preserves trunk growth and uses growing rods. Needs frequent re-operations. Fusion shortens trunk height and risks crankshaft phenomenon.

Juvenile Idiopathic

May represent missed/late presentation of infantile or early presentation of adolescent.
Seventy-percent will progress.

Adolescent Idiopathic

Scoliosis Research Society defines as curve more than 10° on AP standing radiograph.
Common, overall prevalence of 1.2–4.5 %
More common in girls
Typically right convex

Treatment

Depends on age and curve size.
Try to delay operation until approaching skeletal maturity if possible to lessen height loss and crankshaft (anterior column continues to grow and spine buckles and twists around posterior fusion mass):
Curves less than 25° – observe until maturity
Curves 25–40° – brace
Curves >40° or progression in brace – surgery

Bracing

Aims to prevent or slow progression of curve whilst allowing skeleton to mature
Will not correct curve
Entirely dose dependent, needs to be worn 23 h a day
Big commitment for patient

Surgery

Indications

Adolescents with curve more than 45°
Relentless curve progression
Major curve progression in spite of bracing
Inability to wean the patient from the brace
Significant thoracic and lumbar pain
Progressive loss of pulmonary function
Emotional or psychological inability to accept the brace
Severe cosmetic changes in the shoulder and trunk

Goals

To achieve solid fusion and to prevent further deformity
To stabilize the curve with a compensated trunk both in the frontal and sagittal planes
To correct the curves (though this is not as important)

Techniques

Anterior vs. posterior vs. combined surgery.
Anterior release traditionally favored for large stiff curves >75°. Newer segmental instrumentation may make this less frequently necessary. May be carried out thoracoscopically rather than through thoracotomy.
Surgical strategies involve pedicle screws, pedicle hooks, transverse process hooks and sublaminar wires.
Modern techniques allow for de-rotation and correction of rib hump without need for formal costoplasty.
Bone graft usually taken locally from spinous processes.

Intra-operative neurological problems monitored with spinal cord monitoring using somatosensory evoked potential (SSEP) monitoring. Can be supplemented with Stagnara wake up test.

If perioperative neurological loss:

- Ensure adequate blood pressure for cord perfusion.
- Check monitoring.
- Relax correction.
- Remove hardware.
- Natural history
  - Many patients will be unaware of their scoliosis even when curves exceed 30°.

– Progression is related to size of curve, area of spine involved, and physiologic age of child.
– Size of curve:

- Larger curves progress faster.
- Thoracic and double primary curves progress more than single lumbar or thoracolumbar curves.
- Physiologic age (based on menarche and Risser status):

Risser stage – 1: curves between 20 and 29° have >65 % risk of progression.
Risser grade 2–4: curves between 20 and 29° have >20 % risk of progression.

Congenital Scoliosis (Figs. 19.4 and 19.5)

Due to abnormal vertebral development
Present at birth
Mostly sporadic but may be associated with dysplasias (SED), Morquio's, etc.

Associations

- Genito-urinary 20 %
- Cardiac 10 %
- Dysraphism 20 %

Examination

Check for packing disorders – CTEV, DDH, and torticollis.
Neurological abnormality.
Evidence of myelodysplasia.
Will need cardiac echocardiogram and renal USS.

MRI later as will need general anesthesia – syrinx and Arnold-Chiari.

