Skills Lab
for orthopedic trauma surgeons

Participant Booklet
Scientific Editor: Emanuel Gautier
Frequently asked questions (FAQs)

Topic: using a screwdriver

What is coupling?
Adequate coupling allows better control and torque application. It prevents the destruction of the coupling mechanism, which, if damaged, will present problems at the time of implant removal.

How do I hold a screwdriver properly?
Holding the screwdriver with two fingers, or with the whole hand, are the two most commonly used methods. Try these or a different method, and then discuss which technique allows more control and torque delivery.

Topic: tightening screws

What is the importance of obtaining optimal torque when tightening a screw?
Since implants are mechanical devices they function best under specific conditions. For cortex screws it has been proven that applying 60–85% of the maximal torque the bone allows, ensures adequate bone purchase without losing fixation (stripping of screws in overtightening, or a loose plate or screw in undertightening).

What happens if a screw is undertightened or stripped? Which is worse?
In both cases you lose fixation. If it is undertightened the screw will have some fixation although it will not be optimal, because load transfer through friction will be diminished. If you strip a screw it loses almost all of its fixation strength. So stripping a screw is worse than undertightening it.

Why can we not use a device that will allow us to restrict torque application on a cortex screw?
Purchase and fixation of cortex screws depends both on the screw and the bone quality. Since bone quality varies greatly from person to person it is impossible to develop such a device.

Is there any difference in tightening unlocked versus locked screws?
Locked screws fix directly to the plate; you do not get the feeling of cortical purchase that you get with cortex screws because they engage in the plate directly.

Does it make a difference which screw on the plate is wrongly tightened?
The screws immediately on either side of the fracture resist most of the pullout force on a plate, so it makes a difference to the plate fixation if you over- or undertighten these screws in particular.

What can be done if we accidentally strip a screw?
A stripped screw is useless, and can be either removed (and the plate hole left empty) or the screw can be repositioned in a different direction.

How can I achieve the skill of optimally tightening screws?
Practice either in simulations (as in this exercise), during surgery with an attending surgeon, or in surgery alone (by trial and error).
Test your surgical skill

Torque measurement of bone screws

Tasks

1. Insert electronic screwdriver into screw head so that it is properly engaged; leave screwdriver engaged in the same screw for the whole session
2. Tighten the screw until you feel you have reached optimal torque
3. Press the marked button on the screen
4. Now exceed optimal torque so that screw thread in bone is stripped
5. Press again the marked button on the screen and analyze result
6. Repeat steps using different screws and different bone models

Learning outcomes

- Feel and achieve optimal torque in different bone qualities
- Practice over- and undertightening of screws
- Investigate potential problems when inserting the screwdriver into the screw head

Take-home message

Optimal torque should be between 60% and 85% of maximum torque

Optimal tightening of screws

Screws need to be tightened between ~60% and ~85% of their maximum torque

- If torque is too high, the interface between screw and bone is destroyed and purchase is lost
- If torque is too low, the screw can’t transmit forces applied
Frequently asked questions (FAQs)

What happens if I plunge?
It means you have penetrated the soft tissue and can damage soft-tissue structures, such as vessels or nerves.

How do I avoid penetrating soft tissue?
There are several techniques to avoid plunging, such as using shorter drill bits or letting the K-wire protrude less from the collar chuck. It is also important to have sharp instruments to reduce the amount of pressure you put on the drill. Discuss if placing yourself in a different position or holding the drill with one or two hands has any effect on plunging. If time permits, try the exercise again, modifying these factors.

How do drill bits become blunt?
Drill bits not only become blunt by drilling through bone; they also become blunt with friction against other tools as they go through the cleaning/sterilization process and/or when they are inappropriately stored. An everyday example is your tool box at home where drill bits are separated into compartments in order that they are not in contact with each other. This is not only for presentation purposes but also to keep them sharp by avoiding contact friction.

When perforating metaphyseal or osteoporotic bone do you feel the second cortex?
You may not feel when your drill bit passes through the second cortex, as metaphyseal and osteoporotic bone have very thin and delicate cortices. You should be particularly careful when drilling through these bone types.
Test your surgical skill

**Soft-tissue penetration during drilling**

**Tasks**
1. Observe the difference between a sharp and a blunt drill bit
2. Drill hole through both bone cortices using sharp or blunt drill bits, or K-wire; try to minimize soft-tissue penetration
3. Check degree of damage done by soft-tissue penetration

**Learning outcomes**
- Learn to differentiate between sharp and blunt drill bits
- Develop feeling for penetration of opposite bone cortex and compare results using blunt and sharp drill bits or K-wires
- Assess possible damage to soft tissues and neurovascular structures

**Take-home message**
- Use sharp drill bits to avoid uncontrolled penetration into muscles, nerves, and vessels
- Blunt drill bits must be replaced

**Observe the surface of the very tip of the drill bit**
- Sharp: no reflection of light on the tip
- Blunt: light is reflected on the tip

**Method**
- Plasticine representing soft tissue
- Bone

**Measurement of depth of penetration**
- Plasticine representing soft tissue
- Bone

**Take-home message**
- Use sharp drill bits to avoid uncontrolled penetration into muscles, nerves, and vessels
- Blunt drill bits must be replaced

**Test your surgical skill**

**Soft-tissue penetration during drilling**
Frequently asked questions (FAQs)

Why does heat necrosis occur?
As the drill bit or K-wire rotates and passes through the cortex, friction occurs. Ultimately friction is the source of heat production (for example, heat is created by rubbing your hands together).

