

# Orthopedic Rotation Introduction

## Curriculum and Course Objectives

### Course Objectives Overview

*Upon completion of this rotation, the student should be sufficient in the following*

- Take an orthopedic-focused history.
- Exhibit regional orthopedic physical examination skills.
- Interpret orthopedic radiographic examinations.
- Formulate a reasonable differential diagnosis.
- Create treatment plans for orthopedic conditions.
- Write pre- op notes and daily progress notes in Epic.
- Surgical skills and aseptic technique in the operating room (assisting, suturing, gowning, and gloving, etc.).
- Basic knowledge of splinting and casting both in the OR and in the office, and knowledge of their use/indications. Be prepared to assist in placement of cast/splint.
- Be able to recognize the appropriate limitations of a primary care physician in dealing with more complex or emergent orthopedic problems, where referral to an orthopedic specialist would be prudent, as well as show an understanding of surgical vs. non-surgical options.

### Curriculum

\*Objectives are listed as an example. Students are expected to know all topics related to cases that are experience as well as those that will be reviewed during daily education.

#### General

##### **Objectives:** Torn Medial Meniscus of the Knee

- Be able to define the symptoms of a torn medial meniscus.
- Be able to describe the pathology and anatomy of a torn medial meniscus.
- Be able to perform a physical exam of the knee including the drawer test, Lachman's test, lateral pivot/shift test and McMurray's maneuver.
- Be able to differentiate this diagnosis from patellar chondromalacia, recurrent patellar dislocation, and Osgood-Schlatter's.
- Be able to rule out additional ligament injury.
- Be able to prescribe a plan of treatment.

##### **Objective:** Painful ARC Syndrome of the Shoulder

- Be able to define the symptoms of painful arc syndrome.
- Be able to describe the pathology and anatomy of painful arc.
- Describe the anatomy of the rotator cuff.
- Be able to perform a physical exam of the shoulder, including shoulder impingement sign, shoulder apprehension test, and drop arm test.

- Be able to differentiate this diagnosis from bicipital tendonitis, frozen shoulder, and recurrent shoulder dislocation.
- Be able to prescribe a plan of treatment.

**Objective:** Colles Fracture of the distal radius

- Be able to define the symptoms of a Colles Fracture.
- Be able to describe the pathology and anatomy of a Colles fracture. Be familiar with the principles of metaphyseal fractures.
- Be able to perform a physical exam of a fractured wrist including an assessment of the neurovascular status in acute trauma.
- Be able to differentiate the diagnosis from a two-bone fracture of the forearm.
- Be able to describe some of the complications including malunions, carpal tunnel, and compartment syndrome.
- Be able to prescribe and defend a plan of treatment either using a cast, external fixation, or internal fixation.

**Objective:** Carpal Tunnel Syndrome

- Be able to define the symptoms of carpal tunnel syndrome.
- Be able to describe the pathology and anatomy of carpal tunnel.
- Be able to perform a physical exam of the hand, wrist, forearm, and elbow including Tinel's sign, Finkelstein's test, and Phalen's test.
- Be able to differentiate this diagnosis from frictional ulnar neuropathy, cervical radiculopathy, arterial disease, and DeQuervain's tenosynovitis.
- Be able to prescribe a plan of conservative splint treatment as well as surgical treatment.

**Objective:** Tendon Lacerations of the Hand

- Be able to discuss the difference in anatomy between flexor and extensor tendons.
- Know the importance of the location of the laceration.
- Be able to prescribe initial treatment and know the importance of infections in the hand.

**Objective:** Fracture of the Hip

- Be able to define the symptoms of a hip fracture.
- Be able to describe the pathology and the anatomy of the femoral neck as well as a peritrochanteric fracture.
- Be able to perform a physical exam of a fractured hip including the significance of shortening and malrotation.
- Be able to differentiate a femoral neck fracture from an intertrochanteric hip fracture.
- Be able to prescribe and defend a plan of treatment for either hip pinning or prosthetic hip replacement.

**Objective:** Sprain/ Fracture of the Ankle

- Be able to define the symptoms of a sprain or a fracture.
- Be able to describe the pathology and anatomy of an ankle sprain, a malleolar fracture, or a combination of the two.
- Be able to perform a physical exam of the ankle and foot including a stress test of the ankle ligament.

- Be able to differentiate the diagnosis from a grade one and grade three ankle sprain, as well as a fractured lateral or medial malleolus.
- Be able to prescribe a plan of treatment, including the basic skills of a short leg cast application as well as the indications or the need for surgery.

**Objective:** Acute Herniated Lumbar Disc

- Be able to define the symptoms of an acute lumbar disc herniation.
- Be able to describe the pathology and anatomy of an acute disc herniation
- Be able to perform a physical exam of the back including Babinski maneuver, Patrick FABER test, neurologic signs of L1-S1 radiculopathies.
- Be able to differentiate this diagnosis from spinal stenosis, spondylolisthesis, lumbar facet syndrome, and osteopathic somatic dysfunction.
- Be able to prescribe a plan of treatment including the application of osteopathic principles.
- Differentiate between neurogenic and vascular classification.

**Objective:** Pediatric Supracondylar Elbow Fracture

- Be able to describe the fracture and its relation to the growth plate. Differentiate from a lateral condylar fracture.
- Describe the classification.
- Be aware of the possible complications.
- Discuss how children's fractures differ in general from adults.

**Objective:** Developmental Dislocation of the Hip

- Be able to describe the pathophysiology
- Be able to perform Ortolani's and Barlow's tests.
- Be familiar with other pediatric problems of clubfoot and torticollis.
- Know the principles of initial treatment.

**Splinting and Casting**

Reading: *Appendix C*

**Objective: Splinting and Casting**

- Indications for splinting and casting
- Materials
- Techniques
- Complications

**General Principles of Internal Fixation**

Reading: *Appendix D*

**Trauma**

Reading: *Appendix E*

**Objective:** Severe Multiple Trauma Patient

- Discuss the differences of shaft fractures.
- Be able to do a proper exam of the injured extremity(s) including neurovascular status and open injuries. Consider the case of the comatose patient.
- Classification for open fractures

- Be able to describe the initial approach to treatment with consideration to treatment of complications and overall rehabilitation.

**Objective: Osteosarcoma**

- Be able to discuss the difference between malignant and benign tumors of the bone.
- Differentiate this from an osteochondroma, multiple myeloma, and metastatic disease.
- How does the age of occurrence vary?
- Differentiate this from osteomyelitis.
- Be able to define the symptoms of a malignant/non-malignant bone tumor.
- Be able to discuss treatment options. Surgery, chemo-radiation.

**Objective: Benign Bone Tumors**

- Osteoid Osteoma
- Osteoblastoma
- Osteochondroma
- Enchondroma•••
- Giant Cell Tumor

**Objective: Malignant Bone Tumors**

- Osteosarcoma
- Chondrosarcoma
- Ewing's Tumor
- Multiple Myeloma
- Metastatic Tumors

# Expectations

- Attendance at Monday morning Fracture conference: 6:30AM in the third floor residents' lounge.
- Attendance at daily orthopedic learning: 6:30am at the third floor residents' lounge. Various readings will be assigned daily and will be available for the month in advance. Have reading complete and be prepared to discuss.
- Before attending a surgery, round on the patient with the resident at 6:00AM, and write a pre-op note (or assist/observe while the resident writes his/her pre-op note). You are expected to know why the patient is having surgery and have a good idea of the diagnosis and what has been tried and failed to get them to this point.
- If you have participated in a surgery and the patient has been admitted, round and write a note before the 6:30 am meeting every morning until the patient is discharged.
- Be punctual.
- Attend organized hospital educational opportunities (calendar of grand rounds tacked outside conference room next door to doctors' dining room).
- Look good. In the office this means nice business casual clothing with a white coat.
- Be personable to patients and others.
- Participation in the orthopedic ambulatory care experience in the office setting by assisting in:
  - Systematic collection of historical data.
  - Methodical physical examination.
  - Order the appropriate testing and imaging.
  - Formulation of a working diagnosis.
  - Development of a treatment plan.
  - Charting the decision making process.
- Participation in the operating room as an operative assistant on major and minor procedures.
- Attendance at orthopedic emergencies in the emergency room and assisting in:
  - History taking and physical exam.
  - Patient work-up/ decision making.
  - Review of lab and X-ray data.
  - Traction or splint or cast application or wound treatment, etc.
  - Development of a treatment and follow-up plan.
  - Charting of the decision making process.
- In the OR, ask the resident or myself if it is appropriate for you to scrub in. Small cases are probably better if you do not scrub as you will have a better view over my shoulder.
- Make a list of what you see in surgery and in the office. Look these things up. This is how you learn.

# Resources

## **Books** (\*available for check out in third floor lounge)

Orthopedic Secrets\*  
Hand Book of Fractures 4<sup>th</sup> ed  
Netters Concise Orthopaedic Anatomy, 2<sup>nd</sup> ed  
Miller Orthopedic Review  
Essentials of Musculoskeletal Medicine\*  
Essentials of Musculoskeletal Imaging\*

## **Manuals**

Fracture Evaluation (Appendix B)  
Casting and Splints (Appendix C)  
General Principles of Internal Fixation (Appendix D)  
Trauma (Appendix E)  
Bone Tumors (Appendix F)

## **Free Online**

Orthobullets, <http://www.orthobullets.com/>  
<http://www.learningradiology.com/>  
Clinical key, <https://www.clinicalkey.com/>  
Wheeless Orthopedic Textbook: <http://www.wheelessonline.com/>  
MD Consult: <http://www.mdconsult.com>  
UpToDate, available at MetroHealth Hospital  
[www.orthosupersite.com](http://www.orthosupersite.com)

**Library** – 1<sup>st</sup> floor of Metro Health. Available 24 hours/day with Metro badge.  
Many of the above resources are available in the Library in hard copy format

## **Journals**

American Journal of Orthopedics: <http://www.amjorthopedics.com/>  
Journal of the American Academy of Orthopedic Surgeons: <http://www.jaaos.org/>  
American Academy of Orthopedic Surgeons: <http://www.aaos.org/>

## **Sign up for these resources:**

Orthopedics Today, Orthopedics, AAOS Membership, MOS, AOA, AOA, Synthes Resident Resources, Smith & nephew Resources, Biomet, Stryker, Arthrex, Mitek, Wright Medical, Zimmer, Depuy

# Appendix A

To be completed at the end of rotation

	1	2	3	4	5	N/A
Take and orthopedic-focused history.						
Exhibit regional orthopedic physical examination skills.						
Interpret orthopedic radiographic examinations.						
Formulate a reasonable differential diagnosis.						
Create treatment plans for orthopedic conditions.						
Write pre- op notes and daily progress notes in Epic.						
Surgical skills and aseptic technique in the operating room (assisting, suturing, gowning, and gloving, etc.).						
Basic knowledge of splinting and casting both in the OR and in the office, and knowledge of their use/indications. Be prepared to assist in placement of cast/splint.						
Be able to recognize the appropriate limitations of a primary care physician in dealing with more complex or emergent orthopedic problems, where referral to an orthopedic specialist would be prudent, as well as show an understanding of surgical vs. non-surgical options.						

**1: Uncomfortable performing**

**2: Hesitant to perform, Not confident in skills**

**3: Competent, Average**

**4: Comfortable Performing, Solid knowledge base**

**5: Expert**

**N/A: did not get the opportunity to perform**

	Strongly Agree	Agree	Disagree	Strongly Disagree
I was assigned an appropriate level of responsibility in managing patients.				
Effective role models were available at the rotation site.				
I received effective on-site instruction regarding clinical medicine and problem solving.				
The rotation site has adequate learning resources and facilities.				
I feel that I was an important part of the health care team.				
The rotation site provided excellent learning opportunities.				
The preceptor effectively helped me improve my clinical skills and knowledge.				
The preceptor provided useful and timely feedback regarding my work and learning.				
The preceptor treated me fairly and with respect.				

Please describe the main strengths and weaknesses of this rotation:

How could this rotation be improved?

# Appendix B

Print friendly – fits in pocket

## FRACTURE EVALUATION

1. Open/Closed?
2. Neuro-Vasc. intact? Is there: Skin blanching?, Pain at rest?, Degree of swelling: (Mild, moderate, severe, tense). Pulses, color, capillary refill? Is sensory & motor function intact distally?
3. Type of study, views, bone(s) and/or joint(s) involved.
4. Skeletal maturity / Bone quality  
*Note: For multiple fractures, choose the most displaced or whichever involves the joint to describe first.*
5. General fx pattern:
  - Simple / comminuted / severely comminuted.
  - Transverse, short/long oblique, butterfly, spiral.
  - Salter-Harris classification for epiphyseal fxs.
  - Vertebral: Compression, burst.
6. Part of bone broken:
  - Diaphysis, Metaphysis, Epiphysis.
  - Thirds, Jct. of thirds, proximal/distal.
  - Vertebra: Columns or processes
7. Is there extension into an adjacent joint or joint dislocation? If yes, describe the joint space and the articular surface:
  - How does the fx. Involve the joint? (# of joint pieces and location.)
  - Displacement (Direction of fragments as a % or in mm).
  - Step off (Axial loss of height in mm.)
8. Degree of angulation and its direction.
  - For long bones describe the direction of the apex.
  - For smaller fragments, describe the direction that the distal fragment is angulated relative to the proximal fragment.
9. Estimate % and direction of fx displacement. If 100% (AKA bayonet apposition), note amount of shortening in cm.
10. One jt. above & below OK?
11. NPO since?