Classification (MacEwen)

1. Failure of formation

Partial failure of formation (wedge vertebra)
Complete failure of formation (hemivertebra) (Figs. 19.4, 19.5, and 19.6)

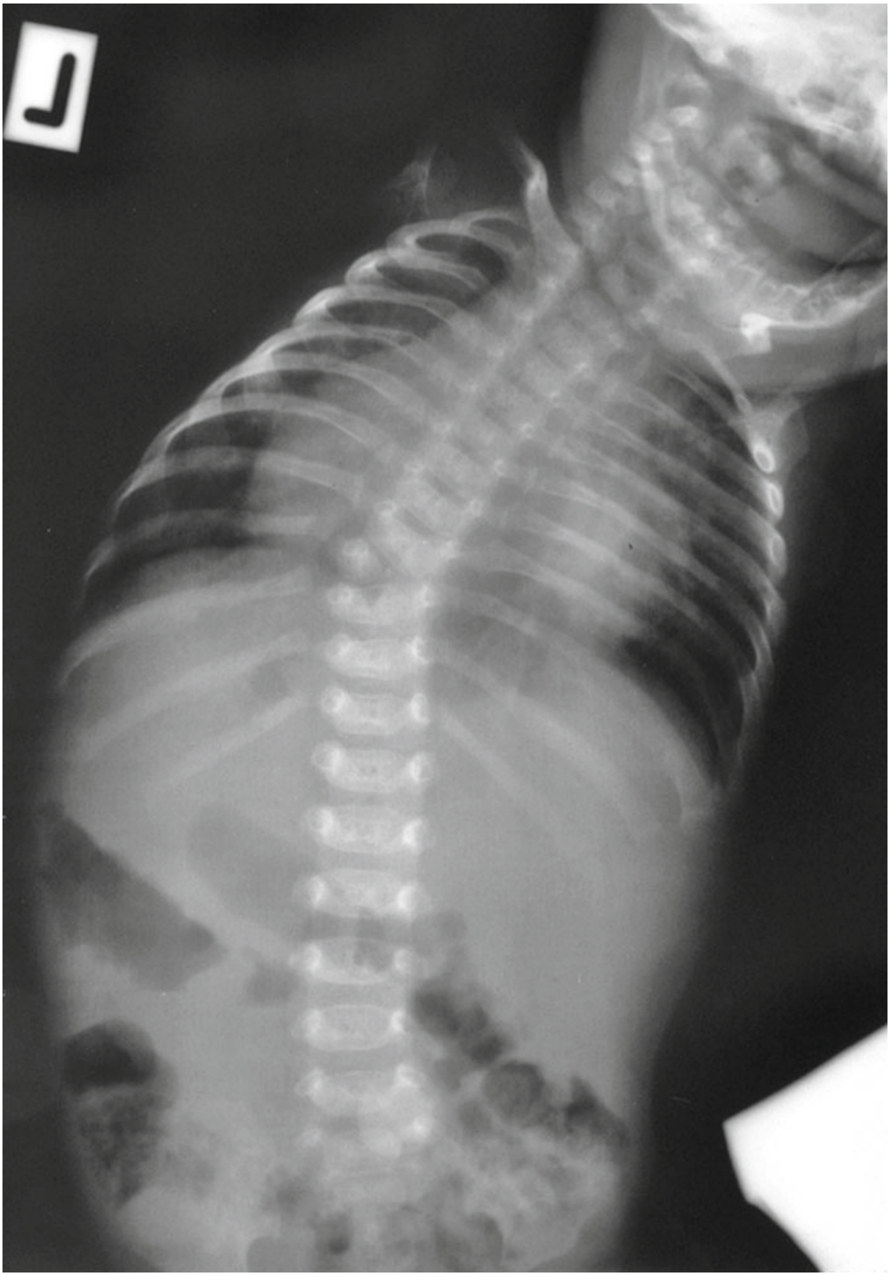
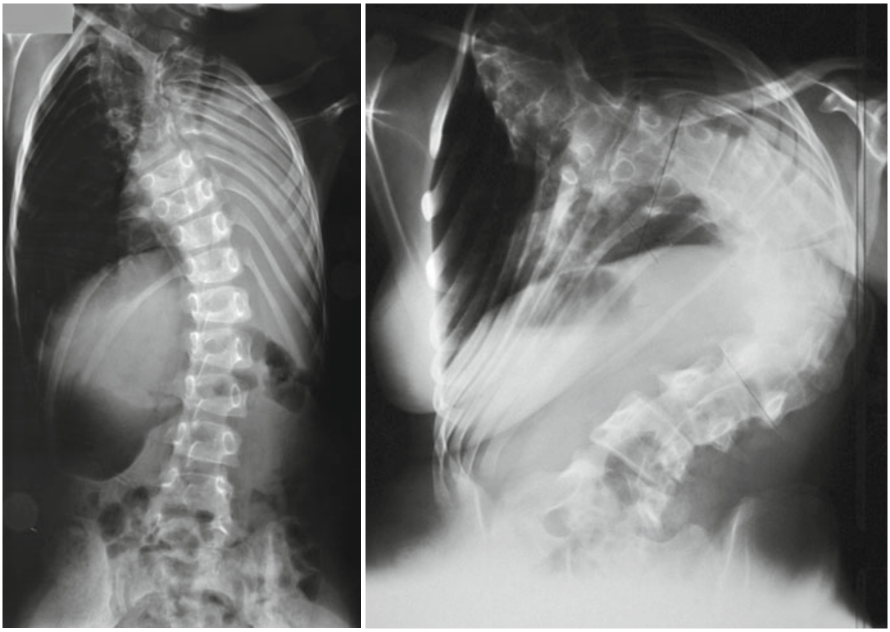


