II Basic Sciences

BIOMECHANICS

Studying the structure and function of biological tissues through the application of mechanical laws.

Definitions

- **Statics:** Study of forces acting on a rigid body at rest or moving at constant velocity.
- **Dynamics:** Study of forces acting on a rigid body in motion.
- **Kinetics:** Study of forces acting on a rigid body to produce movement.
- **Kinematics:** Study of motion of a rigid body without reference to the forces causing the motion.
- **Kinesiology:** Study of human movement.
- **Vector:** a quantity that has both magnitude and direction. Length of the arrow is proportional to its magnitude.
- **Force:** Is a vector quantity that results in change of motion of an object. F = mass x acceleration
  - **Types:**
    - *Tensile*: acting away from the centre of the material.
    - *Compressive*: acting towards the centre of the material.
    - *Shear*: acting parallel (tangential) along the surface of the material.
- **Moment:** force acting at a perpendicular distance from a pivot or axis in a static model. M = F x d.
- **Torque:** rotational movement and angular acceleration generated by a force acting at a perpendicular distance from a pivot or axis. T = F x radius. E.g. a large femoral head in hip arthroplasty has a larger torque leading to more volumetric wear.
- **Hoop Stress:** generated when circumferential force acts perpendicular to the long axis of a cylinder wall.
- **Energy:** is a conserved quantity that presents the ability to do work.
  - **Types:**
    - *Potential:* the energy stored in a body influenced by its position relative to others.

      P.E. = mass x gravity x height.
    - *Kinetic*: the energy possessed by a moving body K.E. = ½ mass x velocity^2.
- **Isotropic:** mechanical properties of a structure are the same in all directions (e.g. metal, woven bone).
- **Anisotropic:** mechanical properties of a structure depend on the direction of loading (e.g. lamellar bone, ligament).

Newton's laws of motion

- **First Law:** An object remains at rest or moves at constant velocity unless acted upon by an external force.
- **Second Law:** The vector sum of the forces acting on an object is equal to the object's mass multiplied by its acceleration. F = ma.
- **Third Law:** Every force has an equal and opposite reaction force.

Working length

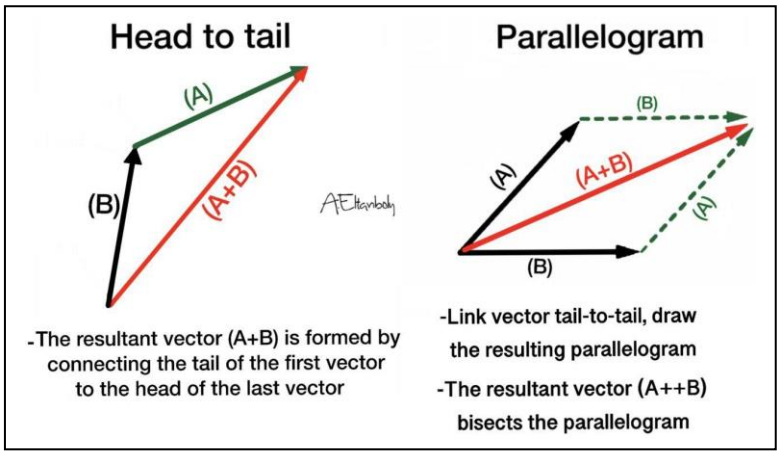
- Defines the unsupported length of a construct.
- The longer the working length, the less the stiffness of the construct as the stress is distributed over a longer portion of the implant.
- With plate fixation, the working length is the distance between the most distal fixation point in the proximal fragment and the most proximal fixation point in the distal fragment.
- In intramedullary nailing in which there's no isthmus contact, the working length is between the proximal fixation and proximal most distal bolt. When using a larger diameter nail with full isthmus contact, the working length is the sum of the unsupported length proximal and distal to the isthmus, thus giving a much stiffer construct.

Bending and torsional forces

- **Stiffness:** is the ability of a structure to resist deformation.
- **Rigidity:** is the ability of a material to resist deformation.
- **Second moment of inertia (I; m^4):** is a measure of the cross-sectional distribution of material in a structure, characterising its bending stiffness. Also known as area moment of inertia and relates to the X and Y axes only.
- **Polar moment of inertia (J; m^4):** is a measure of the the cross-sectional distribution of material in a structure, characterising its torsional stiffness. Also relates to the Z-axis of a structure.

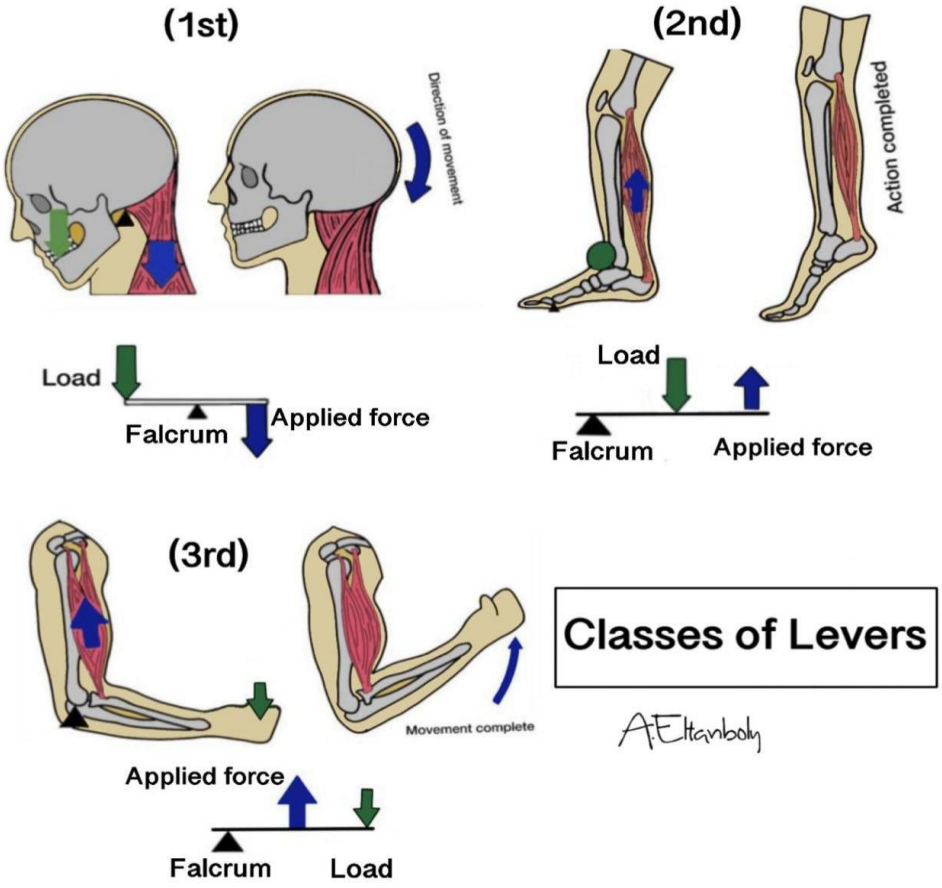
Forces and lever arms

- .A lever is a rigid structure that turns about a fixed point
- There are two methods by which to solve forces about a body:
  - **Trigonometry** used to calculate the value of the resultant force.
  - **Graphically** using either the head to tail or parallelogram method to plot the direction and value of the resultant force.



- There are three classes of levers:
  - **Class 1** (fulcrum is between the force and load): e.g. atlanto-occipital joint between erecter spinae and head. This is also the lever type found in a pair of scissors.
  - **Class 2** (load is between the force and fulcrum): e.g. body weight through the ankle, which lies between the calf muscles (generating the force) and the metatarsal heads (acting as the fulcrum) when standing on tip toes. A nutcracker utilises this class of lever. This is the most mechanically advantageous lever.
  - **Class 3** (force between fulcrum and load): e.g. elbow flexor muscles are between the elbow joint and the hand holding a load. This class of lever works well in situations that require speed and good range of motion.

> - Effort arm: this is the distance between the effort (muscle insertion site) and the fulcrum (joint or pivot point).
> - Load arm: this is the distance between the load (weight of the body part) and the fulcrum (joint or pivot point).
> - The lever system is more efficient muscle is an advantage (when effort arm is greater than the load arm. This explains why the calf muscles can lift more weight than the elbow flexors even when they are equally strong.



FREE BODY DIAGRAMS

- Method of determining the static forces and moments acting about a fulcrum by isolating the body part and ensuring a state of static equilibrium.
- Can't be used for dynamic equilibrium (defines a body remaining in the same state of motion).
- Equilibrium is achieved when the sum of the anticlockwise moments equals the sum of the clockwise moments.
- The centre of gravity in a standing human lies just anterior to S2 vertebral body.
- Force= mass x accerleration
- Weight= mass x gravity
- 1 Newton (N) is the force required to accelerate 1 kg mass to $1 m/s^2$.
- $1 Nm^{-2}$= 1 Pa (Pascal is a unite of pressure
- **Assumptions:**
  - Bones are rigid rods.
  - Joints are frictionless hinges.
  - No antagonistic musle action.
  - Weight of body is concentrated through the centre of mass.
  - Force acts in the direction of the muscle belly.
  - Muscles act only in tension.

- Internal forces cancel each other out.
- JRF is presumed to be compressive only.

❖ **Joint reaction force (JRF):**

- Vector sum of all forces acting on the joint.
- Forece generated within a joint in response to external forces from muscles contractions and body weight
- JRF = BW + Total muscle forces

❖ **Drawing free body diagrams:**

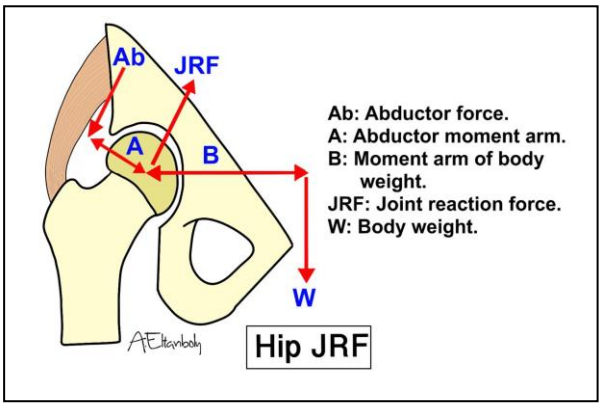
- The fulcrum respresents the joint of interest.
- Comprise a fixed segment and a mobile segment.
- Draw each force to scale at the eequired perpendicular distance from the fulcrum.
- Forces will create a clockwise or anticlockwise moment dependent on which side of the fulcrum they act.

Hip joint

❖ Class 1 lever.
❖ Femur is the fixed segment and the pelvis is the mobile segment when the patient performs a single leg stance.
❖ The body weight vector creates a clockwise moment about the hip joint.
❖ The abductor force vector acts anticlockwise to balance the pelvis.
❖ The abductor force acts at a distance 3 times closer to the fulcrum than the body weight (A = 5 cm Vs B = 15 cm).
❖ The body weight is 5/6th of the total weight in this model since the weight of the single leg is 1/6th.
❖ To calculate the JRF, you first need to calculate the F(Ab):

- **F (Ab) x A = F (BW) x B**
-) FAb] = (F) BW (x B / [A
- F(Ab) = [5/ 6th BW x15 / [5
- F(Ab) = 2. 5BW
- **JRF = F (Ab) + F (BW)**

❖ Coxa vara causes an increase in distance A and therefore reduces F(Ab) and the JRF.
❖ Valgus osteotomy causes a shortening of distance A and therefore increases F(Ab).
❖ Trendelenburg gait involves shifting the patient's body weight to reduce distance B and the resulting moment arm.



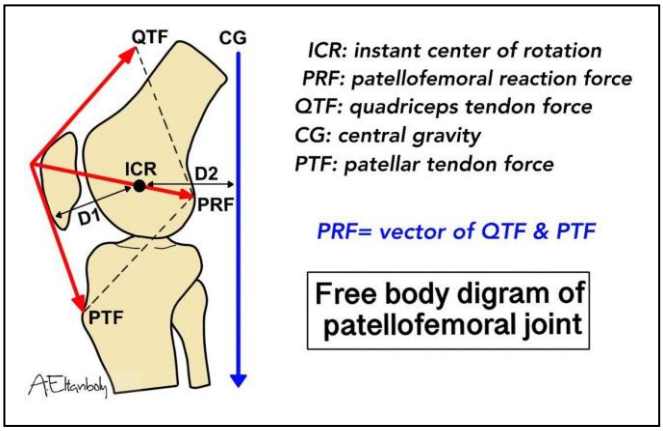
❖ **Ways to reduce the hip JRF:**

- Lose weight to reduce F(BW).
- Holding a walking stick in the contralateral hand (force equal and opposite to the ground reaction force) adds to the abductor moment (force equal and opposite to the ground reaction force) and reduces the .JRF by up to 60%
- Carrying a weight on the ipsilateral side adds to the anticlockwise moment therby reducing the effort needed by the abductor muscle and inttrum redcing the JFR
- In THR: medialise the acetabular cup to reduce the body weight lever arm and increase the femoral component offset to reduce the F(Ab), or lateralising the greater trochanter.

Knee joint

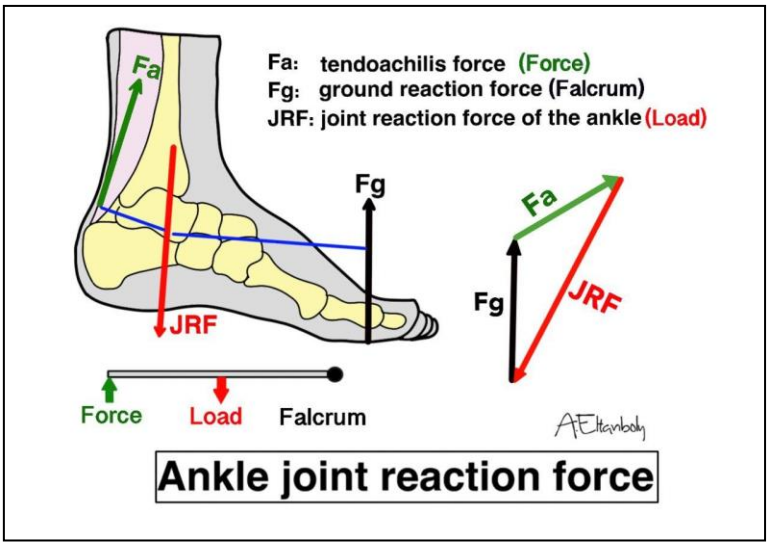
❖ Class 3 lever.
❖ The effort is at the tibial tuberosity where the patella tendon inserts.
❖ The knee joint is the pivot. Femur and tibia can be either the fixed or mobile component dependent on the case.

- There is an increased JRF with the knee in flexion due to the increase pull of the quadriceps muscles.
- **Patellofemoral joint (PFJ):**
  - The patella reaction force (PRF) is the sum of the horizontal force vector of the quadriceps and patella tendons
  - The quadriceps and patella tendon forces are .assumed to be equivalent
  - The JRF is greatest in deep flexion when the horizontal force vectors of both tendons are greatest.
  - Patellectomy reduces the quadriceps moment arm and so increases the quadreiceps .force



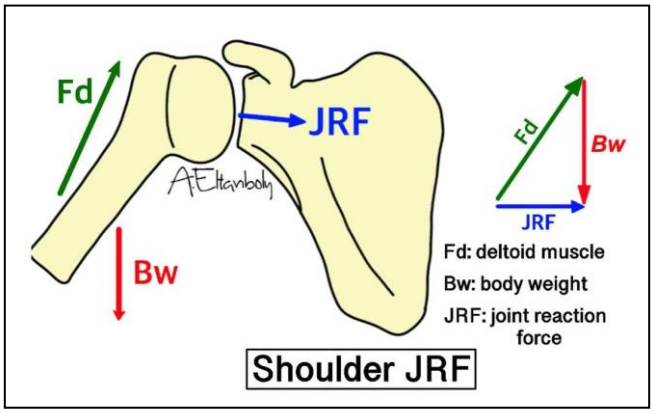
Ankle joint

- Class 1 lever at midstance. Class 2 lever at both heel strike and toe off.
- The heel, ankle and 1st MTPJ are all fulcrums during the gait cycle. The foot is typically fixed and the tibia is mobile.
- Ground reaction force is equal and opposite to the body weight. Used instead of body weight since the foot is in direct contact with the ground.
- Line of gravity is a few cm in front of the ankle joint and produces a dorsiflexion moment.
- The main compressive force in the ankle comes from the powerful plantarflexors.
- The ankle JRF is proportional to the forces generated by the surrounding muscles and the ground reaction force.
- Calculating the JRF during a single leg stance standing on tip toes.
  - This significantly increases the JRF and is very difficult to do even in the presence of early OA.
  - **F (TA) x d = GRF (BW) x 4d.**
  - F (AT) = 4 BW.
  - **JRF = F (TA) + F (BW).**
  - .JRF = 5 BW



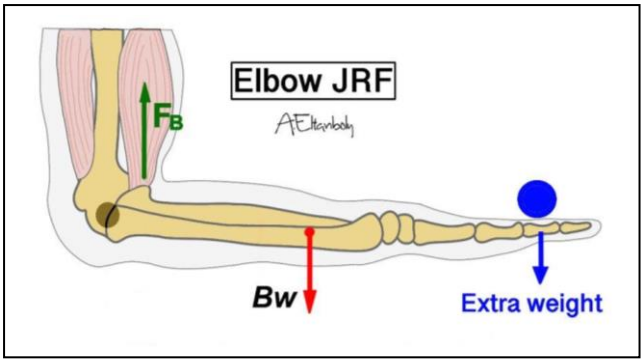
Shoulder joint

- Class 3 lever.
- The glenohumeral joint is the fulcrum. The scapular is fixed and the humerus is mobile.
- This model only considers the deltoid to be the main contributing muscle.
- The deltoid has to counteract the combined weight of the upper limb and any object held in the person's hand.
- Having the elbow flexed when elevating the arm will reduce the weight moment arm and effort required by the deltoid muscle.



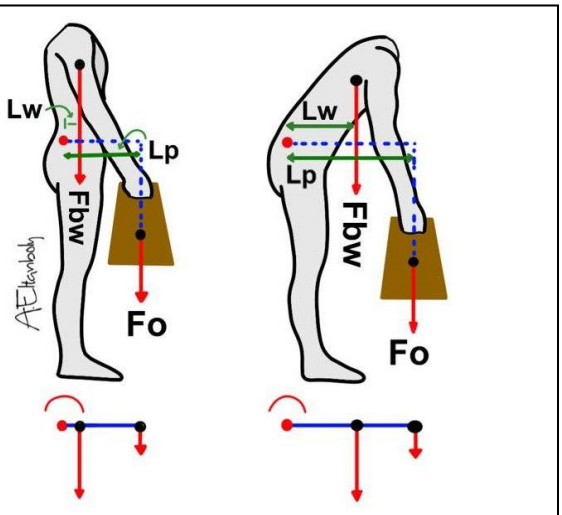
Elbow joint

- Class 3 lever in flexion. Class 1 lever in full extension and when the elbow is over head in flexion.
- Typically illustrated with the elbow joint at 90°.
- The fulcrum is the ulnahumeral articulation. The arm is fixed and the forearm is the mobile component.
- With the forearm in supination, the biceps tendon inserts 5 cm (d) distal to the fulcrum.
- The weight (BW) of the forearm and hand (2 Kg) acts through the centre of gravity which is 15 cm (3d) from the fulcrum.
- Carrying an additional 10 Kg (100 N) weight (W) in the hand acting at about 30 cm (6d) from the fulcrum.
- Calculating the force generated by biceps to maintain this position:
  - **F(B) x d = (BW x 3d) + (W x 6d)**
  - F(B) = 60+ 600.
  -) FB = (660 N.
- Calculating the JRF:
  - **JRF = F (B) – F (BW) – F (W)**
  - JRF = 540 N



Spine

- Class 1 lever.
- Fulcrum is the middle of the intervertebral disc.
- In the L4/5 functional unit, the L5 vertebrae is fixed and the L4 vertebrae is mobile.
- Weight creates a clockwise moment with an increasing moment arm when flexing.
- Erector spinae muscles create an anticlockwise moment with a short moment arm.
- Bending the knees and holding the carried object closer to the body will reduce the weight moment arm and therefore reduce the required counterforce of the spinal muscles.
- This will reduce the JRF within the functional unit.
- Remember to consider the appropriate vector of each force when the functional unit is flexed at a particular angle.

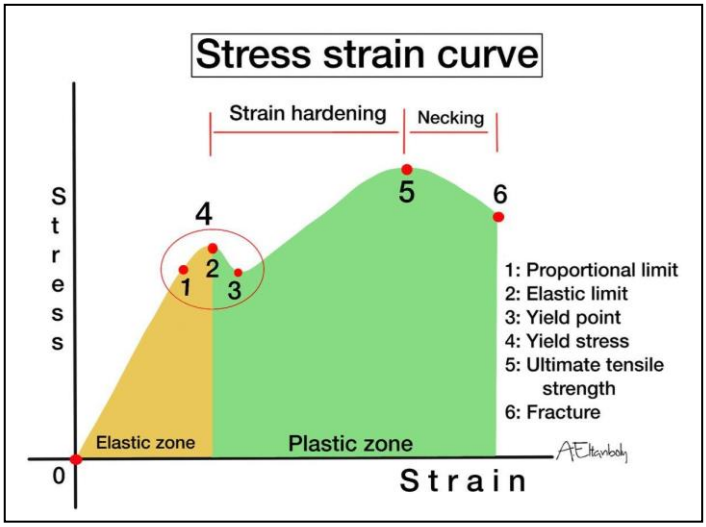


Lw: lever arm for body weight
Lp: moment arm of the weight carried in hand

Free body diagram of the lumber spine when lifting a weight with the spine extended and flexed

STRESS-STRAIN CURVE

- Describes the deformation of a material at distint intervals of load.
- The curve plot is unique to each material.
- The curve differs when compression, tension or shear forces are applied.
- For a structure, its called a load-elongation curve instead.
- **Stress:**
  - Force per unit area (N/m^2) in a structure and represents the intensity of internal force.
  - Point .and direction specific within a structure
  - 1 N/m^2 = 1 Pascal.
  - Can .be tensile, compressive or shear
- **Strain:**
  - Ration or percentage value (no units) of the change in length over the original length (ΔL/L).
  - Change .of material length (deformation) when force is applied
  - Fractures .of cortical bone occur at 2% strain, whilst fractures of cancellous bone occur at 75% strain



- **Stiffness:**
  - Ability .of an object to resist deformation
  - The .steeper the slope the stiffer the structure
- **Strength:** the amount of stress applied to a material before it deforms permanently or fractures (UTS).
- **Elastic zone:**
  - When a material undergoes elastic deformation, which is reversible.
  - Elasticity .is the ability of a material to return to its original length and zero strain when stress is removed
  - Obeys .Hooke's Law in which the stress is proportional to the strain up until the proportionate limit
  - Area under this region represents the amount of energy absorbed by a material and is the resilience.
  - Young's modulus of elasticity measures the ability of a material to resist deformation (stiffness) in the elastic zone and is the gradient of the stress-strain curve (N/m^2). The higher the modulus the stiffer the material.
  - Relative order of Young's modulus of materials from brittle to plastic: ceramic **(350GPa)**, Co-Cr alloy **(250GPa)**, stainless steel **(200GPa)**, titanium alloy **(100GPa)**, cortical bone **(20GPa)**, polymethylmethacrylate

(PMMA) **(3GPa)**, polyethylene **(1GPa)**, cancellous bone **(1GPa)**, tendon/ligament **(0.1GPa)** and cartilage **(0.01GPa)**.

❖ **Yield stress:**
- The transition zone between elastic andplastic (*irreversible*) deformation.
- :Comprises of three points
  - *Proportional limit:* marks the end of the linear relationship between stress and strain.
  - *Elastic limit:* beyond this point there is no return to original length when stress is removed.
  - *Yield point:* end of a phase where there is permanent change in length with no extra stress. Dislocations start to occur.

❖ **Plastic zone:**
- When a material undergoes plastic deformation, which is irreversible.
- Material will not regain its original length when stress is removed.

❖ **Ultimate tensile strength (UTS):**
- Maximum stress (strength reached befor failure).

❖ **Strain hardening:**
- Plastic deformation increases the dislocation density in a material and increases its strength
- The dislocation-dislocation interactions prevent or make it harder for any further movement, thus more stress is required to move them causing the curve to go up until it reaches UTS
- Also known as work hardening and cold working

❖ **Necking:**
- Occurs between the UTS point and failure.
- Stress reduces within a material but the strain increases

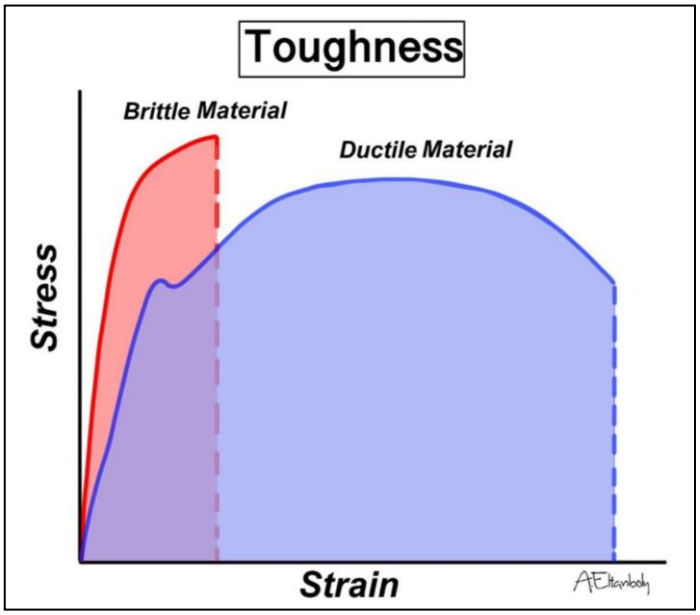
❖ **Toughness:** represents the amount of energy a material can absorb before failue (area under the entire curve).

❖ **Hardness:** measures a material's resistance to surface deformation.

❖ **Brittle material:** this will have little or no plastic deformation e.g. ceramics and PMMA.

❖ **Ductile material:** undergoes a large amount of plastic deformation before failure e.g. metals.

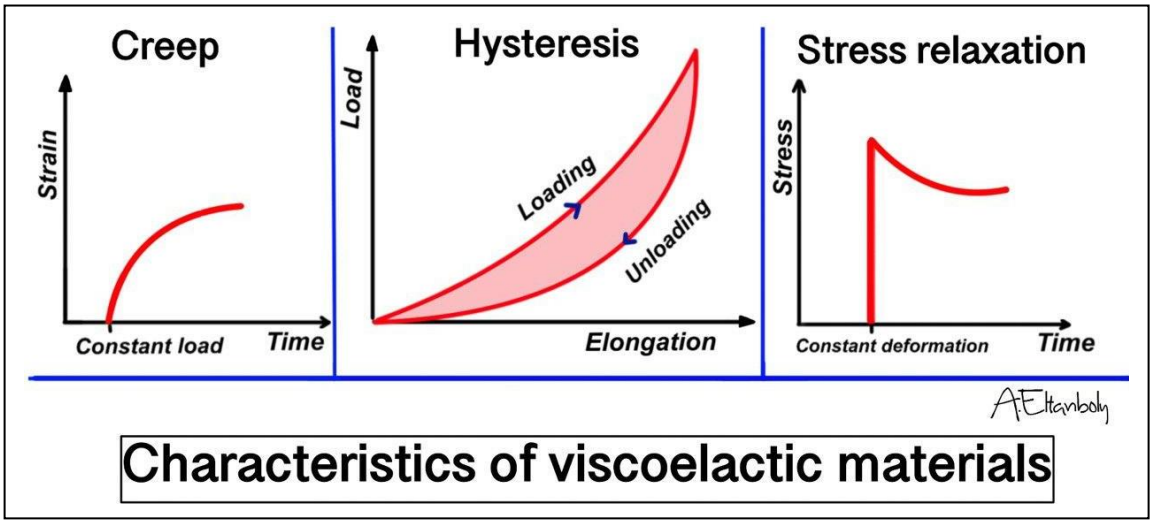
❖ **Compressive stress-strain curve:** is drawn using the negative strain x-axis and negative y-axis.



❖ **Stress shielding:**
- Occurs when there is a Young's modulus mismatch between an implant and the bone.
- Seen with stiffer implants and extensively porous coated stems.
- Proximal coating allows proximal bone loading and protects against stress shielding.

VISCOELASTIC MATERIALS

- **Viscous** behaviour is when a material resists deformation slowly under stress due to internal friction.
- **Elastic** behaviour occurs when a material returns to its original shape as the external force is removed.
- **Viscoelastic material:** (typically biological) combines these two properties and demonstrates time dependent stress-strain behaviour.
- **Characteristics**:
  - **Creep**: time dependent deformation under constant load. E.g. cement, intervertebral disc, Ponseti technique and pretensioning of ACL graft.
  - **Stress-relaxation**: time dependent decrease in stress under constant strain or deformation. E.g. the creation of hoop stresses when putting in a femoral rasp of cementless femoral stem.
  - **Hysteresis**: loss of heat energy is the difference between the loading and unloading curves during each cycle.
  - **Rate dependent strain behaviour**:
    - *Rapid loading* (high strain rate) results in a stiffer more brittle material behaviour.
    - *Slow loading* (low strain rate) results in a ductile material behaviour.



IMPLANT MANUFACTURING

❖ **Casting:** pouring molten metal into a mould to make a particular shape.
❖ **Alloying:**
- Altering the properties of pure metal by adding small amounts of other elements
- Cobalt for stiffness
- Nickel and Chromium for corrosion.

❖ **Metal defects:**
- Grain boundaries are weak areas between crystals.
- Dislocations are defects within the crystals.
- Cracks propagate along grain boundaries. Presence of other elements at boundaries help to stop propogation.

❖ **Work hardening** (strain hardening, cold working)**:**
- Repeated tensile loading of the material causes plastic deformation and increases the density of dislocations.
- Causes a change in grain shape and reduces voids.
- The dislocation-dislocation interactions make it harder for further movement and an increase in strain energy.
- Rolling at room temperature shifts the stress-strain curve to the left increasing stiffness and brittleness.
- Recrystallisation temperature is the temperature at which the deformed grains (due to the working process) are replaced by defect-free grains in the metal.

❖ **Annealing:**
- Heating a cold worked material to just below melting temperature.
- This breaks the dislocations and subsequent cooling allows recrystalisation with reforming of crystal bonds
- This shifts the stress-strain curve to the right and increases the material's ductility.

❖ **Use these headings when asked to talk about a material:** composition, manufacturing, properties and uses.