What factors influence heat generation?
Friction is what produces the heat so all those factors that produce more friction produce more heat. Hence, by using a bigger drill bit or K-wire there will be more surface area available subject to friction. The same thing happens with speed and feed rates: the sharpness of the instrument and the amount of pressure applied affects this rate. If you have a sharper drill tip and you put more pressure on it you will have a faster feed rate. Faster feed rates reduce the contact time of the two surfaces, thereby producing less friction and therefore less heat.

What can I do to prevent heat necrosis due to drilling?
Recent publications have shown [1] that one of the most effective ways to reduce heat generation (and thus thermal necrosis) is irrigation, which can easily be done in the operating room with saline. Another effective way of reducing heat is by having sharp drill bits, which also have the benefit of reducing soft-tissue penetration, as seen in station B (Soft-tissue penetration during drilling).

How does thermal necrosis alter bone fixation?
This can be easily understood by looking at the figure in the poster. Heat produces a conically shaped area of damage around the drill bit. This area is where the screw will get its purchase to the bone. If this area of bone is dead, it has to be remodeled with consequent loosening of screw anchorage. Dead bone is also an active culture site for infection.

Reference
Test your surgical skill

Heat generation during drilling

Tasks
1. Observe the difference between a sharp and a blunt drill bit
2. Drill hole through both bone cortices using blunt or sharp drill bits, or K-wire, with the assistance of the appropriate drill sleeve
3. Leave drill bit in place with tip sticking out
4. Observe on the screen, how the temperature develops
5. Repeat steps 1–4 with different drill bits or K-wires and compare results

Take-home message
- Use sharp drill bits to reduce heat generation and damage to bone
- Blunt drill bits must be replaced

Observe the surface of the very tip of the drill bit
Sharp: no reflection of light on the tip
Blunt: light is reflected on the tip

Learning outcomes
- Learn to differentiate between sharp and blunt drill bits
- Predict heat distribution in bone cortex
- Recognize and compare results from blunt or sharp drill bits or K-wires

Heat generated during drilling causes conically shaped volume of damage to the cortex

Take-home message
- Use sharp drill bits to reduce heat generation and damage to bone
- Blunt drill bits must be replaced

Cell necrosis as a function of temperature and duration of heat exposure

Cell necrosis

Heat generation during drilling

Temperatures
- 90°C
- 80°C
- 70°C
- 60°C
- 50°C
- 40°C
- 30°C
- 20°C
- 10°C
- 0°C

Time of exposure (sec)
0 10 100 1000

Bone

Cell necrosis

Sharpening

Blunt

Reflection of light

No reflection of light
Frequently asked questions (FAQs)

What is a torsional force? How does it produce a fracture?
In lay terms, a torsional force is a combination of horizontal and vertical shear stresses. This happens generally with rotational movements. To put it simply, a torsional force produces a fracture when one section of a bone is forced to rotate in one direction, and another section of the same bone is forced to rotate in the opposite direction.

How is this clinically relevant?
Knowledge about the amount, direction, and concentration of forces at the fracture site, and how the respective fracture patterns look, aids in patient treatment as this is an indicator of trauma energy and a marker for concomitant injuries and/or risk of soft-tissue damage, among other things.
Mechanics of bone fractures

Deformation and fracture pattern under torque

Tasks
1. Insert artificial tibia into fracture machine; tibia plateau goes to the right
2. Pull on the left lever to break the tibia under torque
3. Examine the fracture pattern created

Learning outcomes
• Describe deformation of material under torque
• Discuss typical fracture pattern under torque
• Describe orientation of compressive stress and tensile stress
• Discuss possible implications on soft-tissue envelope

Take-home message
Deformation under torque first creates a spiral fracture inclined 45° on the side under tension, then a longitudinal split on the side under compression

Deformation under torque
• Compressive stress inclined 45°
• Tensile stress inclined 45°

Fracture under torque
• Failure occurs first on side under tension resulting in a spiral fracture inclined 45° with respect to long-bone axis, then
• Longitudinal split on the side under compression
Frequently asked questions (FAQs)

What is bending?
For bending there is a compression (shortening) and a distraction (lengthening) side on the bone. It occurs when the applied force (direct blow) hits the bone on the center of the compression side, literally bending the bone. As bone can only tolerate a small amount of deformation, it will eventually fracture. The bone will fail first on the tension side producing a transverse fracture, and then on the compression side producing a butterfly (bending wedge) fragment or a small spike (incomplete fracture).