# **APPENDIX C: SPLINTING AND CASTING**

## SPLINTING AND CASTING

### **INDICATIONS:**

Temporary immobilization to improve pain and discomfort, decrease blood loss, reduce the risk for fat emboli and minimize the potential for further neurovascular injury associated with:

- Fractures
- Sprains
- Reduced dislocations
- Tendon lacerations
- Deep lacerations across joints
- Painful joints associated with inflammatory disorders

### **MATERIALS:**

- Plaster Rolls or sheets - Strips or rolls of various width made from crinoline-type material impregnated with plaster which crystallizes or “sets” when water is added
- Prefabricated Splint Rolls (Ortho-Glass)- Layers of fiberglass between polypropylene padding
- Stockinette
- Cast padding
- Elastic bandages
- Adhesive tape
- Heavy scissors
- Bucket
- Protective sheets or pads to protect patient clothing
- Gloves

### **PATIENT EDUCATION:**

- Instructions should be both verbal and written
- Explain and demonstrate the importance of *elevation* to minimize swelling and decrease pain
- Apply *ice* bags or cold packs (bags of frozen vegetables also work well) for at least 30 minutes at a time during the first 24-48 hours after injury to decrease swelling and pain
- *Avoid* getting the splint *wet* – some splints may be removable for bathing purposes, otherwise plastic bags may be placed over the splint to keep it dry while bathing
- Explain signs of infection and vascular compromise, instruct patient to seek help for any concerns
- Instruct patient to return for evaluation of damaged/broken or wet splint
- Discuss follow-up guidelines

### **PROCEDURE/TECHNIQUE:**

- Prepare the patient
  - Cover patient with sheet or gown to protect clothing
  - Inspect skin for wounds and soft tissue injuries
  - Clean, repair and dress wounds as usual prior to splint application
  - Apply stockinette to extremity to extend several cm beyond edges of plaster, so that it may be folded back over the edges of the splint after plaster is applied to create a smooth edge
  - Roll on two to three layers of cast padding evenly and smoothly (but not too tight) over the area to be splinted.
  - Extend the padding out beyond the planned area to be splinted so that it can be folded back with the stockinette over the edges of plaster to create smooth edges.

- Each turn of the webril/cast padding should overlap the previous by 25-50 % of its width.
- Place extra padding over bony prominences to decrease chance of creating pressure sores
- An alternative to circumferential stockinette and cast padding is to place 2-3 layers of padding directly over wet plaster, and then apply this webril-lined splint over the area to be immobilized and secure it with an elastic bandage
- Prepare the plaster splint material
  - Ideal length and width of plaster depends on body part to be immobilized in the splint
  - Estimate the length by laying the dry splint next to the area to be splinted
  - Be generous in estimating length, the ends can always be trimmed or folded back
  - Width should be slightly greater than the diameter of the limb to be immobilized
  - Cut or tear the splint material to the desired length
  - Choose thickness based on body part to be immobilized, patient body habitus, and desired strength of splint
    - Average of 8-12 layers
    - Less layers (8-10) for upper extremities
    - More layers (12-15) for lower extremities
    - More layers may be needed for large patients
  - Fill a bucket with cool water, deep enough to immerse the splint material into
    - Using cool water decreases the chances of thermal burns, but takes longer for the splint to dry
- Application of the splint
  - Submerge the dry splint material in the bucket of water until bubbling stops
  - Remove splint material and gently squeeze out the excess water until plaster is wet and sloppy
  - Smooth out the splint to remove any wrinkles and laminate all layers
  - Place the splint over the webril cast padding and smooth it onto the extremity
  - An assistant (or a cooperative and willing patient) may be required to hold the splint in place while you adjust the splint
  - Fold back the edges of the stockinette and cast padding over the ends of the splint
  - Secure the splint with an elastic bandage
  - Place the extremity in the desired position and mold the splint to the contour of the extremity using the palms of your hand. (Avoid using your fingers to mold in order to decrease indentations in the plaster which can lead to pressure sores)
  - Hold the splint in the desired position until it hardens
- Check and finish the splint
  - Check for vascular compromise
  - Check for discomfort or pressure points
  - Apply tape along the sides of the splint to prevent elastic bandages from rolling or slipping, (avoid circumferential tape to allow for swelling)
  - Provide sling or crutches as needed

## **COMPLICATIONS**

### **Compartment Syndrome**

- Usually less common in splints than with circumferential casts
- may occur associated with splints from constricting webril (cast padding) or elastic bandages that cause increased pressure within a closed space on an extremity
- increased pressure leads to inadequate tissue perfusion and loss of tissue (muscle, vascular and nerve) function within the compartment.

- Presenting signs and symptoms: (The “5 P’s” are pathognomonic for ischemia: pain, pallor, paresthesias, paralysis, and pulselessness, but seldom all occur simultaneously, and when they do – indicate a late finding associated with poor prognosis).
- pain in the extremity
- tenderness over the involved compartment
- significant pain with passive stretching of ischemic muscle tissue
- diminished distal pulses and sensation
- delayed capillary refill, and pale cool skin.

#### **Compartment Syndrome Prevention**

- avoid wrapping bandages too tightly or making circumferential splints
- elevate the extremity to decrease swelling
- apply topical cold packs
- no weight bearing
- early (24-48 hour) follow-up for high-risk injuries

#### **Compartment Syndrome Management**

- remove all constricting bandages and splint materials
- consider compartment pressure monitoring
- early consultation with orthopedist and/or vascular surgeon for possible fasciotomy

#### **Pressure Sores**

- Uncommon with short term splinting
- Can result from stockinette wrinkles, irregular wadding of padding, insufficient padding over bony prominences or indentions in plaster form using fingers to mold splint
- If suspected, remove the splint materials and check the skin carefully, care for wounds and revise the splint if necessary

#### **Heat Injury**

- can result from drying plaster which produces heat and may cause burns to underlying skin
- To reduce risk for thermal injury, use cool water to wet the splint material and keep splint thickness less than 12 sheets of plaster

#### **Infection**

- More common with open wounds, but may occur with intact skin
- Clean and debride wounds well prior to splint application
- Consider using a removable splint for periodic wound checks

#### **Joint Stiffness**

- Expected to some extent after any immobilization of a joint
- Avoid prolonged immobilization if possible

#### ***DOCUMENTATION FOR THE MEDICAL RECORD:***

- Note the indication for the splint
- Describe any wounds and their location under the splint
- Document the neurovascular exam findings
- Describe the type of splint applied, area immobilized, and materials used to make the splint
- Indicate what follow-up is planned for re-assessment of injury

#### ***ITEMS FOR EVALUATION OF STUDENT:***

- Understands indications for splint
- Knowledge of different materials needed for splinting
- Ability to apply a functional splint which adequately immobilizes the intended part
- Understands potential complications and their prevention and management
- Explains procedure to patient and answers questions
- Proper documentation in the medical record

# **Appendix D: Principles of Internal Fixation**

## **Principles of Internal Fixation**

Ronald Lakatos, MD, Assistant Professor, Department of Orthopedics, Ohio State University  
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Updated: Nov 6, 2009

# **History of Fracture Treatment**

Fractures have been treated with immobilization, traction, amputation, and internal fixation throughout history. Immobilization by casting, bracing, or splinting a joint above and below the fracture was used for most long bone fractures, with the exception of the femur, for which traction was the mainstay of treatment. In the past, open fractures and ballistic wounds with long bone fractures were not amenable to standard fracture care because of the associated soft tissue injury and the difficulty in preventing sepsis; thus, they usually resulted in amputation, especially during the US Civil War.

Although the concept of internal fixation dates back to the mid 1800s, Lister introduced open reduction, internal fixation (ORIF) of patella fractures in the 1860s. Use of plates, screws, and wires was first documented in the 1880s and 1890s. Early surgical fixation initially was complicated by many obstacles, such as infection, poorly conceived implants and techniques, metal allergy, and a limited understanding of the biology and mechanics of fracture healing. During the 1950s, Danis and Muller began to define the principles and techniques of internal fixation. Over the past 40 years, advancements in biological and mechanical science have led to contemporary fixation theories and techniques.

# **Fracture Repair Biology**

Disruption of the endosteal and periosteal blood supply occurs with the initial trauma, and maintaining adequate blood supply to the fracture site is essential for healing. Hunter described the 4 classic stages of natural bone repair: inflammation, soft callus, hard callus, and remodeling. The inflammation stage begins soon after injury and appears clinically as swelling, pain, erythema, and heat. Disrupted local vascular supply at the injured site creates a hematoma and prompts the migration of inflammatory cells, which stimulate angiogenesis and cell proliferation. After the initial inflammatory phase, the soft callus stage begins with an infiltration of fibrous tissue and chondroblasts surrounding the fracture site. The replacement of hematoma by this structural network adds stability to the fracture site.

Soft callus is then converted into rigid bone, the hard callus stage, by enchondral ossification and intramembranous bone formation. Once the fracture has united, the process of remodeling begins. Fibrous bone is eventually replaced by lamellar bone. Although this process has been called secondary bone union or indirect fracture repair, it is the natural and expected way fractures heal. Fractures with less than an anatomic reduction and less rigid fixation (ie, those with large gaps and low strain via external fixator, casting, and intramedullary [IM] nailing) heal with callous formation or secondary healing with progression through several different tissue types and eventual remodeling.

Anatomic reduction and absolute stabilization of a fracture by internal fixation alter the biology of fracture healing by diminishing strain (elongation force) on the healing tissue at the fracture site. Absolute stability with no fracture gap (eg, via ORIF using interfragmental compression and plating)

presents a low strain and results in primary healing (cutting cone) without the production of callus. In this model, cutter heads of the osteons reach the fracture and cross it where bone-to-bone contact exists. This produces union by interdigitation of these newly formed osteons bridging the gap. The small gaps between fragments fill with membranous bone, which remodels into cortical bone as long as the strain applied to these tissues does not cause excessive disruption and fibrous tissue develops (nonunion). This method of bone healing is known as direct bone healing or primary bone union. Essentially, the process of bone remodeling allows bone to respond to the stresses to which it is exposed.

Based on the mechanical milieu of the fracture as dictated by the surgeon's choice of internal fixation and the fracture pattern, 2 patterns of stability can result that determine the type of bone healing that will occur. Absolute stability (ie, no motion between fracture fragments) results in direct or primary bone healing (remodeling). Relative stability (ie, a certain amount of fragment motion) heals with secondary or indirect bone union.

## **Pins, Wires, and Screws**

### **Pins and Wires**

Kirschner wires (K-wires, 0.6-3.0 mm) and Steinmann pins (3-6 mm) have a variety of uses, from skeletal traction to provisional and definitive fracture fixation. Resistance to bending with wires is minimal, so they are usually supplemented with other stabilization methods when used for fracture fixation, but most commonly, wires are utilized as provisional fixation prior to definitive fixation with a stronger device. Skeletal traction with K-wires is possible with the use of a K-wire tensioner, which, with application, stiffens the wire and allows it to resist bending load.

K-wires and Steinmann pins can provide provisional fixation for reconstruction of fractures while incurring minimal bone and soft tissue damage and leaving room for additional hardware placement. Planning pin placement is important to avoid the eventual permanent fixation devices, and if possible, pins should be placed parallel to screws used for fracture compression. Depending on the diameter, pins may also be used as guidewires for cannulated screw fixation.

Permanent fixation options include fractures in which loading is minimal or protected with other stabilization devices, such as external fixators, plates, and braces. Pin or wire fixation is often used for fractures of the phalanges, metacarpals, metatarsals, proximal humeri, and wrists. K-wires commonly supplement tension-band wire constructs at olecranon, patella, and medial malleolus fractures.

The K-wires can be fully threaded or nonthreaded and have either diamond or trocar points that are simplistic in design and have limited ability to cut hard bone, a process that can lead to overheating. For this reason, they should be inserted slowly when power equipment is used, to avoid thermal necrosis. Image intensifiers are often used for optimal positioning of the fixation, especially with percutaneous insertion combined with closed reduction techniques. The pins may have points at both ends, facilitating antegrade-retrograde fixation techniques; however, they are a potential hazard and should be used with caution.

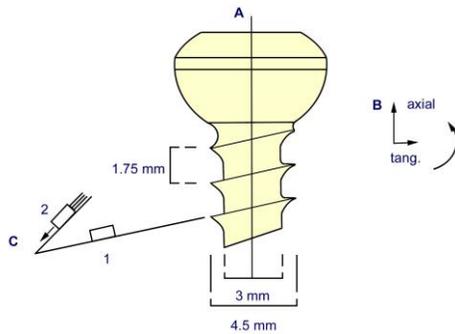
Steinmann pins are larger, may be threaded or unthreaded, and are currently used primarily for long bone traction in conjunction with a Böhler traction stirrup. Early techniques of fracture treatment consisting of pins for skeletal traction and incorporation into a cast were fraught with pin infections, loosening, and loss of reduction. This technique has been replaced with more advanced external

fixation devices, internal fixation methods, and minimally invasive plating and IM devices.

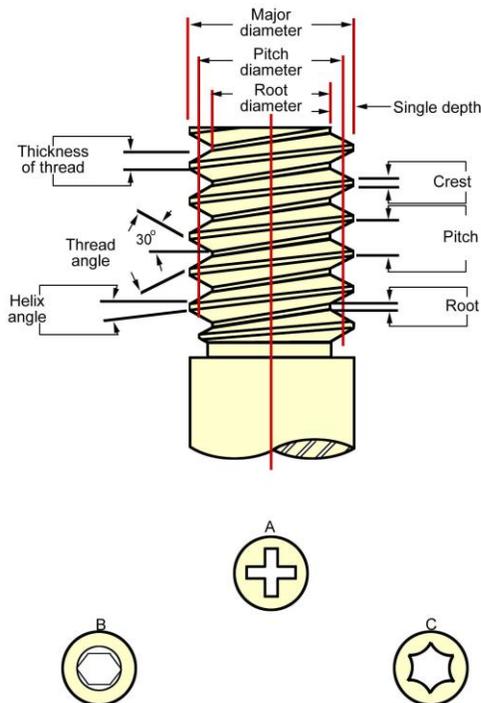
Guidewires for cannulated screws are employed at times for definitive fixation, as they are terminally threaded, allowing for fixation on the opposite cortex. An example of this would be the closed reduction and percutaneous pinning technique for proximal humeral fractures.

## Screws

Bone screws are a basic part of modern internal fixation. They can be used independently or in combination with particular types of implants. The common design of a screw (see Images 1-2) consists of a tip, shaft, thread, and head. A round screw tip requires pretapping, whereas a fluted screw tip is self-tapping. The screw shaft is located between the head and the threaded portion of the screw. The screw thread is defined by its major or outside (thread diameter) and minor or root (shaft diameter) diameters, pitch, lead, and number of threads. The distance between adjacent threads is the pitch.