Stainless steel

❖ **Composition:**
- Steel comprises of carbon and iron, but the addition of > 4% chromium turns it into stainless steel.
- **316L** (specific type used in orthopaedic implants) – (60% iron, 20% chromium, 3% molybdenum, 16% nickel (and low carbon 0.03%

❖ **Manufacturing:**
- Casting of liquid / molton metal into a cast to create the desired shape.
- Wrought involves rolling and shaping the casted metaagl.
- Cold working is rolling the metal at room temperature to increase its UTS, but this makes it more brittle.
- Annealing is heating the metal to about half of its melting temperature to make it more ductile and workable.
- Hot working is heating the metal to about 60% of its melting point (above recrystallisation temperature) whilst working it to also increase ductility.
- Alloying to add other elements to change its properties.
- .Quenching is immersing the hot metal in cold water or oil to reduce crystal grain size and increase hardness The quicker the rate of cooling, the smaller the grain sizes.
- .Passivation is formation of an oxidised layer to protect against corrosion

❖ **Properties:**
- Low amounts of carbon reduces brittleness.
- The addition of molybdenum reduces pitting corrosion.
- Chromium generates an oxidation layer, providing further protection against corrosion.
- Advanteges:
  - *Stiff (.(with a high Young's modulus*

- *Ductile.*
- *Tough.*
- *Good fatigue & corrosion resistant.*
- *Cheap.*

▪ Disadvantages:

- Susceptibile to crevice and galvanic corrosion (with Co-Cr heads) and does not self-passivate.
- Prone to causing stress-shielding due to a bigger Young's modulus mis-match with bone.

❖ **Uses:** plates, screws intrameduallary nails, K-wires and external fixator pins.

Titanium alloy

❖ **Composition:** Ti-6Al-4V – 90% titanium, 6% aluminium and 4% vanadium.

❖ **Manufacturing:** see stainless steel notes.

❖ **Properties:**

▪ Advantages:

- High fatigue resistance biphasic hexagonal.
- High fatigue resistance [biphasic ∝ (hexagonal-close packed) and β (body-centred cubic) phases giving different metal atomarrangements] which is ideal for load bearing implants such as nails.
- About 1.6 times tougher than stainless steel.
- Self-passivation creates an oxide layer, which protects against corrosion including galvanic.
- Lower density and is therefore lighter than other metals.
- Biocompatible.
- Less Young's modulus mis-match with bone reducing stress-shielding and anterior thigh pain.

▪ Disadvantages:

- Low wear resistance makes it unsuitable for bearing / articulating surfaces.
- Poor notch sensitivity in which small scratches can propagate rapidly.
- Vanadium ions are cytotoxic when released.
- Cold welding with locking screws when there's a physical disruption of the passivation layer.
- Expensive due to more difficult fabrication process.

❖ **Uses:** plates (those used in pelvic fracture fixation can be contoured very easilty), screws intrameduallary nails and femoral stems. Tritanium from Stryker is a reticulated porous titanium coating for titanium alloy components which gives a higher porosity (65-70%) compared to titanium (30-35%) and cobalt-chrome beads (35-40%), allowing for excellent bone ingrowth.

Cobalt-based alloy

❖ **Composition:** Alloy used in orthopaedics has 60% cobalt, 30% chromium and 5% molybdenum and trace elements.

❖ **Manufacturing:** see stainless steel notes.

❖ **Properties:**

▪ Advantages:

- Excellent resistance to crevice corrosion.
- Excellent biocompatibility with low risk of allergic reaction and immune response.
- Ductile.
- Excellent wear resistance and toughness due to imperfect lattice structure allowing the formation of dislocations during work hardening and annealing.

▪ Disadvantages:

- Poor scratch profile forming peaks and troughs.

- Expensive.
- Stress-shielding due to high stiffness and Young's modulus.

❖ **Uses:** Ideal for bearing surfaces such as femoral heads in THR and the femoral component in TKR. Too stiff to be used for plates and nails due to the problem of stress shielding.

Ceramic

❖ **Composition:** Metallic and non-metallic elements ionically bonded in a highly oxidised environment.

❖ **Manufacturing:**

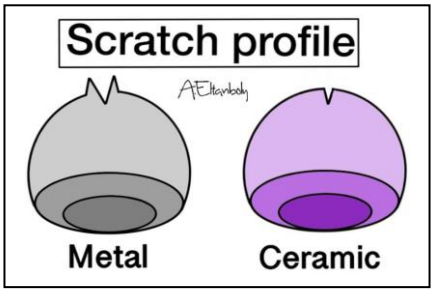
- Cermaic powder and water are mixed and pressed into shape using pre-fabricated casts to try and reduce the grain size(smaller grain size gives a strong ceramic).
- Drying will evaporate the water but result in an increase in porosity.
- Sintering hot isostatic pressing) involves heating the ceramic to below melting point under extreme pressure to bind individual grains more tightly. This reduces the porosity and increases the density and toughness.
- The higher the density and lower the porosity, the tougher and less brittle the ceramic.
- Changes to the manufacturing process and transformational toughnening adding other elements (have substantially improved the mechanical properties of progressive generations of ceramic.
- **Types:**
  - *Bioactive:* Calcium-hydroxyapatite *[*) $(Ca_{10}PO)_6OH)_2$], silicon and tricalcium phosphate.
  - *Bioinert:*
    - 1st generation – Alumina (aluminium oxide – yellow colour) had very low friction and wear characteristics but had the problem of low fracture toughness.
    - 2nd generation – Zirconia (zirconium oxide) has reduced grain size and porosity making it more ductile and 2-3 times tougher than alumina. It had the major problem of phase transformation in which the crystal structure ages at room temperature making it unstable and risk of fracture.
    - 3rd generation – Zirconia Toughened Alumina (ZTA) combines the fracture toughness of zirconia and wear resistance and chemical stability of alumina. The addition of strontium oxide helps to stop crack propagation. Yttrium oxide (yttria) is also added to help stabilise zirconia at room temperature and prevent phase transformation. It also forms platelet like crystals, which help prevent initiation and crack propagation. Commonly used ceramic is the Biolox Delta, which comprises 80% alumina, 17% zirconia and 3% strontium oxide. The pink colour is due to the added chromium oxide, which improves the hardness of the composite material.
    - Oxinium is an alloy comprising 97.5% zirconium and 2.5% niobium, which under extreme heat and oxygenation undergoes surface transformation to form a 5 µm thick ceramic layer (zirconium oxide) on the surface of a metal core. Oxinium combines the strength and hardness of metal with the smoothness and wear characteristics of ceramic. It is used as a bearing surface in patients with metal allergy and is expensive.

❖ **Properties:**

- Advantages:
  - Hard – 3rd hardest known material, which is scratch resistant with a good scratch profile (forming troughs only unlike metals which create surface asperities when scratched).
  - Smooth – low surface roughness with a low coefficient of friction.
  - Wettable – excellent effinity for lubricant by forming strong hydrogen bonds with fluid.
  - High wear resistance – lowest wear rates of any bearing combination, generates much smaller debris particles compared to polyethylene, making it less biologically active.
  - Bioinert – chemically inactive with no problems of corrosion.
  - Resists deformation – is extremely stiff and not subject to creep.

- Disadvantages:
  - Brittle – no plastic deformation before failure.
  - Fracture – increased risk with high BMI and smaller head size(0.04% risk with new ceramics)، and is more likely to involve the liner rather than the head. Clearing the multiple sharp fragments produced after a fracture requires synovectomy and use of a another ceramic head**.**
  - Not tough – with a very little plastic phase.
  - Squeaking – component malpositioning can lead to edge loading and loss of fluid film lubrication.
  - Stripe wear – crescent shaped wear pattern resulting from component seperation during swing phase loose soft)tissues) **and** then edge loading on re-engagement during heel strike. It's clinical significance is unknown.
  - Less modularity – fewer neck length options.
  - Expensive**.**

❖ **Uses:** As a bearing surface in hip arthroplasty.



Polyethylene

❖ **Composition:** long chain polymer made up of the monomer ethylene (C_2H_4) joined by covalent bonds.

❖ **Manufacturing:**

- **Polymerisation:**
  - Addition polymerisation of ethylene gas at low temperature and low pressure forms a powder.
  - Alumanium-titanium catalyst initiates the reaction by breaking the monomer C=C bond.
  - Propagation phase of the reaction creates the linear polyethylene chains.
  - This is known as the Ziegler process.
  - Initially used polyethylene was known as high-density polyethylene (HDPE).
  - Later improvements gave rise to the ultra- high molecular weight polyethylene(UHMWPE) ,which has exceptionally better mechanical properties.
- **Processing:** :The formed powder is put into the desired shape by a number of different ways
  - Ram bar extrusion involves forcing the powder resin into rods followed by machining.
  - Sheet compression involves applying pressure over time to form sheets followed by machining.
  - Direct compression moulding involves pressing the heated resin directly into the desired shape. **This is the preferred processing method which gives lower rates of wear.**
  - Both ram bar extrusion and sheet compression require machining to form the component, thus the

surface is not as smooth as in direct compression moulding. There's also the problem of chain scission, which releases free radicals and increases the risk of brittleness.

- Polyethylene has a semicrystalline structure because the chains are ordered in both an amorphous .(disordered) and crystalline (ordered) way
- Gamma radiaition is used to generate free radicals that allow cross-linking between polyethylene chains in the amorphous areas. This forms cross-linked polyethylene (XLPE), which has a greater denisty and percentage crystallinity. However, the unbonded free radicals pose a problem because they are free to react with oxygen and compromise the mechanical properties of polyethylene.
- The problem of residual free radicals is addressed by sequential irradiation and annealing, or use of an anti-oxidant agent such as Vitamin E. This has given rise to 2nd generation of XLPE.

▪ **Packaging:**

- The early method of sterilising polyethylene involved using gamma radiation in air, which resulted in oxidation and detimental loss of mechanical properties.
- Current methods of sterilisation include using gamma radiation in a vacuum, which will reduce the problems associated with oxidation.
- Alternative methods of sterilisation include using ethylene oxide or inert gas (Argon or Nitrogen) . But you don't get additional cross-linking with this.

❖ **Properties:**

- Ductile.
- Cheap.
- Less Young's modulus mis-match with bone.
- XLPE is more resistant to both deformation by creep and crack propagation. It also has improved resistance to adhesive and abrasive wear.
- XLPE has a higher crystallinity giving it a decreased fatigue resistance and toughness compared to UHMWPE.

❖ **Uses:**

- Polyethylene is used as a bearing surface in arthroplasty.
- UHMWPE is better suited for use as a bearing surface in knee arthroplasty because it can better withstand high contact stresses and shear forces.
- XLPE is better suited for use as a bearing surface in hip arthroplasty because it has greater wear resistance in such a highly conforming articulation.

BONE CEMENT

❖ **Composition:** synthetic material formed by an exothermic polymerisation reaction between a powder and liquid.

- **Powder:**
  - Prepolymerised polymethymethacrylate- PMMA(polymer).
  -) Radiopacifierbarium sulphate or zirconium.(
  - Intiator (.(Benzoyl peroxide
  - Antibiotic(e.g. gentamicin) must be wide spectrum –, long elution time(6- 8weeks(, thermally stable and shouldn't compromise mechanical stability of cement.
  - Colouring(chlorophyll dye in palacos, ethanol and ascorbic acid in CMW).
- **Liquid:**
  - Methylmethacrylate(monomer).
  - Accelerator(N,N-dimethyl-p-toluidine).
  - Inhibitor(hydroquinone).
- The coming together of benzoyl peroxide and N,N-dimethyl-p-toluidine starts the polymerisation process as the former decomposes and generates benzoyl radicals.
- The carbon-carbon double bonds are broken down and new single bonds are formed to give long chain polymers that are linear and relatively free of cross-linking.
- The reaction is exothermic and energy inefficient.
- **Use of antibiotics in cement:**
  - Using pre-mixed cement containing antibiotics is better than those prepared by yourself because it can be difficult to achieve equal mixing, especially when using more than one antibiotic.
  - Can use up to 2g of antibiotics per 40g cement mixture.
  - Mimimum inhibitory concentration (MIC) is the minimum antibiotic concentration required to kill all bacteria. This is calculated in vitro.
  - It's thought that the MIC for gentamicin is 3 days, after which it goes below the treatement level but continues to be released for 2 weeks.
  - Once antibiotics in the cement becomes ineffective, the cement becomes a foreign body on which the biofilm will form.
  - Bacteria biofilm like the rough surface of the cement and so that's why it's important to remove all cement in revision THR to prevent it acting as a source of re-infection.

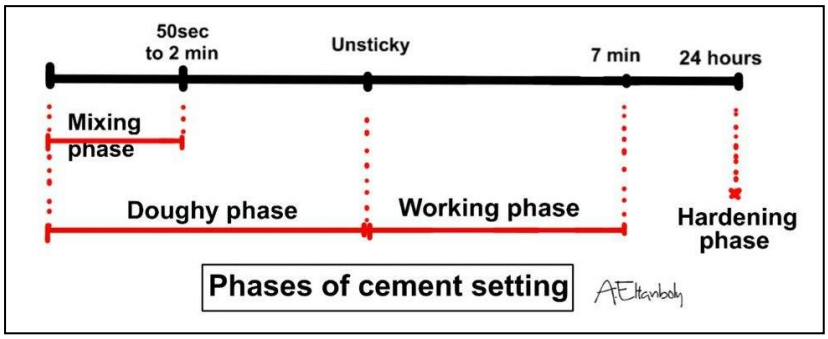
❖ **Phases of cement setting** (e.g. for non-fast setting cement):

- **Mixing phase -** 50 secs to 2 mins for under vacuum.
- **Dough phase**
  - From start of mixing until the cement becomes non-sticky to touch.
  - If the cement is inserted too early, blood mixes into it reducing its strength.
  - Increased humidity lengthens the dough phase.
- **Working phase**
  - Implantation phase, from end of the dough time to the beginning of setting.
  - 7 minutes have so far passed from the starting point.
  - Increased temperature, mixing and handling all reduce the working phase.
- **Hardening phase** - Implant should be kept still as cement is still notch sensitive. Hardening will take 24 hours.
- **Setting time**
  - From mixing until the cement reaches maximum heat and becomes hard.
  - In vivo temperatures are reported to be between 40°C and 56°C.
  - Increased theatre temperature and humidity reduces setting time.

> - Viscosity is a measure of the internal resistance of a fluid to deformation under shear

forces.

- *Low viscosity cement*: long doughy phase.
- *Medium viscosity cement*: reaches doughy stage later than high viscosity.
- *High viscosity cement*: shorter doughy phase.



❖ **Uses:**

- Commonly used for implant fixation in arthroplasty where it acts as a grout and not an adhesive. The interdigitation with bone creates the friction or hoop streses at the interface.
- Void filler in the management of non-malignant lesions.
- Vertebroplasty in osteoporotic vertebral collapse.
- Treatment of osteomyelitis and in the 1st stage of periprosthetic joint injection. Elution of antibiotics can be improved by increasing the surface area, increasing the antibiotics concentration and using more than one aantibiotic.
- Masquelet technique ustilises an antibiotic cement spacer to form a biomembrane, which can then hold bone graft in the treatment of traumatic segmental bone defects.
- Preparation before use in arthroplasty:
  - Pulse lavage to clear contamination and reduce the risk of fat embolism.
  - Mixed under vacuum to reduce pore size and avoid formation of bubbles to reduce cracks and increase tensile strength.
  - Pressurisation to enhance interlocking and strengthen the bone-cement interface.
- Cementing technique:
  - *1st generation:* hand mixing and finger packing.
  - *2nd generation:* use of pulse lavage and cement restrictor.
  - *3rd generation:* vacuum mixing and pressurisation.
  - *4th generation:* proximal and distal centraliser.

❖ **Properties:**

- Exhibits all the behaviours of a viscoelastic material.
- .High compressive strength
- Poor tensile and shear strength.
- Loses some ductility when mixed with antibiotics.

❖ **Types:**

- **Optipac** (Zimmer-Biomet):
  - High viscosity cement.
  - Uses a closed vacuum mixing system to minimise exposure to monomer fumes.
  - Reports better cement mixing and reduced porosity to improve the cement's fatigue life.
  - Contains gentamicin.

- **Simplex** (Stryker)**:**
  - Medium viscosity cement.
  - High fatigue strength and low creep (plastic deformation).
  - Sterilisation with gamma radiation thus has a higher risk of fatigue.
  - Contains 1g Tobramycin.
- **Palacos** (Heraeus)**:**
  - High viscosity cement.
  - Green dye.
  - Shorter waiting period with an extra long working phase.
  - Palacos R+G contains gentamicin.

- **Copal** (Heraeus)**:**
  - High viscosity cement
  - Copal contains either gentamicin and clindamycin (G+C) or gentamicin + vancomycin (G+V)
- **CMW** (DePuy)**:**
  - CMW 1 and CMW 2 are both high viscosity cements but the latter is fast setting. CMW 3 is a medium viscosity cement with setting time comparable to CMW 1.
  - .Also available with gentamicin

❖ **Barrack & Harris radiographic grading for quality of cementing in arthroplasty:**

- .Grade A – Whiteout with no distinguishable radiolucent lines at the bone-cement.
- Grade B – Radiolucent line covering %50> . .of the bone-cement interface
- Grade C – Radiolucent line covering 50% ..of the bone-cement interface
- Grade D – Compelete 100% radiolucent line and/or abscent cement to the stem.

❖ **Which cement would you use?**

- :Palacos R+G because
  - High viscosity with a short dough time but long working time.
  - Greater visibility with the green colour through the addition of chlorophyll.
  - The carrier is peanut oil, which is highly refined and so unlikely to produce an allergic reaction.
  - Contains gentamicin, which provides cover against gram +ve & -ve Bacteria.
  - Sterised using ethylene oxide which preserves mechanical integrity.
  - NJR data – THR revision ratesis 3.3% at 10 years compared with 4.2% when using other cement. TKR revision rates is 4.1% at 10 years compared to 4.4% when using other cement.

❖ **Bone cement syndrome**

- Spectrum from hypoxia, hypotension, cardiac arrhythmia and cardiac arrest.
- Proposed causes because the mechanism is not fully understood:
  - MMA monomer mediated model.
  - Embolic model.
  - Complement activiation.
  - Multimodel model.

Recommendations – BOA, BGS and AAGBI guidelines

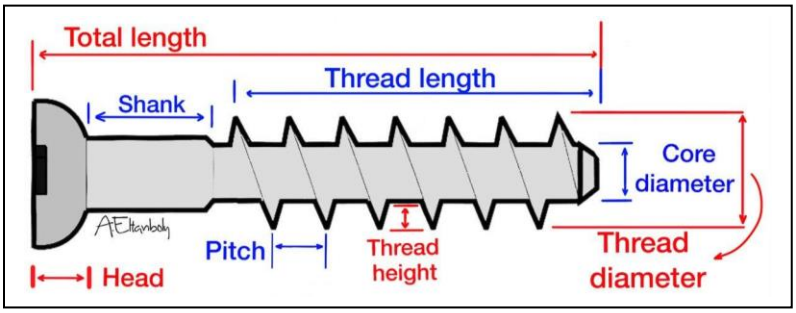
- There should be a***three-stage process*** to reduce the incidence of problems in patients undergoing cemented hemiarthroplasty for hip fracture.
  1. Identification of patients at high risk of cardiorespiratory compromise:
     a) Increase age.
     b) Significant cardiopulmonary disease.
  2. Preparation of the team and identification of roles in case of severe reaction:
     a) .Pre-operative multidisciplinary discussion when appropriate
     b) .Pre-list briefing and WHO Safe Surgery checklise time-out
  3. Specific intraoperative roles:
     a) *Surgeon*: inform the anaesthetist in plenty of time that you are about to cement. Thoroughtly wash and dry the femoral canal after inerting an intramedullary femoral shaft plug. Apply cement in a retrograde fashion and consider using a suction catheter. Avoid vigorous pressurisation in patients considered to be at risk of cardiovascular compromise.
     b) *Anaesthetist:* ensure adequate resuscitiation pre- and intra-operatively. Confirm to the surgeon that you are aware there about to cement. Maintain vigilance for signs of cardiorespiratory compromise. Aim for a **systolic blood pressure within 20% of the pre-induction value.** Prepare vasopressors in case of cardiovascular collapse.

SCREW

- Device that converts rotational force into linear motion.
- Working length of a screw is the length of bone traversed by the screw.
- Both bending and torsional stiffness are proportional to the 4th power of the screw's core radius.

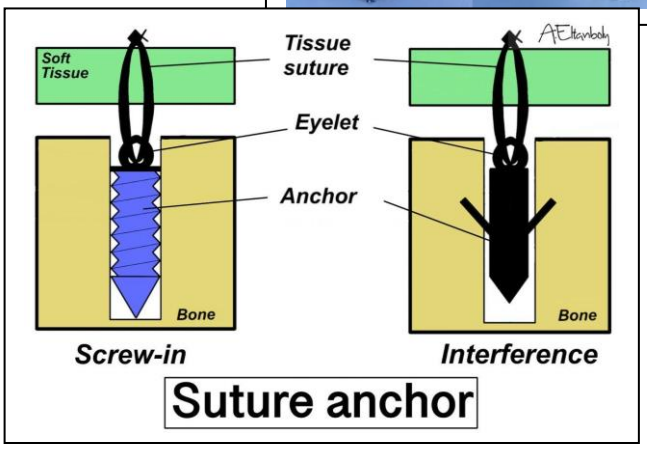
Parts of a screw

- **Head:**
  - Attachment for the screw driver and helps to arrest forward motion as it compressed through a plate.
  - Has a conical part to allow for countersinking.
  - The hexagonal and star shapes give multiple points of contact and shares the torque to limit slippage.
- **Run out:** Transitional area between the head and thread (allows for counter sink), is the weakest part of the screw.
- **Shaft:** Dictates the bending and rotational strength.
- **Thread:** Represents the outer diameter:
  - Deeper thread gives greater resistance to pull out.
  - Thread depth = (outer diameter – core diameter) / 2.
  - Outer diameter dictates the screw's pullout strength.
- **Pitch:** Distance between threads. Cortical screws having finer pitch than cancellous screws.
- **Tip:** Blunt or self-tapping.
- **Flute:** Found in self-tapping screws to help remove bone debris. Is sharp and doesn't require a pilot hole.
- **Lead:** The distance advanced with full revolution.



Screw types

- **Cortical**
- **Cancellous:** The spiral tip creates own thread as it pushes bone away rather than removing it. There are fully or partially threaded screws, with the latter being used to in cases requiring fracture compression.
- **Bolt:** For rotational stability with a wider inner diameter and small inner thread, not designed to provide pullout strength.
- **Suture anchor:** Used when inadequate soft tissue makes it impossible to to perform a direct end-to-end repair. They are screws or interference screws.



- **Reverse cutting:** Easier to remove.
- **Locking:**
  - Screw head locks into the plate to form one structure and reduce the risk of implant failure.
  - The screw's larger core/thread ratio means it has resistance to bending but relatively decreased pullout strength.
  - Bicortical is more rigid axially and rotationally.
  - Subtype is the variable angled locking screw with a rounded head allowing for 15°of screw angulation either way.
- **Variable pitch screws** e.g. *Herbert screw*:

- Differential pitch: the distal end of the screw is able to advance more with each turn because of the larger pitch of the leading threads compared to the trailing threads. This will therefore provide compression across the fracture.
- Cannulated: lower thread depth results in decreased pullout strength.
- Self-tapping and self-drilling.
- Headless.

❖ **Screw core diameter determines the drill bit size:**

Screw core diameter (mm)	Size of drill bit (mm)
7.3 (cannulated)	5.0
6.5 (cancellous)	3.2
5.0 (locking)	4.3
4.5 (cortical)	3.2
4.0 (cancellous)	2.5
4.0 (locking)	3.2
3.5 (cortical)	2.5
2.7 (cortical)	2.0
2.0 (cortical)	1.5
1.5 (cortical)	1.1

How to maximise pullout strength

❖ Greater thread depth by increasing the outer diameter and reducing the inner diameter.
❖ More threads by reducing the pitch and having a longer screw.
❖ Using a locking screw.

Screw function

❖ **Positional:** such as a syndesmotic screw.
❖ **Compression:** a lag screw that provides intrafragmentary compression at a fracture.
❖ **Blocking:** helping to direct the passage of an intramedullary nail to maintain alignment
❖ **Lagging technique:**
- :By techniquethreaded into the opposite cortex)pilot hole (and slides through an over-drilled glide hole)equal to the outer diamter of the screw (in the near cortex .The screw must purchase into the far cortex only to achieve intergramentary compression.
- :By designsame can be achieved by using a partially threaded screw since there's no purchase proximally.
- The drill holes need to be in line with each other and at90to the fracture °, or you risk fracture displacement as the screw is inserted.

❖ Lag screw is weak against shear and bending forces, therefore consider using a plate in the neutralisation mode to protect the fixation**Countersink:**
- Increases the surface area between the screw head and bone, thus reducing the stress(stress= force/area).
- Only required for cortical bone.
- ,Countersinking cancellous bone will leave it weak to resist stress as it's much softer. Consider using a washer which acts as a 1-hole plate and spreads the load, even with thin cortical bone.

INTRAMEDULLARY NAIL

- Usually considered a load sharing device.
- Can be a load bearing device if there is significant bone loss.
- Remember that load sharing or load bearing are concepts and not devices.

Generations of femoral nails

- **1st** – Antgrade.
- **2nd** – Reconstruction (recon) nail with two proximal hip screws and a proximal diameter of 13 mm.
- **3rd** – Proximal femoral nail (PFN) / Gamma / Intramedullary hip screw
  - Sliding screws.
  - Wider proximally at 16 mm.
- **4th** - Trigen InterTAN nail which allows for compression of the fracture.
  - Interlocking screws.
  - Provides axial, rotational, and angular stability.
  - Disadvantage of increased radiation exposure.

What affects bending and torsional stiffness of intramedullary nails?

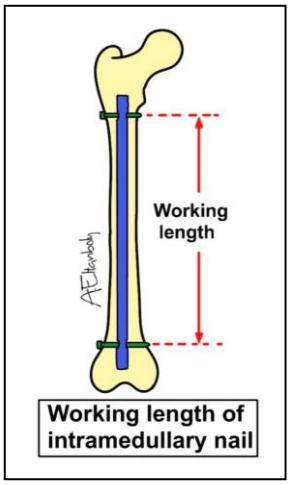
1.Material properties: Titanium Vs Stainless steel.

2.Structural properties:

- *Bending stiffness* (second moment of inertia; I) is proportional to the 4th power of the nail diameter (cylindrical structure). For a solid nail the equation is; $I = \pi r^4/4$. For a hollow nail the equation is $I = \pi (r_o^4 - r_i^4)/4$ which relates to the outer and inner radii of the cylinder. The more material further from the axis, the greater the resistance to bending.
- *Torsional stiffness* (polar moment of inertia; J) is proportional to the 4th power of the nail diameter. For a solid nail the equation is; $J = \pi r^4/2$ and for a hollow nail the equation is $J = \pi (r_o 4 - r_i 4)/2$.

3.Working length:

- Length of bone between most proximal and first distal fixation points.
- Reaming allows the insertion of a bigger diameter nail filling the isthmus thus creating a stiffer construct with a reduction in the working length.
- Fragmented fracture increases the working length and the patient has to be partial weight bearing.
- Transverse fracture gives a shorter working length and the patient can be fully weight bearing.
- Bending stiffness $\propto 1 / WL^2$
- Tortional stiffness $\propto 1 / WL$



Working length of intramedullary nail

4.Slotted nails

- Allow compression at the isthmus through tighter fit.
- Decreased nail mass would reduce the nail's stiffness and therefore ability to resist forces.
- The slot design disrupts hoop stresses causing reduces stiffness and resistance to torque.

5.Hollow nails:

- More flexible to anatomical variations than solid nails.
- Decreased stiffness due to reduced mass, which is compensated by reaming to insert a larger nail.

- Increased risk of persisting bacterial infection.

6.End caps:

- Prevents bone ingrowth into the nail.
- Extends the nail height if it's over inserted.
- Hole weaken the nail.
- Use of the Coremus™ IM nail Extractor System to remove more than 80 different types of IM nails.

EXTERNAL FIXATOR

❖ **Types:**

- Uniplanar – demonstrates anisotropic behaviour.
- Biplanar – used for unstable fractures.
- Modular – e.g. Hoffman (designed by surgeon from Geneva).
- Ring – demonstrates isotropic behaviour in a static mode (Ilizarov) or dynramic mode (TSF).
- Bridging: spanning a joint or fracture site.

❖ **Indications:**

- Intra-articular fractures with metaphyseal comminution.
- Open fractures.
- Closed fractures with significant soft tissue damage.
- Can be used for fractures with bone loss and osteomyelitis.
- Deformity correction

❖ **Principles:**

- Avoid placing pins within the zone of injury.
- Cool the bone to avoid bone necrosis by irrigating whilst drilling and using the stop-start technique.
- Safe corridors to avoid NV injury. Circular frames require safe corridors on both sides of the bone.
- Increase rigidity (see below).
- Convert to ORIF within 2 weeks to reduce the risk of infection.

❖ **Ways to increase rigidity of a monolateral system:**

- Most important factor is to achieve primary fracture stability by having anatomical reduction.
- Second most important factor is to maximise the pin diameter (<1/3 bone diameter to avoid fracture).
- Minimise the bone to rod distance to reduce near cortex stress (allow 2 inches for dressing change).
- Reduce working length of pins.
- Use the near-near far-far pin configuration by placing the central pins as close as possible to the fracture (outside the zone of injury) and the peripheral pins farther from the fracture.

- Addition of pins and bars in the same or different planes.
- Placing the pins in multiple planes.
- Using HA coated pins (the thread-shank junction is the weakest point so ensure it's buried inside the bone to strengthen it).

❖ **Ways to increase rigidity of a ring fixator system:**

- Increase the diameter of the wires, 1.8 mm for adults and 1.5 mm for children.
- Increase the wire tension, 130 N for adults and 110 N for children.
- Prevent ring deformation by having one wire above and one wire below the ring.
- Increase the crossing angle, ideally aiming for 90°.
- Increase the number of wires and/or rings.
- Use opposing olive wires to prevent slippage of wires.
- Use the smallest ring that's practically possible.
- Use slotted bolts.

PLATES

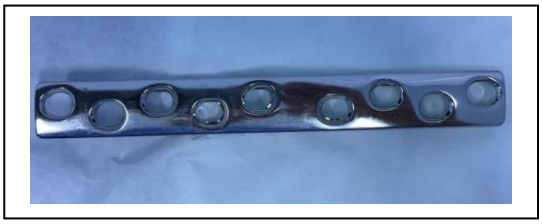
❖ **Definition:** Stripe of bio-compatible material containing holes that accept conventional and/or locking screws.

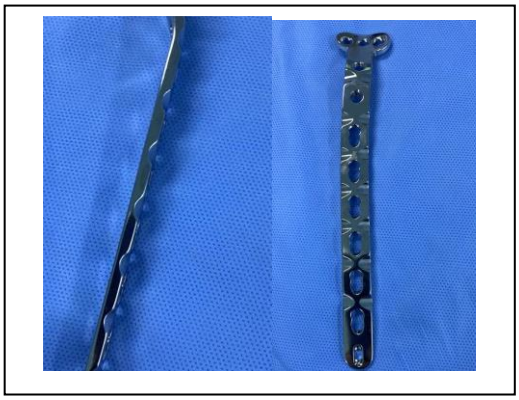
❖ **Principles:**

- Load bearing device
- Tension band:
  - Place the plate on the tension side of the bone to resist gaping.
  - Bone is strongest in compression so it doesn't need support on that side.
- Working length:
  - Is the distance betwen the two screws closet to the fracture.
  - Represents the unsupported section of bone either side of the fracture.
  - Decrease the working length to decrease strain across the fracture and increase stiffness.
- Use 6 - 8 cortices on each side of the fracture to neutralise torsional forces.
- Bending stiffness.
  - Is propotional to the cube value of the plate thickness.
  - $I = bh^3 / 12$; the 'h' is the thickness of the plate.
  - A4.5 mm(large fragment plate) has twice the bending stiffness of a3.5 mm(small fragment plate).