How is this clinically relevant?
Knowledge about the amount, direction, and concentration of forces at the fracture site, and how the respective fracture patterns look, aids in patient treatment as this is an indicator of trauma energy and a marker for concomitant injuries and/or risk of soft-tissue damage, among other things.
Mechanics of bone fractures

**Deformation and fracture pattern under bending**

**Tasks**
1. Insert generic bone tube into fracture machine with the smiley face visible
2. Pull on the lever to break generic bone under bending
3. Examine the fracture pattern created

**Learning outcomes**
- Describe deformation of material under bending
- Discuss typical fracture pattern under bending
- Compare compression and distraction sides
- Discuss possible implications on soft-tissue envelope

**Take-home message**
Deformation under bending first creates a transverse fracture on the side under tension, then an oblique fracture, with or without wedge, on the side under compression

**Deformation under bending**
- Shortening on the side under compression
- Lengthening on the side under tension
- Neutral zone in between

**Fracture under bending**
- Failure occurs first on the side under tension resulting in transverse distraction fracture, then
- Failure on the side under compression results in oblique fracture with or without bending wedge
**Frequently asked questions (FAQs)**

**What is axial compression?**
It is a load that is applied along the main axis of the bone. As the bone is compressed in one direction, it suffers a transverse expansion in the other, so as it gets shorter it gets wider. As a result, there is an oblique or a Y-shaped fracture pattern in addition to the depression. Usually this fracture pattern occurs in the metaphyseal zone of the bone as a result of a fall. There could be associated injuries along the path of the force.

**How is this clinically relevant?**
Knowledge about the amount, direction, and concentration of forces at the fracture site, and how the respective fracture patterns look, aids in patient treatment as this is an indicator of trauma energy and a marker for concomitant injuries and/or risk of soft-tissue damage, among other things.
Mechanics of bone fractures

**Deformation and fracture pattern under axial load**

**Tasks**

1. Place artificial cancellous bone in vice and apply axial load until it fractures.
2. Remove material from vice and examine fracture pattern.

**Learning outcomes**

- Describe deformation of material under axial load.
- Discuss typical fracture patterns under axial load.
- Distinguish between compressive, tensile, and shear stresses.
- Discuss possible implications on soft-tissue envelope.

**Take-home message**

The resultant stress of compressive and tensile stress is shear, which is the main reason for failure of bone in compression.

**Deformation under axial compression**

Deformation under axial compression creates not only compressive but also tensile stress, where the resultant of these is shear stress.

**Fracture under axial load**

- **Short bone**: oblique fracture or double oblique fracture with longitudinal split (see illustration).
- **Long bone**: buckling, similar to failure under bending (without illustration).

Orientation of compressive, tensile, and shear stresses.

The resultant stress of compressive and tensile stress is shear, which is the main reason for failure of bone in compression.
Frequently asked questions (FAQs)

What is callus and how does it make a fracture stable?
Callus is the scar the bone creates to heal itself. It is the 'classical' means by which a fracture consolidates. It has been called indirect bone healing and it comprises four phases: inflammation, soft callus, hard callus, and remodeling.

The body produces a mass of tissue surrounding the fracture (granulation tissue) that slowly becomes more rigid. Granulation tissue has a high tolerance against deformation but is not very rigid. A certain amount of movement is necessary for granulation tissue to form. It then differentiates into fibrous tissue, which is more rigid, then into cartilage, woven bone, and finally it becomes laminar bone, which is the most rigid and least flexible (stiff) of all. As the callus forms and matures, its cross section expands and it becomes more rigid, thus fostering stability.

As tissue differentiates, the amount of movement possible at the fracture site diminishes. This works as a cycle, since a more rigid construct promotes tissue differentiation into bone. However, if there is no motion, there is also no stimulus for the tissue to differentiate. The exact amount of motion or load, by which bone formation is promoted, is unknown. Too much or too little motion can produce nonunion, unless there is no motion from the beginning, in which case the fracture heals by different means, ie, direct bone healing.

Please check the back of all three cards for station E for a complete set of FAQs for this station.
Fracture healing

Mechanics of callus (1/2)

Tasks

1. Bend the two ends of the model, which represent bone fragments; note low stiffness.
2. To simulate soft callus formation, inject beads into the flexible middle portion of the model; note increase in stiffness.
3. To simulate tissue transformation, extend the other end of the model to extract air; note increase in stiffness.

Learning outcomes

- Identify the importance of the increasing cross-section.
- Identify the importance of tissue transformation between fragments.

Take-home message

- Apposition of callus leads to an increase of cross-section and thus of stiffness in the fracture zone.
- Callus transforms over time.