## Common screw.



**The screw thread is defined by its major or outside and minor or root diameters, pitch, lead, and number of threads. Bottom: Screw head drive types.**

The lead is the distance a screw advances with a complete turn. Lead is the same as pitch if the screw is single threaded, and lead is twice the pitch if the screw is double threaded (faster screw insertion). The root diameter determines the screw's resistance to breakage (tensile strength). Screws are referred to by their outer thread diameters, bone type for intended use (cortical or cancellous, determined by pitch and major/minor diameters), and proportion of thread (partially or fully threaded).

Screw pullout strength can be affected by several factors. Bone composition (density) is the primary determinant of screw fixation. The total surface area of thread contact to bone (root area) is another factor in pullout resistance. Pretapping the screw hole theoretically reduces microfracture at the thread-bone interface but requires an extra step for insertion. Self-tapping screws have been shown to have no clinical difference from pretapped screws for fracture or plate fixation, eliminate the tapping step, and are now the industry standard. The fluted portion of the screw tip has less thread contact with the bone, so slight protrusion at the opposite cortex is recommended.

Pitch, the distance between adjacent threads, affects purchase strength in bone. Increasing the pitch increases bone material between the threads but decreases the number of threads per unit of distance.

The industry standard for the screw head is a hexagonal recess, which provides a large contact surface between the screw head and screwdriver and allows for optimal transmission of torque. A cross-type screw head is used on some screws in the 2.0 and smaller screw (minifragment) sets (see Image 2). The star design or TORX head found in industry has been adapted to the screw heads for the Association for the Study of Internal Fixation (AO/ASIF) locking plates and has been shown to be superior for torque and resistance to stripping.

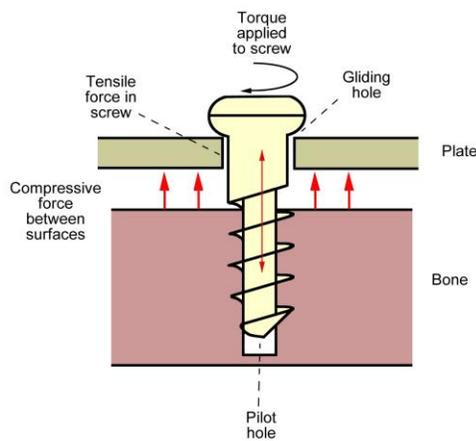
Several forces are involved with screw insertion and tightening. Torque is applied through the screwdriver to the screw head in a clockwise rotation to advance the screw in the predrilled path or, in the case of a cannulated screw, over a guidewire; this advancement produces a circumferential force along the thread. For cortical screws, the drill diameter is slightly larger than the root (shaft) diameter of the screw. Axial tension is created with impingement of the screw head on the cortex or plate, generating tension through the screw. To optimize these forces, screws should ideally be inserted at 80% of the torque needed to cause them to strip. An estimated 2500-3000 newtons of axial compression force can be applied to the average screw. Over time, the amount of compressive force decreases slowly as the living bone remodels to the stress; however, the fracture healing time is usually shorter than the time it takes for substantial loss of compression and fixation.

The 2 basic types of screws available for the variability of bone density are cortical and cancellous screws. Cortical screws are designed for compact diaphyseal bone, whereas cancellous screws are designed for the more trabecular metaphyseal bone. Cortical screws have a smaller major (thread) diameter, decreased pitch, and a shallower thread than cancellous screws. Standard nonlocking cortical screw diameter choices include 1.5, 2.0, 2.7, 3.5, and 4.5 mm.

Cancellous screws typically have a larger major (thread) diameter and pitch and a greater difference between major and minor (shaft) diameters in comparison to cortical screws, providing more surface area for bone purchase. These screws are intended for use in metaphyseal fixation, where bone is softer. Cancellous screws are available in sizes 4.0 and 6.5 mm, and cannulated sizes vary from 4.0-7.5 mm.

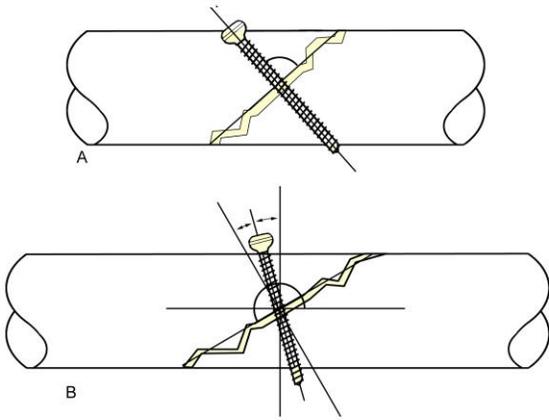
Tapping is not usually necessary in metaphyseal bone, as cancellous bone is porous relative to compact diaphyseal bone and usually requires only the initial pilot hole or cannulated screw guidewire. With subsequent screw insertion, there is compression of the bone along the path of the threads, which increases the local bone density in contact with the thread, thereby potentially increasing screw purchase. Tapping may be considered in strong metaphyseal bone to avoid stripping if advancement of the screw is difficult.

Positional or neutralization screws are to attach an implant, such as a plate, to bone by compression between the plate and bone. This function is modified when the screw is used to lag across a fracture through the plate or when used for fracture compression, as with a dynamic compression screw. For a positional screw, the pilot hole is drilled with the appropriate-size bit (shaft diameter) for the screw to be inserted (eg, a 3.2-mm drill bit for a 4.5-mm screw) using a centering guide for the plate hole. A depth gauge is used to determine appropriate screw length, and the thread cut is then made with an appropriate tap or without a tap when self-tapping screws are used or screws are placed in metaphyseal bone.



**Top: Biomechanics of cannulated and noncannulated screws. Bottom: Ideally, lag screw fixation produces maximum interfragmentary compression when the screw is placed perpendicular to the fracture line.**

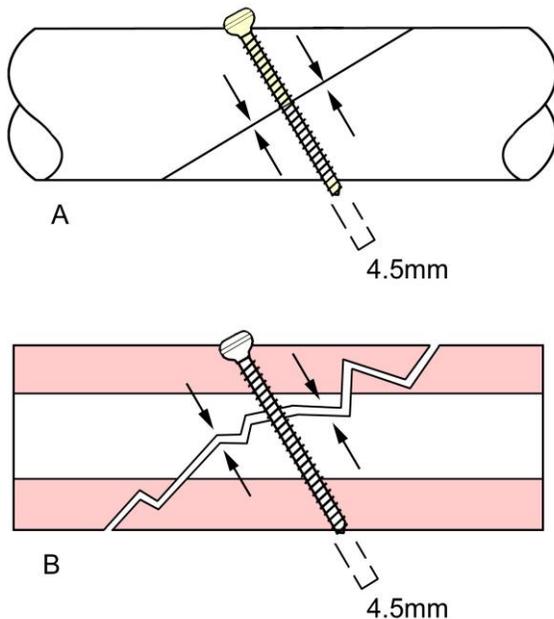
Interfragmentary lag screws provide compression across 2 bone surfaces using the lag technique. A lag screw is a form of static compression and is applicable to intra-articular fractures to maintain reduction and diaphyseal fractures for stability and alignment. Ideally, lag screw fixation produces maximum interfragmentary compression when the screw is placed perpendicular to the fracture line. Most lag fixation techniques require additional stabilization to neutralize the axial bending and rotational forces applied to the bone during functional postoperative care. This is provided by a neutralization or buttress plate or external fixation.



**Optimal inclination of the screw in relation to a simple fracture plane.**

If lag screws are to be used without neutralization plate fixation, especially in long spiral fractures (>2 times the diameter of the involved bone), the ideal inclination of the screw is halfway between the perpendiculars to the fracture plane and to the long axis of the bone. Placing the screw perpendicular to the long axis of the bone can also be considered, because longitudinal or shear compression may cause the screw or screws to tighten. Interfragmentary screw fixation alone may be appropriate for avulsion injuries in which shear forces generate metaphyseal and epiphyseal intra-articular fractures, provided bone quality is good.

A fully threaded screw can serve as a lag screw (see Image 5) with the near cortex overdrilled to the size of the screw's major (thread) diameter (4.5 mm in the example). Once the near cortex is drilled, which provides a gliding hole, a drill sleeve with the outer diameter of the drill bit (4.5 mm) is inserted into the hole and the standard drill bit (3.2 mm shaft diameter) is used to drill the far cortex. As the screw threads grasp the distal cortex, compressive forces are generated through the axis of the screw to the screw head, causing the fracture fragments to be compressed. This same mechanical effect can be generated by a partially threaded screw, with all threads entirely within the opposite bony fragment.



**T-lag screw.**

Cannulated screws are now provided by most trauma manufactures in sizes from minifragment to 7.5 mm, usually with a cancellous thread, but cortical patterns are also available, as they are more commonly used in periarticular/metaphyseal bone. The guidewire is usually placed under fluoroscopic control and allows for initial provisional fixation.

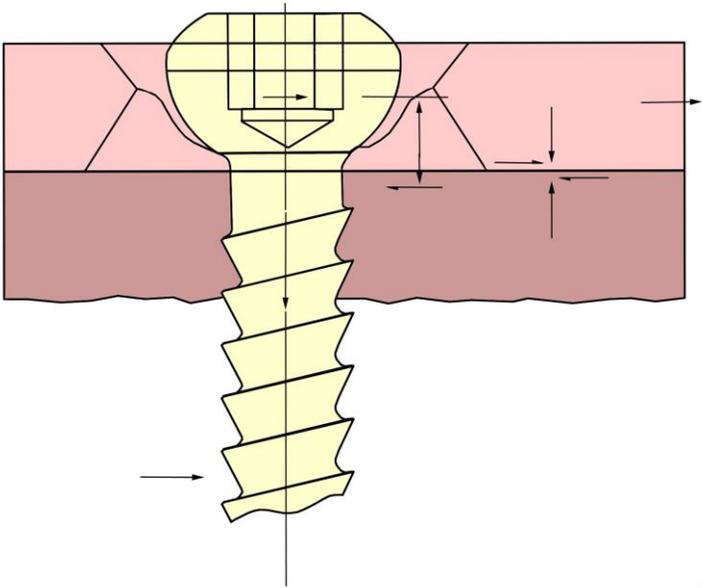
Cannulated screws allow for a percutaneous technique, such as is used with hip pinning, or may be used with limited open reduction techniques and can help minimize soft tissue dissection and periosteal stripping. Most designs are now self-drilling and self-tapping, but some may require predrilling over the guidewire with dense bone. The guidewires are usually terminally threaded, although nonthreaded are available, and when drilling over the wire, it is recommended not to drill over the threaded portion, because the guidewire may be inadvertently removed along with removal of the drill bit. This could result in difficulty relocating the drill hole through soft tissue or loss of provisional fixation.

The pullout strength of cannulated 7-mm cancellous screws versus 7-mm noncannulated screws and 3.5-mm cannulated and noncannulated screws has been tested in 2 studies, and no significant difference was noted regarding pullout strength. However, these studies are specific to these screw designs, and similar fixation properties cannot necessarily be applied to other screw designs and sizes. It should also be considered that the relative costs of cannulated screws are often 10 times that of similar-sized noncannulated screws; therefore, noncannulated screws should be used when technically feasible.

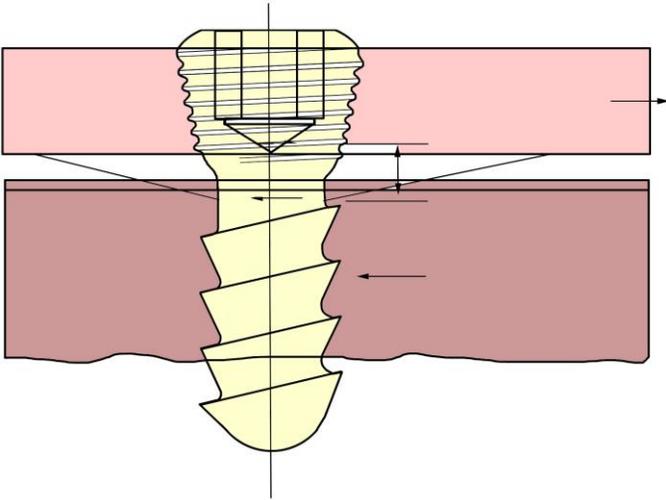
Self-tapping screws have the advantage of eliminating a step during screw insertion, thereby decreasing operative time. The fluted design of the screw cuts a sharp path in the predrilled hole, eliminating the need for tapping. Baumgart and associates showed that insertion torque and pullout strength were comparable for tapped and self-tapping screws. Only if the cutting tip did not protrude through the second cortex did they find a reduction of pullout strength of approximately 10%.

Schatzker and associates went on to prove that self-tapping screws inserted at 80% of thread-stripping torque and then removed and reinserted 12 times did not lose any significant holding power. When inserting a self-tapping screw as a lag screw, care should be taken with technique to avoid missing the opposite cortex, as these screws are often at an angle to the diaphyseal shaft, or there may be difficulties with advancing the screw while also tapping, especially with hard cortical bone. It is not unreasonable to consider tapping this opposite cortex first to help with alignment and advancement of the lag screw.

Locked screws are incorporated in more recent plate designs and may be inserted as unicortical or bicortical screws, depending on the type of plate and fracture. These screws, with reduced pitch, produce minimal axial force, if any, and provide biomechanical fixation by locking the screw head into the plate with a tapered thread, perpendicular to the plate. Some newer designs allow for some variable angulation of the locking screws. Biomechanically, locking screws function more like a bolt than a screw, and the system acts generally like an internal-external fixator. These systems are discussed further in Plates, below.