❖ **Types:**

- **One-third tubular plates:**
  - These thin (1 mm) plates are tubular with a1/3rd of the circumference of a cylinder.
  - They have circular holes to allow fixation with non-locking screws.
  - They very easily contour to the shape of the bone.
- **DCP (Dynamic Compression Plates)**:
  - These are thicker plates, which are useful with fixing simple fractures.
  - Have oval rather than circular holes, allowing for fracture compression by eccentrically placed screws.
  - They can be both broad and narrow depending on their intended application.
- **LC-DCP (Limited Contact-Direct Compression Plates)**:
  - This next generation of plates were invented by Perrin in 1969.
  - Reduced contact surface area preserves more of the periosteal blood supply.





- **LCP (Locking Compression Plates)**:
  - These plates have combi-holes to allow the use of both locking and non-locking screws.
  - When the locking screws engage into the plate' ,s threadsthe construct becomes a fixed angle device and acts as an internal external-fixator.
  - Useful in osteoporotic bone with better pull out strength of the whole construct.
  - They are very useful in bridging comminuted fractures.
  - These plates also have the limited contact design and when locked tend to sit off the bone protecting the periosteal blood supply.
  - Can use unicortical screws in the presence of obstructing irremovable metalwork.
  - Construct stability is determined by the screw-plate interface not the bone- .plate interface
  - Locking screws have a greater core diameter and lower pitch because the stiffness of the construct depends on the bending stiffness and not on the screw pull out strength.
  - Stability is increased by using bicortical locking screws, increasing the number of screws and/ or using a longer plate.
  - Disadvantages is that the plates are more expensive, problems of cold welding with difficulty in removing the screws and the need to ensure there is no screw divergence(with standard locking screws) from the hole(>5°, because cross threading reduces the overall bending stiffness by30-60 .(%
  - Contoured LCP such as the distal femoral LCP has the added option of variable angle locking screws, which provides the added benefit of multiplanar fixation

❖ **Fixation modes:** *The following refer to the modes in which the different plates are applied and are not specific to a particular plate.*

- **Neutralisation:**
  - Typically used in conjunction with lag screw fixation which aims for absolute stability by interfragmentary compression.
  - Provides protection to the fixation by neutralising rotational, bending and shearing forces.
- **Compression:**
  - The plate is used to compress a simple fracture aiming for primary bone healing.
  - Prebending the plate(concave side to the bone) will avoid fracture gapping at the opposite cortex as the near cortex is being compressed.
  - The hole is made eccentrically in the non-locking combi-hole. As the screw is tightened, it will slide down the angled side and result in movement of the bone fragment relative to the plate, thus .compressing the fracture

- **Bridging:**
  - Used in cases of comminuted fractures.
  - Provides relative stability(secondary bone healing).
  - Relatively longer working length.
  - Preserves remaining blood supply to fracture fragments by leaving the area undisturbed.
  - Don't put screws across the bridged part of the fracture.
- **Buttress / Antiglide:**
  - The plate creates an axilla into which the leading spike of cortical bone is driven.
  - Converts shear force into compression force at the fracture apex.
  - Buttress when applied to intra-articular fractures.
  - Antiglide when applied to diaphyseal fractures.
  - The plate must conform to bone.
  - Provides relative stability(secondary bone healing).

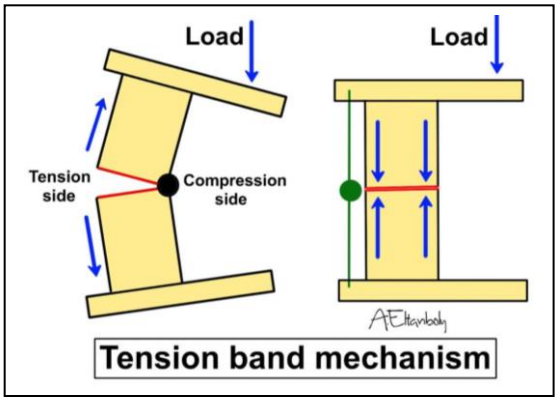
TENSION BAND

❖ **Definition:** Device that transforms a distraction tensile force into a compression force by shifting the centre of rotation from the compression side to the tension side.

❖ **Pre-requisites:**
- The plate or wires applied to the tension side needs to be strong enough to withstand the tensile forces.
- Need to neutralise rotational forces with K- wires/ screws.
- Need a strong opposite cortex to bear the resulting compressive force.
- Fracture should not be comminuted because it will lead to collapse on loading.

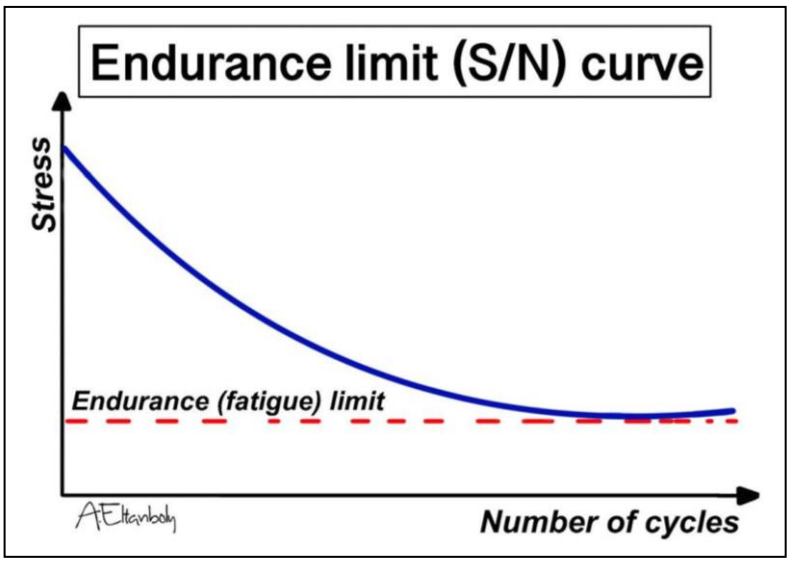
❖ **Devices:**
- K-wires and cerclage wire
- Plate

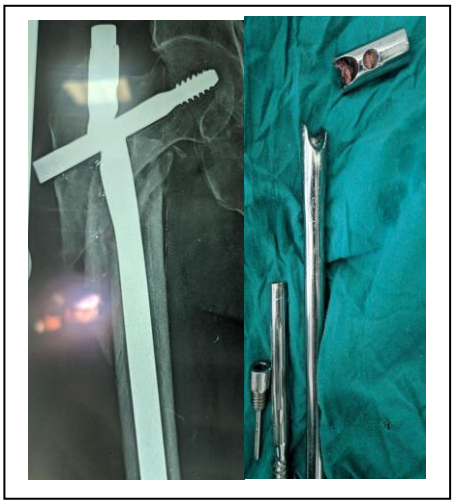
❖ **Sites:**
- Olecranon, patella, medial malleolus, GT fracture of humerus and 5th MT are some of the common sites.
- *Patella*:
  - The quadriceps muscle and patellar tendon exert tension on the anterior aspect.
  - K-wires reduce the fracture to provide bony contact.
  - .Cerclage wire resists tensile forces
  - Energy is transferred towards the articular surface to give compression.
- Used for fixation of small fractures that can't be fixed with other techniques.
- Tension band plating of the femur by putting in on the lateral surface.



S-N (STRESS-NUMBER OF CYCLES) CURVE

- Describes the fatigue behaviour of a material under cyclical loading.
- Also known as an **endurance limit curve**.
- The X-axis represents the number of cycles on a logarithmic scale.
- The Y-axis represents the stress applied on a logarithmic scale.
- **Endurance limit** is the stress level at which the material will not fail regardless of the number of cycles applied.
- **Fatigue failure** describes the progressive failure of a material due to cyclical loading at a stress level below the UTS but above the endurance limit. Starts at stress riser points and with each load the material gets thinner and thinner.
- Orthopaedic implants are designed to withstand 10 million cycles before failure (1 million cycles per year). It's important to know what environment the implant will operate in, i.e. at, above or below the endurance limit.
- In a TKR, the round or flat tibial insert design with a small contact surface area means the polyethylene is always operating at or above the endurance limit. That is why UHMWPE with it's increased toughness is used.
- In a THR, the increased congruency and contact surface area means the polyethylene operates below the endurance limit. That is why highly cross-linked polyethylene with its excellent wear properties is most suitable.





TRIBOLOGY

- Describes the science of interacting surfaces in relative motion with each other.
- Friction, lubrication and wear all take place between moving surfaces.

Friction

- Describes the resistance to sliding between bodies in contact.
- **Dry friction** can be either static (friction at rest) or dynamic (friction on movement).
  - **(Amonton's) 1st law of dry friction:**
    - Frictional force is directly proportional to the applied load.
    - $F = \mu L$ (μ is the surface coefficient of friction and L is the applied load).
    - Increasing the load will drive the surface asperities into each other and so increase friction.
    - μ for articular cartilage < ceramic-on-ceramic < metal-on-metal < metal-on-poly.
  - **(Amonton's) 2nd law of dry friction:**
    - Static friction is independent of apparent area but dependent on true area.
    - Apparent area is the external physical area of area.
    - .True area relates to the total surface area of the asperities in contact with each other
    - .Friction is a function of the mean height of the asperities and mean surface roughness
  - **(Coulomb's) 3rd law of dry friction:**
    - Dynamic frictional force is independent of the sliding velocity.
- **Wet friction** relates to the viscosity of a fluid and describes the internal fluid friction between the layers.
  - **Newton's law of viscosity:** describes the relationship between shear stress and shear strain in a fluid under load at a given temperature and pressure.
  - Viscosity = shear stress / shear strain.
  - **Newtonian fluid** (e.g. saline, synovial fluid in RA - due to degradation over time) is one that demonstrates a proportional relationship between shear stress and shear strain. The viscosity remains constant independent of the shear rate.
  - **Non-newtonian fluid**) e.g .synovial fluid (is one that doesn't demonstrate a proportional relationship between shear stress and shear strain.
    - :Pseudoplastica non-newtonian fluid such as synovial fluid undergoes ,shear thinningthe viscosity reduces as the shear rate increases in a non-linear fashion.
    - Dilatant:a non - ,newtonian fluid which undergoes shear thickeningthe viscosity increases as the shear rate increases.

Viscosity versus shear rate graph for newtonian and non-newtonian fluid

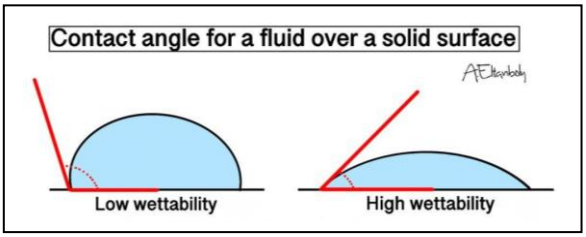
Lubrication

- Process to reduce friction between opposing surfaces by interposition of lubricant.
- The lubrication type between two surfaces depends on the **Lambda ratio** and is described by the **Stribeck curve**.

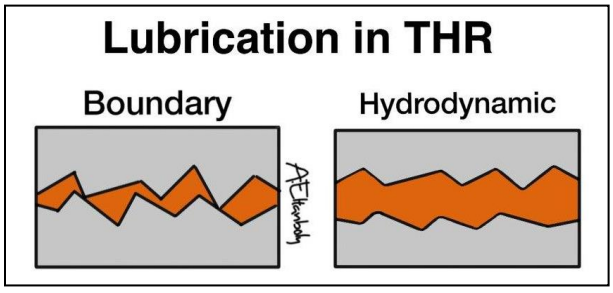
❖ Lambda ratio (λ) = thickness of fluid film / height of asperities (Ra) reflecting surface roughness
❖ Divided into two types:
- **Boundary lubrication** (thin film):
  - Single lubricant layer. Lubricin monolayer prevents direct contact between joint surfaces.
  - Contact between asperities due to high surface roughness.
  - .$\lambda < 1$
- **Fluid film** or **Hydrodynamic lubrication** (thick film):
  - Movement creates the fluid film.
  - Thick film of fluid resulting in separation between the two surfaces.
  - Usually requires low loads at high speed.
  - $\lambda > 3$.

Stribeck curve - plotting the coefficient of friciton versus (Viscosity x Speed) / Load on the x-axis

❖ **Factors that determine Lubrication:**
- Velocity at which the bearing surface operates.
- Load - magnitude and direction.
- Surface geometry and roughness.
- Wettability:
  - Affinity of surface material to lubricant.
  - Ceramic has greater weatability than metal.
  - Measured using the Theta contact angle.
  - Small angle < 45° - hydrophilic and better lubrication.
  - Large angle > 90° - hydrophobic.
- Lubricant viscosity.



❖ **Lubrication in prosthetic joints**
- The aim is to try and get hydrodynamic lubrication in order to limit the amount of surface wear.
- Factors that affect lubrication:
  - Radial clearance - aim for mid-polar contact between the head and socket. Any mismatch will result in early wear. Polar contact will occur if the head is too small whilst equatorial or eccentric contact will occur if the head is too big.
  - Sphericity < 7 μm.
  - Surface roughness.
  - Material.
- Hip resurfacing is rarely considered now and if so then only in a very select patient group of males with a minimum head diameter of 50mm to achieve the fluid film lubrication.

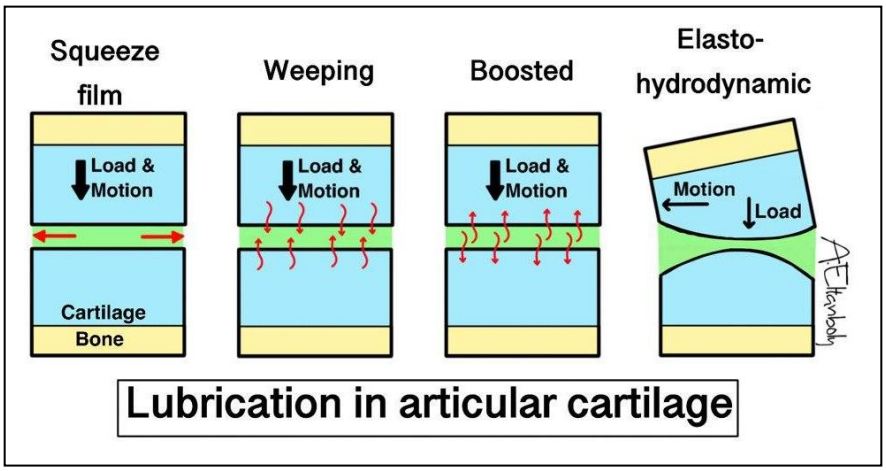


❖ **Lubrication in native joints** - mainly get fluid flim lubrication
- **Static**:
  - Squeeze film - as the surfaces get closer, hydrostatic pressure increases in the synovial fluid.

- Weeping - fluid exudes from the loaded articular cartilage to increase the surface gap.
- Boosted - low molecular synovial components are pushed into articular cartilage resulting in an increase in concentration of remaining hyaluronic acid.

▪ **Dynamic** - wedge of fluid forms as the two surfaces move relative to each other:
- - Hydrodynamicsurfaces are assumed to be rigid and come together at an angle.
- Elastohydrodynamic(EHD) - surfaces are assumed to be compressible and so under load the cartilage is deformed resulting in fluid being trapped and pressurised to enable load support .
-) MicroelastohydrodynamicMEHDassumes that the asperities are deformable - (, thus trapping and causing pressurisation of the fluid to support the load.

▪ **Lubrication type during the gait cycle** (there is increase in surface wear during times of boundary lubrication).
- - Initial contactSqueeze film
- - StanceEHD and MEHD.
- - Prolonged stanceBoundary and boosted.
- Toe- - offBoundary ,weeping and EHD.
- Swing–Hydrodynamic .



Wear

❖ **Wear** is the progressive loss of material from the bearing surface secondary to either mechanical or chemical action.
❖ **Effective joint space** defines the area around the prosthetic joint where fluid can dissipate freely.
❖ **Mechanical wear:**
- ▪ **Adhesive**: bonding between two surfaces pressed together and material is pulled away from the weaker side.
- ▪ **Abrasive**: asperities of the harder material or loose 3rd body material eroding into the softer surface.
- ▪ **Fatigue**: delamination and catastrophic wear of the subsurface (where it's weaker and more likely to break and fracture prematurely) material occurs when it's functioning at or above the endurance limit e.g. in knee polyethylene tibial inserts.

❖ **Chemical (corrosion) wear** is the dissolution of metal in a solution such as body fluid.
- ▪ **Crevice**:
  - Metal surfaces by a stagnant solution in crevices.
  - Relative increase in H^+ concentration and lower pH.
  - Disruption of the metal's passivation layer and making it susceptible to corrosion.
  - 316L stainless steel is most prone to crevise corrosion.

- **Pitting**: this is a localised form of crevice corrosion, which results in the formation of tiny holes sometimes deep to the surface.
- **Galvanic**:
  - When a battery is set up between two electrochemically dissimilar metals in a solution.
  - The more reactive metal (e.g. aluminium) acts as the anode and gives up electrons.
  - The less reactive (e.g. copper) metal acts as the cathode and receives the electrons.
  - Don't mix metals such as stainless steel and cobalt-chrome.
  - Inclusion corrosion is when impurities within the material interact with the base metal.
- **Fretting**:
  - Combination of mechanical wear and crevice corrosion.
  - The micro-motion between two surfaces disrupts the protective passivation layer.
  - This weakens the material making it more susceptible to fail under load.
  - Examples such as under a screw head or in trunnionosis.

❖ **Quantification of wear:**

- **Volumetric**:
  - Total volume of material wear.
  - Directly relates to the square of the head radius (increasing sliding distance).
  - Dependant on type of articulation, lubrication and load.
- **Linear**: this is the straight distance the head has worn into the liner and relates to the height of the material.

❖ **Modes of wear:**

- **1st degree wear:** between surfaces intended to articulate e.g. head and liner.
- **2nd degree wear**: between bearing and non-bearing surfaces e.g. head and acetabular shell.
- **3rd degree wear**: between normal bearing surfaces and 3rd body material.
- **4th degree wear**: between two non-bearing surfaces e.g. backside of acetabular liner and shell.

❖ **Factors contributing wear in joint replacements:**

- **Patient factors:**
  - Activity level and cultural demands.
  - BMI.
  - Co-morbidities.
- **Surgical factors:**
  - Soft tissue balance.
  - Surgeon experience.
  - Presence of3rd body material.
  - Implant positioning and orientation.
- **Implant factors:**
  - Modular Vs mono-block.
  - UHMWPE thickness.
  - Fixation method.
  - Implant constraint.
  - Type of bearing material used.

❖ **Wear rates:**

- **Titanium**: poor resistance to wear and so not useful as a bearing surface.
- **UHMWPE**: 0.1-0.2 mm (100-200 /μmyear.(
- **HXLPE**: smaller wear particles and more resistant to wear (40 /μmyear.(
- **Metal-on-metal**: small metal particles (50 nm) and more resistant to wear (5/μm year.(
- **Ceramic**: lowest wear rate (2.5 /μmyear(

Osteolysis

This describes the progressive periprosthetic resorption of bone in response to wear debris.

- **Stage 1 - Generation of wear particles:**
  - Size of wear articles is very important.
  - Those of 0.1-.μm size can be indigested by macrophages and are considered active such as polyethylene 10
  - Metal particles resulting from MoM articulations are much smaller(μm) and so don 50' t activate macrophages. Instead they are thought to cause a T- lymphocyte mediated type IV hypersensitivity reaction involving cytotoxic T-cells.
- **Stage 2 - Phagocytosis**
  - Macrophages are activated and recruit others by releasing pro-inflammatory mediators (cytokines):
    - TNF∝, Interleukins(IL1 and IL6(, PDGF, prostaglandins
    - Osteoclast activating factor.
    - Oxide radicals, hydrogen peroxide, acid phosphatas
  - Osteoclast activation:
    - Release of MMPs to break down the matrix.
    - Activation of the RANK- RANKL pathway(increased by TNF∝ and VEGF)leads to bone resorption .
- **Stage 3 - Prosthesis micromotion:**
  - Periprosthetic osteolysis will cause loss of bony support and result in micromotion.
  - Ongoing micromotion leads to an increase in particle wear and further loosening.
  - Urinary N-telopeptide is a marker for bone turnover and levels are elevated in osteolysis.
- **Stage 4 - Debris dissemination:**
  - The local inflammatory response causes an increase in hydrostatic pressure.
  - The increase in hydrostatic pressure leads to dissemination of debris into the effective joint space.
- This dissemination further propagates osteolysis.**Consequences of wear and wear particles:**
  - Synovitis.
  - Osteolysis and aseptic loosening.
  - Systemic distribution.
  - Immune reaction.
  - Increased friction of the joint.
  - Misalignment of the joint and catastrophic failure.

COLLAGEN

- Most common protein in the body making up 30% of total protein content.
- Structured protein synthesised mainly by **fibroblasts** but also chrondroblasts.
- The amino acids of glycine, proline and lysine are required with contribution from Vitamin C.
- The proline and lysine are hydroxylated to hydroxypropline and hydroxylysine.
- Intracellularly, the amino acids form individual **left-handed molecular chain.**
- 3 of these chains come together to form a **right handed triple helix procollagen**.
- Type I collagen comprises of two ∝1 and one ∝2 chains.
- The type and combination of polypeptide chains differs for the different collagen types.
- Before procollagen becomes extraceullar its ends are cleaved off by enzyme peptides to form **tropocollagen**.
- One end of the helix is the N-terminal and the other is the C-terminal, these are markers of collagen turnover.
- These tropocollagen chains are arranged in a **quarter-staggered array** linked by H-bonds to form **microfibrils**.
- Further aggregation of microfibrils result in the formation of **collagen fibres**.
- The triple helical structure provides the tensile strength and the quater-staggered array gives compressive strength.
- **Types:**

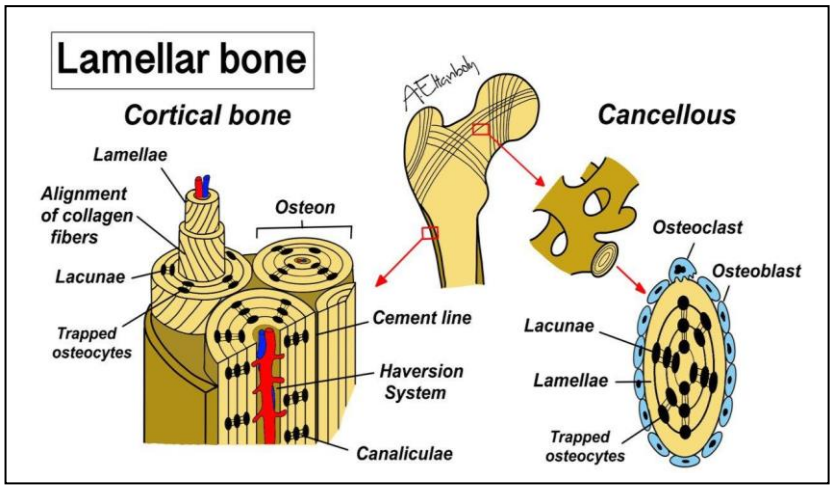
Types	Where it's found & associated pathologies
I	- Bone, tendon, ligament, annulus fibrosis, meniscus, fibrocartilage, skin - *Osteogensis imperfecta, Ehlers Danlos.*
II	- Hyaline (articular) cartilage, nucleus pulposus & inner annulus - *Chondrodysplasias*
III	- Skins, blood vessels - *Proliferative repair phase of tendon and ligament healing and soft callus. Ehlers Danlos, Dupuytren's contracture and adhesive capsulitis*.
IV	- Basement membrane - basal lamina - *Goodpasture syndrome*
V, VI & IX	- Small amounts in articular cartilage - *Multiple epiphyseal dysplasia (MED) - defect in Type IX.*
VII & VIII	- Epithelial basement membrane
X	- Produced in zone of hypertrophy (provisional calcification zone) and Involved in endochondral ossification.

STRUCTURE OF BONE

Lamellar (mature) bone

- **Cortical:**
  - Makes up 80% of the skeleton.
  - High young's modulus of 20 Gpa.
  - Stronger mechanically.
  -) Anisotropicbehaves differently when loaded in different planes.(
  - Slow turnover.
  - Osteoblasts deposit bone in concentric thin sheets of lamellar arrangement.

- Haversian system(:(Osteon
  - Functional unit of bone.
  - Concentric layer of osteocytes surrounded by concentric layers of lamella.
  - Lamellae are from collagen produced by osteoblasts.
  - Haversian canal contains capillaries, venules(intravascular supply) ,nerves and lymphatics.
  - Outer margin is delineated by cement lines. These have no osteocytes and are not connected by collagen fibres making them weak areas and the sites of fracture propogation.
- Volkmann's canals:
  - Run perpendicular to the Haversian canals.
  - Connect blood vessels between Haversian canals.
  - Transmit blood vessels from the periosteum (extravascular supply) into bone.



❖ **Cancellous (trabecular):**

- Anisotropic.
- Lower young' s modulus of1 Gpa.
- Higher turnover compared to cortical bone.
- Parallel interconnecting sheets of trabeculae to afford maximum strength for minimum mass(less dense).
- Highly porous which is very vascular and filled with red marrow.
- Haversian system no present.

Woven (immature) bone

❖ Found in fracture callus, pathological bone (tumour, OI, Paget's disease etc) and embryonic long bone formation.
❖ Randomly arranged collagen fibres and hypercellular.
❖ Isotropic (behaves the same when loaded in different planes).
❖ Rapid turnover.
❖ Lacks mechanical properties.

BONE BLOOD SUPPLY

❖ **Three sources of blood supply:**

- **Nutrient artery system** (diaphyseal):
  - Enter the diaphyseal cortex through the nutrient foramen.
  - After entering the medullary canal, it sends ascending and descending artery branches.

- High pressure system because it's derived from the systemic circulation.
- Supplies the inner2/3.rd of cortical bone

▪ **Metaphyseal-epiphyseal system**: arises from the peri-articular vascular plexus e.g. geniculate arteries.

▪ **Periosteal system**:

- Mostely capillaries and supplies the outer 1/3rd of cortical bone.
- Via muscle attachments.
- .Low pressure system
- Dominant blood supply in children.

❖ **Blood flow:**

▪) **Centrifugal**inside to outside (flow occurs in mature bone and is disrupted when reaming the medullary canal.

▪) **Centripetal**outside to inside (flow occurs in fractured and immature bone as the periosteal system dominates.

BONE COMPOSITION

❖ Bone is a composite (made up of materials that have different mechanical properties) dynamic form of specialised hard connective tissue, which is composed of cells (10%) and extracellular matrix (90%).

❖ It has viscoelastic properties.

❖ **Functions:**

▪ Locomotion.

▪ Protection- ribcage and skull.

▪ Haematopoietic cells(WBC and RBC).

▪ Calcium haemostasis(main store of calcium).

Growth factors and cytokines

❖ **BMPs** (bone morphogenetic proteins):

▪ Osteoinductive leading to bone formation.

▪ Activiates mesenchymal cells to differentiate into osteoblasts.

▪ Belongs to the TGF family.

▪ **BMP-2**) osteogenic:(

- Used in bone healing in open tibia fractures and spine fusion.
- Thought to Improve rotator cuff healing.
- Adjunct to decompression in AVN.

▪ **BMP-3** :Antagonisesthe action of BMP - 2and is not osteoinductive.

▪ **BMP-4, 6, 9** :osteogenic

▪ **BMP-7** :is osteogenic and used for long bone non-unions .

▪ **BMP-12** :thought to improve rotator cuff healing.

❖ **TGF-β** (Transforming growth factor beta):

▪ Produced by platelets.

▪ Stimulates production of type II collagen and proteoglycans.

❖ **IGF** (Insulin-like growth factor):

▪ Produced by platelets.

▪ Most abundant growth factor in bone.

▪ .Directs bone healing

- Stimulates osteoblasts and chondroblasts.

❖ **PDGF** (platelet derived growth factor):
- Produced by platelets and monocytes.
- Signals inflammatory cells to migrate to the fracture site.

❖ **FGF (fibroblast growth factor)**:
- Produced by endothelial cells.
- Stimulates many different cells types and is involved in angiogenesis and callus formation.

❖ **TNF** (tumour necrosis factor):
- Produced by inflammatory cells.
- Involved in the regulation of immune cells. High levels are seen in autoimmune and inflammtory conditions as well as cancers.

❖ **ILs** (interleukins):
- **IL-1:**
  - Produced by macrophages.
  - Activates osteoclasts and causes osteolysis.
  - Part of the inflammatory cascade in RA that leads to joint damage.
  - Anakinra is an IL- 1anatagonisted used in the treatment of RA .
  - Increased in OA and associated with disc damage.
- **IL-6:**
  - Produced by macrophages.
  - Causes osteolysis.
  - Highest correlation with periprosthetic infection
  - Activates osteoclasts in multiple myeloma.
  - Increased in OA.
- **IL-10:**
  - Inhibits osteoclast formation.
  - Improves patella tendon healing.

❖ **Corticosteroids**:
- Produced in the adrenal cortex.
- Decrease GI absorption and renal reabsorption of calcium.
- Inhibtis osteoblasts.
- Prolonged exogenous use can lead to secondary hyperparathyroidism.

Cells

❖ **Osteoblasts:**
- Differentiate from**mesenchymal stem cells** along with fibroblasts and chondroblasts.
- Express receptors to PTH, PTHrP, Vitamin D metabolites, gonadal and adrenal steroids, cytokines and GFs.
- Bone forming cells.
- Regulate osteoclast function.
- **Produce:**
  - Unmineralised matrix containing type I collagen called **osteoid**.
  - ALP
  - Osteocalcin
  - RANK- L(ligand):
    - Member of TNF cytokine family.
    - Produced in response to activiation by PTH.

- Can be stimulated by bone cancer cells.
- Binds to and activates RANK cell surface receptors on immature osteoclasts.
- Functions as key factor for osteoclast differentiation and activation.
- **Denosumab** inhibits *binding* of RANK-L to RANK and treats postmenopausal osteoporosis.

- Osteoprotegrin (OPG):
  - Blocks the binding of RANK-L to RANK receptors and so inhibits osteoclast formation and activation.
  - Acts as a decoy to RANK-L inhibiting activation of RANK on osteoclasts.
  - Responds to chemical, mechanical and electrical stimualtion.