Transformation of callus

- Hematoma
- Granulation tissue
- Bridging bone at periphery
- Remodeling of callus
- Resorption of callus

Increase of cross-section of callus

No callus
- High angulation under external loading
  - High tissue strain, low stiffness

Callus
- Low angulation under external loading
  - Low tissue strain, high stiffness

From flexible to rigid
What is direct and indirect bone healing?
There are two paths a fracture can take to heal. In direct healing the bone heals without or almost without any callus formation. That means that the osteons (bone forming units) cross the fracture site as if there was no fracture at all. It is as if the bone ‘forgets’ there was a fracture. For this to happen there must be no movement at the fracture site (absolute stability).

In indirect healing a callus develops as explained in the answer to the first FAQ. Some movement (load) must be present in order for indirect healing to develop (relative stability). Once again the exact amount of movement required is unknown.

What other factors are involved in direct/indirect healing?
Besides the ‘movement’ condition (ie, absolute stability for direct healing and relative stability for indirect healing) both direct and indirect healing needs an adequate blood supply. This cannot be overemphasized. Preserving blood supply is one of the most (if not the most) important factors for achieving union. In the past, operative techniques called "biologic osteosynthesis" were developed that maximized blood supply preservation. This kind of technique should be used every time a fracture is treated, either by open, minimally invasive, percutaneous, or closed means.

Please check the back of all three cards for station E for a complete set of FAQs for this station.
Fracture healing

Mechanics of callus (2/2)

**Histological callus formation**

a. Periosteal and primary angiogenic bone formation

b. Bone formation far from fragment end in vascularized zone

c. Interfragmentary callus formation
How do movement at the fracture site, gap width, and tissue deformation relate to each other?
For any given movement (angulation) the gap width and the amount of cells in the gap will determine the amount of deformation each cell undergoes. To put it simply, the sum of all displacements per cell in a gap is equal to the total displacement of the whole gap. With more cells in a gap, the same displacement will cause less stress in each cell. Wider gaps will fit more cells in them, thus tolerating deformation better. This relationship between movement, gap, and deformation is not only true at a histological level. If, for example, strain accumulation between a three-part fracture and a highly comminuted fracture are compared, you will notice that with more comminution every fragment undergoes less strain and movement. Grasping this concept is essential to understanding the kind of stability needed for each fracture pattern.

Simple fractures have small gaps containing few parts. Allowing any movement can lead to high-stress concentration and deformation, which can lead to nonunion. With that in mind no movement (absolute stability) would be preferable to promote direct healing.

However, comminuted fractures have larger gaps and many parts, leading to low strain accumulation and very little movement in each fragment. Since only a small amount of movement is necessary for callus formation, comminuted fractures can be treated with relative stability and indirect healing. In theory, absolute stability could be provided to each fragment to promote direct healing in comminuted fractures. However, in order to fix each of the fragments, you would have to sacrifice blood supply, which is a key element in fracture healing. This method was used in the past, with operative techniques that strip the bone of its surrounding tissue and fix every part of the fracture together. This technique led to unacceptably high nonunion and infection rates.

How do absolute and relative stability relate to bone healing?
Absolute stability promotes direct bone healing, whereas relative stability induces indirect bone healing.

Please check the back of all three cards for station E for a complete set of FAQs for this station.
Fracture healing

Mechanics of interfragmentary tissues

Tasks
1. Slowly pull granulation model horizontally from one side
2. Note degree of cell deformation as a function of initial gap width

Learning outcomes
• Define absolute and relative stability
• Define the importance of initial gap width onto cell deformation under the condition of relative stability
• Define the effect of tissue differentiation on deformation

Take-home message
Under relative stability the cells in a small fracture gap can be destroyed because of too high strain

Model
Granulation tissue with cells between two bone fragments

Cell deformation under bending
(not shown in demonstration)
• Compression or distraction of cells in the gap under bending
• Cell destruction when elongation exceeds one cell unit

Cell deformation under traction
• Numbers indicate cell diameter units
• In each step, the gap is increased by 1 unit
• Relative deformation of the cells is shown

Cell destruction

Increase 1 cell unit
Increase 2 cell units
Why do we have different reduction techniques?
In order to understand reduction one must also take into account what kind of fixation and stability is going to be used. In that order there will be some discussion on the difference between anatomical reduction and anatomical alignment (according to articular vs nonarticular fractures) and between absolute and relative stability (a topic discussed at station E: Fracture healing).

What is anatomical reduction and anatomical alignment?
Anatomical reduction is a technique where you put back together all the fracture fragments in their original anatomical positions to reestablish the original shape and form of the fractured bone. Anatomical reduction is used to reduce articular fractures.

Anatomical alignment refers to reestablishing the original axis of the bone without as much regard to the exact position of every fragment. It is used in metaphyseal and diaphyseal fractures.