**Conventional plate screws.**

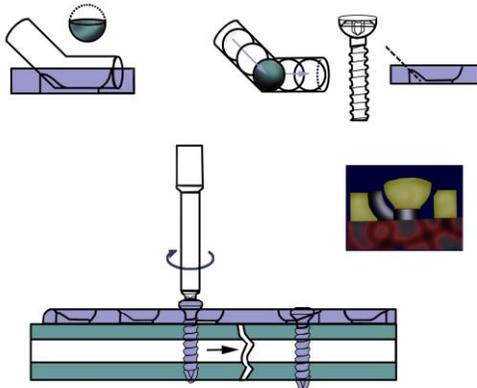


**Locked plate screws.**

# Plates

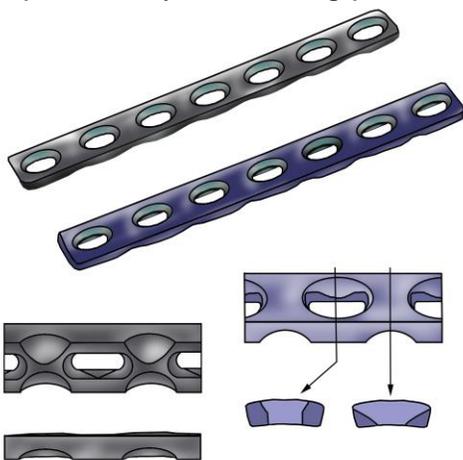
## Plate types

Plates are provided in various sizes and shapes for different bones and locations. Dynamic compression plates (DCPs) are available in 3.5 mm and 4.5 mm sizes. The screw holes in a DCP are shaped with an angle of inclination on one side away from the center of the plate. When tightened, the screw head slides down the inclination, causing movement of the bone fragment relative to the plate. As one bone fragment approaches the other at the fracture, compression occurs. The shape of the holes in the plate allow for 25° of inclination in the longitudinal plane and 7° inclination in the transverse plane for screw insertion.



**Dynamic compression principle: The holes of the plate are shaped like an inclined and transverse cylinder. Like a ball, the screw head slides down the inclined cylinder. Because the screw head is fixed to the bone via the shaft, it can only move vertically relative to the bone. The horizontal movement of the head, as it impacts the angled side of the hole, results in movement of the bone fragment relative to the plate and leads to compression of the fracture.**

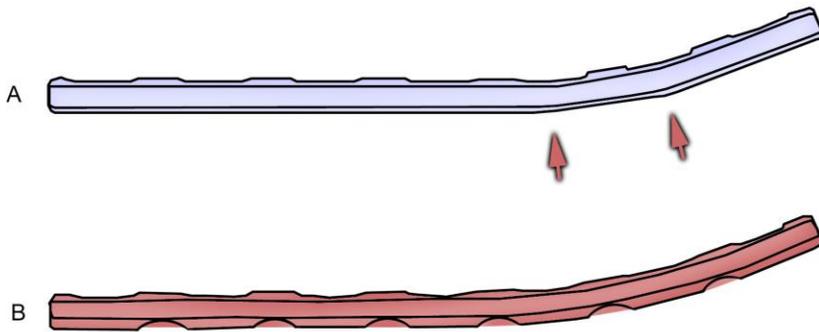
Limited-contact DCPs (LC-DCPs) were designed to limit possible stress shielding and vascular compromise by decreasing plate-to-bone contact by 50% (see Image 11).



**The structure of a limited-contact dynamic compression plate.**

Theoretically, this leads to improved cortical perfusion with increased preservation of the periosteal vascular network and reduces osteoporosis under the plate. The regular DCP has an area of

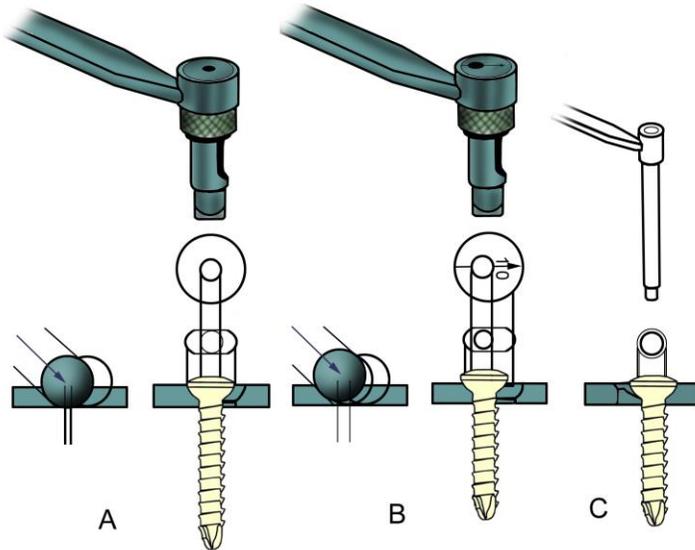
decreased stiffness located at the plate holes and, with bending, has a tendency to bend at the holes with a segmented pattern, whereas the LC-DCP, with a different geometric design incorporating the holes and plate undersurface, allows for gentle bending distributed throughout the plate.



**In the dynamic compression plate (A), the area at the plate holes is less stiff than the area between them. During bending, the plate tends to bend only in the areas of the hole. The limited-contact dynamic compression plate (B) has an even stiffness without the risk of buckling at the screw holes.**

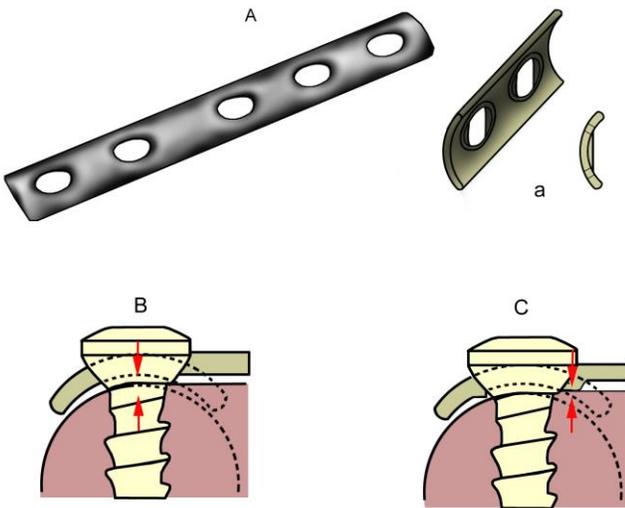
Finally, the LC-DCP is designed with plate hole symmetry, providing the option of dynamic compression from either side of the hole and allowing compression at several levels. In general, standard DCP style plates were replaced years ago with updated designs by most manufacturers with variations on the LC-DCPs, and in turn, these plates have been replaced by all manufacturers with plates capable of both locking and nonlocking functions. Some specific nonlocking-style plates are still retained in use, as they function well for a variety of specific fractures, such as the one-third tubular plate for lateral malleolar fractures and the 3.5 mm recon plates for periacetabular fixation.

Techniques for the application of both the DCP and LC-DCP are the same (see Image 13). Screws can be inserted in neutral position or a compression position, depending on the desired mechanical result. The DCP uses a green guide to insert a neutral screw, which adds some compression to the fracture owing to the 0.1-mm offset. The gold guide produces a hole 1 mm off-center, away from the fracture, and allows for 1 mm of compression at the fracture site with tightening of the screw. The LC-DCP universal drill guide allows for either neutral or eccentric placement of screws. When creating an eccentric hole to one side or another, the guide is slid to the end of the plate hole without applying pressure and the hole is drilled. By placing pressure against the bone with the drill guide, the spring-loaded mechanism allows for centralization of the hole for neutral screws, particularly if the screw must be inserted at an angle to the plate.



**The application of the drill guides depends on the proposed function of the screw. A: Neutral position. B: Compression.**

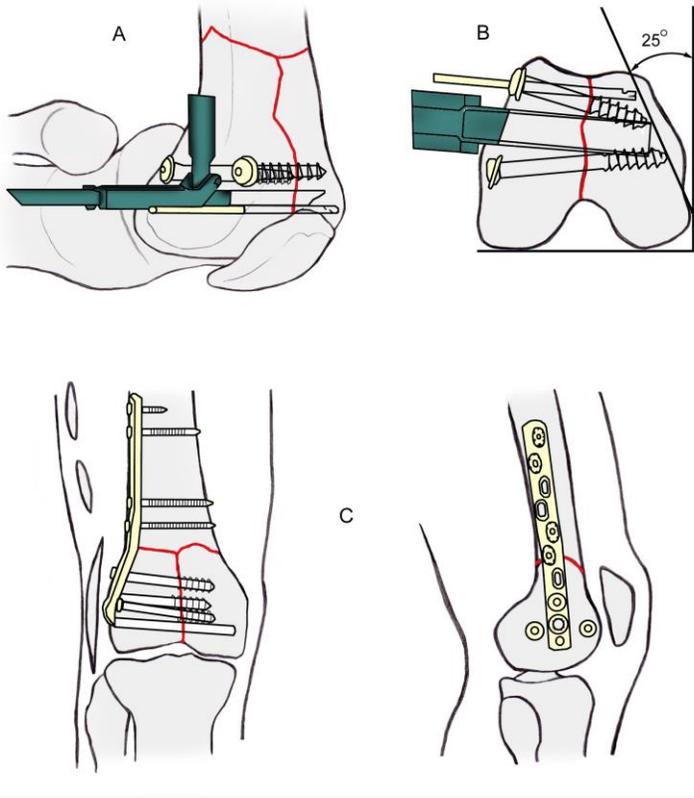
The 3.5 one-third tubular plate is 1 mm thick and allows for limited stability. The thin design allows for easy 2-dimensional contouring and is primarily used on the lateral malleolus and, on occasion, the distal ulna, although the locking version may be a better option. The oval holes allow for limited fracture compression with eccentric screw placement.



**The 3.5 one-third tubular plate is 1 mm thick and allows for limited stability. The thin design allows for easy shaping and is primarily used on the lateral malleolus and distal ulna. The oval holes allow for limited fracture compression with eccentric screw placement.**

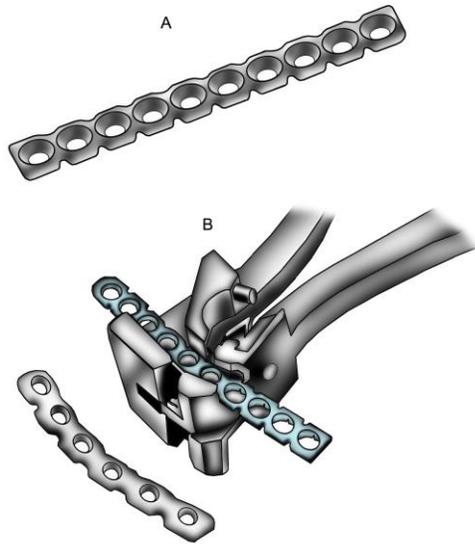
Improvements by all manufacturers have been made for plates used for almost all areas of the body that require placement of a plate near a joint and over extended areas of diaphyseal bone. The refinement of contour, along with screw head modification, reduces hardware prominence and increases fixation options.

The 95°-angled plates are useful in the repair of metaphyseal fractures and reconstruction of the femur (see Image 15), as they provide very rigid fixation. They are technically demanding, and proper insertion requires the blade to be inserted with consideration of 3 dimensions (ie, varus/valgus angulation, anterior/posterior position, flexion/extension rotation of plate). The screw barrel devices are considered somewhat easier to insert because the flexion/extension of the plate is correctable after insertion of the screw.



**Angled or blade plates are useful in repair of metaphyseal fractures of the femur, but their popularity has declined with the rise of sliding screw plates and locking plates. Proper insertion requires careful technique, with the blade inserted with consideration for 3 dimensions (varus/valgus blade angulation, anterior/posterior blade position, flexion/extension rotation of blade/plate).**

Reconstruction plates are thicker than one-third tubular plates, but they are not quite as thick as DCPs. Designed with deep notches between the holes, they can be contoured in 3 planes to fit complex surfaces (eg, around the pelvis and acetabulum). Reconstruction plates are provided in straight and slightly thicker and stiffer precurved lengths. As with tubular plates, they have oval screw holes, allowing potential for limited compression.



**Reconstruction plates are thicker than third tubular plates but not quite as thick as dynamic compression plates. Designed with deep notches between the holes, they can be contoured in 3 planes to fit complex surfaces, as around the pelvis and acetabulum. Reconstruction plates are provided in straight and slightly thicker and stiffer precurved lengths. As with tubular plates, they have oval screw holes, allowing potential for limited compression.**

Cable plates incorporate a large fragment plate with cerclage wires to be used with a tensioning device. These are used primarily with femoral fractures surrounding or adjacent to prosthetics (femoral hip or knee implants). Cortical allograft struts are often incorporated for osteoporotic bone.

### **Plate functions**

Standard plate fixation requires exposure of the fracture site, hematoma evacuation, and reduction of the fracture with possible interfragmentary lag fixation. After a fracture occurs, the periosteal blood supply is dominant, and this network of connective tissue must be preserved to optimize healing. Excessive periosteal stripping and careless soft tissue techniques can impair local blood supply and prolong healing.

Diaphyseal plate fixation associated with an anatomic reduction and interfragmentary compression provides absolute stability. Plates are often indicated in articular fractures to neutralize the axial forces on the interfragmentary screws, compressing cancellous bone to facilitate its healing. A fracture anatomically reduced without a gap and fixed with absolute stable fixation will undergo primary healing.

Dead bone at the fracture site is resorbed by osteoclasts of the cutting cones, as these cells traverse the fracture site. The osteoclasts are closely followed by ingrowth of blood vessels and mesenchymal cells and osteoblast infiltration. Stress shielding of the bone is rarely caused by the plate relieving axial load to the bone. Plate-induced osteoporosis is caused by disruption of the local vascularity to the bone cortex secondary to an impediment of centrifugal cortical blood flow by the plate.

Osteoporosis under a plate should be kept in mind after removal of hardware, because the bone also has the mechanical disadvantage of empty screw holes. This vascular-caused cancellization of the

cortical bone in diaphyseal areas usually resolves within 2 years of plate application, so it is safe to remove a plate at this time with the refracture rate being minimal. Plates applied to metaphyseal areas may have the option of earlier removal depending on the amount of diaphyseal extension and healing.

Bridge plating is used for comminuted unstable fractures in which anatomic restoration and absolute stability cannot be achieved. Minimal exposure and indirect reduction techniques are used to preserve the blood supply to the fracture fragments for healing, and a plate is attached to the 2 main fragments spanning the area of fracture. The plate is used to provide proper length, axial alignment, and rotation, but it is obviously limited for any load.