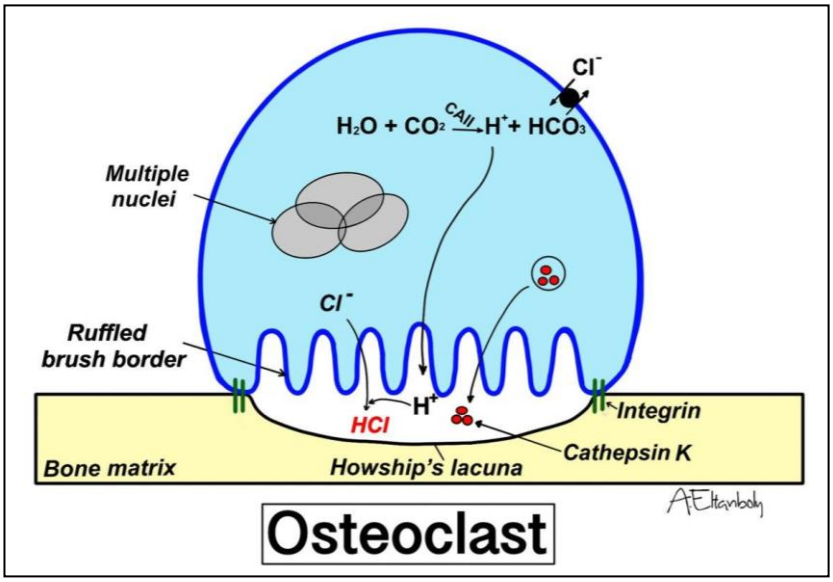
- **Stimulated** by PTH, Vitamin D, oestrogen, BMP, PDGF, IGF and TGF-β.
- **Inhibited** by TNF, hydrogen peroxide, povidone iodine, steroids, COX-2 inhibitors.
- Fate of osteoblasts:
  - .Undergo apoptosis
  - .Become osteocytes which is stimulated by calcitonin and inhibited by PTH
  - .Become bone lining cells

❖ **Osteocytes:**

- Derived from osteoblasts surrounded by matrix and maintain bone mass.
- **Stimulated** by calcitonin.
- **Inhibited** by PTH and bisphosphonates.
- Communicate **with** each other via canaliculi and have signal molecules that detect chemical changes.

❖ **Osteoclasts:**

- Bone resorbing cells.
- Lineage is from**haematopoietic stem cells** along with monocytes and macrophages.
- Once **osteoclast** precursor cells are activated, they fuse together to form **multinucleated giant cells**.
- Have a **ruffled (brush) border** to increase the surface area for bone resorption.
- They can be found in pits called**Howship's lacuna**, which are bone cavity sites undergoing resorption.
- These cells attach to the bone surface via**integrins** to seal the area.
- Produce**carbonic anhydrase**, which is an enzyme for the conversion of CO_2 and H_2O into H^+ and HCO_3^-.
- The formation of HCL beneath the the ruffled border dissolves the inorganic calcium hydroxyapatite.
- **Tartrate-resistant acid phosphatase (TRAP)** and **cathepsin K** enzymes hydrolyse the organic matrix.



- **Stimulated** by RANK-L, IL1, IL6, PTH (indirectly via osteoblasts) and cancer cells.
- **Inhibited** by:
  - Calcitonin(through direct receptors) causes the dissolution of the ruffled border.
  - Bisphosphonates cause either apoptosis or inhibit formation of the ruffled border.
  - .Oestrogen
  - .IL10
  - OPG binds to RANK-L and is inhibited by corticosteroids.

❖ **Bone lining cells:**

- Dormant cells present on the surface of the bone and become osteoblasts when activated.
- Recuited by osteocytes.
- Lay down new bone if stores are low.

Matrix

❖ **Organic (30%):**

- Type I collagen provides the tensile strength of bone.
- Proteoglycans provide some compressive strength of bone.
- -Noncollagenous proteins:
  - Osteocalcin- most abundant
  - Osteonectin- regulates calcium
  - Osteopontin
  - Growth factors and cytokines(IL1 ,IL 6and BMP.(

❖ **Inorganic (70%):**

- Calcium reservoir
- Calcium hydroxyapatite($Ca_{10}(PO_4)_6(OH)_2$) provides the compressive strength of bone.
- Calcium phosphate.

Bone marrow

❖ **Red:**
- Contains mesenchymal stem cells(pluripotent and self-regeneration).
- Most commonly found in flat bones and epiphysis/metaphysis of paediatric long bones.
- .Haematopoietic

❖ **Yellow:**
- Most commonly found in the diaphysis of long bones.
- Contains fat cells.

Periosteum

❖ Outside covering of the bone and is made up of two layers.
❖ Inner (cambium):
- Vascular.
- Forms callus and enlarges the diameter of the diaphyseal bone.

❖ Outer:
- Fibrous.
- Contiguous with the joint capsule.

❖ Functions:
- Supplies blood to the outer third of the bone.
- Provides attachment to muscles, ligaments and tendons.
- Prevents spillage of bone components into surrounding tissue.

Summary of bone formation

❖ Dynamic process involving balance between bone formation and resorption.
❖ In order to form normal healthy lamella bone you need the formation of osteoid followed by its mineralisation.
❖ **Formation of osteoid (unmineralised bone):**
- Under the control of the RANK/ RANK- L/ OPG complex.
- When stimulated, the osteoblasts release RANK-L, which activates osteoclast precursor cells to differentiate into the mature multinucleated osteoclast cells to carryout bone resorption.
- Through a feedback mechanism, bone resorption is switched off when OPG from osteoblasts works to mop up the RANK-L.
- These two processes happen at the same time.
- Osteoblastic activity greater than osteoclastic activity will result in osteopetrosis.
- Uncoupling of osteoblastic and osteoclastic activity occurs in Paget's disease.

❖ **Mineralisation of the formed osteoid:**
- For this to happen, both calcium and phosphate are required in normal amounts.
- This is controlled through the actions of all the hormones involved in bone metabolism discussed in the' Bone Metabolism' .section

BONE OSSIFICATION

❖ **Endochondral:**
- Cartilage is replaced by bone.
- Foetal long bone development and longitudinal growth of physis.

- Secondary (indirect) fracture healing.

❖ **Intramembranous:**

- Direct laying down of bone without a cartilage model.
- Mesenchymal cells differentiate into osteoblasts.
- Foetal bone development of flat bones.
- Applied in distraction osteogenesis.

BONE METABOLISM

❖ Dynamic process involving a balance between bone formation and resorption.

Elements

❖ **Calcium**

- 99% of body calcium stored in the skeleton as calcium hydroxyapatite.
- Normal range of 2.2 - 2.6 mmol/L
- In plasma(1%):
  - 55% free ionised form(measured on gas analysis).
  - 45% bound to proteins and this is decreased with low albumin.
- Amount required:
  - 1500mg/day for postmenopausal women ,in pregnancy and for wound healing.
  - 2000mg/day for lactating mothers.
  - 750mg/day for adults.
  - mg 5000/day for rickets
- Functions:
  - Bone mineralisation.
  - Muscle contraction.
  - Nerve conduction.
  - .Coagulation

❖ **Phosphate**

- 85% of body phosphorus is stored in the skeleton.
- Normal range of0.97-1.45 mmol/L
- Important in enzyme function.

Hormones and other regulators

❖ **Parathyroid hormone**

- Produced**chief cells** .of the parathyroid glands. Most common cause of hypocalaemia in thyroidectomy
- **Teriparatide** is the synthetic form.
- **Effects**:
  - Blood: Increases serum calcium and decreases serum phosphate levels.
  - :Bone
    - Stimulates osteoblasts to secrete IL-1, IL-6 and other cytokines to activate osteoclasts.
    - Pulsed levels gives an anabolic effect and continous levels gives a catabolic effect.
  - GI tract:
    - Stimulates conversion of 25(OH) Vit D3 to $1,25(OH)_2$ Vit D3 (active form).
    - Increase absorption of calcium from small intestines.

- .Kidney: Increases calcium absorption and phosphate excretion

❖ **Calcitonin**

- Produced by**para-follicular C-cells** .of the thyroid gland
- **Effects**:
  - :*Blood*decrease serum calcium and phosphate levels.
  - :*Bone*oppose osteoclastic bone resorption by decreasing numbers and activity of osteoclasts.
  - *GI tract*:inhibitory effect on intestinal absorption of calcium and phosphate .
  - *Kidney*: increases the excretion of calcium and phosphate.

❖ **Vitamin D:**

- Natural steroid
- From diet and sun exposure.
- 7-dehydrocholesterol is converted to cholecalciferol (vitamin D3) in the skin by UV light.
- Vitamin D3 is then hydroxylated by 1α hydroxylase in the liver to the inactive 25-hydroxycholecalciferol Vit D3.
- This inactive form can be changed into the active form of 1, 25hydroxycholecalciferolVit D 3 under the action of the enzyme 1α hydroxylase in the kidneys.
- In the elderly and those with renal disease, hydroxylation is reduced.
- **Effects**:
  - :*Blood*increase serum calcium and phosphate levels.
  - :*Bone*promotes mineralisation of osteoid and maintains serum calcium levels by osteoclast activation.
  - *GI tract*:increases intestinal absorption of calcium and phosphate .
  - :*Kidney*decreases calcium and phosphate excretion.

❖ **Oestrogen**

- Inhibits bone resorption and therefore prevents bone loss.
- Consequently, it doesn't stimulate bone formation and there is no increase in bone density.
- Associated with an increased risk of breast cancer and heart disease, but decreased risk of endometrial cancer.

❖ **Thyroxine**

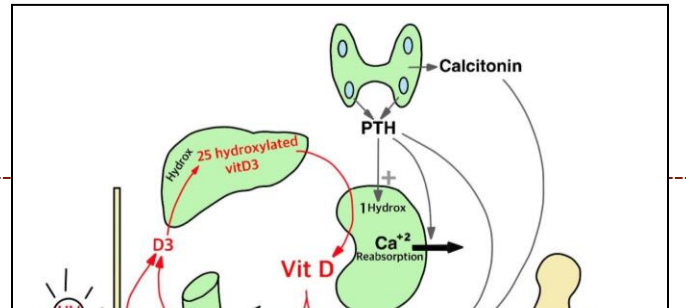
- Regulates skeletal growth at the physis by stimulating chondrocyte growth, type X collagen synthesis and ALP activity.
- Increases bone resorption and can lead to osteoporosis.

❖ **Growth hormone**

- Increases serum calcium by increasing absorption in the GI tract and decrease urinary excretion.
- Acts on the proliferative zone of the growth plate.
- Over secretion by a pituitary adenoma results in gigantism when the physes are open and acromegaly when they have closed.

❖ **Summary:** all these regulators work by **feedback loops** to control calcium metabolism.

- Both1,25)OH ($_2$Vit D 3and PTH respond to a drop in calcium levels.
- Calcitonin reponds to an increase in calcium levels.
- Increase in serum phosphate causes a reduction in active Vit D levels.
- Increase in active Vit D3 causes a reduction in PTH throught the negative feedback loop because the active Vit D will work to increase serum calcium levels.



Disorders of mineralisation

❖ Associated with normal osteoid formation.

❖ **Hypercalcaemia**

- **Symptoms:**
  - Polyuria, polydipsia, confusion, muscle weakness, vomiting, constipation, peptic ulcer and pancreatitis.
  - Basal ganglia calcification on x-rays.
- **Causes**:
  - Malignancy throught the activation of RANK/ RANK- L(PTHrP mediated).
  - Primary hyperparathyroidism producing elevated PTH.
  - Vitamin D mediated(toxicity) milk-alkali syndrome.
  - High-bone turnover conditions such as Paget's disease.
  - Familial hypocalciuric hypercalcaemia due to a mutated calcium sensing receptor.
- **Treatment**:
  - Hydration- enhances glomerular filtration and excretion of calcium.
  - Diuretics- inhibits calcium resorption in the distal renal tubules.
  - IV bisphosphonates- inhibit osteoclast function.
  - Dialysis.

❖ **Hypocalaemia**

- **Symptoms:**
  - ,*Paraesthesia*convulsions and mood swings.
  - *Trousseau' - s sign*carpopedal spasm after BP cuff inflation.
  - *Chvostek' - s sign*facial muscle contractions initiated by tapping on facial nerve.
- **Causes**:
  - :*Rickets* Inadequate Calcium& phosphate prior to closeure of physis
    - Nutritional.
    - Vitamin D resistant - familial hypophosphatemic rickets (X-linked dominant) need to replace both calcium and phosphate levels.
    - Vitamin D dependent type 1 - problem with 1α hydroxylase enzyme and can't activate Vit D.
    - Vitamin D dependent type 2 - don't have the receptor for 1,25 (OH_2) Vit D3 to act properly.
  -) *Kidney failure*renal osteodystrophy.(
  - *Hypoparathyroidism.*
  - *Pseudohypoparathyroidism.*
  - *Pancreatitis.*

- *Hypoproteinaemia*

▪ **Treatment**: Calcium gluconate infusion with cardiac monitoring in the acute setting.

❖ **Hyperparathyroidism**

▪ **Symptoms:** bones (fractures, generalised osteopaenia, acro-osteolysis), stones, groans (GI) and psychic moans.

▪ **Causes**:

- :*Primary*adenoma ,hyperplasia and rarely carcinoma.
- :*Secondary*kidney failure and hypocalaemia.
- :*Tertiary*parathyroid acquired autonomy insecretion of PTH due to gland hyperplasia .

Types	Serum Ca	Serum Ph	Serum PTH
Primary	↑	↓	↑
Secondary	Normal or ↓	↑	↑
Tertiary	↑	↑	↑

▪ **Treatment**:

- Parathyroidectomy is calcium> 2. 85mmol/L or T-score >-2.5.

❖ **Pseudohypoparathyroidism**

▪ High levels of PTH caused by lack of response from the dysfunctioning PTH receptor.
▪ Can be associated with McCune-Albright's hereditary osteodystrophy.
▪ Get hyperplastic parathyrid glands due to chronic over secretion of PTH.
▪ Kidneys become resistant to PTH.
▪ No response to the exogenous hormone.
▪ Get bone changes consistent with hypeparathyroidism.
▪ .Causes hypocalaemia
▪ Brachydactyly, low intelligence and exostosis.

❖ **Mechanical properties of different bone types**

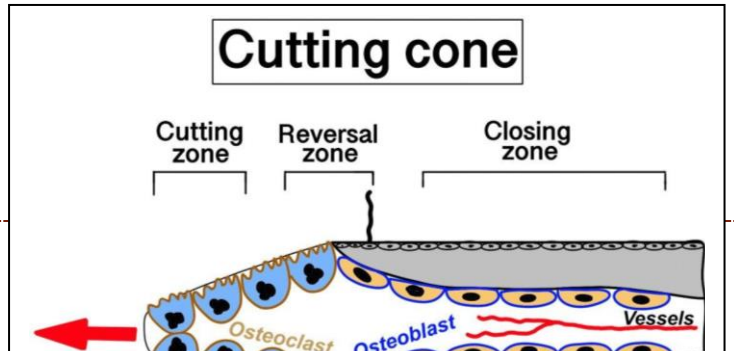
▪ **Osteoporotic bone**: yield point occurs at the same strain as normal trabecular bone but at a lower stress value, meaning the bone is less stiff and more brittle (lies between the normal and osteomalacia bone on the load-elongation curve).
▪ **Osteomalacia bone**: this bone is more complaint thus having lower stiffness and higher ductility (far right of normal bone on the load-elongation curve).
▪ **Osteopetrosis bone**: is highly mineralised and so has greater stiffness and brittleness (to the left of normal bone on the load-elongation curve).
▪ **Paediatric bone**: is less mineralised and has a lower modulus of elasticity resulting in lower stiffness and higher ductility. Paediatric bone is able to absorb a lot of energy before it fails.

FRACTURE HEALING

- Fracture healing can be either primary or secondary and this is mainly determined by the strain environment.
- Surgeons can manipulate the mode of healing.
- **Perren's strain theory.**
  - Differentiation of progenitor cells depends on the amount of strain at the fracture site:
    - **<2%** = differentiation into osteoblasts and form **woven bone**.
    - **2 - 10%** = differentiation into chondroblasts and form **fibrocartilage tissue**.
    - **10 - 100%** = differentiation into fibroblasts and form **fibrous connective tissue** (fibrous union)
    - **100%** = differentiation into fibroblasts and form **granulation tissue** (non-union).

Primary (Direct) bone healing

- This describes laying down of bone directly without a cartilage anlage.
- Intramembranous ossification.
- There is direct osteonal (cortical), cancellous and periosteal healing.
- Need to have **absolute stability** and **bony contact** across the fracture site.
- Interfragmentary compression can be achieved with a lag screw, partially threaded screws or plates.
- This will result in a strain environment of <2%.
- The cells cross the fracture site in a **cutting cone** formation.
  - **Cutting zone**.osteoclasts cross fracture gap to resorb bone and leave a path for bloos vessels and osteoblasts :
  - **Reversal zone**: vascular bundle forms the Haversian system.
  - **Closing zone**: osteoblasts migrate to form mature mineralised Haversian bone.
- The cutting cone can drive straight across a fracture gap of **<50 μm** and this is known as **contact healing**.
- **Gap healing** occurs when the gap of **50-100 μm** is too wide for the osteoclasts to directly cross. In this situation, blood vessels span across first carrying mesenchymal cells, which differentiate into osteoblasts to help reduce the gap for the cutting cones to then cross.
- There is no callus formation at the fracture site when primary healing occurs.
- **Direct cancellous healing:** due to little or no strain in the cancellous honeycomb bone structure, blood vessels are able to move from the high to low oxygen environment (fractured part) through the vast pores. They take their cell population with them and osteoblasts are able to lay down new bone.



Secondary (Indirect) bone healing

- This describes laying down of bone via a cartilage anlage.
- Enchondral ossification.
- Occurs when there is **relative stability** at the fracture site with non-rigid fixation.
- Fracture management with braces, plasters, IM nail, external fixators and bridging plate fixation.
- Callus formation at the fracture site.
- Occurs when there's a strain environment of 2-10%.
- **Stages of fracture healing:**
  - **Haematoma** (minutes):
    - .Vessel injury starts the coagulation cascade
    - .Formation of the fibrin clot
    - Low oxygen environment.
  - **Inflammation** (hours-days):
    - Angiogenesis(high to low oxygen tension).
    - Delivery of cell population to fracture site.
    - Neutrophils release several cytokines including IL-1, IL-6, PDGF, FGF, VEGF TNFα and TGF-β.
    - Osteoclasts resorb the bone ends.
    - Macrophages remove debris.
  - **Soft and hard callus** (weeks-months):
    - Different tissue types are put down to gradually reduce the strain from100 %to >2.%
    - The fracture gap is gradually reduced.
    - The strain level will determine the final tissue type at the fracture.
    - Soft callus forms during the first2-4 weeks and comprises types II and III collagen.
    - This is converted to hard callus(woven bone) over1-4 months and is made up of Type I collagen.
  - **Remodelling** (months-years)
    - Occurs under the action of the osteoblasts and osteoclasts.
    - The disorganised woven bone matures into organised stress orientated lamellar bone.
    - **Wolff's law** states that bone remodels in response to the mechanical stresses placed on it.
    - **Piezoelectric theory** states that remodelling occurs in response to electric charge:
      - Shift of fluids through Volkmann canals result in movement of charged particles and changes in electric potential.
      - Tension side is (+ve) and therefore stimulates osteoclasts.
      - Compression is (–ve) and therefore stimulates osteoblasts.

❖ **Diamond concept** (Giannoudis et al, Injury 2007) states that bone regeneration requires the presence and utilisation of:

- Growth factors(osteoinductive).
- Scaffolding(osteoconductive).
- Mesenchymal cells(osteogenesis).
- Mechanical environment(vascular status and stability).

FRACTURE NON-UNION

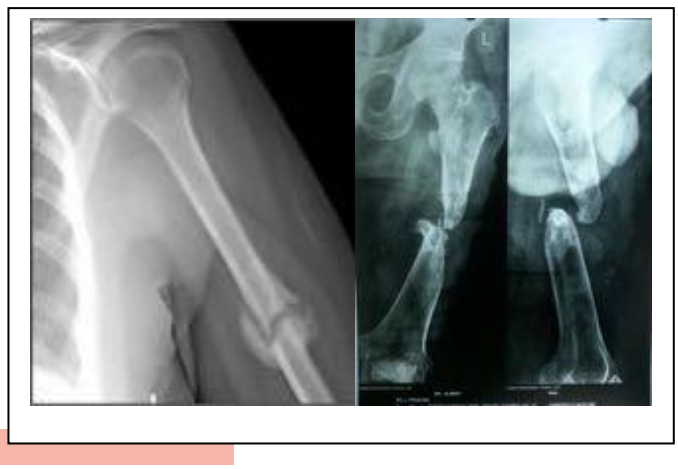
- **FDA definition:** fracture that is at least 9 months old and has not shown progressive signs of healing for 3 consecutive months.
- Failure of healing without further intervention within the expected time (e.g. distal radius 6 weeks, tibia 3 months).
- **Clinical union:** the absence of tenderness, abnormal motion and pain on loading.
- **Radiological union:** the presence of bridging bone in 3 out 4 cortices (AP and lateral views).

Factors affecting fracture healing

- **Local:**
  - Extent of soft tissue trauma.
  - Bone loss.
  - Infection.
  - Inadequate blood supply.
  - Comminution(compromises of blood supply to the an intercalary segment).
  - Inadequate mechanical stability at the fracture site.
- **Systemic:**
  - Diabetes mellitus- decreased cellularity of fracture callus).
  - Poor nutrition- Vitamin D and protein.
  - Associated head injury- increase formation of callus and enhanced healing.
  - :Smoking
    - Inhibits angiogenesis as bone is remodelled.
    - Nicotine increases aggregation of platelets.
    - CO displaces O2 from Hb resulting in lower oxygen tension in tissues.
    - Cotinine urine testing.
    - ,Bisphosphonatesquinolones)e.g .ciprofloxacin(, steroids and NSAIDS.

Types of non-union

- **Hyertrophic:**
  - Normal biology.
  - Lack of stability with a high strain environment.
  - No need for bone graft.
- **Atrophic:**
  - A problem with the biology.
  - Sclerotic bone edges.



Treatment

- Address any fracture instability leading to hypertrophic non-union:
  - Dynamisation.
  - Exchange nailing for a larger and stiffer nail. Reamings generate autograft.
  - Freshen up the bone ends, aim to maximise intrafragmentary compression and increase stability.
- Identify modifiable risk factors when treating atrophic non-union.
  - Use bone graft.
  - Exogen:
    - Low intensity pulsed ultrasound(LIPUS) accelerates fracture healing.
    - Stimulates chondroblasts and osteoblasts, and enhances blood flow.
    - Application for20 min/day.
    - Has NICE approval in the UK for treatment of long bone non- unions after9 months.
- **Infected non-union:**
  - Radical surgical debridement of infected and non-viable bone ends.
  - Achieve bony stability.
  - Dead space management using the**Masquelet technique**) two-stage procedure:(
    - After debridement, a cement spacer is used to fill the void.
    - A fibrous membrane forms around the cement spacer.
    - When the cement spacer is removed, it leaves behind a space encapsulated by the fibrous membrane.
    - At a later date this space can be filled with bone graft.

BONE GRAFT

❖ **Bone graft** is any material which assists and supports the mechanical and biological properties of bone healing.
❖ It's either used for structural stability resulting from bone loss or to enhance fracture healing in non-union.

Classfication according to qualities

❖ **Osteoconductive:** provides a 3D scaffold and structural framework for new bone to grow one e.g. cancellous bone.
❖ **Osteoinductive:**
- Contains biological factors such as BMP andTGF-β (e.g. Allomatrix) that stimulate bone growth and promote differentiation of mesenchymal cells.

❖ **Osteogenic:** contains live mesenchymal cells, osteoblasts and osteocytes.

Classfication according to source

❖ **Autograft:**
- Gold standard.
- Harvested from the same individual.
- Taken using an osteotome or harvesting system(Reamer Irrigator Aspirator- RIA by Synthes) and not a saw to avoid thermal necrosis.
- Taking too much bone ecentrically can result in a stress fracture.
- The graft can be cortical, cancellous, cortico-cancellous or even bone marrow aspirate.
- Vascularised autograft is best for irradiated bone, large defects or sites of non-union with poor blood supply:
  - Free fibula strut graft(peroneal artery) is useful for diaphyseal reconstruction and in C-spinal fusion.
  - Free iliac crest(deep circumflex iliac artery) is useful for metaphyseal reconstruction.
  - Dorsal distal radius(1,2-intercompartmental supraretinacular artery) for avascular scaphoid fractures.
- **Advantages**:
  - Osteoconductive, osteoinductive and osteogenic.
  - Sterile.
  - Rapid incorporation via**creeping substitution**.
  - No risk of disease transmission.
  - Not immunogenic.
- **Disadvantages**:
  - Donor site morbidity(scar, haematoma, infection and pain).
  - Limited volume.

❖ **Allograft:**
- Harvested from the same species.
- Fresh allograft has both osteoconductive and osteoinductive properties becuase BMP are preserved.
- **Processing and storage:**
  - :Fresh frozen
    - Typically femoral heads that have BMP preserved.
    - Less antigenic and still preserves biomechanical properties.
    - Problems with storage as they require very cold temperatures.
  - Freeze dried:
    - Osteoconductive but has poor mechanical properties.
    - Some osteoinductive properties as it contains collagen, BMP-2 & 7, TGF-β, residual calcium.
    - No mesenchymal cells

- Least immunogenic.
- Produced by the removal of minerals from cortical bone
- Can be stored at room temperature
- Screened for HIV, HBV, HCV, HTLV-1 and syphilis.

- Demineralised bone matrix(DBM):
  - Highly processed allograft derivative (up to 40% mineral content removed by acid wash).
  - Inferior structural integrity and poor mechanical properties.
  - Osteoconductive and osteoinductive (presence of some growth factors).

- **Advantages**:
  - More volume available.
  - No donor site morbidity.
- **Disadvantages**:
  - Highest risk of disease transmission and immunogenicity.

❖ **Bone substitute:**

- Synthetic, inorganic or a biologically organic combination can be used instead of autograft or allograft.
- It could be ceramic(hydroxyapatite, tricalcium phosphate, calcium sulphate) ,growth factors)DBM ,BMP-2 &7 (or composite)with collagen.(
- **Ideal bone substitute**:
  - Biocompatible.
  - Osteoconductive, osteoinductive and osteogenic.
  - Resorbable.
  - Easily moulded into a bone defect and has a short setting time.
  - Thermally non-conductive and sterilisable.
  - Radiolucent.
  - Readily available at reasonable cost.
- Fastest to slowest resorption time: calcium sulphate, TCP and then HA.
- Examples:
  -) *Allomatrix*Wright :(DBM putty with a calcium sulphate carrier.
  -) *ChronOS*Synthes:(
    - Resorbs faster (4-12 weeks) than bone growth occurs but has a very high compressive strength.
    - Osteoconductive (used to fill non-weight bearing bone defects).
    - Increased rate of serous drainage at surgical site.
    - Ineffective in the treatment of non-unions.
    - Powder, pellet or putty form.
    - Need to mix it with blood to form a cohesive mixture that is easy to handle.
  -) *Cerement*Bonesupport:(
    - Consists of 60% calcium sulphate and 40% HA.
    - Used as a filler and provides some structural support.

❖ **Xenograft:**

- Graft taken from another species.
- Rarely used due to the high risk of immunogenicity.

Graft incorporation

❖ Process of envelopment and interdigitation of the donor bone tissue with new bone deposited by the recipient.

❖ Incorporation can be either full or partial replacement of the graft tissue.

❖ **Primary stage:**

- Inflammation and haematoma formation: platelets attract macrophages and fibroblasts by chemotaxis.
- Revascularisation.
- Osteoblasts differentiation.

❖ **Secondary stage:**

- **Cortical bone**:
  - Osteoclasts remove all the bone graft followed by ostoblasts laying down new osteoid via cutting cones.
  - Slow process.
- **Cancellous bone**:
  - Incorporates via creeping substitution with the simultaneous resorption of graft by osteoclasts and laying down of new bone by osteoblasts.
  - Quicker process.

Setting up a bone bank

❖ **Complex process considering:**

- **Donor selection**
- **Donor consenting:**
  - From the patient if they're alive or next of kin if deceased.
  - Also need consent to test for blood borne viruses and have access to medical records.
- **Donor screening:** exclude those at high risk of infection, malignancy and inflammatory conditions.
- **Graft harvesting.**
- **Graft preparation:**
  - Debridement
  - Ultrasonification.
  - Alcohol wash to denature the proteins and decrease the bacterial load.
  - Antibiotic treatment to further decrease the bacterial load.
  - Sterilisation with gamma radiaition
  - Demineralisation by using acid to remove protein and reduce an immunogenic reaction.
- **Graft preservation:**
  - Fresh, fresh-frozen or freeze- dried(e.g. croutons).
  - Use within1 year if kept at-20° C and use within5 years if kept at-70°C.
- **Graft distribution:** not many hospitals have a bone bank on site because it's expensive to run.

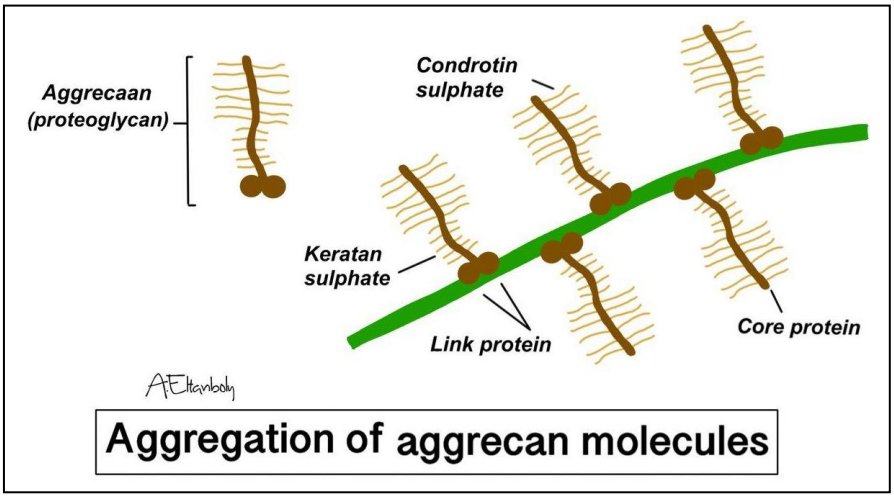
ARTICULAR CARTILAGE

- Also known as **hyaline cartilage**.
- Highly specialised connective tissue made up of **cells (5%)** and **extracellular matrix (95%)**.
- Avascular, aneural, alymphatic and not immunogenic.
- Nourished by synovial fluid and underlying cancellous bone mainly by diffusion (reason to load early in trauma).
- Thickness 5 – 7 mm in weight bearing joints.
- Has a very low coefficient of friction at 0.002, which is 30 times smoother than modern bearing surfaces.
- Anisotropic.
- Biphasic solid and liquid behaviour (hydrostatic pressure giving resistance to compression when taking on water).
- Viscoelastic behaviour when loaded.
- Physiologic loading and hydrostatic pressure changes are chondroprotective.
- **Functions:**
  - Shock absorption.
  - Decrease friction.
  - Distributes load.
- Other types of cartilage:
  - *Physeal* – growth plate.
  - *Fibrocartilage*–.Tendon, ligament insertion into bone, volar plate
  - *Elastic cartilage*–Trachea, auricle, epiglottis .
  - *Fibroelastic* –Meniscus .