How is all this clinically relevant?
The surgical treatment of a fracture comprises three main steps that ought to be included in a complete preoperative plan: surgical approach, fracture reduction, and fracture fixation. Reducing the fracture is one of the difficult steps in this surgical process and is often underestimated. Since there are many reduction techniques and reduction-aiding devices, getting to know and adding them to your surgical arsenal is important if you want to successfully reduce any kind of fracture. Developing a refined surgical reduction technique that respects the biological principles of fracture fixation (open, closed, or minimally invasive) is a major step in becoming an accomplished surgeon.
Techniques of reduction

Direct and indirect reduction

Tasks
Examine bone models; reduce fractures directly or indirectly, according to fracture pattern, location, and surgical approach

Learning outcomes
• Differentiate between direct and indirect reduction
• Relate both techniques to specific indications and bone segments

Take-home message

Direct reduction
• Fracture site is exposed, hands or instruments directly manipulate fracture fragments
• Reduction achieved is directly visible

Indirect reduction
• Fracture site is not exposed, reduction is performed by applying corrective forces and moments at a distance from the fracture
• Reduction is checked clinically or using image intensifier, x-rays

Metadiaphyseal segment
Indirect reduction to obtain
• Length
• Axial alignment
• Rotational alignment

A diaphyseal fracture is a black box
• No visualization
• No direct contact

Articular segment
Anatomical reconstruction of the joint surface

Direct reduction

Indirect reduction, ligamentotaxis
Frequently asked questions (FAQs)

Why do we have different reduction techniques?
In order to understand reduction one must also take into account what kind of fixation and stability is going to be used. In that order there will be some discussion on the difference between anatomical reduction and anatomical alignment (according to articular vs nonarticular fractures) and between absolute and relative stability (a topic discussed at station E: Fracture healing).

What is anatomical reduction and anatomical alignment?
Anatomical reduction is a technique where you put back together all the fracture fragments in their original anatomical positions to reestablish the original shape and form of the fractured bone. Anatomical reduction is used to reduce articular fractures.

Anatomical alignment refers to reestablishing the original axis of the bone without as much regard to the exact position of every fragment. It is used in metaphyseal and diaphyseal fractures.

How is all this clinically relevant?
The surgical treatment of a fracture comprises three main steps that ought to be included in a complete preoperative plan: surgical approach, fracture reduction, and fracture fixation. Reducing the fracture is one of the difficult steps in this surgical process and is often underestimated. Since there are many reduction techniques and reduction-aiding devices, getting to know and adding them to your surgical arsenal is important if you want to successfully reduce any kind of fracture. Developing a refined surgical reduction technique that respects the biological principles of fracture fixation (open, closed, or minimally invasive) is a major step in becoming an accomplished surgeon.
Techniques of reduction

Use of reduction clamps

Tasks
1. Examine a variety of reduction clamps/forceps
2. Apply different tools at different anatomical sites

Learning outcomes
- Identify the degrees of freedom for each clamp
- Recognize difficulties in the application of the different devices
- Analyze biological advantages and shortcomings of different clamps

Take-home message
Use proper tools according to the anatomical and technical conditions

Pointed reduction clamps
- Matta clamp
- Weber clamp

Toothed reduction clamp
- Spanier clamp

Pelvic reduction clamps
- Faraboeuf clamp
  - Compression
  - Shear
  - Pull and push
- Jungbluth clamp
  - Compression and distraction
  - Shear
  - Pull and push

Bone holding clamp
- Verbruge
  - Reduction onto the plate
- Compression
  - Pulling the plate end towards the screw

Collinear reduction clamp
- Allows minimally invasive direct reduction
Frequently asked questions (FAQs)

How does an IM nail work?
Depending on the fracture pattern and the final bone-nail construct, an IM nail works as an internal splint with more or less load-sharing characteristics. If cortical contact between the main fracture fragments is achieved after reduction, most of the load will pass through the bone. Nails provide relative stability and are the standard of care for diaphyseal long-bone fractures. Since nailing provides relative stability, then you would expect healing by callus formation.

Why should I lock the nail?
Locking the nail allows better control of torsion and length, and load sharing through the bolts. A nail that is not locked depends on the contact (friction) between the nail and the bone to restrict motion of the fragments (radial preloading), whereas a locked nail will share the load through the nail-bolt and the bolt-bone interface, achieving a more stable construct.

How do the shape and the size of a nail affect its biomechanics?
Shape and size of a nail are important factors that determine its biomechanical characteristics. Nail rigidity is proportional to its diameter. That means that the broader the nail, the harder it is to bend and/or break. The shape of the nail dictates how it will behave as it contacts the surrounding cortical bone. A slotted nail increases the radial compression (when introduced in a canal smaller in diameter than the nail) thus increasing friction and contact stresses to the cortical bone. Slotting has the disadvantage of reducing torsional stiffness, a problem that is dealt with by locking the nail.

Please check the back of all three cards for station G for a complete set of FAQs for this station.
Mechanics of intramedullary fixation

**Nail design**

**Tasks**
Examine various nail designs; discuss the advantages and disadvantages of each

**Learning outcomes**
- Describe different nail designs and their mechanical characteristics
- Explain radial preload and corresponding concept of stabilization

**Take-home message**

**Nail designs**
- Slotted nail with cloverleaf section
- Solid nail
- Cannulated nail
- Prevot nails

**Connection of nail to bone with radial preload needs**

**Slotted nail**
- A slotted nail increases the radial preload

**Reaming**

**Mechanics**
- Cylindrical medullary cavity
- Long-distance contact between bone and nail

**Biology**
- Necrosis of the inner two thirds of bone cortex
Frequently asked questions (FAQs)

What is radial preload?
Radial preload is the elastic deformation of a nail with respect to its cross-section. It provides high friction between nail and bone which allows it to anchor. It is mainly achieved with slotted nails.