With more recent advances of combining minimally invasive plate techniques utilizing locking plate technology, plate devices act more as an internal fixator. This approach began in 2001 with the Less Invasive Surgical Stabilization (LISS) plate (Synthes; West Chester, Pa), which is advanced in the submuscular tissue through a small incision over the periosteum but does not necessarily contact the bone along the length of the plate. This technique limits the disruption of periosteal blood supply that is seen in conventional plating systems, as the fixation is through the locking screws, thereby not necessitating compression to the plate for stability. The early development of this concept with the Point Contact Fixator (PC-Fix) system (Synthes) in the 1990s, and then later with LISS, takes advantage of unicortical, self-drilling, self-tapping screws with threaded screw heads that lock into the screw hole of the plate and minimize soft tissue disruption.

Once the LISS plate is aligned with the central shaft of the bone, screw placement can be accomplished percutaneously with a radiolucent guide attachment to the plate. Unicortical screws are recommended for use in diaphyseal bone, with longer screws for use in the metaphyseal area, thereby functioning as a fixed-angle device.

Currently, most manufacturers offer new locking plate products. These devices range from standard straight plates of all sizes with locking and standard screws, to anatomically specific plates that act as fixed-angle devices. These new plate designs incorporate improved contour with locking screw options for fixation, offering significant advantages over the conventional designs for certain fractures. Proximal and distal humerus, distal radius, distal femoral, and proximal (bicondylar) and distal tibial fractures are examples of injuries that benefit from this technology, having the improved ability to hold a fracture in its anatomic position and resist applied forces while healing. Conventional plates, which rely on friction forces against the plate from screw fixation and buttressing in metaphyseal and articular fractures, are limited in resisting applied loads versus locking fixation.

In contrast, certain shaft fractures with stable patterns and adequate room for fixation have proven high union rates with conventional plating (humeral shaft, radius, and ulna shaft), and any significant difference between the 2 techniques is difficult to realize with proper surgical technique. Current recommendations are to use locking screws in situations with limited fixation options, osteoporotic bone, or need for fixed-angle support. For example, a simple lateral plateau fracture that requires buttress fixation and with which the bone quality is reasonable can be adequately treated with a conventional nonlocking lateral plate.

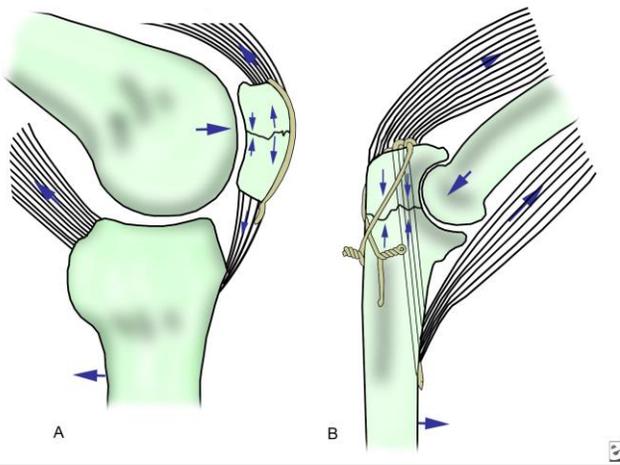
Currently, most LC-DCP small and large conventional plate sets have been reduced as utilization of specialty plates has increased with periarticular design and locking capability, the surgeon deciding which screws are locking or nonlocking, depending on the fracture. As with cannulated screws, locking screws can vary in cost, ranging from 8-15 times the cost of a conventional screw, and therefore should be used when needed based on the fracture pattern and expected loads. This cost

issue is lessened to some degree when taking into account the need for revision surgery due to failure of fixation or malunion; thus, a balance of usage guided by conventional wisdom, common sense, and biomechanical and outcome studies is recommended.

## Tension-Band Principle

Plates and other constructs can be used to function as a tension band if an eccentrically loaded bone (eg, the femur) has the device placed on the tension (convex) side of the bone. Using load-strain diagrams, Frederic Pauwels, who first described the tension-band concept, showed that a curved tubular structure placed under an axial load had a tension side and a compression side. With this theory, he described the application of internal fixation on the tension side to convert tensile forces into compressive forces at the fracture site.

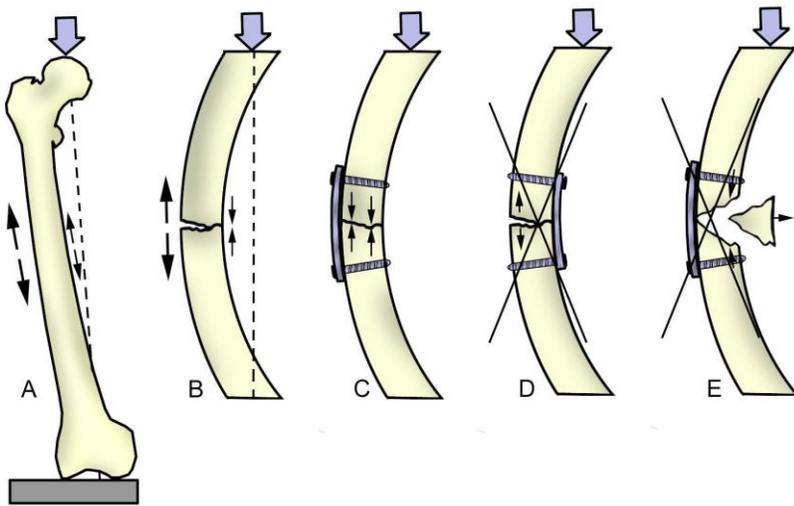
With static compression applied by the implant (eg, tensioning of wire, compression with plate), dynamic compression then develops with joint flexion, as with a patella or olecranon fracture, or with load, as with lateral femoral plating. With this technique, the internal fixation device must have the strength to withstand the tensile distraction forces created by muscles during motion, and the bone on the opposite side of the plate must be able to withstand the compressive forces as a medial buttress.



### Tension-band principle.

Wires and plates are usually quite strong under pure tension forces, but with bending forces added, fatigue can occur rapidly. If bony support is compromised on the cortex opposite from the tension device (eg, from fragmentation, osteoporosis), bending stresses can develop, causing failure of fixation. Wiring techniques commonly include longitudinal K-wires for rotational and axial alignment control in the case of bone fragmentation.

Conversely, fixation on the concave side of the bone occurs in rare situations, such as with medial plating of a femur or anterior plating of the humerus. In these situations, fractures have minimal resistance to bending stresses, and gapping can occur on the convex side, resulting in failure of fixation. Therefore, attempts should be made to limit potential bending forces to fixation to prevent fixation failure. The tension-band principle can be applied to wires, cables, suture, plates, and external fixators as long as the basic principles are followed.



**Tension-band principle at the femur.**

## Intramedullary Nails

In the 1930s, Küntscher refined nailing techniques, with the result of IM nails becoming the standard for femoral shaft fixation. Later developments resulted in IM devices being options for proximal and distal metaphyseal/articular fractures and for tibial and humeral fractures. IM nails allow for stable fixation of diaphyseal fractures with early mobilization of joints, early ambulation, and weightbearing of extremities. As metallurgy and designs have improved, the indications and techniques for IM devices have increased. Specially designed nails now exist for each bone, different entry portals, and specific fracture patterns. IM nails have advantages over plates and external fixation because the intramedullary location allows for axial alignment and load sharing.

The location and type of fracture determines the device to be used, and devices are named accordingly. IM devices can be described based on dimensions of length, diameter, curvature, locking options, cross-sectional geometry, material, and insertion site options as determined by the bone and fracture being addressed.

A nonlocking cloverleaf Küntscher nail is an example of a centromedullary nail, which is inserted in line with the femoral canal and relies on longitudinal interference with bone-to-nail contact at multiple points to maintain axial and rotational stability of the fracture.

Condylocephalic nails such as Ender pins or Rush rods were a significant device in the early years of fracture fixation. These solid devices were smaller in diameter and were inserted in the condyles or the metaphyseal region, advanced across the fracture either antegrade or retrograde, and embedded in the opposite metaphysis for stability. These nails were usually inserted in clusters of 2 to 4 for bending stability but had limitations with rotational and axial forces.

Initial simple IM devices relied on reestablishing bony realignment and contact along with interference fit in the medullary canal for stability. This was enhanced by the cloverleaf designs, which added a dynamic lateral compression within the canal for additional stability. As nail designs progressed, interlocking options were added, which improved the stability and fracture fixation options, increasing their indications.

Interlocking screws increase the working length of the nail from a simple interference fit, not attainable with nonisthmal shaft fractures or fractures without stable bony contact, to semirigid fixation at the ends of the nail, which is capable of resisting axial and rotational forces. The working length of a nail corresponds to the fracture areas between the sites of fixation and, therefore, can vary from several millimeters with a simple transverse fracture to the entire length of nail between the locking screws in fractures with fragmentation or an unstable pattern.

The working length of the nail is increased when the locking screws are located as close to the ends of the nail as is structurally possible, increasing the potential fracture indications. By the 1980s, examples of second-generation interlocking nails included the Grosse-Kempf nail and, later, the Russell-Taylor nail. Currently, all nail manufacturers include basic interlocking screws and other notable features on third-generation nails, such as proximal femoral head/neck screws and dynamic screw slots.

Reconstruction-type nails and gamma-style nails with a reinforced proximal section that allow for fixation into the femoral head and neck region are cephalomedullary nails. These nails increase the fixation options for proximal femoral fractures. Recon nails are a variation of a standard piriformis-start antegrade femoral nail, whereas cephalomedullary nails are devices starting at the tip of the greater trochanter, which is not in line with the anatomic axis of the femur; this explains the increased size required to accommodate the larger proximal fixation screw and the stress from the offset position.

Tibial nails have also evolved over the years in a similar fashion. With the introduction of locked femoral nails, the same principles of static and dynamic locking were applied to the tibia. By changing nail design and improving the metallurgy, more configurations for locking were possible, thus expanding the indications for tibial nailing to the proximal and distal end segment of extra-articular fractures.

Locking configurations can be static or dynamic. A statically locked nail implies the presence of proximal and distal screws in a nonslotted hole, allowing for control of axial translation and allowing for rotation, with the nail performing more as a load-bearing implant. This application is appropriate for unstable fracture patterns or locations and is certainly a consideration if immediate, full weightbearing is needed, as is sometimes the case in patients with multiple traumatic injuries. As with any fracture reduction, attention to accurate length restoration and rotation is important for avoiding malreduction and leg-length inequalities. Avoidance of fracture distraction is important to minimize the risk of delayed union or nonunion, especially in the humerus and tibia.

Dynamic locking allows the shaft to axially translate several millimeters while rotational control is maintained. This was originally accomplished by leaving the locking screw hole farthest from the fracture empty. This is rarely performed now. Brumback et al demonstrated that dynamic locking leads to malunions, and they recommended static locking for all long bone fractures treated with IM fixation. More recently, nails are constructed with a slotted locking screw hole, allowing placement of the locking screw so that the nail moves along the slot (approximately 5 mm) while the screw controls rotation. With these improved nails, a dynamic option for fractures with an obviously stable fracture pattern (eg, isthmic location, Winquist fracture pattern II or less) is available to help stimulate healing with axial loading. A statically locked nail may be converted to dynamic lock by removing the static position screws at one end of the nail.

Cross-sectional geometry varies widely with manufacture and design and with fracture indication. Nails may be solid, open-section (slotted), or solid-section cannulated of various shapes, including

cylindrical, square, triangular, cloverleaf, and multigrooved or multifluted. Solid nail designs may be necessary for smaller-diameter devices, but they do not allow for insertion over a guidewire, and they are difficult to extract if broken. Additionally, recent femoral designs have been replaced with cannulated versions. Bending and torsion strength is altered by changing wall thickness, materials, and, possibly, the number of (adding) channels or slots. A channel along the length of the nail potentially allows for revascularization, but with the advent of locking screws, the sharp flutes or edges of earlier nail designs were not necessary for rotational control.

Torsion and bending resistance in a cylindrical structure is proportional to the fourth power of its radius. By increasing the radius away from the load axis by a thicker wall or greater diameter, the rigidity increases. Increasing the diameter of an IM nail by 1 mm increases its rigidity by 30-45%, but this would require additional reaming of the canal. Excessive reaming may weaken the diaphyseal bone and increase the possibility of thermal necrosis. For torsion, the rigidity decreases inversely to the working length, and with bending, the stiffness is inversely proportional to the square of the working length; therefore, the shorter the effective working length of the nail fixation and fracture combination, the stiffer the device.

IM implants provide stable fixation, but healing occurs primarily through the formation of periosteal callus. Reaming of the medullary canal increases the working length of an IM implant by elongating the isthmic region with a uniform diameter, thereby increasing the potential implant-to-bone contact. In addition, this allows for a larger-diameter and stronger nail to be inserted than with an unreamed nail, which often allows larger-diameter locking screws, decreasing potential implant failure.

Reaming of the medullary canal damages the medullary vascular system and increases the IM pressure and temperature, with devitalization and necrosis of the diaphyseal cortical bone. In animal studies of blood flow to long bone diaphyseal regions, reaming can cause necrosis of the inner half of the cortex, but this is followed by a strong hyperemic response in the periosteal and muscular blood flow. These changes appear to be reversible over a 12-week period.

Diaphyseal reaming also weakens the bone, and the recommendation is that the cortex should not be reamed to less than half of its original thickness. Additionally, any instrumentation of the medullary canal, including placement of a guidewire and reaming, embolizes marrow contents to various organs, including the pulmonary system. IM pressure can be reduced by the presence of a fracture, slowing the rate of reamer insertion, increasing the speed of the reamer, and allowing the reamer tip to incorporate a small shaft relative to the diameter of the reamer, with deep flutes designed for depressurization of the canal. Although this type of embolization is performed in humans undergoing transesophageal echocardiography, its clinical significance is still debated with regard to its effect on pulmonary function in patients with multiple injuries.

Unreamed nailing has been studied as an option to reamed nails, and various studies have demonstrated improved preservation of endosteal blood supply and more rapid revascularization than occurs with reamed techniques. This advantage is limited. Blood flow rapidly improves with reamed fixation, provided the soft tissue envelope is adequate. Most recent clinical studies have revealed improved healing rates for both femoral and tibial fractures (excluding severe open injuries) with reamed nails versus nonreamed nails.