Constituents and microscopic structure

- **Cells:**
  - Chondrocytes differentiate from mesenchymal stem cells.
  - Produce extracellular matrix (collagen and proteoglycans).
  - Reduce in number and size with OA and age.
- **Extracellular matrix:**
  - **Water** makes up 65-80% of the weight.
  - **Collagen:**
    - Mainly **type II** (90%).
    - Smaller amounts of types VI (allows chondrocytes to stick to the matrix), IX (constraints the proteoglycan matrix) and X (found near the calcified zone).
    - Provides tensile strength.
  - **Proteoglycans:**
    - Provides compression strength.
    - **Aggrecan** molecule is the largest in size and most abundant by weight.
      - Each molecule possesses > 100 **chondroitin sulphate** (CS) and **keratan sulphate** (KS) chains (glycosaminoglycans).
      - These chains are connected to a **core protein**.
    - Each aggrecan molecule is bond to a**hyaluronic acid backbone** via **link proteins**.
    - It's the negative charge of the sulphate and carboxyl groups on the glycosaminoglycans that give proteoglycans their hydrophilic property. This allows them to take on water and be able to resist compression.
    - In arthritis:
      - The weakness of the type II collagen meshwork cross-linking will fail to resist the swelling pressure

of the existing proteoglycans.
- This will result in an increase in water content.
- There is a reduction in proteoglycan concentration and increased degeneration.
- Resulting subchondral cysts, sclerosis and eburnation (subcondral bone converts to dense smooth surface that resembles ivory).



Macroscopic structure

- It has a layered structure that has a decreasing water and collagen content, whilst an increasing concentration of proteoglycans when going from superficial to deep.
- The large proteoglycans can't pass the network of collagen fibres explaining their small concentration superficially.
- **Superficial** (tangential):
  - Thinnest layer making up 10-20% of the total thickness.
  - Highest water and collagen content.
  - Almost entirely made of collagen fibres, which lie horizontally parallel to the joint surface to resist shear stress.
  - Flat chondrocytes parallel with lamina splendens.
  - Covered with lubricin.
- **Intermediate** (transition zone):
  - Thickest layer making up40-60 %of total thickness.
  - Collagen fibres are obliquely orientated.
  - More rounded chondrocytes.
  - Represents transition of shear to compression loading.
- **Deep basal** (radial zone):
  - Represents 30% of the total thickness.
  - Collagen fibres lie perpendicular to the joint surface and resist compression.
  - Spherical and more concentrated chondrocytes.
  - Arranged in columns.
- **Tidemark:**
  - Acellular boundary between uncalcified and calcified cartilage.
  - Diffusion barrier.

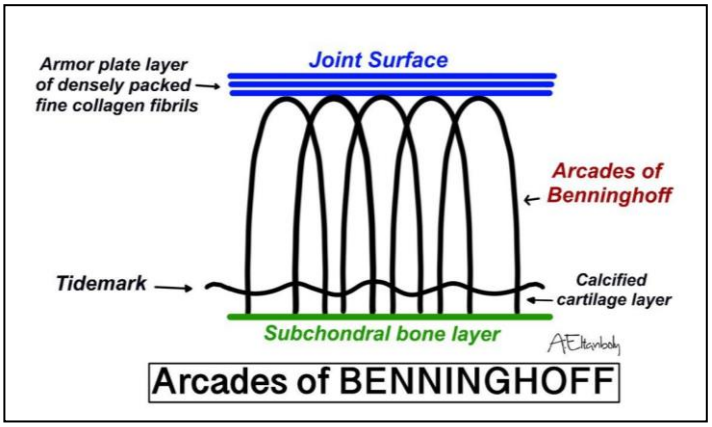
- Damage in the layers above it have poor healing potential.
- Penetrating or damaging this layer will result in healing by laying down fibrocartilage (containing type I collagen rather than hyaline cartilage) from undifferentiated marrow mesenchymal stem cells. Theory behind microfracturing and abrasion chondroplasty.

❖ **Calcified cartilage:**

- Contains HA crystals which anchor the cartilage to the subchondral bone an act as a barrier to blood vessels.

❖ **Arcades of Benninghoff:**

- 3D structural representation of the collagen fibre arrangement spanning the zones described above.
- Allows cartilage to withstand both shear and compressive forces.



Components	Changes	
	Age	Osteoartheritis
H2O	↓	↑
KS:CS	↑	↑
Cellular activity	↓	↑
Number of cells	↓	↓
Proteoglycans	↓	↓
Modulus of elasticity	↑ (stiffer)	↓ (more elastic)

SYNOVIUM

❖ Function is to produce synovial fluid, which is a ultrafiltrate (dialysate) of plasma.
❖ Provides nutrition to articular cartilage and lubrication to the joint surface.
❖ **Constituents:**

- Contains all component of blood plasma except cellular elements and coagulation factors.
- Hyaluronic acid.
- Lubricin.

❖ **Cells** (synoviocytes)**:**

- **Type A** have a phagocytic activity and are activated in RA.

- **Type B** produce synovial fluid.
- **Type C** are precursors to cell types A and B.

❖ **Fluid make-up:**

- ***Normal:***
  - WBC <200/ml and <25% are neutrophils.
  - Equal glucose and protein amount to serum.
  - Clear straw coloured.
- ***Inflammation:***
  - WBC is raised at 2000-50000/ml and <50% are neutrophils.
  - Glucose is lower than in serum at 25 mg/ml.
  - .Cloudy yellow-green colour
- ***Infection:***
  - WBC >50000/ml and >80% are neutrophils.
  - Glucose remains lower than serum at 25 mg/ml or a synovial:serum glucose ratio of <0.5.
  - Presence of pus.

LIGAMENTS AND TENDONS

	Ligaments	Tendons
Cell	• Tenocytes - tendon specific fibroblasts.	
Extracellular matrix	• Type I collagen, water, prostaglandins and plasma proteins.	
Structure	• Type I collagen is less parallel, but layered giving strength between planes.	• Type I collagen is more organised and parallel giving greater tensile strength.
Composition	• Higher in elastin, proteoglycans and water.	• Higher in collagen and less viscoelastic.
Function(s)	1- Augment static mechanical stability to joints. 2- Prevents excessive or abnormal movements. 3- Provides proprioceptive feedback.	• Transmits tensile load from muscle to bone and stores energy like a spring.
Blood Supply	• From the insertion site with bone.	1- Vinculae in sheathed tendons. 2- Paratenon in unsheathed tendons. 3- Bone insertions
Insertion	Direct via 4 zones (e.g. ACL): 1 - Parallel collagen fibres 2 - Parallel collagen fibres intermeshed with unmineralised fibrocartilage. 3 - Fibrocartilage become mineralised. 4 - Mineralised fibrocartilage fuses with bone. Indirect (e.g. superficial MCL): 1 - Superficial fibres insert into the periosteum. 2 - Deep fibres insert into the bone via perforating Sharpey collagen fibres.	

- **Aponeurosis:**
  - .Fibrous sheet or flat expanded tendon giving attachement at the origin or insertion of flat muscles
  - .It also performs the function of a fascia for other muscles
- **Tendon covering:**
  - **Paratenon:**
    - .External most covering of unsheathed tendons such as patellar and achilles tendons
    - .Good vascular supply and heal better
    - .Facilitates gliding
  - **Sheath:**
    - .Hand flexor tendons
    - .Vinculae supply blood to only one tendon segement with avascular areas getting nutrition by diffusion
    - .Prone to adhesions
- **Tendon Layers:**
  - .Epitenon: tissue membrane (under any existing paratenon) that produces synovial fluid and aids gliding
  - .Endotenon: binds the fascicles
  - .Fascicles: groups of collagen bundles

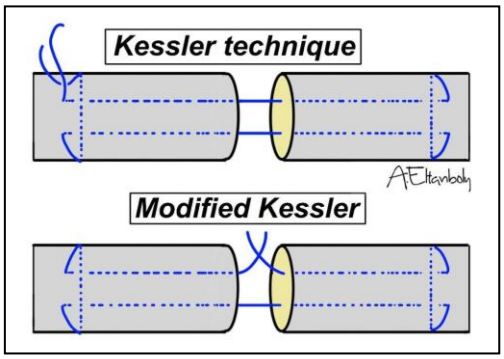
Healing

- **Haematoma (1-15 mins):** Platelets are activated along with the coagulation cascade resulting in a fibrin clot.
- **Inflammation: (1-7 days):** Involvement of neutrophils and macrophages with activation of angiogenesis.
- **Repair: (7-21 days):** Fibroblasts produce type III collagen, which is weak and disorganised.
- **Remodelling:** (18 months):
  - Type I collagen replaces type III collagen.
  - Weakest at 7- 10 days.
  - Most strength is recovered after 21 days.
- Early range of motion stimulates collagen formation, promotes orientation and prevents adhesion formation.
- **Tendinosis:**
  - Chronic or repetitive use leading to a degenerative process in the absence of inflammatory cells.
  - Vascular ingrowth.
  - Hypercellularity with fibroblast hypertrophy and disorganised collagen.
- **Enthesitis:** inflammation at the bone-tendon junction.
- **Ligament injuries:**
  - Tensile strength reduces in age and steroid use.
  - **Grade 1 (strain)** .causes pain but no instability
  - **Grade 2 (partial tear)** causes pain, some laxity with a firm end-point (bracing and return to sport in 6 weeks)
  - **Grade 3 (complete tear)** causes less pain with laxity and no end-point (bracing, with surgery in selected cases).

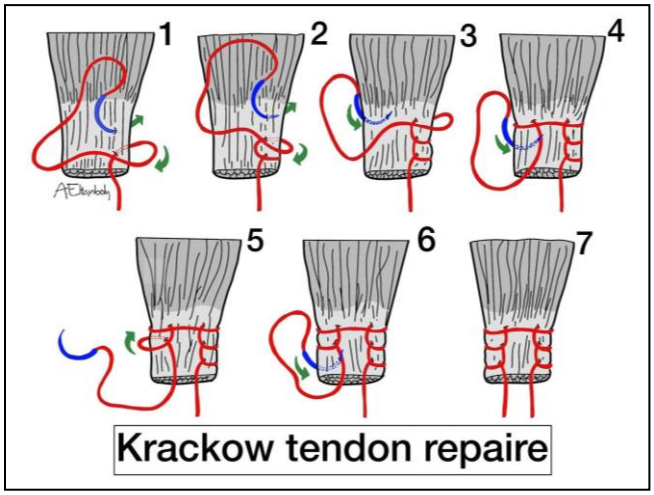
Surgical repair

❖ **Kessler repair:**

- .Used for flexor tendons of the hand
- .Use a non-cutting needle
- .Comprises a 4-strand repair with 4/0 nylon using the modified technique (gives 80% of the repair strength)
- suture for the epitendious continous suture (gives 20% of the repair strength) prevents adhesions and 0/6 .makes gliding smooth
- Greater tensile gap strength is achieved withlocking each loop by placing the vertical component of the suture behind the transverse component relative to the cut tendon end.



❖ **Krackow repair:** below shows the running locking suture technique that is also commonly used in the repair of large tendons such as the quadriceps, patella and achilles.

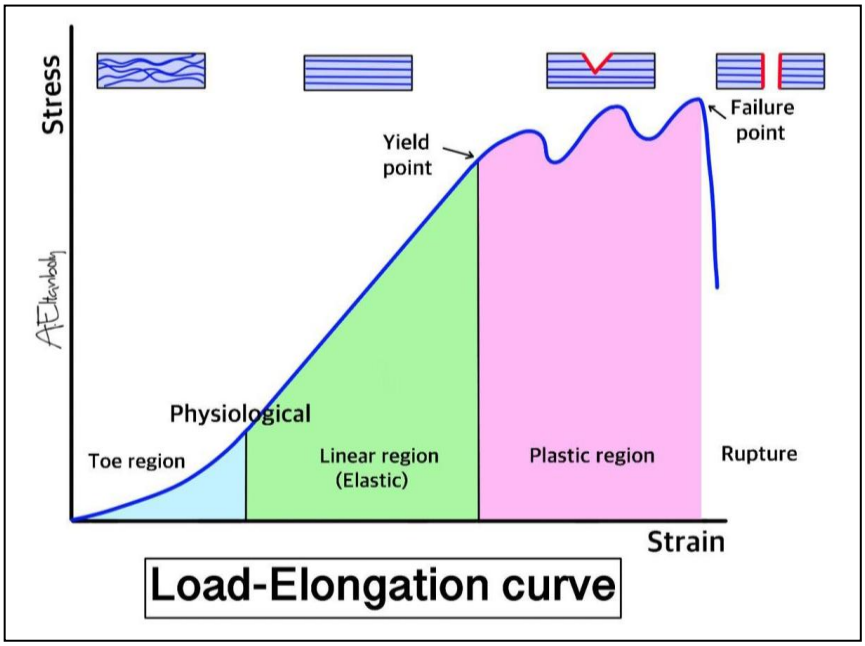


❖ **Dermal patches:**

- .Example is graft jacket
- .Processed from donated human skin
- .Serve as a framework to support cellular repopulation and vascularisation

Load-elongation curve for tendons and ligaments

- Equivalent to the stress-strain curve of materials.
- **Toe region:** crimped fibrils become aligned parallel to the direction of loading.
- **Linear region:**
  - .The elastic region obeys Hooke's law
  - .Steeper than the toe region
  - .Intermediate loads
- **Plastic region:**
  - The yield point is also known as **P_L**.
  - .Dips in the graph represent sequential failure of fibrils
- **Failure region:**
  - The UTS point is also known as **P_{MAX}**.
  - .Occurs under high loads
- **Tendons:**
  - Carry higher loads.
  - Recruit fibres quickly.
  - Collagen is less crimped and therefore have a smaller toe region.
- **Ligaments:** Recruit fibres gradually due to the arrangement of collagen resulting in an elongated toe region.

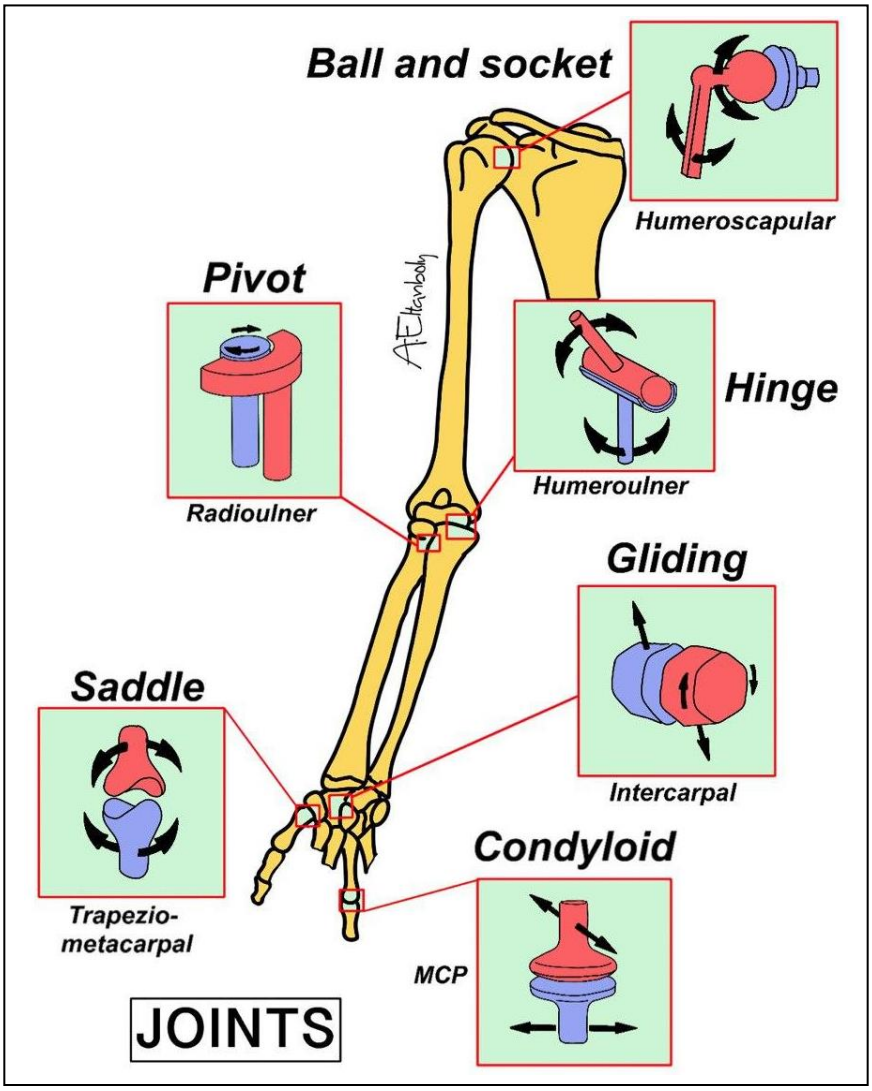


JOINTS

❖ **Connection:**

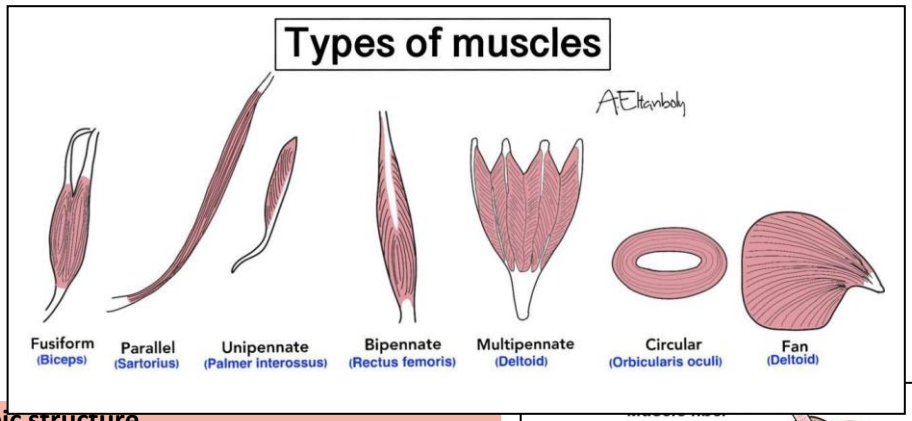
- **Fibrous**: bones are connected by fibrous tissue (e.g. skull, DRUJ, distal tibio-fibular joints).
- **Cartilaginous**: bones connected by hyaline or fibrocartilage (e.g. intervertebral).

❖ **Geometry:**



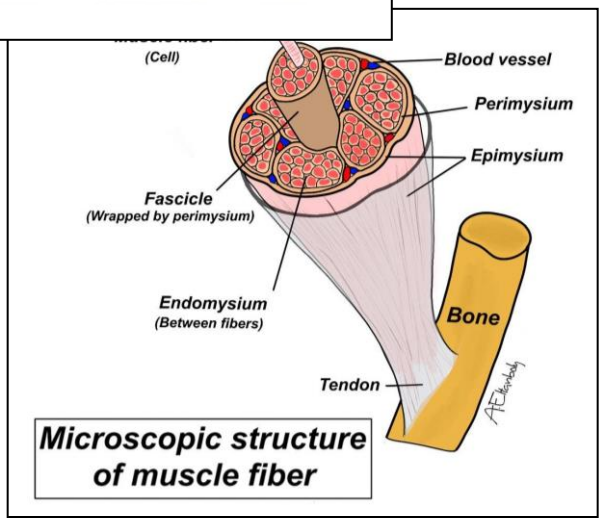
MUSCLES

- **Function:** facilitate, glycogen storage and protects organs.
- **Motor unit:**
  - Consists of the the motor neuron and the muscle fibres it innervates.
  - A small unit gives precise control.
  - A large unit gives less control but greater force.
- **Satellite cells:**
  - Also known as myosatellite cells, these are muscle stem cells that stay dormant until muscle injury occurs.
  - They are responsible for producing new muscle fibres and new satellite cells in response to injury.
- **Sarcolemma** is the muscle cell membrane.
- **Types of muscle:**
  - Parallel e.g. Sartorius.
  - .Fusiform e.g. biceps
  - Fan e.g. pectoralis major.
  - Pinnate (fascicles attach obliquely to tendon): Unipinnate (e.g. palmar interossei), Bipinnate (e.g. rectus .femoris) and multipinnate (e.g. deltoid)
  - Circular (e.g. orbicularis oris).
  - .Triangular (e.g. deltoid)



Macroscopic structure

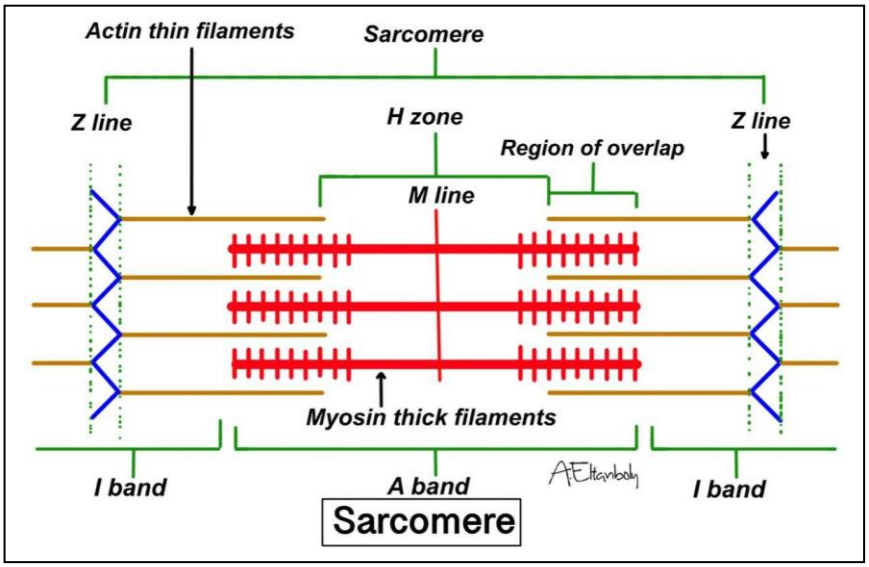
- Basic functional unit of muscle is the **sarcomere.**
- Sarcomeres come together to form **myofibrils.**
- Groups of myofibrils form **muscle fibres**, which are covered by **endomysium**.
- Bundles of muscle fibres form the **fascicles**, which are covered by **perimysium**.
- **Epimysium** covers the outer surface of the muscle trunk.



Microscopic structure

- Sarcomere is the basic contractile unit.
- Meaures 2.5 μm when relaxed and shorter at the myotendinous junction.
- **Comprises:**
  - **Myosin** (thick filaments) containing 6 binding sites.

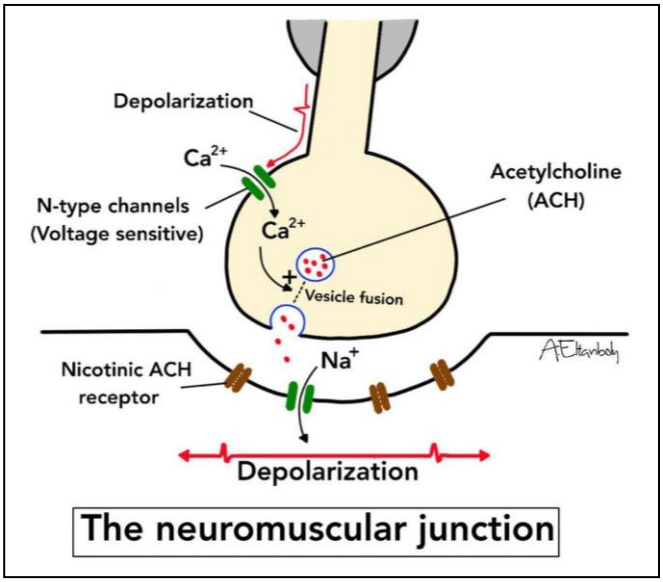
- **Actin** (thin filaments).
- **Tropomyosin**.
- **Troponins I, C** and **T**.
- **Anisotropic band (A)** is the thicker darker myosin filament anchored to the M-line
- **H-zone** is the myosin only with no overlap and gets shorter with muscle contractions.
- **Isotropic band (I)** is the lighter coloured gap between the A-bands and represents actin filaments only.
- **Z-line** marks the boundary between adjacent sarcomere units.
- **M-line** runs through the centre of the sarcomere connecting the myosin filaments.



Excitation-contraction coupling theory

- A nerve impulse triggers an action potential, which arrives at the motor neuron end-plate.
- This causes **diffusion of calcium** into the nerve, which causes **release of acetylcholine** (ACh) from vesicles into the synapse.
- ACh binds to the **ACh receptors** on the post-synaptic neuron.
- ACh **opens Na^+ ion channels** letting Na^+ in.
- Resting muscle fibres have a resting potential of −95 mV.
- The Influx of Na^+ ions reduce this charge.
- When the end-plate potential reaches a **threshold voltage of −50 mV**, the action potential is created.
- This results in **the release of calcium** from the sarcoplasmic reticulum through the T-tubules and into the muscle cytoplasm.

- Enzyme acetylcholinesterase breaks down ACh.
- Resting potential is restored by inflow of potassium ions.
- Botulinum toxin blocks the release of ACh from the pre-synaptic neuron.
- The antibodies in myasthenia gravis block ACh receptors at the motor end-plates.



The neuromuscular junction

Sliding filament theory

- The myosin and actin bind as a **hexagonal lattice** with myosin's 6 binding sites for actin.
- Tropomyosin blocks these binding sites with troponin I (inhibitory).
- As calcium comes in it binds to troponin C.
- The troponin C and calcium units together with troponin T work to move the blocking tropomyosin-troponin I unit.
- Actin can now bind to the free myosin binding sites causing a sliding motion and **contraction to occur.**
- This action requires ATP as energy. As the sarcomere shortens, there is release of ADP and P_i.
- A new ATP molecule attaches to the myosin head causing the cross-bridge to detach.

Muscle metabolic systems

- **Anaerobic:**
  - **ATP** (adenosine triphosphate):
    - Kreb's cycle generates ATP from glucose and fatty acids.
    - .Basis for creatine phosphate supplementation
    - .For intense muscle activity lasting <20 seconds
  - **Lactic:**
    - Hydrolysis of glucose.
    - .Converts carbohydrates into energy
    - .For intense muscle activity lasting 20-120 seconds
- **Aerobic:** For longer duration of exercise.

Types of muscle contraction

- Force of muscle is proportional to its cross-sectional area and fibre size.
- Overloading leads to muscle fibre hypertrophy.
- Velocity (amplitude) of contraction is related to the muscle length.
- Power = Force x velocity.
- A short fat muscle will produce the same power as a long thin muscle.
- **Isometric:**

- Length of muscle stays constant while force and resistance is changing.
- No joint movement.
- Pushing immovable object.

❖ **Isotonic:**
- Length of muscle changes while force is contant.
- .Moving muscles by moving joints
- .Biceps curls using weights

❖ **Isokinetic:** muscle contraction with contant velocity (best method to maximise strength).

❖ **Concentric:** shortening of muscle on contraction (up part of the biceps curl). Gives strength.

❖ **Eccentric:** lengthening of muscle on contraction (down going part of the biceps curl). Gives control and is when a muscle is at increased risk of rupture.

❖ **Polymetric:** the muscle undergoes lengthening and shortening at the same time (e.g. jumping up and down on boxes).

❖ **Types of musle exercise:**
- **Closed chain**: distal end of the extremity is fixed e.g. squat or pull up.
- **Open chain**: distal end of extremity is free (increases JRF) e.g. leg extension and hamstring curl.
- **Passive stretch**: muscle passively lengthens e.g. hamstrings while touching toes.

❖ **Golgi tendon organ:**
- .Provides proprioception in muscle
- .Monitor tension developing in muscle via stretch receptor
- .Located in the myotendinous junction
- .Prevents damage during excessive force generation
- .Stimulation results in reflex muscle relaxation

Types of muscle fibres

❖ Muscle contraction speed and duration depends on the type of muscle fibre**.**

❖ **Type I:**
- Slow twitch and has a reddish appearance due to the high amount of myoglobin (slow red ox).
- Is aerobic and therefore requires O_2 (oxidative metabolism).
- Numerous mitochondria.
- Low strength.
- Fatigue resistant.
- Good for endurance activities, balance and posture.

❖ **Type II:**
- Fast twitch.
- White in appearance.
- Anaerobic metabolism (glycolytic)
- **Type IIa** (oxidative and glycolytic metabolism)**, type IIb** (mainly glycolytic metabolism)**.**
- High strength.
- Sparse mitochondria in type IIb.
- **Type IIb** fatigue quickly whilst type IIa has intermediate fatigue resistance.
- Considered to be**sprinting fibres.**

Muscle injury

❖ Neutrophils are the first cells to appear following acute muscle injury.

❖ Damaged muscle cells release calcium from sarcoplasmic reticulum.

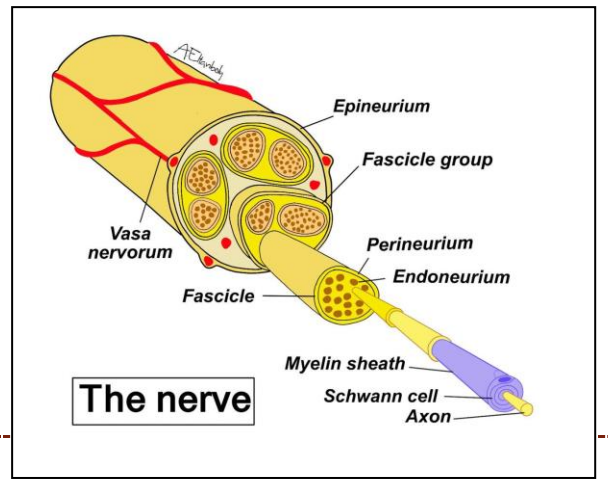
- This activates proteases and lipases, which break down muscle and cell wall; further exacerbting damage and release of free-radicals.

- **Soreness:** due to oedema and inflammation causing a raised CK level.
- **Strain:** occurs at the myotendinous junction with inflammation followed by fibrosis.
- **Ischaemic injury:** secondary to compartment syndrome.
- **Crush injury** resulting in rhabdomyolysis.
- **Malignant hyperpyrexia:** prolonged muscle contraction secondary to anaesthetic agent.
- **Atrophy:**
  - From disuse or nerve injury.
  - Get fatty infiltration.
  - Loss of cross-sectional area.
  - Occurs faster in muscles crossing a single joint.
  - Most changes occur during initial days of diuse.
  - More prominent if immobilisation occurs without tension.
- Muscle needs blood and nerve supply to heal.
- The more proximal the injury, the worse the prognosis.

NERVES

Macroscopic structure

- **Endoneurium** surrounds individual axons and protects against stretch.
- **Perineurium** surrounds group of axons to form fascicles and also protects against stretch
- **Epineurium** surrounds groups of fascicles to form a peripheral nerve and they protect against compression.
- **Blood supply:**
  - **Extrinsic vessels**: segmental vessels that run in the connective tissue surrounding the nerve trunk and form vasa nervorum.
  - **Intrinsic vessels**: longitudinally oriented capillaries within the endoneurium. The tight junctions between endothelial lining cells provide the blood nerve barrier.