Fig. 19.4 Congenital hemivertebra (Courtesy of Magdi E. Greiss, Whitehaven, Cumbria, UK)



Figs. 19.5 and 19.6 Congenital scoliosis (Courtesy of Magdi E. Greiss, Whitehaven, Cumbria, UK)

2. Failure of segmentation

   Unilateral (unilateral unsegmented bar)
   Bilateral (block vertebra)

3. Mixed

   Elements of failure of formation and of failure of segmentation

Prognosis

Depends on:

1. Type of vertebral anomaly – Most severe scoliosis occurs in unilateral unsegmented bar with contralateral hemivertebrae at the same level. Next in severity is a scoliosis caused by a unilateral unsegmented bar alone, followed by two unilateral fully segmented hemivertebrae, a single fully segmented hemivertebra, and a wedge vertebra. The least severe scoliosis is caused by a block vertebra. Congenital scoliosis caused by unclassifiable anomalies can be difficult to predict and requires careful monitoring.

2. Site of the anomaly – The rate of deterioration of the resulting scoliosis is most severe in the thoracic and thoracolumbar regions (Fig. 19.7) and usually is less severe in the cervicothoracic and lumbar regions. On the other hand, a mild cervicothoracic curve may produce an unsightly appearance because of the head and neck tilt and the elevation of the shoulder line. Lumbar curves do not cause much cosmetic deformity unless decompensation or pelvic obliquity occurs.
3. Age of the patient at the time of diagnosis – Rapid progress occurs during the pre-adolescent growth spurt. Scoliosis presenting as a clinical deformity in the first few years of life has a particularly bad prognosis because this indicates a marked growth imbalance that will continue throughout the period of growth, resulting in severe deformity.
4. Balance and pattern of the curve – The more unbalanced the anomalies, the more likely the scoliosis is to progress.

Treatment

Frequently difficult to control with bracing/casts.
Surgical strategy aims for convex growth arrest, allowing concavity to grow and correct curve.
Hemivertebrectomy may be an option.

Neuromuscular Scoliosis

Spinal deformity secondary to abnormality of myoneuronal pathways.
Causes include cerebral palsy, myelodysplasia, polio, Duchenne's, syrinx, Marfan's, etc.
Characterized by early onset with rapid relentless progression.
Bracing may slow progression and delay surgical stabilization.
Typically will need early stabilization for even smaller curves than idiopathic scoliosis, e.g., Duchenne's stabilize at 25°.