In North America, the standard practice is to insert reamed IM nails in all closed femoral and tibial diaphyseal fractures. The contraindication to this practice is with patients who have been in shock, have pulmonary compromise, have elevated serum lactate levels, and have abnormal base deficits and also have multiple injuries. Open fractures are also amenable to reamed nails. Grade IIIB open

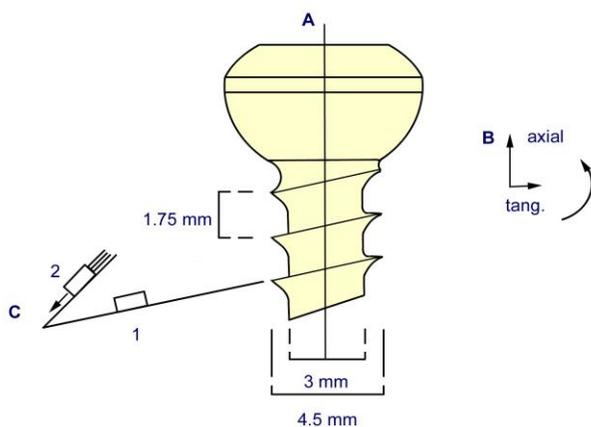
fractures may be a relative contraindication. Humeral nailing still presents problems with union, shoulder stiffness, and neurologic injury when inserting locked screws, so it is not as popular as with the other long bones.

## Biodegradable Fixation

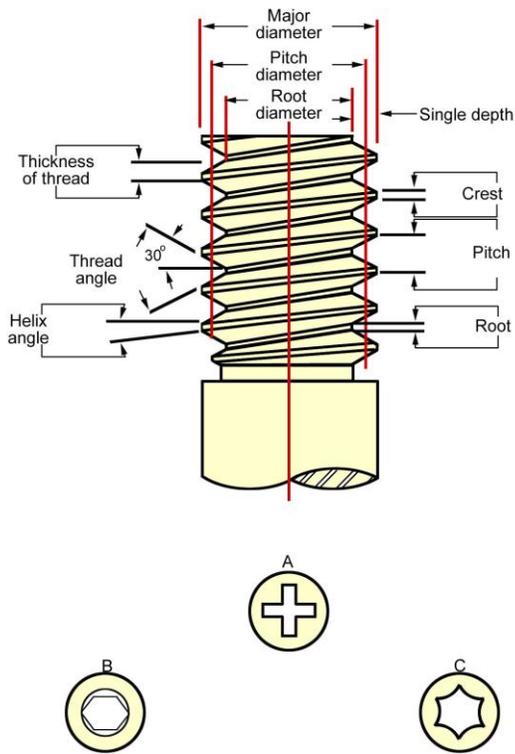
Polymers, including polylactic and polyglycolic acids and polydioxanone, are resorbable suture materials that are currently undergoing continued redesign and refinement for use as rods or screws that reabsorb with time. These devices offer the theoretical advantage of eventual resorption, eliminating the need for later removal, while allowing stress transfer to the remodeling fracture.

Current bioabsorbable implants do not have mechanical properties to match metallic implants; therefore, their indications are limited, and their fixation usually requires protection from motion or significant loading. Degradation rates vary, and local inflammatory reactions, such as chondrolysis noted with placement in proximity to joints, have been reported with some implants. These devices are a consideration when fixation of low stress areas is needed and when later removal is anticipated, such as in pediatric patients or in medial malleolar fractures, syndesmotic fixation, or osteochondral fractures in adults.

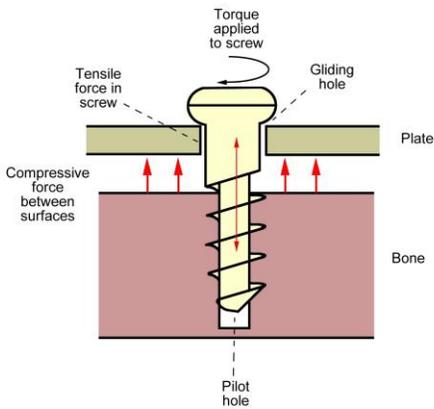
## Multimedia



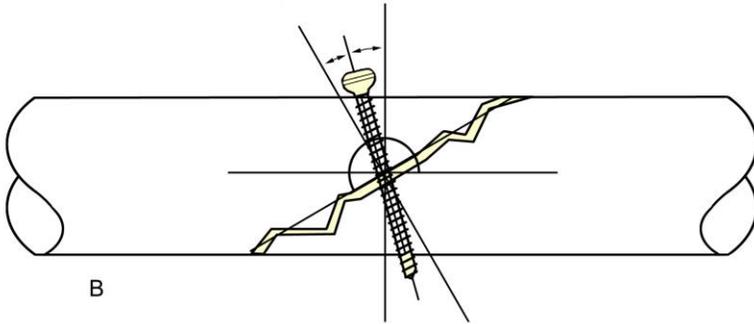
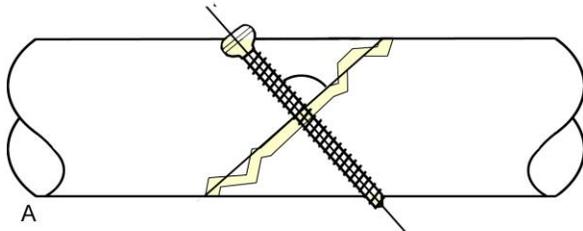
**Media file 1: Common screw.**



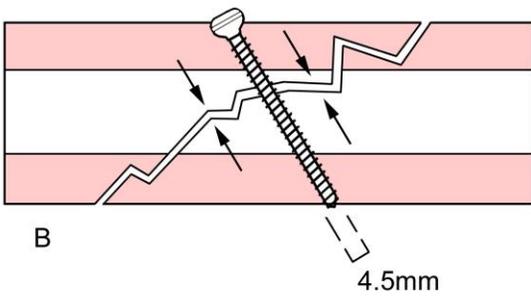
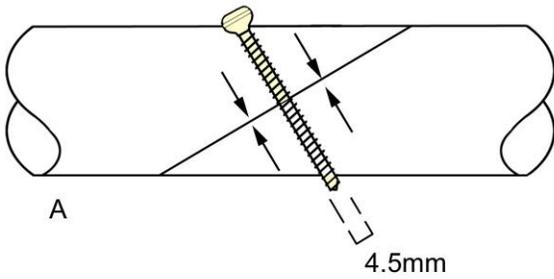
**Media file 2: The screw thread is defined by its major or outside and minor or root diameters, pitch, lead, and number of threads. Bottom: Screw head drive types.**



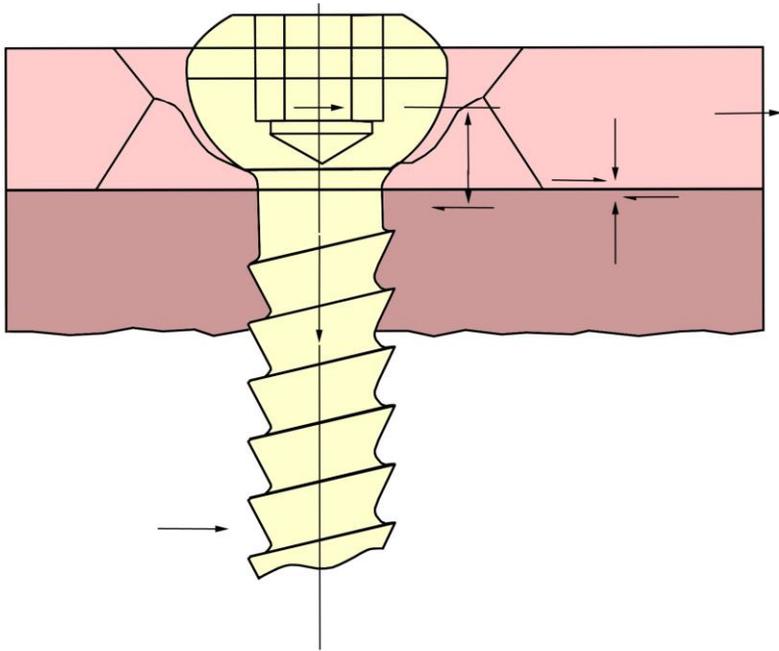
**Media file 3: Top: Biomechanics of cannulated and noncannulated screws. Bottom: Ideally, lag screw fixation produces maximum interfragmentary compression when the screw is placed perpendicular to the fracture line.**



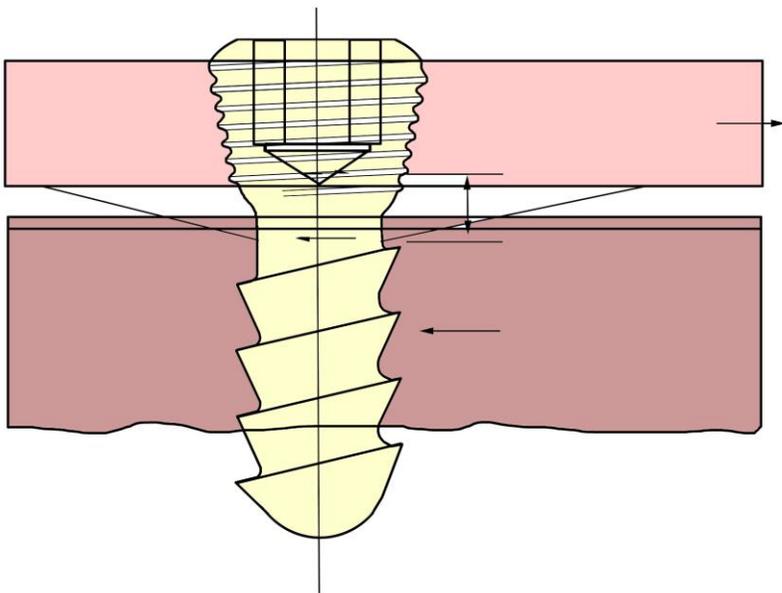
**Media file 4: Optimal inclination of the screw in relation to a simple fracture plane.**



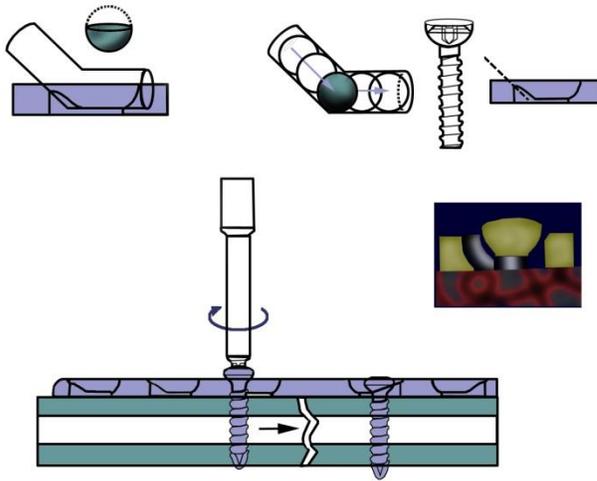
**Media file 5: T-lag screw.**



**Media file 6: Conventional plate screws.**

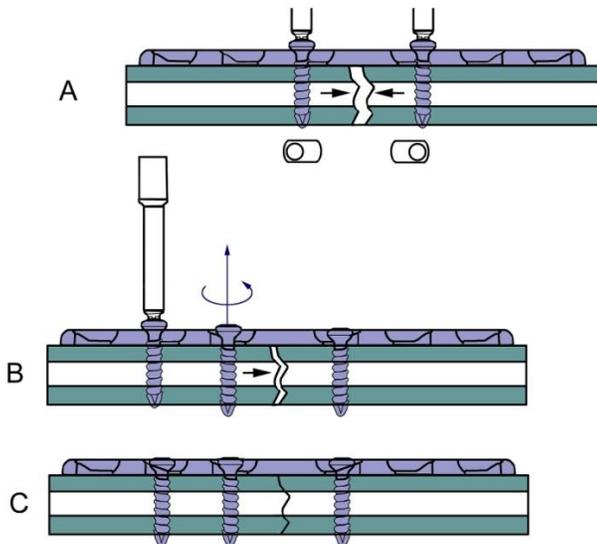


**Media file 7: Locked plate screws.**



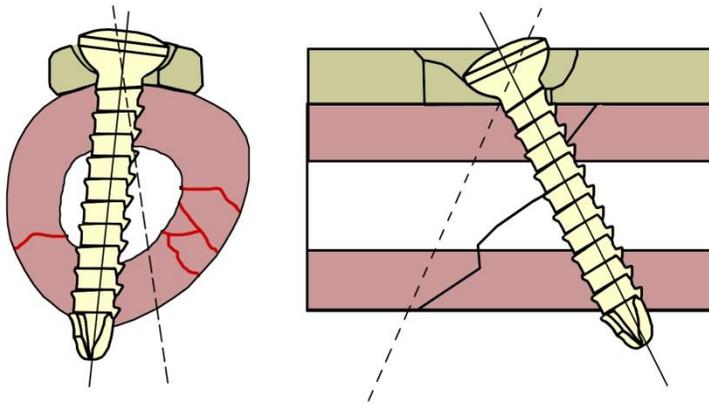
©

**Media file 8: Dynamic compression principle: The holes of the plate are shaped like an inclined and transverse cylinder. Like a ball, the screw head slides down the inclined cylinder. Because the screw head is fixed to the bone via the shaft, it can only move vertically relative to the bone. The horizontal movement of the head, as it impacts the angled side of the hole, results in movement of the bone fragment relative to the plate and leads to compression of the fracture.**

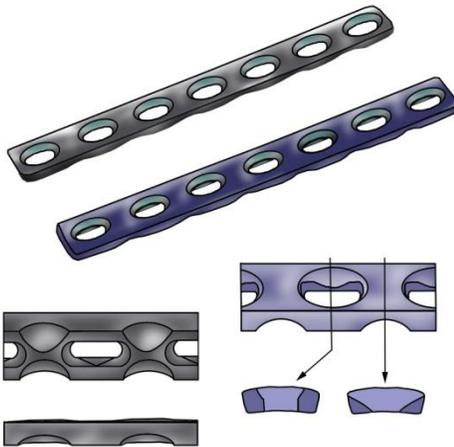


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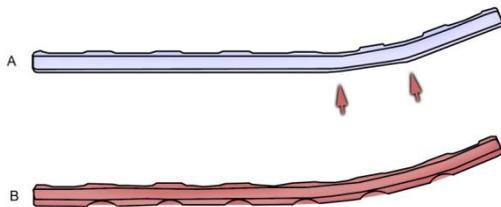
**Media file 9: General principles of internal fixation.**