❖ **Types of nerve fibres:**

- **A-fibres** (myelinated): α
  - **A-α** (20 μm diameter with a 100 m/s conduction velocity): efferent (motor) to skeletal muscle fibres and afferent (sensory) from muscle spindle or tendon sheath receptors.
  - **A-β** (10 μm diameter, 50 m/s conduction velocity): organised sensory receptors.
  - **A-γ** (5 μm diameter, 20 m/s conduction velocity): efferent (motor) to skeletal muscle spindle.
  - **A-δ** (5 μm diameter, 20 m/s conduction velocity): fast pain.
- **B-fibres** (myelinated) 3 μm diameter, 10 m/s conduction velocity: preganglionic autonomic fibres.
- **C-fibres** (unmyelinated) 1 μm diameter, 2 m/s conduction velocity: postganglionic autonomic and thermoreceptor fibres.

Microscopic structure

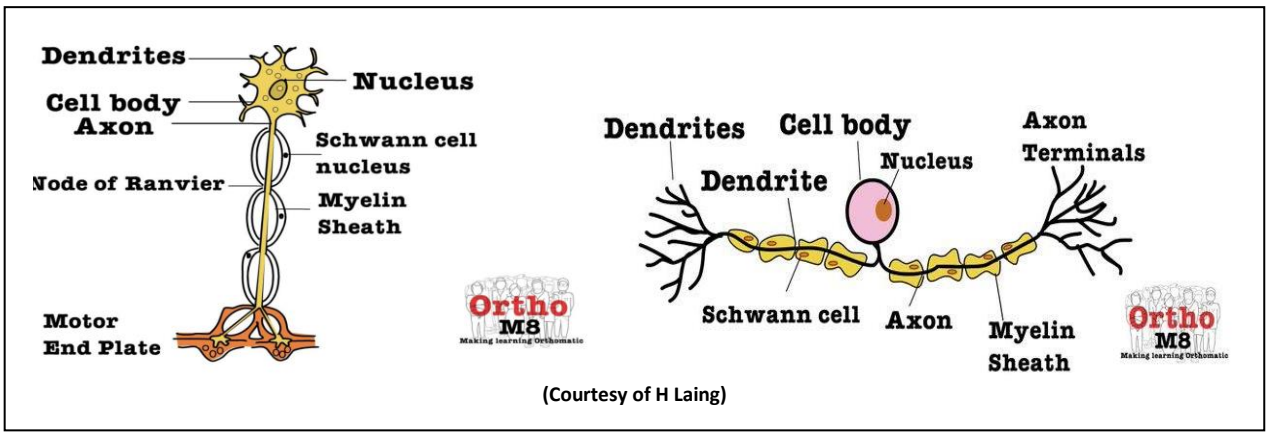
❖ **Neuron** is the basic functional unit of a nerve.

❖ **Constituents:**

- **Cell body:**
  - Also known as a perikaryon contains the nucleus and cytoplasm.
  - .Motor cell body lies in the anterior horn of the spinal cord grey matter
  - .The sensory cell body lies in the dorsal root ganglion
- **Dendrites** are cytoplasmic extensions from the cell body that receive input from other neural cells.
- **Axon** allow the conduction of electrical signals via action potentials towards or away from the cell body. It's .connected to the cell body by the conical projection known as the axon hillock

❖ **Glial cells:**

- These are non-neuronal connective tissue cells that maintain homestatsis, form myelin and provide protection.
- **Schwann cells** produce myelin to cover axons in the peripheral nervous system (PNS).
- **Oligodendrocytes** produce myelin to cover axons in the central nervous system (CNS).
- Myelin increases the velocity of conduction of the action potential.
- The diameter of the nerve determines whether its myelinated(small nerves are unmyelinated).



(Courtesy of H Laing)

❖ **Types of receptor nerve endings (corpuscles) in skin:**

- **Mechanoreceptors** (respond to mechanical stimuli)**:**

- *Meissner*: light touch.
- *Pacini*: pressure, tactile stimulus and vibration.
- *Ruffini*: vibration and stretch.
- *Merkel*: deep pressure.

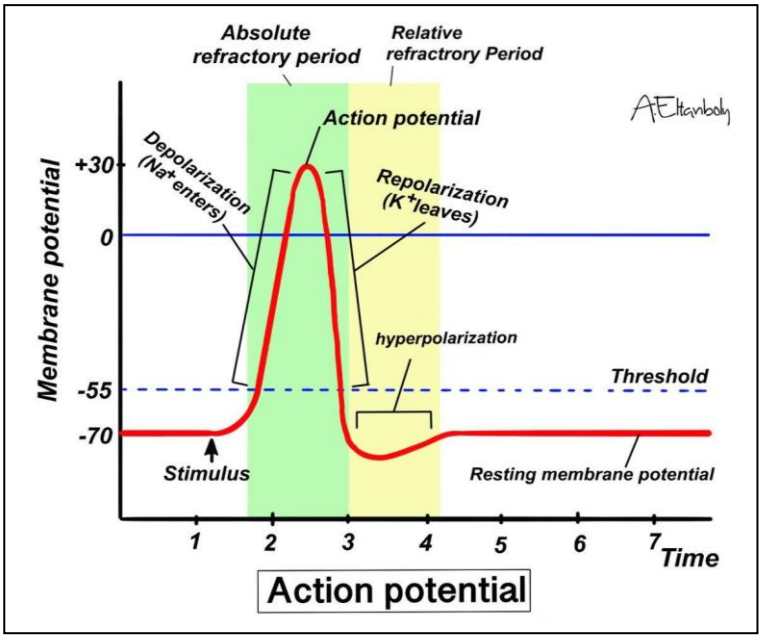
- **Thermoreceptors** (respond to changes in temperature).
- **Nociceptor** (respond to pain caused by damaged tissue).

Nerve physiology

- **Normal resting membrane potential** is -70 mV (reading inside the cell) and set by the ionic concentration across the cell membrane.
- This resting potential is maintained by:
  - .Lipid layer membrane that is impermeable to water soluble ions
  - .Selectively permeable ion channels
  - /$^{+}$Active NaKexchange pump $^{+}$.
  - Donnan equilibrium due to large charged organic molecules that can not cross the lipid bilayer.
- Either a mechanical stimulus or chemical neurotransmitter needs to be strong enough to cross the **threshold voltage of -55 mV** to start an action potential propagation.
- **A sub-threshold stimulus** is one that will not produce an action potential propagation.
- A **summation potential** is when repetitive sub-threshold stimuli become sufficient to initiate a response.
- Once the threshold has been reached, **voltage gated Na^+ channels open** and result in Na^+ entering the cell.
- Reversal of membrane polarity (depolarisation) occurs as the potential reaches the highest point of +30 mV.
- At this point the Na^+ channels close and the **voltage gated K^+ channels open** leading to loss of positive charge and repolarisation starts.
- The K^+ channels are slow to shut and therefore the nerve temporarily goes into a hyperpolarised state.
- The **Na^+/K^+ ATPase pump** then restores the resting membrane potential of -70 mV by pumping 3 Na^+ ions out for every 2 K^+ ions into the cell.
- **Absolute refractory period:**
  - Time in which another stimulus (no matter how strong) will not be able to generate a second action potential.
  - The period is 1-2 ms from the initiation of the action potential to immediately after the peak.
  - At the peak, all Na+ channels become inactivated and cannot be immediately re-opened.
  - Full recovery from inactivation is a voltage and time-dependent process, which means it usually takes about 3-4 ms before all Na+ channels are ready for activation (opening) again.

❖ **Relative refractory period**

- Time in which a stronger than normal stimulus is able to trigger a second action potential.



❖ **Conduction velocity:**

- Faster in:
  - Myelinated axons as the signal skips from one **node of Ranvier** to the next by **saltatory** conduction.
  - .Conduction is therefore passive in myelinated axons and passive in unmyelinated ones
  - .Larger nerves since they tend to be myelinated
  - .Upper limb nerves compared to lower limb ones
  - .Proximal compared to distal
- Reduced in:
  - Hypothermia.
  - .Extremes of age
  - Demyelinating conditions(compressive pathologies).

Nerve injury

❖ **Mechanism of injury:**

- Stretching
- Compression or crush(results in ischaemia, which leads to demyelination).
- Laceration.
- Tumour.

❖ **Retrograde degeneration** (proximal part)**:**

- Shortly after axonal transection, the proximal axon undergoes traumatic degeneration within the zone of injury.
- The zone of injury extends proximally **1 to 2 nodes from the injury site to the next node of Ranvier.**
- The cell body swells and undergoes **chromatolysis**, which is when the Nissl granules (the basophilic neurotransmitter synthetic machinery) disperse, and the cell body becomes relatively eosinophilic.
- The cell **nucleus is displaced peripherally**. This reflects a change in metabolic priority from production of neurotransmitters to production of structural materials needed for axon repair and growth, such as messenger RNA, lipids, actin, tubulin, and growth-associated proteins.

❖ **Wallerian degeneration** (distal part)**:**

- Breakdown of the axon distal to the site of injury starts 48-96 hours after transection.
- The process starts when the macrophages ingest the distal neural tube and clear the myelin debris.
- This causes the tube to collapse after not receiving nutrients from the proximal end.
- The remaining de-differentiated schwann cells proliferate on the remaining endoneurial tubes of the extracellular matrix creating columns of cells called **bands of Bungner**.
- These then produce**neurotrophic factors** to guide the direction of growth.
- Cell body detects that there's been an injury and so changes from a neuroconductive to a neuroregenerative .phenotype with an increase in cellular activity
- The proximal axon tries to find it's way and grow towards the distal tube via the**filopodia**, which are finger like projections trying to find their growth cones in the process called **contact guidance**.
- :There are three main mechanisms that guide the growth of the filopodia
  - **Neurotrophism**.proteins present on denervated motor and sensory receptors and schwann cells :
  - **Neurotropism**: affinity towards neural tissue.
  - **Contact guidance**: affinity towards basal lamina of schwann cells and fibronectin.
- .Nerves grow by 1mm/day
- This can be monitored by the**advancing Tinel's sign** since it resembles an advancing growth cone.
- Tinel sign is pathognomonic of a degenerative nerve lesion and also indicate progression of axonal regeneration.
- The so called Tinel's sign when examining for carpal or cubital tunnel is not totally accurate and instead better described as a**pseudotinel's sign**. This occurs when you tap on the exposed / damaged nerve which has lost its myelin sheath.

Classification of nerve injury

❖ **Seddon classification:**

- .Anatomical based classification
- :Classifies nerve injuries into three categories based on
  - .Presence of demyelination
  - .Extent of damage to the axon
  - .Extent of damage to the connective tissues of the nerve
- **Neuropraxia:**
  - The nerve and axon are in continuity.
  - No damage to the axons or the connective tissues.
  - Segmental demyelination.
  - Non-degenerative.
  - Conduction or physiological block (transient and reversible).
  - No Wallerian degeneration.
  - Full recovery in 3-6 months.
- **Axonotmesis:**
  - Axonal damage.
  - Continuity of the nerve's connective tissues and an intact epineurium.
  - Focal demyelination.
  - Degenerative type.
  - Wallerian degeneration.
- **Neurotmesis:**
  - Connective tissue and axons are fully transected with disruption of the epineurium.
  - Degenerative type.

- No recovery unless surgically repaired.

❖ **Sunderland classification:**

- Anatomical based classification.
- .Expansion of Seddon's classification to distinguish the extent of damage to the connective tissue
  - **Grade I**: correspond to Seddon's neuropraxia.
  - **Grade II**: basement membrane damaged but the endoneurium is intact.
  - **Grade III**: Endoneurium is damaged but the perineurium is intact.
  - **Grade IV**: perineurium is damaged but the epineurium is intact.
  - **Grade V**: corresponds to Seddon's neurotmesis
  - Grades II-IV are all forms of axonotmesis with increasing amounts of connective tissue damage.

❖ Both the Seddon and Sunderland classifications are fine anatomically, but you can't tell clinically, which stage is occurring.

❖ **Birch and Bonney classification:**

- Clinically based classification.
- Divided into either conduction block(neuropraxia) or degenerative block(cutting of the nerve).
- **Conduction block**:
  - .The nerve coverings are intact but the myelin sheath is damaged
  - .This may need a neurolysis in which the nerve needs to be released from scar tissue
  - .If left untreated this can progress to degenerative
- **Degenerative lesion**:
  - .Cutting of the nerve leads to Wallerian degeneration
  - The distal part dies away and is ingested by macrophages as it's no longer receiving nutrients from the .proximal end

Management of nerve injuries

❖ **Triple assessment** will help to identify whether there is an injury, it's location and any evidence of recovery.

- **History:**
  - **Patient factors**) these are going to potentially impact on recovery:(
    - Age is the most important factor with children having the best results.
    - Immunocomprise
    - Poor vascularity
    - Diabetes
    - Peripheral vascular disease
    - Smoking.
  - **Injury factors:**
    - Time period from injury to presentation.
    - Proximal nerve injuries have a worse prognosis compared to distal ones)
    - Those that supply both motor and sensory have a worse prognosis.
    - Motor nerves (e.g. PIN and musculocutaneous) have a better prognosis.
    - Injury with a clean cut has a better outcome and needs to be repaired quickly, whilst blunt or crush has a worse prognosis and you need to wait for the extent of injury to declare itself.
    - Nerve that supplies multiple muscles tends to have a worse prognosis.
    - Associated vascular injury.
- **Examination:**
  - .Injury location
  - .Pick up evidence of recovery through an advancing Tinel sign

- .Examine both motor and sensory modalities

▪ **Neurophysiology:**

- **Parameters for NCS and EMG:**
  - *Latency* is the time between two points and is a measure of signal quality.
  - *Amplitude* is the size in mV of the stimulus and a marker of quantity (the number of functioning axons). Area under the peak is proportional to the number of muscle fibres depolarised.
  - *Conducton velocity* is worked out by measuring the time taken to travel between two points (average is 50 m/s).
  - These parameters should always be compared to the contralateral side and not interpreted in isolation.
- **Nerve conduction studies (NCS)**:detect the activity in a sensory or motor nerve
  - NCS components include a stimulating, recording, ground (placed between the stimualting and recording electrodes and prevents electrocution) and reference (removes background activity and **provides** a zero voltage reference) electrodes.
  - **Nerve** stimulation can be orthodromic (physiological direction of conduction) or antidromic (the reverse).
  - **Sensory** nerves are typically stimulated distally and generate a **sensory nerve action potential (SNAP)**, which is recorded proximally.
  - Sensory axonal loss will result in a smaller SNAP, whilst demyelination produces both a smaller SNAP and prolonged latency.
  - Motor nerves are stimulated proximally and generate a **compound muscle action potential (CMAP)**, which is **recorded** distally.
  - Motor nerve stimulation also gives rise to an antidromic action potential, which conducts to the anterior **horn** cell resulting in its depolarisation. This results in an additional small muscle depolarisation and generation of an **F wave** with a longer latency. A prolonged F wave latency will help to distinguish between proximal motor fibre pathology (at the plexus or root level) and distal general neuropathy.
  - When there is axonal loss, there is a reduction in CMAP amplitude as fewer functioning motor axons exist. There may be a slightly prolonged latency (< 120% of normal limit) and slight slowing in the conduction velocity (> 80% of normal limit).
- **Electromyography (EMG)**looks at muscle activity .
  - Patient provides their own stimulus and so there are no stimulating electrodes.
  - At rest you get no signal, which is represented by a flat line.
  - When the muscle contracts, a **motor unit action potential (MUAP)** is generated.
  - When the nerve is cut:
    - *At rest* you see lots of electrical activity as the nerve is trying to stimulate the muscle with the formation of initial **positive sharp waves** followed by **fibrillations** later on.
    - *During regeneration* you get **polyphasic units** where one nerve is trying to supply lots of different motor units, which have lost their supply.
- **What are we looking for in NCS and EMG?**
  - Localising the lesion by finding the site with the reduced conduction velocity.
  - Identify evidence of recovery and re-generation.

❖ **Ladder of reconstruction:**

▪ *:Two reasons for nerve exploration surgey*

- .Ongoing compression demonstrated by pain or a scan showing compression from a haematoma etc
- No evidence of recovery- no advancing Tinel sign(clinically) and no polyphasic units

(neurophysiologically).
- Therefore, as a nerve surgeon if there is an advancing Tinel sign and the presence of polyphasic units on EMG, you should continue to observe the patient.

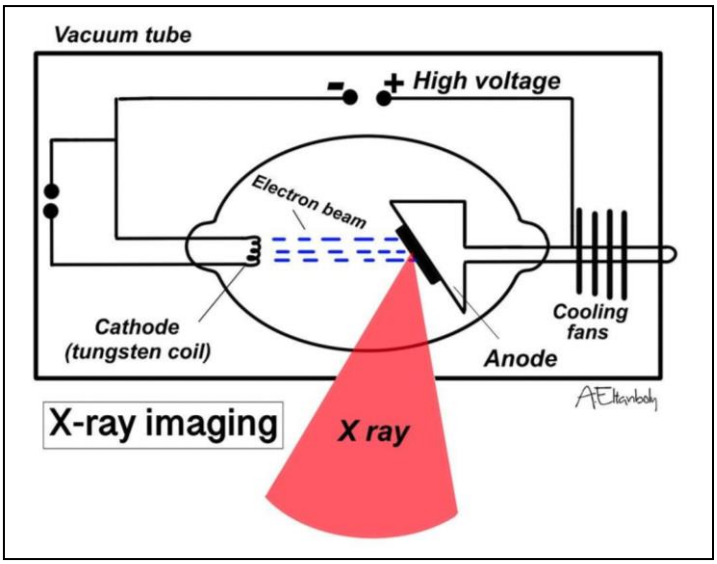
▪ *:Surgical options*
- **Neurolysis** is releasing scar tissue from around a nerve in continuity.
- **Primary/direct repair** involves repairing the epineurium.
  - Clean transaction of a trunk or large nerve.
  - Carried out under microscope.
  - Best for median, ulnar and sciatic nerves.
  - Use 8-0 monofilament (Nylon).
  - Resect the proximal neuroma.
  - Tension free repair.
  - Accurate opposition with fascicular matching.
- **Nerve grafting** is required when a gap can't be bridged.
  - Defect >2.5 cm.
  - Donor sites include the medial & lateral cutaneous nerves of forearm, sural and saphenous nerves.
  - Require the donor nerve to be 15% longer than the gap.
  - Collagen conduits allow for nutrient exchange and accessibility of neurotrophic factors for axonal growth.
  - Original nerve is still supplying the motor endplate.
- **Nerve transfer** is for very large defects that can't be bridged with a graft.
  - Spinal accessory nerve when suprascapular nerve function is lost.
  - Oberlin transfer is the transfer of an ulnar fascicle to the biceps branch of the musculocutaneous nerve to restore elbow flexion.
  - Somsak transfer is the transfer of the branch to long head of triceps to the anterior branch of the axillary nerve to restore deltoid function for abduction and external rotation.
- **Tendon transfer** is considered after 1 year.
- **Muscular neurotisation** is the insertion of a proximal nerve stump into an affected muscle belly.
- **Free muscle transfer**

Peripheral nerve injury BOAST guidelines:
- Seek advice from a specialist.
- Fix the bones first if appropriate and then explore the nerves (remember to record the findings in the notes).
- Urgent repair is best and if this is not possible, then appose the nerve ends with and refer on urgently.
- If there is a palsy post-op, start by reducing the dressings and reposition the limb. If there is no improvement then seek specialist advice regarding possible re-exploration.
- Painful post-op paralysis requires urgentl re-exploration and remember to exclude compartment syndrome.
- NCS and EMGs are rarely needed acutely.
- Seek advice for any brachial plexus injuries within 3 days.

IMAGING

X-rays

- High frequency energy on the electromagnetic spectrum.
- **How is it produced?**
  - **Thermionic emission** is when a tungston cathode is heated to 2200°C in a vacuum generating electrons.
  - The electron beam accelerates towards the anode which is also made of tungsten metal.
  - They strike the rotating (so that it cools down) anode disc and are slowed down generating 99% heat and 1% x-rays in a process called **braking radiation**.
  - .These x-rays are then directed through an aperture and towards the patient
  - X-rays are then either absorbed, reflected or pass through human tissue in a process known as**attenuation**.
  - Tissues containing high atomic nucleus absorb a high proportion of x-rays and so have a**high attenuation coefficient** and appear white.
  - The x-rays hit a plate made from **phosphor crystals** turning it black. The receiver converts x-rays to light which is converted by a video system to a picture.
  - Water and air have a low beam attenuation as the vast majority of x-ray comes through.
  - Bone has a high beam attenuation as very little x-ray is able to pass .through
  - Primary radiation is when the beam is directed from the tube directly to .the x-ray plate
  - Secondary radiation is scatter that causesblurring and exposes staff .and patient to radiation



- **What are they used for?**
  - .Simple bony anatomy to pick up OA, fractures and deformity
  - **Advantages:** cheap, and readily available.
  - **Disadvantages:**
    - Ionising radiation.
    - Limited for soft tissue
    - Limited use in subtle bony injuries.
- **What are the precautions?**
  - Factors to decrease radiation exposure to patient and surgeon.
  - Maximising **distance** between surgeon and radiation beam.
  - Minimising exposure **time.**
  - Use of protective **shielding** of lead apron (> 0.5 mm thick for staff within 2 m) and a thyroid shield.
  - Orienting the fluoroscopic beam with intensifier close to body part to reduce scatter of radiation whilst also covering more body area in one image.
  - **Collimation/conning** reduces the field size and also the radiation dose whilst producing sharper radiographs.
- **How is fluoroscopy different to main x-ray?**

- Allows for performing imaging in real time, which is useful in dynamic assessment.
- .Uses digital substraction techniques to increase the contrast of the area

❖ **Measure of radiation**

- **1 Sievert = 1 Gray** (1mSv is a dose produced by exposure to 1milliGray of radiation).
- **1 Gray = 100 Rad Gray**)unit of ionising radiation.(
- Whole body exposure of**20mSv** is the maximum acceptable radiation dose per year.
- **1mSv** gives 1:20000 chance of cancer induction.
- Typical radiation amounts:
  - Natural background radiation= 2.7mSv/year)equals about 100CXRs(.
  - Transatlantic flight= 0.08mSv.
  - DEXA= 0.001mSv.
  - CXR= 0.02mSv.
  - Lumbar spine= 1mSv.
  - Bone scan= 4mSv.
  - CT head= 2mSv.
  - CT chest= 8mSv.
  - CT abdo/ pelvis= 10mSv.
  - 1minute of fluoroscopy =1mSv.

CT scans

❖ **Computer tomography** is a complex form of x-ray.

❖ High frequency energy on the electromagnetic spectrum.

❖ Medical CT was invented by Sir Hounsfield in 1973 for which he was awarded the noble prize.

❖ **How does it work?**

- Components include a gantry, collinear detectors, couch and control room.
- Everytime the**gantry rotates** around the patient it send out **fan-shaped x-ray beams** which are then absorbed, reflected or transmitted dependent on the tissueattenuation coefficient.
  - The attenuation coefficient is measured in **Hounsfield units (HU)**.
  - Water has **0 HU**.
  - Bone has **1000 HU**.
  - Air has **-1000 HU**
  - Windowing(e.g. bone, liver, lung etc) is centering the image on a particular attenuation value.
- With each rotation of the gantry, an axial image is generated comprising a number of**pixels**.
- Each pixel corresponds to a volume of tissue known as a **voxel**.

❖ **Advances:**

- **Helical or spiral CT scanning**) involves the gantry continuously rotatingmultiple slices at the same time (around the patient as they move alongon the couch .
- **Multidetector CT scanning** involves a single gantry turn with multiple detectors making this very quick.
- **Positron emission tomography (PET) CT scanning** looks at metabolic activity which can be overlaid with a CT scan to provide anatomical location for the activity picked up on the PET (**co-registered image**).
  - Inject Fluorodeoxyglucose (FDG) which is a Fluorine-18 radioisotope combined with glucose.
  - FDG enters the cell via the cell membrane glucose transporters and accumulates in the cell.
  - Greater accumulation in areas of high metabolic activity.
  - Each emitted positron collides with an electron generating photons.
  - Crystals in the PET camera absorb the photons converting it into an electric signal and image.
  - This image is then superimposed onto a CT scan image to provide an exact anatomical location.

❖ **What is it used for?** (advantages)

- .For complex bony anatomy and 3D modelling

- .Complex fracture assessment for pre-operative planning
- .Assess for evidence of union
- .Assessment of bony deformity
- .CT myelography carried out using intra-thecal iodine contrast injection (useful when an MRI can't be done)

❖ **Disadvantages**

- Ionizing radiation and high doses of radiation.
- .Metallic artefact
- .Limited soft tissue contrast

MRI scans

❖ Magnetic resonance imaging involves the application of a **strong magnetic field** and a **radiofrequency excitatory pulse**.

❖ **How is it produced?**

- Hydrogen nuclei (protons) spin and have a precession (wobble).
- Application of a magnetic field causes the protons to form a **longitudinal magnetisation vector** in line with the magnetic field.
- At this stage the precession of the protons is out of phase with one another.
- Applying a radiofrequency pulse causes the direction of magnetisation to tilt by 90 ° and the protons form a **transverse magnetisation vector** and the **precession changes to being in phase.**
- Removing the RF pulse causes everything to return to the original state and releasing energy(relaxation).
- .This energy is picked up by detectors and then processed to create an image
- **Relaxation times:**
  - **T1 relexation time**: time taken for longitudinal magnetisation vector to recover to 63% of normal once the RF pulse stops.
  - **T2 relexation time**: time taken for the transverse magnetisation vector to decay to 37% of normal.
- **Spin echo:**
  - **Time to repetition (TR):** time between two RF pulses in ms. A long TR will allow longer recovery of the T1 pulse until the next pulse occurs.
  - **Time to echo (TE):** time between when the RF pulse stops to when the signal is measured in ms. A long TE will give a better chance to detect changes in the T2 phase.
- **T1 imaging:**
  - Good for picking up anatomy.
  - Get a short TR(>1000ms) and short TE(>60ms).
- **T2 imaging:**
  - Good for picking up pathology.
  - Get a long TR(<1000ms) and long TE(<60ms).

Tissue	T1	T2
Fat	Bright (enhaned signal)	Bright
Bone Cortex	Dark (low signal)	Dark
Bone Marrow	White	Grey (intermediate signal)
Muscle	Grey	Grey
Tendon & Ligament	Dark	Dark
Fibrocartilage	Dark	Dark
Hyaline Cartilage	Grey	Grey
Water	Dark (hypointense signal)	Bright

- **Fat suppression sequence:**
  - Short Tau inversion recovery **(STIR)**.
  - .Used to differentiate between fat and water on T2 imaging (useful in trauma and tumours)
- **MARS:**
  - Metal arefact reduction sequence.
  - Artefact is much worse with steel than with titanium.
- **Magnetic field strength:**
  - Measured in**Tesla**.
  - Typically use1.5 T and3T.
  - .Higher magnetic field strength gives a better image quality and resolution
- **Use of contrast:**
  - Typically use**gadolinium.**
  - .Enhances oedamatous tissues on T1 imaging making it appear brighter
  - :Contraindications to using contrast
    - In patients with stage 4 CKD (not to use if eGFR < 30) since it causes nephrogenic fibrosis.
    - Pregnancy.
    - Previous sensitivity to contrast media.

❖ **Advantages:**

- Excellent soft tissue contrast and picking up abnormalities.
- Picking up occult fractures.
- Good for assessing malignancy.
- No ionising radiation.
- Can use paramagnetic agents (gadolinium) to enhance the image.

❖ **Disadvantages:**

- Expensive.
- Not readily available.
- .Can be claustrophobic (option of an open MRI or consider alternative imaging)
- Slower image acquisition times.
- :Contraindications and precautions
  - .Pacemaker and defibrillators

- .Cochlear implants and internal hearing aids
- .Implanted nerve stimulators
- .Metal objects in eyes
- .Intracranial clips
- .Mechanical heart valve

Ultrasound

- Form of imaging that utilises **high frequency sound waves.**
- Images interfaces between tissues of different acoustic properties.
- **How are they produced?**
  - An electric current is passed through a transducer made of**piezoelectric crystals**.
  - .This causes a shape change in the crystals resulting in energy release in the form of sound waves
  - .Waves are sent out and reflected back by tissues
  - The reflected sound waves are then picked up by another transducer, which generates a signal after its .piezoelectric crystals also undergo a shape change. This signal is converted into an image
  - A high frequency probe generating frequency of3-50 MHz(above the audible limit) is used for superifical tissues.
  - .The duration between sound wave emission and detection reflects the depth of tissue
- **Uses of ultrasound:**
  - Materials can be either **echogenic** (able to reflect the sound waves) or **hypoechoic** (doesn't reflect the sound waves).
  - More reflection of sound waves results in the generation of a brighter signal.
  - Fluidfilled tissues appear black on the image because it's **anechoic** (ultrasound waves go straight through).
  - Fat is highly echogenic.
  - .Ultrasound is very useful in assessing masses, tendon ruptures and effusions
  - **Doppler Effect** assesses whether blood is moving towards or away from the probe, and its relative velocity.
  - **Transoesophageal echo** is an important diagnostic imaging tool crucial during cardiac surgery.
- **Modes:**
  - **A-mode** (amplitude mode) is the simplest type with a single transducer and used for pin-point destructive wave energy directed at tumour or a renal calculus.
  - **B-mode** (brightness mode) involves the use of a linear array of transducers, which simultaneously scan a plane that be viewed as a 2D image.
  - **M-mode** (motion mode) involves a rapid sequence of B-mode scans whose images follow each other on screen e.g. visualising a cardiac valve.
- **Advantages:**
  - No ionising radiation or precaustions required.
  - Inexpensive,
  - Portable, dynamic and non-invasive.
  - .Readily available
- **Disadvantages:**
  - Operator dependant.
  - .Can be difficult to interpretate
  - Dynamic element lost following the scan
  - Limited use for bone.

Nuclear medicine

❖ **Bone scan**

- .Imaging that detects the distribution of injected radioisotopes to assess the rate of bone turnover
- .Emitted gamma radiaiton from the radioisotope is detected by specific gamma cameras
- :Different radioisotopes can be used
  - **Technitium-99**: has affinity for osteoblasts, metabolically active bone (bone turnover) with a 6hr half-life.
  - **Gallium**: affinity for inflammatory cells (leucocytes) and bacteria.
  - **Indium**: affinity for leucocytes.
- **How are they produced?**
  - For example when giving Tc-99 intravenously, it has to be bound to a carrier molecule such as .methylene diphosphonate (MDP)
  - The Tc-99m complex binds to the hydroxyapatite crystals in bone and is a good marker of osteoblastic .activity and increased vascularity
  - .As the Tc-99m binds, it breaks up and releases gamma radiation (photoemission)
  - **Triple phase scan:**
    - *Flow* (dynamic) phase in the first 1-2 minutes and represents the entire blood flow (angiogram).
    - *Blood pool* (equilibrium) phase in the next 3-5 minutes and measures soft tissue activity and increased vascularity from dilated capilaries in inflammation or infection.
    - *Static* (skeletal) phase over the next 4 hours and marks skeletal activity from infection, tumour, AVN, Paget's disease, stress fracture, non-union and aseptic loosening.
- **Cold scan:** in multiple myeloma and metastatic renal and thyroid lesions because of less osteoblastic activity.
- **Flare phenomenon:** paradoxical increase in uptake following chemotherapy as result of bony repair.
- **Superscan:**
  - Intense symmetric activity in bones with diminished renal and soft tissue activity.
  - Occurs in diffuse metastatic spread, lymphoma, metabolic bone disease, renal osteodystrophy, hyperparathyroidism, wide spread Paget's disease and osteomalacia.
- **Disadvantages:**
  - Radiation dose equivalent to 63 chest x-rays.
  - Non-specific.
  - Lasts 6 months following commencement of chemotherapy – use PET scan.