What is reaming and what advantages/disadvantages does reaming have?
Reaming is drilling the IM channel. It enlarges the endosteal diameter of the bone. It helps to increase the contact area between bone and nail by smoothing the internal aspect of the cortical bone. It also allows for a bigger nail to be inserted, thus improving bending and torsional stability. Another advantage of reaming is that the debris produced by the reamer, to a certain degree, acts as an autologous bone graft that can help the fracture heal faster. However, reaming also has disadvantages. It disturbs endosteal circulation by physically destroying the medullary vessels and by heat generation. In addition, during reaming the IM pressure elevates, raising some concern about fat embolism. This should be taken into account especially in patients with concomitant injuries, such as blunt thoracic trauma or ADRS.

Please check the back of all three cards for station G for a complete set of FAQs for this station.
### Take-home message

#### Nailing without interlocking

**Needs**
- Nail with proper length and diameter

**Prerequisites**
- Fractures in middle third of diaphysis
- Partial contact between main fragments

Be aware of the need for adequate rotational stability

### Residual instability

#### Nail too short
- Nail does not engage in the distal metaphysis
- Distal fragment unstable

#### Nail too thin
- No contact between nail and bone in fracture zone
- No radial preload
- Instability at fracture site

---

### Tasks

Examine stability of different nail constructs

### Learning outcomes

- Describe indications for nailing without interlocking
- Identify common problems using nails that are too short or too thin
- Describe possible problems of nailing without interlocking
What is static and dynamic locking and how does it affect fixation?

Interlocking bolts placed proximally and distally to the fracture site restrict translation and rotation, providing a stable environment for the fracture to heal. Since there is a small amount of motion at the nail-bolt interface some movement of the fracture is expected. This explains why interlocked nails provide relative stability, relying on callus formation for the definitive healing of the fracture. As seen in Station E: Fracture healing, for a callus to be formed some micromovement at the fracture site should be present.

Dynamic locking allows more movement than static locking. It allows compression forces at the fracture site when the patient bears weight. With that in mind, some conditions have to be fulfilled before locking a nail dynamically. There must be contact between the fracture fragments, either by direct cortical contact (as in transverse fracture patterns) or by means of a soft/immature callus (as in delayed unions) so that the fracture itself has some stability and could benefit from the compression. If the fracture is not stable enough, it will not benefit from the extra motion and nonunion may result, thus static locking is needed in such cases.

Please check the back of all three cards for station G for a complete set of FAQs for this station.
Mechanics of intramedullary fixation

**Interlocked nailing**

**Tasks**
Examine stability of different nail constructs

**Learning outcomes**
- Describe different nail locking options and possible influences on stability of fixation (dynamic locking, static locking)
- Explain elastic stable intramedullary nailing

**Take-home message**

**Dynamic interlocking**
Requires partial contact between main fragments

**Static interlocking**
In case of no contact between main fragments

**Dynamic interlocking**
- Only distal screws
  - Nail can stick out proximally

**Static interlocking**
- Distal and proximal screws
  - Control of length
  - Control of axis
  - Control of torsion

**Elastic stable intramedullary nailing**
- For diaphyseal and metaphyseal fractures in children
- Minimally invasive
- Elastic nail
- Different diameters
- Precontouring needed
Frequently asked questions (FAQs)

**How does plate length influence screw loading?**
Plates work on screws as a first class lever. In a longer plate the lever arm of the screw is improved and thus the pullout force is reduced. On the other hand, shorter plates act with a short lever arm resulting in high pullout forces on the last screw.

**What is load sharing? Is there any load sharing with plate fixation and if so, under what condition?**
Load sharing means that when a bone with an implant is loaded, the load passes through both the implant and the bone. Load sharing can only happen in plate fixation when there is contact between the bone fragments. For example, if a plate is on the tension side of the bone and a bending load is applied, the compression forces will be handled by the bone while the tension forces will be controlled by the plate. If there is no stable bone contact between the fragments (there is a gap or severe comminution), no load sharing will occur and the entire load will pass through the plate (load shielding). Depending on the fracture pattern and the type of reduction and/or fixation technique that is used, a load sharing or load shielding construct can be achieved. This means that load sharing is not necessarily a good or a bad thing; it can be both depending on the personality and needs of each fracture.