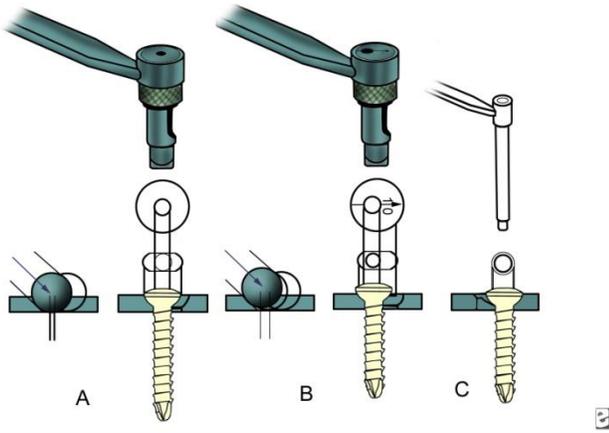
**Media file 10: The shape of the holes of the dynamic compression plate allows inclination of the screws in a transverse direction of +7° and in a longitudinal direction of 25°.**



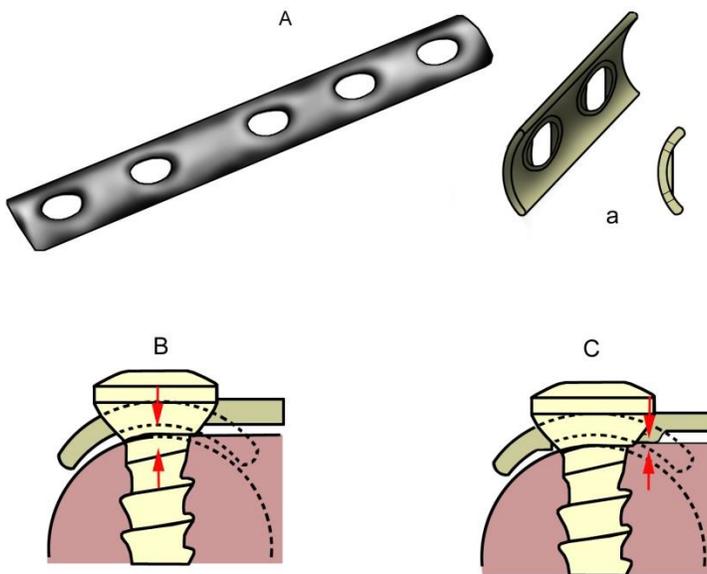
**Media file 11: The structure of a limited-contact dynamic compression plate.**



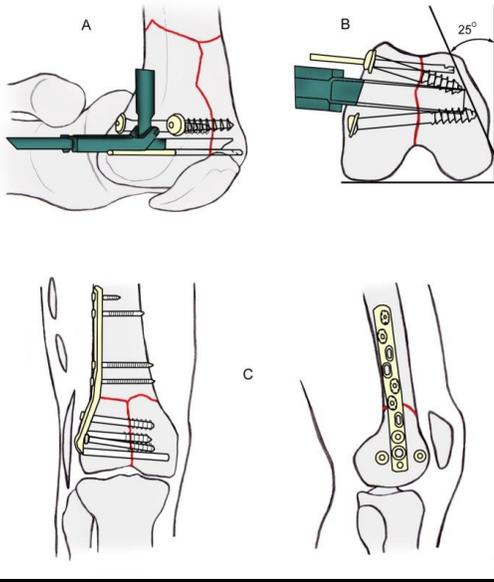
**Media file 12: In the dynamic compression plate (A), the area at the plate holes is less stiff than the area between them. During bending, the plate tends to bend only in the areas of the hole. The limited-contact dynamic compression plate (B) has an even stiffness without the risk of buckling at the screw holes.**



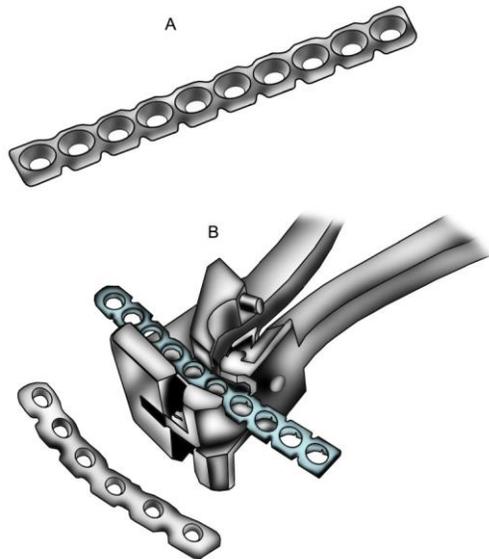
**Media file 13: The application of the drill guides depends on the proposed function of the screw. A: Neutral position. B: Compression.**



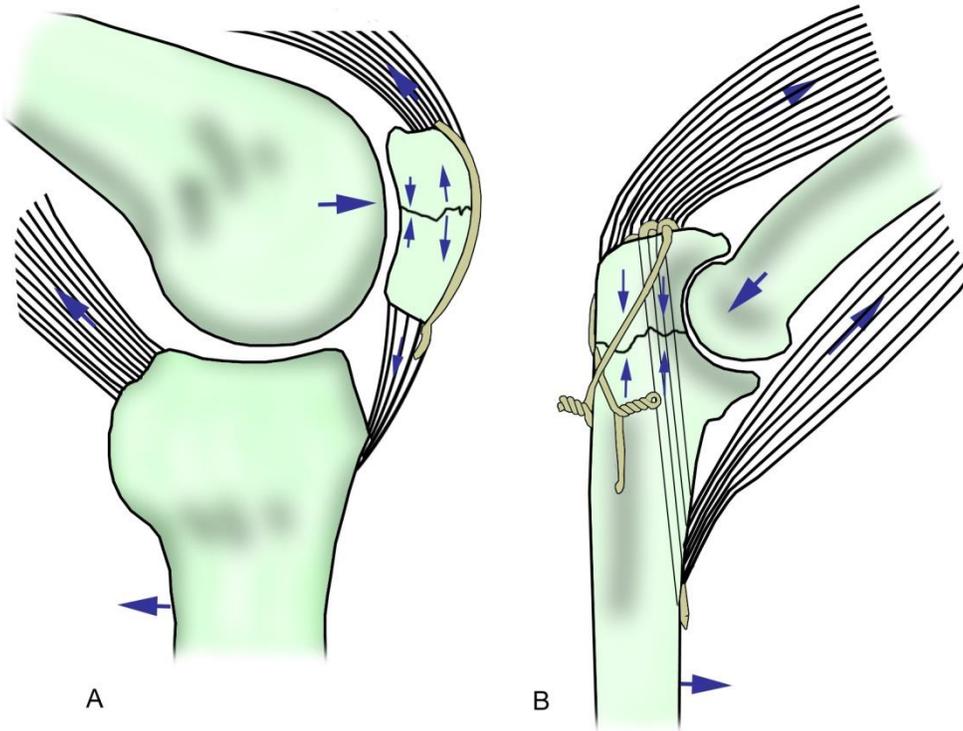
**Media file 14: The 3.5 one-third tubular plate is 1 mm thick and allows for limited stability. The thin design allows for easy shaping and is primarily used on the lateral malleolus and distal ulna. The oval holes allow for limited fracture compression with eccentric screw placement.**



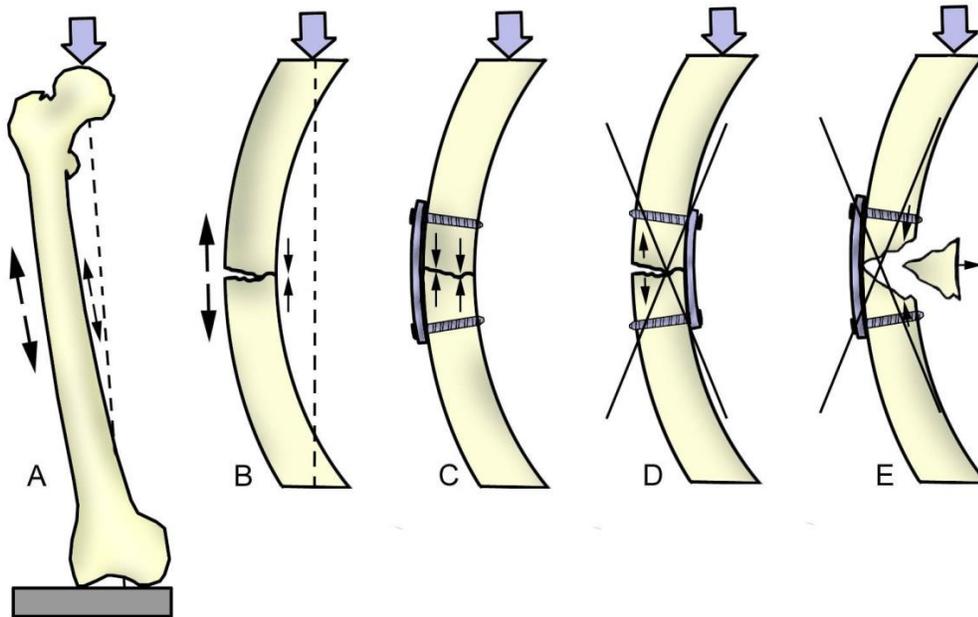
**Media file 15: Angled or blade plates are useful in repair of metaphyseal fractures of the femur, but their popularity has declined with the rise of sliding screw plates and locking plates. Proper insertion requires careful technique, with the blade inserted with consideration for 3 dimensions (varus/valgus blade angulation, anterior/posterior blade position, flexion/extension rotation of blade/plate).**



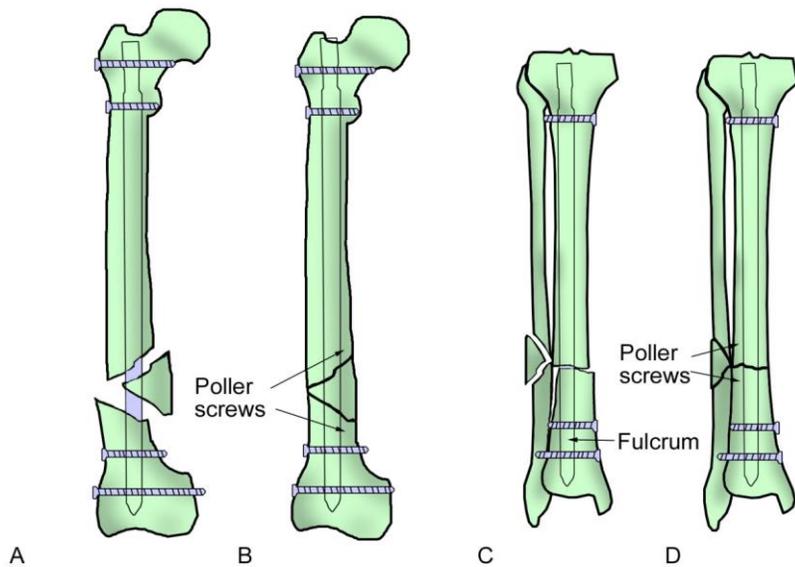
**Media file 16: Reconstruction plates are thicker than third tubular plates but not quite as thick as dynamic compression plates. Designed with deep notches between the holes, they can be contoured in 3 planes to fit complex surfaces, as around the pelvis and acetabulum. Reconstruction plates are provided in straight and slightly thicker and stiffer precurved lengths. As with tubular plates, they have oval screw holes, allowing potential for limited compression.**



**Media file 17: Tension-band principle.**



**Media file 18: Tension-band principle at the femur.**



## Media file 19: Blk screws.

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# **APPENDIX E: TRAUMA**

# **APPENDIX F: BONE TUMORS**

## **Bone Tumors**

Excerpted from “The Hitchhiker’s Guide to the Orthopedic Service” by Lawrence W. Mysliwiec, D.O., Wimbley Press 2002.

### ***Introduction:***

Bone tumors can occur in the bone as primary tumors or as secondary metastatic lesions. Primary tumors are those that originate in the bone. Although these are not as common, they are of great importance. This is particularly true of the malignant or potentially malignant variety. Metastatic disease to bone is about twenty (20) times more common than primary bone tumors.

### ***Types of Bone Tumors:***

Bone tumors can arise from cells of bone, cartilage or fibrous origin, These various lesions are designated by the prefixes osteo-, chondro-, or fibro. The malignant variety of these cell types are typically referred to as sarcomas. This is because of their fleshy appearance on gross examination. The word “sarcos” in Greek means flesh.

There are also lesions that arise from the round hematopoietic cells in the marrow cavity – so called “round cell tumors.” These lesions are designated by such prefixes as myelo-, or lympho-. Because of the inherently pervasive nature of these proliferating marrow cells, these round cell tumors tend to metastasize readily and are considered malignant.

### ***Diagnostic Clues:***

Certain criteria help to provide a differential diagnosis in the work up of bone tumors. This is critical in the work- up of these problems, to avoid serious mistakes in handling the case, which could result in a misdiagnosis, inappropriate treatment, or spreading of a malignancy. Malignant or potentially malignant lesions should be referred to a bone tumor specialist. Clues that help diagnosis include the following:

**Age:** Important for specific types. Eg. Ewing’s Sarcoma in pediatrics

**Location:** Which bone? What location in the bone? Bone cartilage and fibrous lesions tend to arise near or in the metaphysis of the long bones. Round cells occur more often in marrow rich areas – the axial skeleton or the diaphysis of long bones.

**Size:** Larger lesions are apparently more active and more aggressive.

**Reaction:** Bone reacts to lesions and vice versa. The amount of reaction, the ability or inability of bone to wall off and contain the tumor process are important markers of activity.

**Matrix:** Dense calcification is typically seen in bony matrix. Stippling or spotty calcification is typically seen in cartilage tumors.

**Cortex:** Scalloping, expansion or breakthrough are key signs of activity.

**Soft Tissue Extension:** A typical sign of breakthrough outside the bone represent malignant behavior and an increased risk of metastasis.