❖ **WBC (leucocyte) scan:** - WBCs are removed from the patient and tagged with indium before they are reinjected 2-3 hrs later. The patient is then scanned the next day.

- **Patient instructions:**
  - Drink lots of water to allow renal excretion.
  - Use different toilet to the rest of family until isotope is flushed out. Flush the toilet twice.
  - Avoid contact with pregnant women.
  - Will be detected by airport detectors for 1 week.

❖ **PET scan** (Positron Emission Tomgraphy):

- Is very expensive.
- Uses specific radioisotopes of C11, O15 and F18.
- Inject FDG (F-18 fluorodeoxyglucose) – transported and accumulates in areas of high metabolic activity.
- Emit positrons (positively charged) that interact with nearby electrons to result in photon formation.
- .These photons are detected by a ring of multiple detector
- Successful chemotherapy causes decrease in uptake.

❖ **SPECT scan** (Single Photon Emission Computed Tomography):

- .Is cheaper than PET scans
- Uses gamma emitting radioisotopes(Tc-99m ,iodine-123 and iodine-131).
- Images reconstructed in axial, coronal and sagittal planes.
- .Poorer contrast and resolution compared to PET scan
- Useful for posterior spinal elements and areas of decreased uptake.
- Reduce obstruction by underlying tissues.
- Modern SPECT available with integrated CT scanner to locate abnormalities more precisely.

RADIOSTEREOMETRIC ANALYSIS (RSA)

- Assessment of 3D migration and micromotion of joint replacement prosthesis relative to bone.
- Also evaluates polyethylene wear.
- Useful tool for evaluating new prosthesis.
- **Stages:**
  - Radiopaque markers (tantalum beads) embedded into the host bone at time of surgery.
  - Post-operatively the patient has biplanar radiographs in a calibration cage.
  - RSA software forms a reference stero image of the tantalum marker beads.
  - Change in position due to micromotion is picked up by RSA software analysis of future radiographs.
- **Finite element analysis:**
  - Computer generated analysis of forces between two bodies such as the bone-implant interface.
  - Mesh used to divide material into smaller elements.
  - Forces individually calculated and then combined.

ANAESTHETICS

❖ **Pre-operative investigations:**
- *Blood*
- *ECG*: if over 55 or any cardiac/renal/diabetes comorbidities.
- *ECHO*: if there's a history of heart failure symptoms or any suspicion of valvular heart disease,
- *Lung function tests*: if there's history of significant respiratory disease.
- *Pregnancy test*: in patients of childbearing potential.
- *HbA1c* within 3 months if diabetic.
- Referral for sleep studies if suspected obstructive sleep apnoea.

❖ **Body mass index** (BMI):
- Patient' s weight(Kg) divided by the square of their height(m).
- .Expressed in Kg/m^2
- :Ranges
  - (8.5) – underweight.
  - (18.5: 25) – normal weight.
  - (25: 30) – overweight.
  - <) 30) –obese.

- **American Society of Anaesthesiologists (ASA) physical status classification**
  1. Healthy patient.
  2. Patient with a mild systemic disease.
  3. Patient with a severe systemic disease that limits activity, but is not incapacitating.
  4. Patient with an incapacitating systemic disease that is a constant threat to life.
  5. Moribund patient not expected to survive > 24 hours with or without surgery.
  6. Brain dead and operated on for organ donation.

General anaesthesia (GA)

❖ **Components of GA:**
- Loss of consciousness (LOC).
- Analgesia.
- Muscle relaxation.

❖ **Induction**: IV or inhalation.

❖ **Airway/breathing management:** face mask, supraglottic airway (LMA, iGEL) or endotracheal tube (ET tube). Spontaneous breathing or mechanical ventilation

❖ **Maintenance:** IV or inhalation.

❖ **Commonly used anaesthetic drugs:**
- **Induction agents:**
  - **Propofol:**
    - Rapid onset and offset.
    - Loss of airway reflexes.
    - Causes dose related hypotension due to vasodilatation.
    - Can also be used as an infusion for maintenance of anaesthesia (total intravenous anaesthesia-TIVA) or sedation in lower doses.
  - **Thiopentone** (a barbiturate):
    - Causes rapid LOC and hypotension.

- Less commonly used since the introduction of propofol.

- **Katamine:**
  - Causes a dissociative anaesthetic state with an increase in blood pressure and heart rate.
  - Not routinely used in elective setting.
  - Usually in an emergency in patients with cardiovascular compromise.

- **Volatile anaesthetic agents:**
  - **isoflurane**, **sevoflurane** and **desflurane**
  - .Cause hypotenion due to vasodilatation

- **Muscle relexants:**
  - **Suxamethonium** (depolarising)**:**
    - Causes fasiculations, rapid onset and offset (end of action) within minutes.
    - Used for rapid sequence inducton (RSI).
  - **Rocuronium** and **Atracurium** (non-depolarising)**:**
    - Competitive acetylcholine receptor antagonists acting at the neuromuscular junction.
    - Only used in cases which need intubation or the surgery requires it e.g. hip dislocation.
    - Onset is 3-5 minutes with offset being 30-40 minutes depending on dose.
    - Rocuronium can also be used for RSI when given in high doses and has largely replaced suxamethonium.

- **Analgesics:**
  - **Opioids:**
    - *Fentanyl*: potent, rapid and short acting. Often given at induction.
    - *Morphine*: longer acting.
    - *Oxycodone*: similar to morphine but has a better side-effect profile and preferred in renal failure.
  - **Non-opioids:**
    - *Paracetamol.*
    - *NSAIDS.*
    - *Ketamine*: this can cause unwanted hallucinations on emergence from anaesthesia.

- **Anti-emetics:**
  - *Dexamethasone*.
  - *Ondansetron.*
  - *Cyclizine*.

- **Benzodiazepines** such as *midazolam* is for anxiolysis and amnesia.

- **Emergency drugs:**
  - **Vasoconstrictors** e.g. *metaraminol*, *phenylephrine* & *ephedrine*
  - **Anticholinergics** e.g. *atropine* & *glycopyrrolate*.

❖ **Fasting times:**

- 6 hours for solids.
- 2 hours for clear fluids (tea or coffee with no milk, squash, water, pre-op drinks).
- Some centres now allow sips of water until the patient is sent for.
- Oral medications can be taken while fasting but not ACE-i due to risk of refractory hypotension under GA.

❖ **Risks and complications of GA:**

- Airway:
  - *Difficult airway.*
  - *Hypoxia*.
  - *Life threatening airway emergency:* 'Can't intubate, can't oxygenate' (CICO), an indication for front of neck access (cricothyroidotomy) as a rescue technique.

- *Aspiration*: higher risk in patients with severe reflux or delayed gastric emptying (e.g. following trauma or opioid use). RSI used in these cases to secure the airway with a cuffed ET tube as quickly as possible.
- *Laryngospasm/bronchospasm:* more common in patients with recent URTI or asthma.

▪ Breathing:
- *LRTI* post op: more common if PMH of respiratory disease or recent URTI.
- *Pneumothorax*.

▪ Circulation:
- *Hypotension / cardiovascular collapse:* side effect of GA agents compounded by pre-existing risk factors e.g. cardiac disease, sepsis, hypovolaemia. Undiagnosed severe aortic stenosis in the elderly trauma patient is a classic example potentially leading to decompensation and cardiac arrest following induction.

▪ Neurological:
- *Stroke/hypoxic brain injury.*
- *Nerve injury* due to pressure points.
- *Acute post-operative delirium:* more common in the elderly and/or pre-existing cognitive impairment.
- *Accidental awareness under GA:* rare with emergency surgery being a risk factor.

▪ Gastrointestinal: Nausea and vomiting.

▪ Other:
- Sore throat.
- Damage to teeth.
- *Anaphylaxis*:
  - Most common culprits being antibiotics (47%), muscle relaxants (33%), chlorhexidine (9%) according to *RCoA National Audit Project 6 (2018)*.
  - Teicoplanin is 17 times more likely to cause anaphylaxis than alternatives and often given in cases with penicillin allergy, which may in fact not be a true allergy.
- *Malignant hyperthermia:*
  - Rrare reaction to suxamethonium or volatile anaesthetic agents
  - Leading to uncontrolled skeletal muscle contraction.
  - Autosomal dominant inheritance.
  - Characterised by increased temperature, rigidity, tachycardia, high CO_2, low O_2 sats, acidosis, hyperkalaemia, rhabdomyolosis and renal failure.
  - Managed by removal of triggering agent (stopping volatile) and administration of the specific treatment, **dantrolene**.
  - Other supportive measures including cooling and abandonment of surgery is feasible.
- *Suxamethonium apnoea:* rare inherited reduced enzyme activity leading to prolonged muscle relaxation following suxamethonium administration.

Regional anaesthesia

❖ Spinal:

- Single shot of local anaesthetic(usually bupivacaine0.5 -/+ (%opioid)usually diamorphine.(
- This gives2-3 hours of surgical anaesthesia below the waist.
- Rapid onset within5 minutes with max effect by30 minutes.
- Spread of anaesthetic can be manipulated with gravity for the first10-15 minutes if heavy preparation used.
- .A spinal catheter is rarely used to give repeated boluses to prolong the duration of the block
- .Injection below the level of the spinal cord usually L3/4 or L4/5

- .Ultrasound can be used to guide injection if there's difficult anatomy

❖ **Epidural:**

- Catheter inserted into epidural space to administer local anaesthetic mixture (commonly levobupivicaine 0.1% + fentanyl).
- Usually inserted when required for post-operative analgesia, not commonly used alone for surgical anaesthesia.
- **Advantages of spinal and epidural** (central neuraxial blockade - CNB):
  - .Avoids GA and associated complications
  - .Faster recovery
  - .Reduced risk of VTE
  - .Can give sedation with propofol or midazolam as adjunct in theatre
- **Disadvantages of CNB**: rare but serious potential complications:
  - Failure and conversion to GA (1% for spinal).
  - Hypotension due to sympathetic block and vasodilation.
  - Nausea and vomiting.
  - Post dural puncture headache.
  - Infection such as meningitis and epidural abscess.
  - Bleeding and spinal haematoma.
  - High block / total spinal.
  - Nerve damage, which can be transient or permanent.
  - Post op urinary retention more associated with intrathecal opiates.
  - Itching and shivering
  - Can be time consuming if technically difficult.
- **Contraindications to CNB:**
  - Patient refusal.
  - Raised intracranial pressure (risk of coning).
  - Local or systemic infection.
  - Abnormal coagulation (recent anticoagulants, platelets <80).
  - Hypovolaemia.

❖ **Peripheral nerve blockade:**

- **Upper limb:**
  - .Interscalene for shoulder surgery
  - .Supraclavicular and axillary for elbow and hand surgery
  - .Individual nerve blocks
- **Lower limb:**
  - .Femoral
  - .Sciatic
  - Fascia iliaca.
  - Adductor canal.
  - .Popliteal
  - Ankle block.
- **Risk:**
  - Failure to block.
  - .Bleeding
  - .infection
  - Nerve damage (rare).

❖ **Local Anaesthesia (LA):**

- Block nerve conduction by reversibly binding with Na^+ channels in nerve membrane and blocking action potential initiation and propagation.
- **Ester LA:** e.g. **Benzocaine**, **cocaine**, **procaine**, **amethocaine** (Ametop - for topical anaesthesia of skin).
- **Amide LA:**
  - **Lidocaine**:
    - Preparations available with or without adrenaline (causes vasoconstriction, prolonging action and reducing systemic absoption).
    - Maximum dose of 3mg/kg (6mg/kg with adrenaline).
    - 1% contains 10mg/ml.
    - Intra-articular injections can cause chondrolysis.
    - Fast onset (1-2 minutes) with a short duration of action (1-2 hours), which is prolonged with adrenaline to several hours).
  - **Bupivacaine**:
    - Slower onset (10-15 minutes) with longer duration of action (4-6 hours).
    - Most cardiac toxicity.
    - Maximum dose 2mg/kg with or without adrenaline.
    - Available as 0.25% (2.5mg/ml) and 0.5% (5mg/ml).
    - The 0.25% is not considered chondrotoxic.
  - **Ropivacaine** (Naropin): used for local infiltration in hip and knee arthroplasty.
  - **Prilocaine**: used as mixture with lidocaine in EMLA cream for topical skin anaesthesia.

Relevant literature

- Hu et al, BJJ (2009) Meta-analysis: *A comparison of regional and general anaesthesia for total replacement of the hip or knee*. Found that regional anaesthesia seems to improve the outcome of patients undergoing total hip or knee replacement (reduced need for transfusion, reduced incidence of thromboembolic disease.
- Matharu et al, J. Arthoplasty (2020): *Does regional anaesthesia reduce complications following total hip and knee replacement compared with general anaesthesia? An analysis from the National Joint Registry for England, Wales, Northern Ireland* and *Isle of Man*. Found reduced LoS, reduced risk of re-admission, UTI and SSIs with regional anaesthesia compared with general anaesthesia.

PAIN

Acute pain

❖ **Pain definitions:**
- **Pain:** is an unpleasant sensory or emotional experience associated with actual or potential tissue damage.
- **Nociceptive pain**: pain caused by tissue injury and local inflammatory mediators.
- **Neuropathic pain**: pain caused by nerve damage or dysfunction.
- **Chronic pain**: pain lasting longer than the expected time of healing or related to a chronic condition, usually lasting longer than 3 months.

❖ **Afferent pain pathways:**
- Peripheral nerves: types Aδ & C nerve fibers.
- Spinal cord: dorsal columns and spinothalamic tracts.
- Brainstem: thalamus, site of pain modulation.

❖ **WHO step-ladder pain management (1986):**
- Step 1: non-opioids: paracetamol, NSAIDs (ibuprofen/naproxen) +/- adjuvant.
- Step 2: weak opioid (codeine and tramadol) + non-opioids +/- adjuvant.
- Step 3: strong opioid (morphine, oxycodone, fentanyl/buprenorphine patches) + non-opioids +/- adjuvant.

❖ **Drugs used for pain management:**
- **Paracetamol:**
  - Inhibitor of prostaglandin synthesis.
  - Very safe and effective analgesic but overdose can cause significant liver damage.
  - Caution, especially with IV use in patients with low BMI or at risk of liver damage (hepatic impairment, malnourished, anorexia, alcoholism).
- **NSAIDS:** e.g. **ibuprofen**, **naproxen**, **diclofenac**, **ketorolac.**
  - Inhibit cyclo-oxygenase (COX) enzymes, which normally metabolise arachidonic acid into prostaglandins and thromboxane.
  - **COX-1:** results in prostaglandins responsible for maintenance and protection of GI tract. Non-specific COX inhibitors can cause GI damage.
  - **COX-2:**
    - Result in prostaglandins responsible for inflammation and pain.
    - Causes mesenchymal progenitor cells to differentiate into osteoblasts.
    - COX-2 inhibitors can cause decreased endochondral ossification.
    - Selective COX-2 inhibitors (celecoxib, parecoxib), maintain gastric mucosa and less likely to cause renal dysfunction.

> - Giannoudis et al, BJJ (2000): *Nonunion of the femoral diaphysis. The influence of reaming and non-steroidal anti-inflammatory drugs*. Marked association between non-union and the use of NSAIDs after injury and ($p < 0.001$) and delayed union as well.

- **Opioids:**
  - Weak opioids: codeine, dihydrocodeine and tramadol.
  - Strong opioids: morphine, diamorphine, oxycodone, fentanyl and buprenorphine (partial agonist).
  - Cause prolonged activation of Mu opioid receptors.
  - Side effects: respiratory depression, sedation, nausea/vomiting, histamine release (hypotension, bronchospasm, cutaneous signs, pruritus), constipation and urinary retention.
  - Caution as active metabolites can accumulate in renal failure.
  - Reversed by opioid antagonist naloxone (half life of naloxone is shorter than many opioids therefore repeated doses or an infusion may be required).

- **Adjuvant agents**:
  - *Ketamine*:
    - NMDA receptor antagonist.
    - Effective analgesia.
    - Psychomimetic side effects of increased salivation, nausea/vomiting, sympathetic stimulation causing increased BP and HR.
  - *Magnesium*:
    - Competitive inhibition of calcium influx through NMDA receptors.
    - In high doses can cause hypotension, bradycardia and sedation.
  - *Alpha-2 adrenergic agonists:* e.g. clonidine and dexmedetomidine.
    - Inhibit sympathetic pain transmission.
    - Cause dose dependant hypotension, bradycardia and sedation.
  - *Anti-convulsants:* e.g. gabapentin and pregabalin.
    - Inhibition of voltage gated calcium channels.
    - Carbamazepine, which inhibits voltage gated sodium channels.
    - Side effects of dizziness, drowsiness, nausea/ vomiting.
    - Used for neuropathic pain.
  - *Anti-depressants:*
    - Tricyclic antidepressants (amitryptilline and nortriptyline), SNRIs (venlafaxine, duloxetine), SSRIs (fluoxetine, paroxetine).
    - Inhibit pain pathway neurotransmission by inhibiting re-uptake of serotonin (SSRIs) or both serotonin and noradrenaline (TCAs and SNRIs).
    - Used for neuropathic pain.
  - *IV lidocaine:* can be used intra-operatively as an infusion for analgesic effects via blockade of voltage gated Na^+ channels.

> **NICE guidelines (osteoarthritis pain management)**
> - Regular dosing paracetamol.
> - Topical NSAIDs.
> - Oral NSAIDs – COX-2 inhibitors co-prescribed with PPI.
> - Opioids.
> - Intra-articular steroid injections for moderate to severe pain.
> - No strong evidence to offer intra-articular hyaluronan acid injections.

Complex regional pain syndrome (CRPS)

- **Type 1:** initiated by trauma with no identifiable peripheral nerve injury.
- **Type 2:** associated with an identifiable peripheral nerve injury following trauma.
- **CRPS** is a diagnosis of exclusion and so other causes or external signs need to be ruled out.
- **Signs and symptoms of CRPS:**
  - Sensory: hyperalgesia or allodynia.
  - Vasomotor: temperature asymmetry, skin colour changes or colour asymmetry.
  - Sudomotor: oedema, sweating changes or sweating asymmetry.
  - Motor/trophic: decreased ROM, motor dysfunction or tropic changes (hair, nails or skin).

❖ **Budapest diagnostic criteria** (all 1-4 must apply):

1. Continuing pain that is disproportionate to the inciting injury.
2. Shows at least one sign in two of the above categories.
3. Reports at least one symptom in three of the above categories.
4. No other diagnosis better explains the signs and symptoms.

❖ **Stages of CRPS:**

- **Acute(0- 3months :(**burning pain, redness, swelling, warmth, hyperhidrosis, hyperaesthesia, cold intolerance, joint stiffness. Normal x-ray with a positive 3-phase bone scan.
- **Subacute(3- 12months :(**worsening pain, cynanosis, dry skin, stiffness, skin atrophy. Get subchondral osteopenia on xray.
- **Chronic(<12 months) :**diminished pain, glossy skin, fibrosis, joint contractures, loss of hair and nails. The x-ray will show extreme osteopenia.

❖ **Management:**

- Prompt diagnosis and early treatment is key.
- Complex biopsychosocial condition requiring an MDT approach with medical, psychological, physical and occupational therapy components delivered via a pain management programme.
- Avoid surgery in a CRPS affected limb until 1 year after the active process has resolved.
- Surgery should ideally be performed by a surgeon with experience in operating on patients with CRPS with an anaesthetist who is also a pain specialist.
- Amputation can be considered in extreme circumstances but there's a significant risk of phantom limb pain and recurrence of CRPS in the stump preventing successful use of a prosthesis.

❖ **4-pillars of management:**

1. Patient information and education.
2. Pain relief (inc. drugs for neuropathic pain, TENS, sympathetic nerve blockade, spinal cord stimulator).
3. Physical rehabilitation (important to maintain function).
4. Psychological intervention.

Chronic post-surgical pain (CPSP)

❖ **Definition:**

- Pain develops or increases in intensity after a surgical procedure or a tissue injury.
- Pain persists beyond the healing process, ≥ 3 months after the triggering event.
- Localisation: either at the surgical, area of injury or projected onto the innervation area of a nerve in this area.
- Other causes of pain (e.g. pre-existing pain conditions, infection, malignancy) need to be excluded.
- Chronic post-surgical pain can often show characteristics of neuropathic pain.

❖ **Incidence:**

- Amputation (30-85%).
- Hip arthroscopy (7-23%).
- Knee arthroscopy (13-44%).

❖ **Risk factors:**

- Pre-op pain.
- Severe acute post-op pain.
- Surgical factors (location, duration, nerve injury and repeated surgery).
- Patient factors (smoking, high BMI, female, psychological: fear, anxiety, depression, unemployment and addiction).
- Anaesthetic factors (GA > spinal/regional and high perioperative opioid use).

❖ **Preventative management:**

- Aim to minimise acute post-op pain and opioid use in perioperative period by using:
  - A multimodal approach including the use of gabapentinoids pre- and post-op for surgery with high risk of CPSP.
  - Intra-operative agents such as ketamine, magnesium, alpha-2 agonists and IV lidocaine for opioid sparing effects.
  - Spinal or regional anaesthesia where appropriate.
  - Use of local anaesthetic wound infiltration.

PERIPHERAL INSERTED CENTRAL CATHETER (PICC)

- Access from the basilic or cephalic veins and rests in the superior vena cava.
- Requires regular flushing to maintain patency.
- Obtain a chest x-ray to confirm placement before use.
- **Indications:**
  - Chemotherapy
  - TPN
  - Long term antibiotics.

HICKMAN LINE

- Central venous catheter for administration of medications (long term antibiotics and chemotherapy).
- Tunnel created under skin to insert catheter in superior vena cava vein.
- Flush regularly with heparinised saline.

MID-LINE

- Rests in axillary vein distal to the shoulder.
- Radiographic confirmation is not required prior to use.

THEATRE DESIGN

- **Location:** needs to be accessible but separate from main hospital traffic.
- **Floor:** antistatic to reduce the accumulation of particulate matter.
- **Temperature:** 20°C for the surgeon and 25°C for the patient with the use of warming blankets.
- **Humidity:** aim for 40-60%, any lower can risk electrostatic sparks.
- **Illumination:** need 30000 – 40000 lux.

Theatre zone

- **Outer:** open to foot and trolley access and includes the reception, offices, corridor and changing rooms.
- **Clean:** represents the theatre complex and limits access between the reception and theatre.
- **Restricted:** anaesthetic room, scrub room and operating theatre with the need to wear hats and masks and have minimal personnel.
- **Ultraclean:** inside the laminar flow area in which only scrubbed and gowned personnel should enter.
- **Dirty:** has the disposal bins and sluice.

Sources of contamination

- **Airborne:**
  - Accounts for95 %of infection risk.
  - Tested using a microbiology volumetric slit sampler every 3 months with culture plates incubated for48 hours at37C°.
  - Done inside and outside enclosed area.
- **Patient skin**: the importance of careful skin inspection and preparation.
- **Theatre personnel:**
  - Bacteriological count related to number of persons and their movement.
  - From upper respiratory tract.
- **Instruments and theatre fixtures**

Ventilation

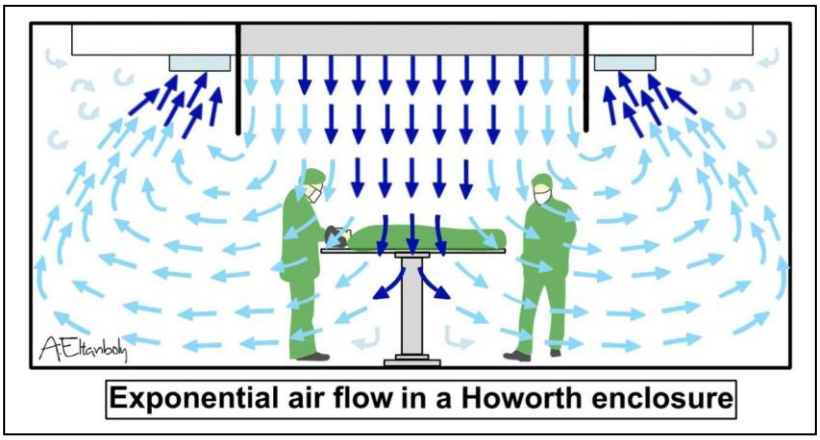
- The aim of a ventilation system is to decrease the number airborne bacteria within an operating theatre.
- This is expressed in terms of colony-forming units per cubic meter (CFU/m^3).
- The cleanliness of the theatre is assessed every 3 months as described above.
- The UK standard is to have < 35 CFU/ m^3 at rest and < 180 CFU/m^3 during an operation.
- This standard can usually be achieved with 20 air changes per hour.
- The operating zone at the centre of theatre has to be ultraclean with < 10 CFU/m^3. The peripheries of the enclourse should be < 20 CFU/ m^3.
- The ultraclean set up is achieved with the use of high efficiency particulate air filters (HEPA) in which > 0.3 μm sized particles are removed.

- **Plenum:**

- Not really used in T&O theatres.
- Positive pressure gradient in theatre with higher pressure within theatre relative to outside.
- Opening of doors and moving personnel makes this system less efficient.
- Clean air is fed in through the ceiling and let out via vents placed just above the floor.

❖ **Laminar flow:** the movement of an entire body of air within a designated space moving with uniform velocity in a single direction along parallel flow lines.

- **Horizontal laminar flow:** Air is blown horizontally across the theatre. This is not used in T&O theatre.
- **Vertical laminar flow:**
  - This is more commonly used.
  - Vertical movement of air limited to the centre of the operating theatre(room within room principle).
  - Addition of a ceiling mounted system can mean it suffers from entrainment of dirty air from the edges towards the wound.
  - Obstacles create turbulance especially at the edges of the air-flow.
  - Require 300air changes per hourto achieve the required cleanliness level .
- **Ex-flow** (Howorth enclosure):
  - Exponential flow of air downwards and outwards in shape of an inverted trumpet.
  - High flow in the centre to carry away contamination generated by the surgical team.
  - More efficient form of laminar flow with entrainment being less of a problem.
  - Requires a smaller number of air changes per hour to maintain the cleanliness level.
  - As in vertical laminar flow the enclosure panels should extend to within2 meters of the floor.



Exponential air flow in a Howorth enclosure

Clothing

❖ Hair should be covered at all times.

❖ Masks worn in operating room to protect the wound from direct airborne contamination. The BOA state that all need to wear them and they should be changed after each operation.

❖ No outside clothes in theatre.

❖ Drapes and gowns made of impervious material.

❖ **Open weave (standard cotton gowns):**

- 80μm pore size.
- Allows easy circulation of air.
- Disadvatages are that it allows skin scales to pass through and has a low resistance to liquid penetration.

❖ **Close weave** (e.g Gore-Tex gowns):

- 20μm pore size.

- Reduce bacterial dispersion especially when wet.
- Inhibit air circulation and can be uncomfortable.

❖ **Disposable non-woven:**

- Spun-laced fibres, wood pulp and polyester all compressed to provide the fabric integrity.
- Most common.
- Bacteria get trapped and therefore can't penetrate
- Low air permeability and moisture vapour transmission rate.
- Single use and expensive.

❖ **Incisional drapes:**

- Hold down the body drapes, but there isn't strong evidence that they reduce SSI.
- NICE recommend that if you're going to use them, then use the iodine impregnated ones.

<u>Relevant literature</u>

- Charnley (1972):
  - Following the introduction of vertical laminar flow, Charnley reported a reduction in the incidence of deep infection from 7% to 0.5% in 5800 THRs during 1960-70.
  - Attributed to air factors in combination with better surgical wound closure and surgical apparel.
- Lidwell et al, Br Med J (MRC trial 1982): *Effect of ultraclean air in operating room on deep sepsis in the joint after total hip or knee replacement: a randomised study.*
  - Over 8000 patients included.
  - Prophylactic antibiotics reduced infection from 2.3% to 0.6%.
  - Further reduced to 0.2% with the addition of ultraclean air and exhaust suits.
  - Vertical laminar flow performed better
- Hooper et al, JBJS Br (2011): *Does the use of laminar flow and space suits reduce early deep infection after total hip and knee replacements? The ten-year results of the New Zealand Joint Registry*.
  - The New Zealand registry showed that the rate of revision for early deep infection was not reduced by using laminar flow and space suits.
- Bischoff et al, Lancet (2017): *Effect of laminar airflow ventilation on surgical site infections: systematic review and meta-analysis.*
  - Showed no benefit for laminar airflow over conventional turbulent ventilation in reducing risk of SSIs in THR, TKR and abdominal surgeries.
  - This work has been criticised because the impact of forced air warming has been under-estimated since this may affect laminar airflow.
  - An RCT study **(Kumin et al)**, The Reducing Implant Infection in Orthopaedics (RIIiO) is currently underway in the UK comparing forced air warming versus resistive fabric warming on SSI rates after hip hemiarthroplasty for hip fracture patients.
- Thomas and Simmons, BJJ (2018): *The effectiveness of ultra-clean air operating theatres in the prevention of deep infection in joint arthroplasty surgery*.
  - Found that ultra-clean air theatres are not being used correctly with poor microbiology performance e.g. not wearing masks, opening instruments outside the enclosures and not limiting theatre traffic.

SURGICAL INSTRUMENTS

❖ **Blades:**
- No. 10 - For skin & muscle.
- No. 11 - Elongated triangular with pointed tip, which is usefu for stab incisions such as in arthroscopy.
- No. 15 - For precise incisions e.g. in hand surgery.
- No. 20 - Large version of No. 10.

❖ **Forceps:**
- Toothed - e.g. Adson used for everting the skin edges.
- Untoothed - e.g. Debakey are non-traumatic and used with blood vessels, nerves and visceral organs.
- Allis - these are used to grasp tough connective tissue.
- Mosquito - used for both haemostasis and fine tissue dissection.

❖ **Scissors:**
- Mayo - used to cut fascia.
- Suture scissors.
- McIndoe - used for careful tissue dissection and cutting.

❖ **Needle holder:**
- Designed to maintain a firm grip of the needle.
- Comprises of a beak(jaw) and a longer body segment.
- The beak of a needle holder is shorter and stronger than that of a hemostat.

❖ **Retractors:**
- Langenbeck
- West - self-retainer at a superifical level with a blade depth of 12mm.
- Travers- self- restainer with a blade depth of18mm
- Norfolk- Norwich- self- retainer providing a greater blade depth of26mm.
- Davis- has a blade depth of50mm.