Surgery – Special Considerations

Nutrition – consider pre-op PEG if low albumin. Poor wound healing, high infection rate and increased mortality.
Poor bone quality – anticonvulsants, small stature, and disuse.
Cardiac abnormality esp. Duchenne's and Friedrich's.
Respiratory compromise – Duchenne's, myotonic dystrophy, ventilator dependent, and sepsis.

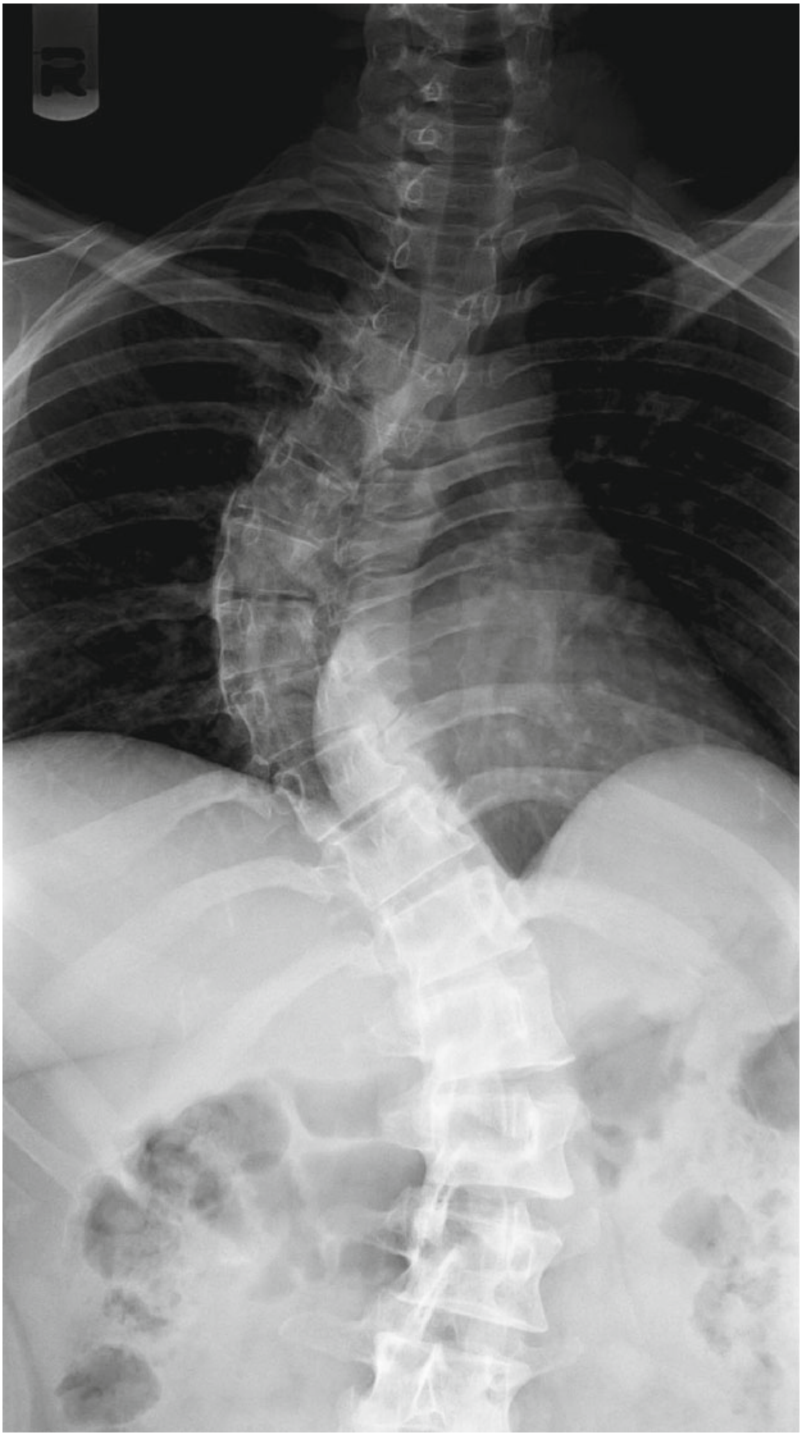


Fig. 19.7 Thoracolumbar scoliosis (Courtesy of Dilip Malhotra, Bahrain)

Aims of Surgery

Create a stable balanced spine over a stable balanced pelvis.
Long fixation.
Segmental fixation with multiple anchor point.
Higher likelihood of fusing to pelvis.