### ***Staging:***

Histological Grading

0 – No risk of metastasis. Benign. Eg. Osteoid Osteoma, Enchondroma.

- 1 – Low risk (<15%) of mets. Eg. Giant cell tumor, Osteoblastoma
- 2 – High risk (>15%) of mets. Eg. High grade Osteosarcoma

Local Extent

A – Intra compartmental

B – Extra Compartmental

Metastasis:

III: Metastasis present

### **OO: Osteoid Osteoma**

Benign reactive bone lesion, less than 2 cm. Nidus is richly innervated, thereby painful. Intense night pain. Rx Aspirin.

**Age:** 75% between 5-20 years old. Rarely under 5 or over 40.

**Site:** 80% intra or juxta cortical long bones (femur, tibia). 10% intra spinal (posterior element, painful scoliosis).

**X-Ray Pattern:** round nidus surrounded by intense blastic reaction (less sclerotic in rarer intramedullary). Hot bone scan. Nidus on CT.

**Pathology:** Pea shaped nidus (red early vascularized. Yellow white in mature mineralized). Dense reactive bone surrounds it.

**Histology:** Irregular non-malignant trabeculae rimmed by regular osteoblasts in a rich vascular stroma (many giant cells).

**Differential:** Infection, stress fracture, cortical chondroma, spondylolysis.

**Treatment:** NSAID, accurate location and removal of nidus, Some may mature and disappear without treatment.

### **OC: Osteochondroma**

Most common benign tumor of bone (10% all primary bone tumor).

**Age:** usually under age 20.

**Site:** Metaphyseal. Most often around the knee or shoulder. Multiple hereditary always found at knee.

**X-Ray pattern:** Bone excrescence with continuity of periosteum, cortex, and marrow coming off of normal host bone, either sessile or pedunculated (points away from joint).

**Pathology:** Normal bony projection with a cartilage cap with overlying bursa.

**Histology:** Normal bone and cartilage cap.

**Differential:** Periosteal sarcoma, chondrosarcoma, myositis ossificans, fibrous dysplasia (v. sessile type).

**Treatment:** resection for painful or bothersome lesion. Only 1% malignant transformation, but 10% occurrence with multiple hereditary exostosis indicates serial x-ray or bone scan follow up.

### **EC: Enchondroma**

Benign cartilage tumor. 2% of primary bone tumors. Most common tumor found on the hands and feet.

**Age:** 2<sup>nd</sup> and 5<sup>th</sup> decades mostly.

**Site:** Metaphyseal. 50% in long bones. Esp knee or shoulder, 50% in hands and feet.

**X-Ray Pattern:** Radiolucent cauliflower shaped. Lobulated or scalloped margin. Matrix calcified as punctuate, stippled, or ring-like. 3-4cm of long bone, smaller in hand or foot.

**Multiple lesions:** Ollier's disease. Often leg length problems.

**Marfucci's syndrome:** longitudinal striated bone ends with soft tissue hemangiomas or phleboliths.

**Malignant transformation:** 25% of Ollier's and almost 100% of Marfucci's. Rare in solitary.

**Differential:** bone infarct, chondromyxoid fibroma, GCT, ABC, UBC

**Pathology:** islands of benign mature cartilage encased by lamellar bone.

**Histology:** lacks any malignant features (no double nuclei, not hypercellular, no mitosis etc...)

**Treatment:** curettage and bone graft.

**SBS: Simple Bone Cyst**

True bone cyst. Epithelial lines. Protein rich fluid. Benign but likely to recur especially under age 10. 65% associated with pathologic fractures in kids.

**Age:** almost exclusively children (under age 20)

**Site:** 95% arise in central metaphysis next to physis. Expands and migrates toward diaphysis with bone growth. 65% in proximal humerus; 25% femur, prox tibia.

**X-Ray:** Radiolucent, well defined. Central metaphysis. Symmetric. Expansion and symmetric thinning of cortex. Sharp or fairly sharp borders (vs OS or ABC). Uni or multi loculated. Often >5cm. MRI shows fluid filled. Fallen fragment sign is fracture. Fracture occurs in 2/3 of cases. Shepherd's crook in femur malunion .

**Pathology:** True bone cyst. In theory a "synovial rest." Membrane lining (vascular connective tissue with scattered osteoclast like GC's). Filled with clear or sanguinous protein rich fluid. 10% cementum in walls.

**Differential:** Lytic OS, ABC, EG, Fd, Ob.

**Treatment:** Methylprednisone (scaglietti). Curette and bone graft. Fracture treatment (only 15% heal spontaneously).

**Prognosis:** Under 10- unpredictable recurrence. Over 10 – 80% success rate with treatment

**OS: Osteosarcoma (conventional type)**

Second most common primary bone malignancy (15%). Variable (protean) appearance. Malignant osteoid and/or woven bone. Highly virulent. Pain and/or swelling. Pathologic fracture.

**Age:** 85% under 30. Peak 15-25 years old. Important pediatric malignancy.

**Site:** knee 50%, shoulder 10%, metaphyseal 90%. Very rare in spine, ribs, phalanges.

**Xray Pattern:** remember proteus! Classic look: large cumulus clouds of bone, periosteal reaction (Codman's, sunburst), soft tissue mass, cortical break through. Rarer look: more lytic, no soft tissue mass. 10% diaphyseal. Even rarer 1% epiphyseal.

**Pathology:** Large, destructive, variably gritty. Color of OS varies with % tissue content – more bony (yellowish white), more fibrous (white), more necrosis (grey), more hemorrhagic (dark red), more cartilage (bluish, translucent), former hemorrhage and or giant cells (tan).

**Histology:** highly variable. Presence of malignant stromal cell produced osteoid, some (variable) bone formation, permeation through marrow and bone. Less aggressive OS with minimal cell atypical (R/O early fracture callus, Ob), rich in reactive giant cells (R/O GCT), rich in hemorrhage and cystic spaces (R/O ABC), rich in small cells with minimal bone (R/O Ewings), rich in cartilage (R/O CS). Rich in epithelious (R/O met CA), rich in histiocytes (R/O malignant fibrous histiocytoma).

**Treatment:** A most malignant tumor. 85% lung mets at Dx. Surgery along – less than 2 years.

Adjunct chemo and limb salvage (if possible). 60-70% 5 years. Death secondary to pulmonary mets.

**MM: Multiple Myeloma**

Malignant marrow plasma cell tumor.

**Incidence:** most common primary bone tumor (50%).

**Age:** mean 65. Almost all over 40.

**Locus:** in the red marrow. 90% axial (skull, spine, ribs). 10% long bones (femur, humerus).

**X ray appearance:** typical multiple punched out lytic lesions (1-3 cm). atypical is generalized osteopenia.

**Distinguishing marks:** 99% lack sclerotic margins. Often negative bone scan (solved on MRI), 1% sclerotic in POEMS syndrome (polyneuropathy, organomegaly, endocrinopathy, myeloma, skin changes).

**Differential:** multiple-mets, osteoporosis, hyperparathyroid; solitary giant cell, chondrosarcoma, renal or thyroid CA.

**Pathology:** bone marrow aspirate – fields of round cells. Plasma cells immature, atypical. ID staining. Abnormal beta and gamma globulin chains (urine Bence Jones, serum protein electrophoresis).

**Treatment:** 1) radiation and chemotherapy (prednisone and alkaran) 2) fracture surgery for actual or impending pathologic fracture.

### **M: Metastatic Bone Disease**

Malignancy occurring secondarily in bone, Metastatic from some primary organ site.

**Incidence:** secondary bone malignancy 20X more common than primary malignancies altogether.

Commonest: breast, prostate, lung, renal, thyroid

**Age:** most over age 50. Rarely under 30 except for neuroblastoma seen under age 5 (R/O Ewings)

**Locus:** predilection for skeleton via Batson's plexus. 90% spine. Ribs, pelvis, hip, humerus also high.

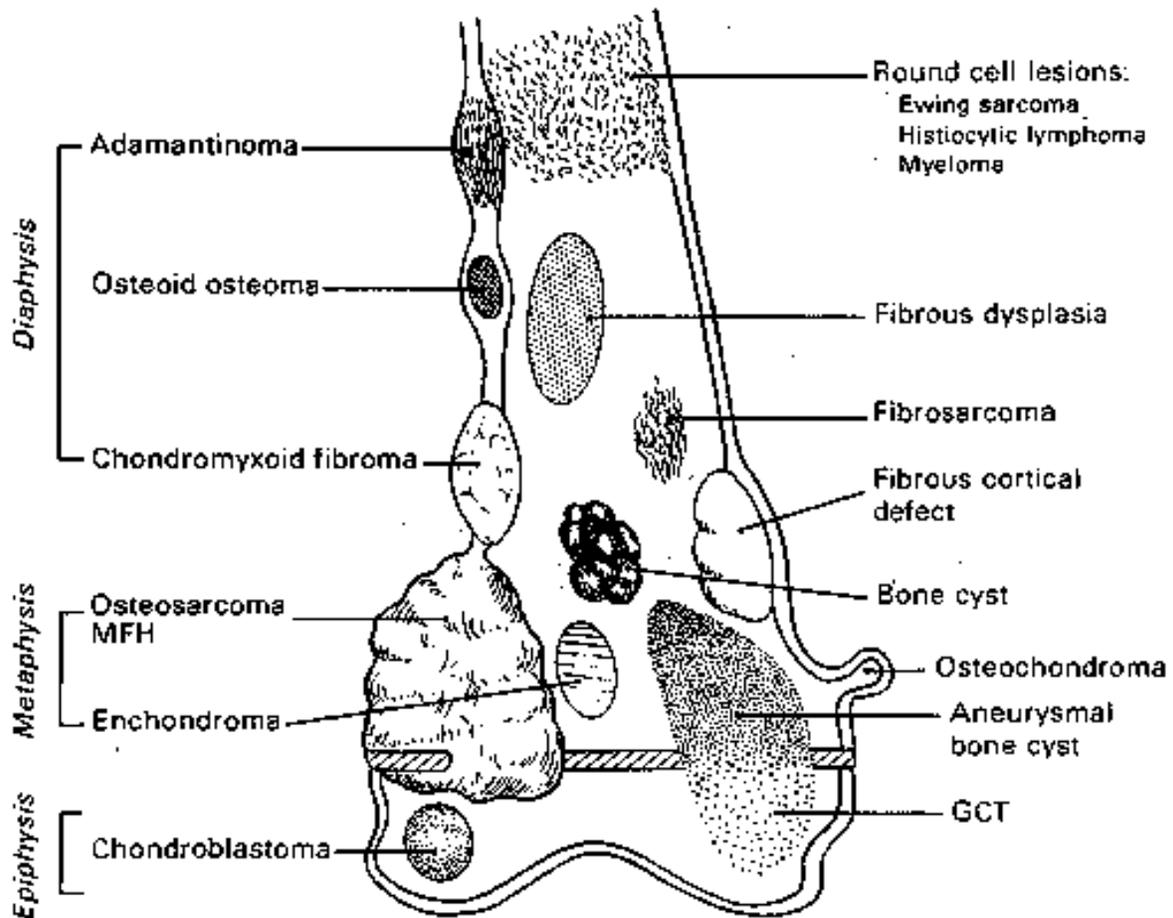
**X-Ray appearance:** lytic: lung, kidney, breast, thyroid, GI. Blastic: prostate, scirrhous breast, bladder, GI. Mixed: breast, lung, prostate, bladder. Oat Cell. Bone scan highly sensitive (25% normal plan films). MRI. CT good for selective evaluation.

**Distinguishing Marks:** monostotic blow out lesion: kidney, thyroid. Peripheral or acra (hands, feet): lung, kidney. Ivory Vertebrae: prostate. Lost pedicle: lung oftentimes.

**Differential:** multiple myeloma, melanoma, primary sarcoma.

**Pathology:** a metastatic carcinomatous tumor, usually squamous or glandular pattern (less often spindle) – usually surrounded by dense fibrous stroma. Immune staining helps ID.

**Treatment:** radiation and chemo. Palliative surgical fixation or prosthetic resection.



## APPENDIX G: DIRECTIONS

### FROM METRO HEALTH HOSPITAL TO METRO HEALTH SW PLAZA

Total Estimated Time: 6 minutes

Total Estimated Distance: 3.12 Miles

1. Start out going NORTH on Byron Center AVE SW toward MAIN ST. 1.9 MI
2. Turn RIGHT onto 44<sup>th</sup> ST SW 0.7 MI
3. Make a U-Turn onto 44<sup>th</sup> ST SW 0.5 MI
4. End at 2215 44<sup>th</sup> St SW Ste 100  
Wyoming, MI 49519

### TO METRO HEALTH HOSPITAL TO METRO HEALTH ROCKFORD

Total Estimated Time: 29 Minutes

Total Estimated Distance: 23.20 Miles

- |     |   |         |
|-----|---|---------|
| 1.  | Start out by going NORTH on BYRON CENTER AVE SW toward MAIN | ST      |
|     | 0.4MI   |         |
| 2.  | Turn RIGHT onto GEZON PKWY SW                               | 2.2 MI  |
| 3.  | Turn SLIGHT RIGHT onto 54 <sup>th</sup> ST SW               | 0.3 MI  |
| 4.  | MERGE onto US-131 N toward GD RAPIDS                        | 12.8 MI |
| 5.  | Take the WEST RIVER DR exit, EXIT 91                        | 0.5 MI  |
| 6.  | Turn LEFT onto W RIVER DR NE                                | 2.1 MI  |
| 7.  | W RIVER DR NW becomes W RIVER RD NE                         | 2.0 MI  |
| 8.  | W RIVER RD becomes W RIVER DR NE                            | 0.0 MI  |
| 9.  | W RIVER DR NE becomes W RIVER RD NE                         | 0.6 MI  |
| 10. | Turn LEFT onto MI-44 E/ NORTHLAND DR NE                     | 1.2 MI  |
| 11. | Turn LEFT onto Northland DR NE                              | 1.1 MI  |
| 12. | Turn RIGHT onto BELDING RD NE                               | 0.1 MI  |
| 13. | END at 4685 Belding Rd NE<br>Rockford, MI 49341             |         |