Please check the back of all three cards for station H for a complete set of FAQs for this station.
Mechanics of plate fixation

**Loading of the plate screws**

### Tasks

1. Compare screw holding force by weighting each plate model
2. Compare effect of working length of screws by rotating handles on the three bone-plate constructs

### Learning outcomes

- Explain how lever arm influences screw loading
- Define the term “screw working length”

### Take-home message

- Short lever arm = high pull-out force on the screw
- Long working length = low stress on the screw

---

**Lever arm and pull-out force**

**Long lever arms decrease screw loading**

A short lever arm leads to a high pull-out force on the screw. Increasing the lever arm reduces the pull-out force.

### Working length of screw

**A short working length** exists when there is thin bone cortex or monocortical screw insertion. This results in **high stress** at the interface.

**A long working length** exists when there is thick bone cortex or bicortical screw insertion. This results in **low stress** at the interface.

Length of screw thread in contact with bone influences stress at screw-bone interface.
How does a gap influence plate fixation?
The main influence a gap has is that it changes the loading and deformation of the plate and alters plate-bone construct stiffness. As explained before, with no bone contact a load shielding construct is achieved where the entire load is absorbed by the plate, thus increasing the risk of plate fatigue failure. The size of the gap is related to the magnitude of deformation; greater gaps without any bone contact allow more fracture angulation and thus high plate deformation. For a given gap size, the presence of intercalated bone fragments (ie, comminution, callus) that reduce the maximum possible angulation will reduce plate deformation. But even small gaps can produce high stress concentration and plate deformation, depending on the span width. With simple fracture patterns, if no compression is achieved and a small gap is left, the distance between the inner screws (the span width) defines the loading of the plate. Screws close to the gap will allow for a short segment of the plate to be loaded with stress concentration in that area and high plate deformation.

What is the working length of a screw?
The working length of the screw is the threaded zone of each screw that is anchored in bone. It influences the stress in the bone-screw interface. Longer working lengths are achieved with thick cortical walls and bicortical screw purchase, whereas low working lengths are present in thin (osteoporotic) bone and in monocortical screws.

Please check the back of all three cards for station H for a complete set of FAQs for this station.
Mechanics of plate fixation

**Stiffness of plate fixation**

### Tasks
Test bending stiffness of plate-bone models under different bending directions or plate positions

1. Plate on tension side
2. Plate in lateral position
3. Plate on compression side

### Internal fixation without gap
Bending of plate-bone construct; different bending directions

1. **Load sharing**

2. **Partial load sharing**

3. **No load sharing**

### Internal fixation with large gap
No load sharing for all bending directions

1. **No load sharing**

2. **No load sharing**

3. **No load sharing**

### Learning outcomes
- Explain principle of load sharing between implant and bone
- Identify influence of a fracture gap on stiffness of fixation and on plate loading
- Explain the influence of the bending direction on the load sharing of the plate-bone composite construct

### Take-home message
To share load, an implant must be attached to the **tension side** of the bone
Frequently asked questions (FAQs)

How is all this clinically relevant?
Depending on the fracture pattern and the type of fixation needed, understanding the principles explained here can lead to better surgical technique that avoids unnecessary failures. For example, simple fracture patterns can be reduced ensuring tight bone contact which produces a load sharing construct. On the other hand, when dealing with severe comminution or bone loss, adequate screw placement and loading protection (ie, long weight-bearing protection) are necessary to reduce the probability of plate failure. Finally, keeping in mind that longer plates reduce pullout forces and that a long screw working length improves the bone-screw interface, reducing the stresses at this level is key in choosing the right plate size for each fracture and ensuring bicortical purchase of the screws.

Please check the back of all three cards for station H for a complete set of FAQs for this station.
Mechanics of plate fixation

**Loading of the plate**

### Tasks
1. Test bending stiffness of plated bone models by loading each with your hands
2. Compare and discuss

### Learning outcomes
- List reasons for plate failure
- Identify actions to avoid plate failure
- Explain importance of overspan width and screw position on plate loading

### Take-home message
- Short segments of plate will break under repetitive stress
- Incarcerated bone fragments lead to load sharing

---

#### Plate loading and overspan width

**Small gap** with screws inserted *close* to gap
- Short segment of plate loaded
- Stress concentration

---

#### Gap width and plate deformation

A large gap leads to high angulation and thus a high deformation of the plate under load

**Small gap** with screws inserted *at a distance* from gap
- Long segment of plate loaded
- Stress distribution

---

Incarcerated bone fragments, even with relatively loose connection to soft-tissues, reduce maximum angulation and thus plate deformation
Frequently asked questions (FAQs)

What is a composite beam system?
A composite beam system is a construct of two or more separate beams connected to each other. By connecting the beams their resistance to bending is multiplied by eliminating the shear stress between them.

How does a composite beam system relate to plate fixation?
Plate fixation is a composite beam system in which the plate (one beam) is connected to the bone (second beam) by screws. As the two structures are connected, shear stresses are reduced and the stiffness of the construct is greatly improved.