Characteristic Curve Patterns

Neurofibromatosis – short sharp curve
Cerebral palsy – long c-shaped curve and marked pelvic obliquity

Neurofibromatosis and Scoliosis

Autosomal dominant disorder characterized by formation of multiple neurofibromata
Central and peripheral forms

Typical spinal deformities:

- Short, sharp curve over few segments
- Widened vertebral foraminae
- Scalloped vertebrae
- Rib penciling, thin ribbon like ribs
- Dural ectasia (also seen in Marfan's)
- Cervical kyphosis

Postural Scoliosis

Non-structural mobile curve
Not associated with spinal abnormality
No rotational component

Scheuermann's Disease (Juvenile Kyphosis)

Most common cause of structural kyphosis of thoracic and thoracolumbar spine.
Most commonly seen in skeletally immature adolescents, usually males.

Eetiology is not known. Osteochondrosis of the secondary ossification centers of the vertebral bodies. There is usually a strong hereditary tendency (may be autosomal dominant).

Criteria for Diagnosis

- Thoracic kyphosis >450 (250–400 being normal)
- Wedging >50 of three adjacent vertebrae
- Thoracolumbar kyphosis >300 (thoracolumbar spine is normally straight)

Associated Conditions

- *Spondylolysis*: Scheurermann's disease causes increased lumbar lordosis which strains L5 pars interarticularis.
- *Scoliosis*: occurs in 25 %.

Differential Diagnosis

Postural round back (no wedging on x-rays), rickets, juvenile osteoporosis, neurofibromatosis, Morquio's and spondyloepiphyseal dysplasia tarda.

Prognosis

If residual kyphosis remains less than 60° at skeletal maturity, the patient has an excellent prognosis for minimal problems in adult life.

Pain may be present but generally ceases when growth is complete. Early development of marginal osteophytes may occur. Acute myelopathy secondary to cord compression at the apex of the thoracic kyphosis has been reported.

Clinical Findings

Hyperkyphosis that does not reverse with hyperextension, tight hamstrings, poor posture, back pain located over apex of kyphosis, back pain involving lower lumbar spine when excessive lordosis is present, and associated neurological deficits are uncommon; thoracic Scheuermann's is not usually associated with pain whilst lumbar Scheuermann's is often symptomatic.

Non-operative Treatment

Pain usually subsides at the end of growth unless deformity is severe.

Young adolescents with kyphotic deformity of <50° and no evidence of progression may be observed.

Exercise and stretching of hamstrings and back may prevent excessive lordosis and hamstring contractures.

Bracing to correct thoracic kyphosis may be useful in patients with pain.

Curve of 50–70°: braces are worn for 1 year round the clock and then at night for 2 years; unlike scoliosis, bracing after skeletal maturity may be effective, and permanent correction can be obtained.

Milwaukee brace is required for thoracic curves; TLSO is required for curves below T-8.

Progressive curve >60–65°: Milwaukee brace is required even if patient has no pain; better prognosis for correction in skeletally immature patients who show good compliance in brace, expect correction of deformity at 1–2 years.

Operative Treatment

Indications

- Thoracic kyphosis >75° and persistent back pain that is unresponsive to non-operative treatment.
- Rigid kyphosis >55° requires anterior release with interbody fusion followed by posterior fusion with compression instrumentation.
- Neurologic deficits secondary to epidural cysts or increased kyphotic angulation – rare indication for cord decompression.

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