What elements contribute to the flexibility and stability of plate fixation?
Almost every element that is involved in plate osteosynthesis contributes in one way or another to the construct's stability and flexibility. Plate characteristics (ie, locking vs conventional plate, steel vs titanium), plate position (tension or compression side), plate size (cross-section and length), screw characteristics (size, number, anchorage), bone characteristics (quality, cross-section), fracture pattern (simple vs complex and comminuted bone defects), and fixation technique (compression, bridging, buttress, or neutralization plate) all play an important role in the biomechanical behavior of a specific osteosynthesis construct and in the healing process of the bone.

How is all this clinically relevant?
Understanding the principles of plate fixation is necessary to create an adequate preoperative plan and choose the right implant for every specific fracture and patient.
Mechanics of plate fixation

Stiffness of composite beam systems

Tasks
Compare stiffness of beam models

Learning outcomes
- Describe the bending stiffness of isolated beams with respect to composite beams
- Recognize plate fixation of fractures as a composite beam system
- Describe importance of plate position on overall stiffness of internal fixation using plates

Take-home message
- Plate alone is relatively weak
- Stiffness of plate depends on bending direction
- Important increase of bending stiffness when bone and plate are tightly connected
- Composite system with plate on tension side is the most rigid construct under the condition that the fracture can be axially loaded

In plate osteosynthesis stiffness¹ and strength² depend on these elements

<table>
<thead>
<tr>
<th></th>
<th>Bone</th>
<th>Fracture</th>
<th>Plate</th>
<th>Screws</th>
<th>Fixation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Cross-section</td>
<td>- Simple versus comminuted fracture</td>
<td>- Cross-section</td>
<td>- Anchorage</td>
<td>- Splinting</td>
</tr>
<tr>
<td></td>
<td>- Quality of bone</td>
<td>- Contact versus noncontact situation</td>
<td>- Material</td>
<td>- Number and position</td>
<td>- Compression</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Bending direction</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ stiffness = the ability of a material to withstand deformation
² strength = the ability of a material to withstand destruction
Frequently asked questions (FAQs)

How do you prevent coupling problems when removing a screw?
The main way to prevent destroying the coupling mechanism of a screw is ensuring adequate screwdriver-screw coupling when placing and removing the implant. The surgeon must feel and see that the screwdriver has fully attached to the screw and has a good grip. When removing the implant, care should be taken to check that all tissue has been removed from the coupling hole to allow perfect matching between driver and screw. Turn the driver slowly with your hands while pushing it against the screw head. Feel if there is a good catch between the screwdriver and the screw. If it feels loose, recheck its position.

Ensure the adequate tools for removing the implant are available; that is, having a screwdriver that is the right size and shape. Do not use damaged screwdrivers. Finally, do not underestimate any surgical procedure. Always use a careful surgical technique and pay attention to every detail.

What should be done if a coupling problem develops or if a head breaks (or is broken)?
Ensure all the necessary instruments are available for difficult implant removal. If no instruments are available, consider rescheduling the surgery or reconsider the necessity of implant removal. Always remember that the first rule of medical action is do no harm, so always carefully consider a harm/benefit analysis when faced with failed implant removal.

Finally, remember to explain to your patient before the removal surgery that there is a possibility of failure to remove the implant. That way he/she will know there is always a slight chance that, even after the procedure, the implant may not have been successfully removed.
Damaged implant removal

Challenges and solutions

Tasks

1. **Destroyed coupling mechanism**
   - Insert conical extraction bolt (a) in screw head and try to remove screw

2. **Broken screw removal procedure**
   - Remove bone around screw with appropriate sized hollow reamer (b)
   - Use extraction tube (c) to remove screw shaft

Take-home message

- Use undamaged screw driver
- Clean hexagonal coupling mechanism of screw head
- Everything in the removal set is left threaded

Learning outcomes

- Identify the function of different instruments to aid screw removal
- Remove screw with destroyed coupling mechanism
- Remove broken screw

---

**Problem 1**
Destroyed hexagonal coupling mechanism of screw head

**Problem 2**
Broken screw, screw shaft stuck inside bone

---

Intact

Destroyed
Hazards and legal restrictions

Check hazards and legal restrictions on www.aofoundation.org/legal

Hazards

Great care has been taken to maintain the accuracy of the information contained in this publication. However, the publisher, and/or the distributor, and/or the editors, and/or the authors cannot be held responsible for errors or any consequences arising from the use of the information contained in this publication. Contributions published under the name of individual authors are statements and opinions solely of said authors and not of the publisher, and/or the distributor, and/or the AO Group. The products, procedures, and therapies described in this work are hazardous and are therefore only to be applied by certified and trained medical professionals in environments specially designed for such procedures. No suggested test or procedure should be carried out unless, in the user's professional judgment, its risk is justified. Whoever applies products, procedures, and therapies shown or described in this work will do this at their own risk. Because of rapid advances in the medical sciences, AO recommends that independent verification of diagnosis, therapies, drugs, dosages, and operation methods should be made before any action is taken. Although all advertising material which may be inserted into the work is expected to conform to ethical (medical) standards, inclusion in this publication does not constitute a guarantee or endorsement by the publisher regarding quality or value of such product or of the claims made of it by its manufacturer.