❖ **Suction:**
- Frazier - used for small bleeding and comprises a fine tip with a proximal hole to allow suction control.
- Yankauer- commonly used with a large opening.

❖ **Chucks:**
- AO have quick coupling for drill bits and screw drivers.
- Jacob chuck is the traditional one.

STERILISATION

❖ **Sterilisation** is the process by which <u>all</u> viable organisms are destroyed.
❖ **Autoclave** - uses steam and high pressures.

- **Gamma irradiation.**
- **Ultraviolet** light is for surface sterilisation only.
- **Gas** - using Ethylene oxide or Hydrogen peroxide are used for items that are moisture or heat sensitive but the disadvantage is that they're flammable.
- **Flash sterilization** - is a modification of standard steam sterilisation and is useful for rapid sterilisation. It places iteam on an open tray.

SURGICAL SITE PREPARATION AND MANAGEMENT

Shaving

- Only carryout If necessary.
- If required, aim to remove the hair using clippers as close to incision time as possible, i.e. in the anaesthetic room.
- Shaving the surgical site the night before surgery is associated with a higher SSI risk compared to other methods of removal or no hair removal.
- Increased SSI risk associated with shaving is attributed to microscopic cuts in the skin that provide portal of entry for bacteria and a focus for bacterial multiplication.

Skin decontamination

- **Antiseptic** refers to any process that reduces the number of viable organisms (unlike sterilisation).
- **Alcohol** (70%):
  - Rapid active bactericidal action causing cell death by desiccation.
  - Good solvent and should not be used on open wounds or mucous membrane because it could burn tissues.
- **Povidone-iodine** (Betadine):
  - Should be allowed to dry and only lasts 30-40 minutes.
  - Bactericidal action by releasing iodine, causing death of bacteria, viruses and fungi.
  - Avoid using it in woman who are less than 32 weeks pregnant, or those with hyperthyroidism.
  - Inactivated by blood, faeces and pus.
- **Chlorhexidine:**
  - Safe and does not interfere with wound healing. Can't be used with open wounds or mucous membranes.
  - Wider spectrum than Betadine.
  - Broadbactericidal action against bacteria, viruses and fungi by disrupting the cell membrane.
  - The 2% concentration (Chloraprep) lasts 48 hrs whilst the 0.5% only lasts several hours.
- **Acetic Acid**
  - Comprises of 1-part vinegar and 4-parts Normal Saline.
  - Useful in multi-organism wound infections.

> - Darouiche et al, NEJM (2010): *Chlorhexidine-Alcohol versus Povidone-Iodine for Surgical-Site Antisepsis.* Randomly assigned849 to either group with the primary outcome being any SSI within30 days after surgery.
>   - Found that chlorhexidine-alcohol was superior to povidone-iodine in preventing SSI.

Skin closure

❖ **Sutures:**
- Absorbable:
  - Monofilament- e.g.) PDSabsorbed by 6months(,) Monocrylabsorbed by 90days (,) Biosynabsorbed by 90days.(
  - Braided- e.g.) Vicrylabsorbed by 60days(
- Non-absorbable:
  - Monofilament- e.g. .Nylon and Prolene
  - Braided- e.g. .Ethibond and Fiberwire
- Dyed (provides easy visualisation for removal) or undyed.
- Round bodied (for friable tissues) or cutting needle (for closure of wounds).

❖ **Bn Donati-Allgöwer suture pattern:**
- Mattress suture with one side being through the subcutaneous tissue.
- Does not result in kinking or folding of the skin and so doesn't compromise blood flow.

- Smith, BMJ (2010): *Sutures versus staples for skin closure in orthopaedic surgery: meta-analysis.*
  - Found a significantly higher risk of developing a wound infection when using staples rather than sutures.
  - This conclusion was drawn on the back of included studies with substantial limitations.
- Krishnan et al, CORR (2019): *Is the risk of infection lower with sutures than with staples for skin closure after orthopaedic surgery? A meta-analysis of randomised trials.*
  - Included 17 RCTs with a total of 2446 patients, of which 5 RCTs (501 patients) were at low risk of bias.
  - Concluded that there remains weak evidence to support the use of either and choice should be based on local availability, surgeon preference and cost.

Drains

❖ **Parker et al, Cochrane Database Syst Rev. (2007):** *Closed suction surgical wound drainage after orthopaedic surgery*.
- No significant difference in incidence of wound infection, haematoma, dehiscence or re-operations between those using drains and those not using drains.
- Blood transfusion required more frequently in those who received drains.
- Need for wound dressing reinforcement and bruising was more common in the group without drains.

DRESSINGS

- Prevent post-operative contamination by providing a barrier and absorb exudate.
- Normal dry skin contains up to 1000 bacteria per gram of tissue.
- Exposed and moist areas of skin contain up to 100000 bacteria per gram of tissue.
- They are either permeable (non-occlusive) or impermeable (occlusive) to both water and air.
- **Impermeable dressings:**
  - **Tegaderm pad & Opsite:**
    - Non-adherent absorbent pad bonded to a larger thin transparent film dressing.
    - Allows the passage of moist vapour and oxygen but impermeable to water and micro-organisms.
  - **Intrasite gel:**
    - Hydrogel dressing.
    - Free flowing and fills cavity space.
    - Rehydrate hard necrotic tissue.
    - Absorb slough and exudate.
    - Use secondary foam dressing to retain moisture.
    - Can come in sheets.
  - **Jelonet, Mepitel and Adaptic:**
    - Reduce adherence in granulating wounds.
    - Used as transfer medium for skin graft.
  - **Aquacel:**
    - Sealed dressing, which creates an acidic and hypoxic environment that reduces in-growth of bacteria.
    - Uses hydrofibre technology with a soft absorbant material.
    - It transforms into gel on contact with wound exudate and entraps bacteria.
  - **Foam dressing:**
    - Absorbs exudates.
    - Permeable to oxygen and vapour but not to water.
  - **Melolin:**
    - Low adherent and highly absorbent.
    - Useful in light to moderate exuding wounds.
  - **Inadine:**
    - Povidone-iodine fabric dressing with antimicrobial properties.
    - Non-adherent and used in the management of abrasions, superifical burns and surgical wounds.
    - Shouldn't be used in patients with severe renal impairment, pregnant or breast-feeding women.
- **Haemostatic therapy:**
  - **Sorbsan & Kaltostat (alginate dressings):**
    - Derived from seaweed.
    - Absorbant, haemostatic dressing which forms a viscous gel.
    - Comes in a rope, ribbon or pad form and used for infected wounds and cavities.
    - Used for exudating and bleeding wounds.
  - **Surgicel:**
    - Absorbable haemostat.
    - Made of an oxidized cellulose polymer
  - **Surgiflo:**
    - Haemostatic matrix with thrombin and acts as an adjunct to primary haemostasis control.
    - Provides matrix for platelet adherence.
    - Accelerates formation of platelet-fibrin clot.
- **Negative pressure wound therapy (NPWT):**

- **Vacuum Assisted Closure (VAC):**
  - Comprises a sterile reticulated polyurethane sponge cut to conform to wound size and shape.
  - Adhesive plastic sheet applied over the skin and sponge to create an air-tight seal for the vacuum.
  - Vacuum commonly set at 125 mmHg (range of 50 to 200 mmHg).
  - Removes excess fluid and promotes granulation tissue formation with healing by secondary intention.

> - WOLLF (Wound management of Open Lower Limb Fractures) RCT trial, Costa et al, JAMA (2018): *Effect of negative pressure wound therapy vs standard wound management on 12-month disability among adults with severe open fracture of lower limb*.
>   - Randomised 460 patients (> 16 years of age) from across the UK Major Trauma Network.
>   - Did not demonstrate improvement in self-reported disability index, deep SSI or quality of life at 12 months.
>   - Did not support the use of NPWT in severe open fractures.

- **PICO:**
  - Provides incisional negative pressure for closed surgical wounds at risk of oozing.
  - The fluid is then abdorbed into the dressing.

> - WHIST (Wound Healing in Surgical Trauma) RCT trial, Costa et al, JAMA (2020): *Effect of Incisional negative pressure wound therapy vs standard wound dressing on deep surgical site infection after surgery for lower limb fractures associated with major trauma*.
>   - Findings do not support the use of incisional negative pressure wound therapy in this setting.

❖ **Maggot therapy** (larval therapy):
- Introducing live maggots into non-healing skin and soft tissue.
- Debride wounds by only dissolving necrotic and infected tissue.
- There is disinfection of the wound, stimulation of healing and inhibition of biofilm formation.

CASTS

❖ Provide neutralisation of bending, torsion and compression forces across a fracture by immobilisation.
❖ Applied over a stockinet, Velband or Softban.

❖ **Materials used:**

- **Plaster of Paris:**
  - Dehydrated natural Gypsum (calcium sulphate dihydrate).
  - Mixed with water causing an exothermic reaction resulting in insoluble calcium sulphate.
  - Porous and so protects patient's skin from moisture.
  - Easy to apply and mould to maintain fracture position.
  - Use8 layers to prevent burns and achieve the correct strength.
  - **Cast index = sagittal width / coronal width**
    - Measurements taken from the inner edge of cast at the fracture site.
    - Aim for **0.7**. Anything > 0.8 has an increase risk of fracture displacement.
- **Fibreglass** (glass-reinforced plastic - GRP)
  - Comprises a polymer matrix and glass fibre
  - Has x3 strength of PoP and a third of the weight.
  - SoftCast
  - Flexible and conforming
  - Not very good when you want moulding to maintain fracture reduction.
  - Can unwind.
- **Polyester**
  - DeltaCast
  - ScotchCast
  - More rigid and can crack

REDUCING INTRA-OPERATIVE BLEEDING

❖ **Pre-operative care:**
- Erythropoietin - erythrocyte stimulating glycoprotein made by the kidneys.
- Tranexamic acid - 1g prior to incision.
- Use of iron, Vit B_{12} and Folate supplemnts.

❖ **Intra-operative care:**
- Diathermy.
- Tourniquet.
- Controlled hypotensive anaesthesia.
- Local adrenaline infiltrated into soft tissue.
- Cell salvage.
- Use of topical haemostatic agents and fibrin sealants.
- TXA:
  - Can give a further 1g before wound closure.
  - Can use 3g of topical preparation,
  - Introduce this into the cavity before deflating the tourniquet.
  - Make sure to bathe the bony surfaces and periarticular tissues for about 5 minutes.
  - Then remove with a sucker before routine irrigation and closure.

❖ **Post-operative care:**
- Use of reinfusion drains.
- Checking FBC 24 hours after surgery.

Tourniquets

❖ This is a device which is applied proximal to the site of surgery in order to achieve a bloodless field or to control haemorrhage.

❖ **Types:**
- Non-pneumatic type used on digits and in haemorrhage control.
- Pneumatic type uses an inflatable cuff together with an automatic timer and audio-visual alarm for abnormal pressure, air leakage and time.

❖ **Limb occlusion pressure (LOP):**
- Minimum pressure required to occlude arterial blood flow distal to the cuff.
- Depends on the systolic BP, limb circumference and shape.
- Higher at subcutaneous tissues and mid-point of the tourniquet.

❖ **Inflation pressure:**
- The amount of pressure used depends on age, skin condition, circumference of limb and co-morbidities.
- There is no consensus on what tourniquet pressure should be used.
- Use as low pressure as possible to provide arterial and venous occluion.
- Upper limb use 50- 75mmHgabove systolic pressure .
- Lower limb use 100- 150mmHgabove systolic pressure .

❖ **Cuff width:**
- At least equal to the limb diameter.
- Wider cuffs require lower pressures to stop blood flow.

❖ **Cuff length:** recommend 3 to 6 inches of overlap to achieve the necessary hold.

❖ **Padding:** 2-3 layers of soft padding to distribute pressure evenly deep to cuff and to avoid pinching of skin.
❖ **Exsanguination:**
- External compression using a Reece-Davis exsanguinator or esmarch bandage.
- Simple elevation of the limb for one minute.
- Digital pressure over the brachial artery in cubital fossa plus elevation.
- Contraindicated in infection and malignancy.

❖ **Tourniquet time:** The absolute limit of tourniquet time has never been firmly established but 2 hrs is the most widely accepted. This is because intracellular stores of creatine phosphate are depleted by 2 hrs and ATP by 3 hrs. Can reinflate it after 5 minutes if absolutely required.
❖ **Contraindications:**
- Infection can enhance anaerobic metabolism.
- Peripheral vascular disease.
- Sickle cell disease: hypoxia, stasis and acidosis may lead to sickling.
- Poor skin and crush injuries.

❖ **Relative Contraindications:**
- Intramedullary nailing: blood flow helps to decrease thermal bone injury.
- Open fractures.

❖ **Complications:**
- Nerves are most susceptible to mechanical pressure whilst muscle is most susceptible to ischaemia.
- **Local**:
  - Rises with increasing time (avoid going longer than 2 hours).
  - Post-tourniquet paralysis.
  - Bone and muscle necrosis.
  - Direct vascular injury.
  - Post-op swelling and stiffness.
  - Wound haematoma.
  - Post tourniquet syndrome which is characterized by oedema, stiffness, pallor, weakness, numbness and pain. Usually resolves within 6 weeks.

❖ **Systemic**
- Re-perfusion injury.
- Myoglobinuria.
- Renal failure
- Altered acid-balance.
- Cardio-pulmonary decompensation.

Electrosurgery

❖ Electricity is used to generate heat (up to 1000°C) and thermal destruction of tissue.
❖ Cutting and coagulation of body tissue with the application of high frequency current.
❖ A frequency above 100 kHz is safe and will avoid nerve and muscle stimulation (electrocution does not occur).
❖ Called radio-frequency because it's within the band width used in domestic radios.
❖ Active and return electrodes.
❖ Generator via a foot or hand switch.
❖ **Types:**
- **Monopolar:**

- Current is established between diathermy electrode and electrical plate.
- Plate should have an area> 70cm ,^{2}which is 10000times larger surface area than the electrode to reduce the chance of burning.
- Larger impedance(current is passed through tissue) with high voltage(in1000s).
- Heating is inversely proportional to contact area.
- Apply to an area of free smooth skin with large underlying muscle.
- The area should be shaved because hair reduces the contact area and the plate might not stick properly.
- Don't apply onto scars, bony prominences or underlying prosthesis.
- Position of the plate can lengthen or shorten the circuit and therefore impact on the the efficiency of the operating electrode.
- Generated smoke contains toxic chemicals such as hydrogen cyanide in addition to viruses and cancer cells. The newer devices have built in suction.
- :Cutting
  - Continuous current with a low voltage
  - Generates high local temperatures and vaporises the cells.
  - Pure - allows for narrow cutting and can be used on skin.
  - Blended - associated with coagulation.
- :Coagulation
  - Intermittent (pulsed) current at higher voltage.
  - No tissue damage but allows a coagulance to form.

▪ **Bipolar:**

- Current is passed between two electrodes within diathermy forceps.
- Has lower impedance and lower voltage(in the100s).
- Safer and avoids risk of damage from passage of current through surrounding tissues.
- Used when operating on peripheral or end organs(fingers, toes and penis) since it avoids the effect of channelling that occurs with monopolar diathermy.
- Diathermy of choice when the patient has a pacemaker.
- Doesn't allow for cutting.

❖ **Use with pacemaker and Implantable Cardioverter Defibrillator (ICD):**

- Risk of electrical interference can lead to inhibition or increase in pacing.
- Must carryout a preoperative check.
- Ensure the self-adhesive return electrode is away from the cardiac device implant site.
- Deactivate the ICD pre-operatively, monitor the ECG and have an external defibrillator in close proximity.
- Use a magnet to deactivate the ICD in an emergency.

❖ **Complications:**

- Burn from contact with metal (always cover these) because current passes through areas of lowest impedance.
- Always ensure that there's no pooling of alcoholic skin preparation as this increases the risk of burns.
- Risk of explosions from anaesthetic or bowel gas.
- Theatre staff exposure to smoke products, which can contain infectious organisms. Use high filtration face masks.

BLOOD TRANSFUSION

❖ **Autotransfusion:**

- Non-processed: patient's pre-donated blood is given to them postoperatively.
- Processed: cell salvage in which blood is filtered and centrifuged to remove the plasma.

❖ Jehovah's Witnesses:

- Will not accept any allogeneic blood products from volunteer blood donation.
- May accept autologous cell-salvage blood but not pre-donated blood.
- Consider pre-operative erythropoietin for bone marrow stimulation to produce RBCs.

VTE PROPHYLAXIS

- Aim is to prevent symptomatic deep vein thrombosis (DVT) and fatal pulmonary embolism (PE) (controversial).
- Coagulation cascade is a series of reactions leading to the formation of fibrin and platelet activation resulting in clot formation.
- **Department of Health** recommends DVT/PE risk assessment of all surgical and medical patients with reduced mobility. Need to weigh thrombosis and bleeding risk.

Virchow's triad

- **Blood flow stasis:**
  - Immobility> 3days results in a x 10higher risk of VTE.
  - General anaesthesia results in a x2 higher risk of VTE.
  - Obestiy with a BMI> 30results in a x 3higher risk of VTE.
  - Age> 60years increases the general risk .
- **Hypercoagulability:**
  - Oral contraception pills and hormone replacement therapy.
  - Thrombotic states- neoplasia, dehydration, MI and CVA.
  - Thrombophilia- Factor V Leiden factor and anti-phospholipid syndrome.
  - Pregnancy in the first6 weeks.
- **Endothelial injury:**
  - Varicose veins results in a x1.5 higher risk
  - Inflammation or infection
  - Previous VTE.

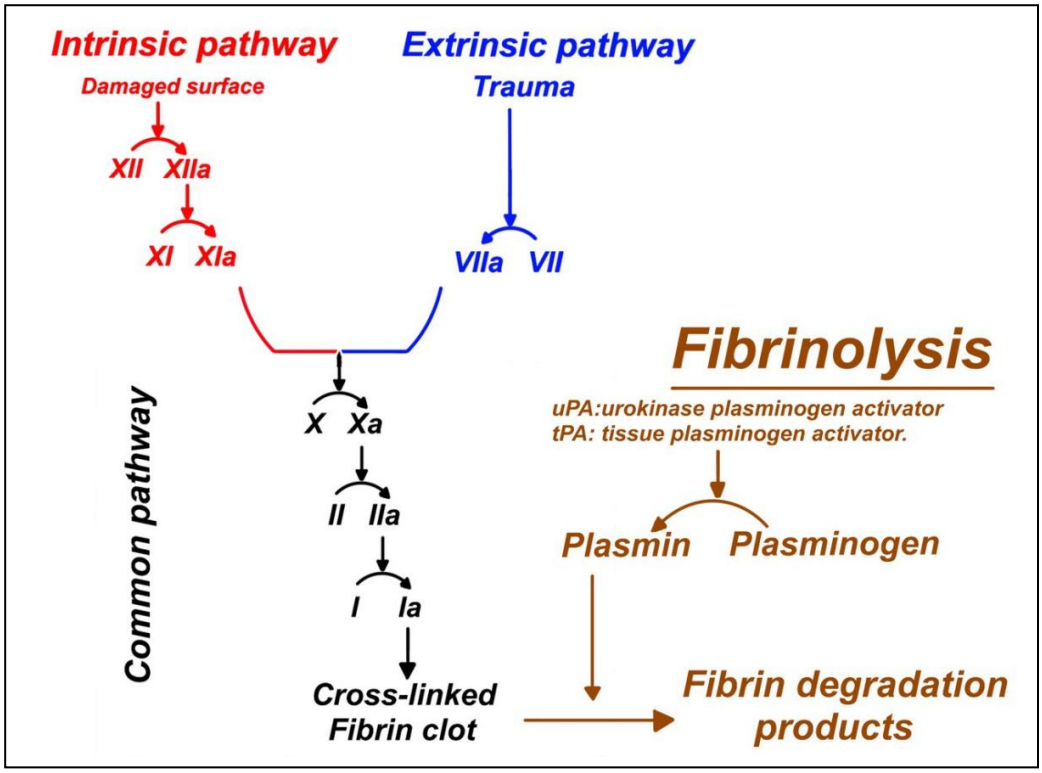
Coagulation cascade

- Coagulation has two main pathways**:**
  - **Intrinsic pathway** (contact activation)
  - **Extrinsic pathway** (tissue factor activation)
- Both pathways will result in the activation of factor X (Stuart-Power factor) which results in a cascade of reactions known as the **common pathway.**
- **Intrinsic pathway:**
  - Damaged endothelial surface results in activation of platelets and secretion of inorganic polymers which activate factor XII (Hageman factor).
  - Activated factor XII (XIIa) then activates factor XI into XIa.
  - Factor XIa activates factor IX into IXa.
  - Factor IXa in addition to VIIIa activate factor X into Xa.
- **Extrinsic pathway:**
  - This pathway is initiated by tissue trauma, which results in the release of tissue factor (TF).
  - Called extrinsic because it requires factors that are not normally present in the blood.
  - TF in addition to activated factor VII (VIIa) result in activation of factor X into Xa.
- **Common pathway:**
  - Activated factor X in addition to activated factor V (Va) result in the conversion of prothrombin (factor II) into thrombin (factor IIa).
  - Thrombin (IIa) converts fibrinogen (factor I) into fibrin (Ia) which is the solid base for formation of a thrombus.
  - Thrombin also activates factor XIII into XIIIa (fibrin stabilising factor) which stabilizes the formed clot.
- **Fibrinolysis:**

- This is a normal body process, which prevents formed blot clots from excessively growing.
- This starts by the activation of plasminogen into plasmin, which breaks down fibrin in the thrombus into fibrin degradation products (FDPs).
- Coagulation is regulated by protein C and its co-factor protein S. Both inhibit coagulation by inhibiting factors Va and VIIIa.

❖ **Tranexamic acid:**

- Anti-) fibrinolytic agent that inhibits plasminogen activationblocks lysine binding site on plasminogen (moleculaeto plasmin leading to fibrinolysis.
- Promotes and stabilisers clot formation.



Chemical prophylaxis

❖ **Aspirin:**

- Inhibits production of prostaglandin and thromboxane.
- Inhibit platelet aggregation (platelet lifespan is 10 days).
- Monitored by measuring bleeding time.

❖ **Warfarin:**

- Blocks vitamin K dependent factors (II, VII, IX, X).

- Takes 2-3 days for inactive factors produced by the liver to replace original ones.
- Monitor prothrombin time (PT time) and calculate the international normalised ratio (INR) - extrinsic pathway.
- Reversal by vitamin K, fresh-frozen plasma (FFP) or prothrombin complex concentrate (Octaplex or Beriplex).
- Increased effect with Omega-3 fish oil and decreased with green tea.

❖ **Heparin:**

- Enhances anti-thrombin III to inhibit factor Xa.
- Inactivates thrombin which prevents activation of fibrinogen to fibrin.
- Monitor activated partial thromboplastin time (APTT) – intrinsic pathway.
- Heparin induced thrombocytopaenia (HIT) in which platelet count drops to less than 50% of pre-drug levels.
- Reversed with protamine.

❖ **Low-molecular weight heparin (LMWH):**

- Example is clexane(molecular weight less than8000 Daltons).
- Inhibits factor Xa via antithrombin III with less effect on thrombin compared to unfractionated heparin(UFH).
- Start6-12 hrs after surgery.
- Single daily dose.

❖ **Dabigatran:**

- Direct thrombin inhibitor.
- Start 1–4 hrs after surgery.
- Routine clotting profile tends to be inaccurate but thrombin time(TT) and prothrombin time can also be used.

❖ **Rivaroxaban and Apixaban:**

- Direct factor xa inhibitors.
- Start6-10 hrs after surgery.
- Stop2 days before surgery, which corresponds to4-5 half-lives.
- No antidote.
- TT sensitive but can also use PT.

❖ **Fondaparinux:**

- Inhibits factor Xa via antithrombin IIIa.
- TT sensitive but can also use PT.
- Start6 hrs after surgery.
- Decreased incidence of DVT compared to enoxaparin in hip fractures and knee arthroplasty.
- Reduced risk of HIT.
- Highest bleeding complications and so don't use in conjunction with epidural.

❖ **Dextran:**

- Polymer of glucose monomers.
- Dilute coagulation factors.
- Decrease platelet function by reducing von Willebrand factor.

❖ **Octaplex:**

- Prothrombin complex concentrate.
- Combination of blood clotting factors II, VII, IX and X.
- Prepared from human FFP.
- Used in cases of significant bleeding in patients with coagulopathy (INR> 8.0).
- Also used when already anticoagulated patients must undergo emergency operation.

❖ **Herbal supplements:** Gingko, ginseng, and garlic all increase bleeding by effecting platelet function.

Mechanical prophylaxis

- Thromboembolic deterrent stockings (TEDS) produce graduated pressure and work by reducing venous stasis.
- Intermittent pneumatic compression.
- IVC filter if contraindication to anticoagulation such as a recent stroke.

Contraindications to VTE prophylaxis (Inscrease bleeding risk)

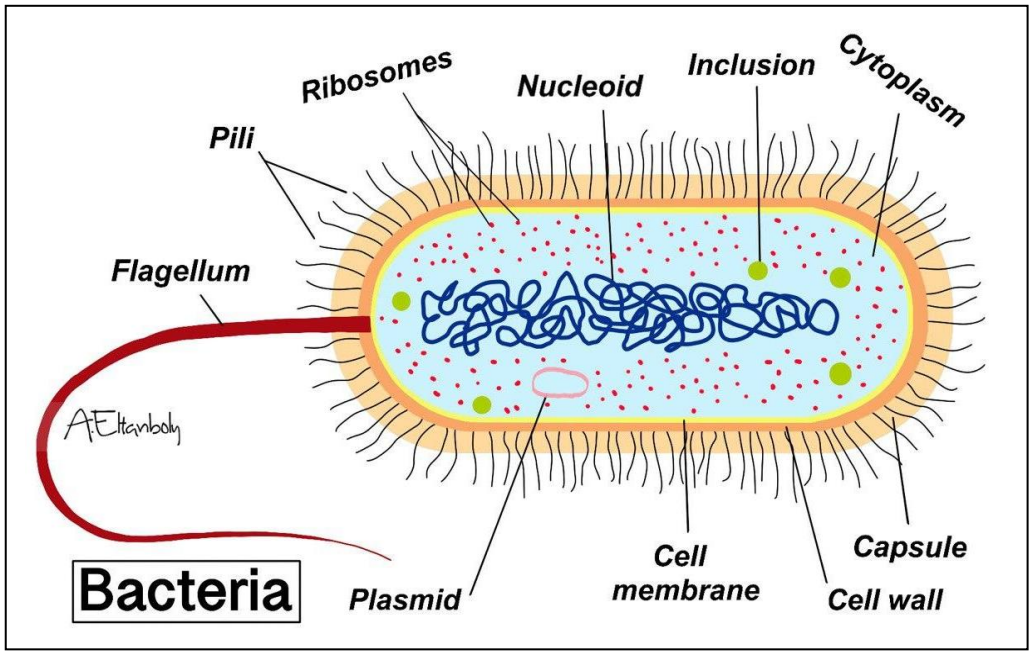
- Active bleeding.
- Acute major trauma.
- Acute liver failure.
- Thrombocytopaenia with a platelet count less than 75.
- Head and spinal injury, acute stroke.
- On anticoagulation with an INR >2.
- Bleeding disorders (haemophilia).
- Uncontrolled hypertension > 230/120 mmHg.
- Lumbar puncture, epidural or spinal anaesthesia in the previous 4 hours or next 12 hours.
- INR > 6.5 need to speak with the on-call haematologist.
- INR 2 – 6.5 give 1mg IV vitamin K.
- High risk of complications when reversing in the presence of a prosthetic heart valve or VTE within 3 months.

PREVENTION OF SURGICAL SITE INFECTION

- Stop further operating and investigate if there are recurrent problems.
- Carryout a root-cause analysis if there is a high incidence of SSI.
- Follow a systematic approach of investigating and addressing pre-op, intra-op and post-op factors.
- **Pre-op:**
  - Adequate nutrition.
  - Optimise medical conditions:
    - HbA1c should be < 7%.
    - Hold off short-acting insulin and oral medications on morning of surgery.
    - Give half dose of long-acting insulin.
  - NICE shows there is no evidence or benefit in preoperative showering or bathing with chlorhexidine over other soap wash or placebo in reducing SSI.
  - Treat infection.
  - Shaving.
  - Equipment sterilisation.
  - Screening for MSSA and MRSA.
  - Stop smoking and checking serum cotinine levels to confirm this.
- **Intra-op:**
  - Ultraclean air.
  - Minimise traffic and personnel.
  - Theatre personnel and patient clothing.
  - Prophylactic antibiotics.
  - Hand decontamination.
  - Skin preparation, with chlorhexidine being first choice unless contraindicated and surgical site not next to mucous membrane.
  - Meticulous tissue handling and haemostasis.
  - Closure methods.
- **Post-op:**
  - Occlusive dressing allows hypoxic and acidic environment to form, which retards growth of skin pathogens.
  - Dedicated elective wards.

MICROBIOLOGY

Bacteria structure



Bacteria resistance

❖ **Mechanisms:**

- Phagocytosis of the drug (beta lactamase).
- Genetic mutation (mecA gene in MRSA).
- Altered cell wall permeability.
- Biofilm formation.
- Ribosome alteration.
- Active efflux pumps.

❖ **Two main types of resistance:**

- **Intrinsic resistance:**
  - The bacteria have properties that prevent antibiotics acting on them.
  - Such as changes in cell wall permeability, efflux pumps and enzyme production.
- **Extrinsic resistance:**
  - The bacteria develop resistance to an antibiotic to which it was previously sensitive.
  - Due to chance mutations and drug resistance gene (this is mediated via plasmids).
  - :*Plasmid*
    - Is an extra-chromosomal circular DNA that replicates independently of host DNA.
    - Carries antibiotic resistance genes that benefit survival of organisms.

Bacteria types

❖ **Gram +ve:**
- Thick wall made of peptidoglycan.
- Stained purple by crystal violet.

❖ **Gram -ve:**
- Thin wall.
- Stained pink withsafranin or carbol fuchsin.

❖ **How to carryout a gram staining:**
1. Smear the bacteria onto a slide and allow it to air dry for 20 minutes
2. Heat fix by passing the slide over a flame a few times.
3. Apply crystal violet dye onto the slide and let the rest wash off with water.
4. Apply iodine which binds the crystal violet to the peptidoglycans of gram positive bacteria.
5. Apply alcohol wash which removes the crystal violet dye from gram negative bacteria but the gram positive bacteria retain it.
6. Counterstain with safranin (pink dye). Let it stand for 1 minute and then rinse off with water. The gram negative bacteria are therefore stained red.

❖ **Actions of bacteria:**
- Colonise (skin & bowel).
- Infect.
- Release toxins.

❖ **Types of bacterial infections:**
- Pyogenic defines the process in which bacterial infection generates pus.
- Granulomatous describes a process of chronic infection.

❖ **Testing for infection:**
- Gram staining.
- Cultures.
- Blot analysis (detects DNA).
- Antigen testing (Montoux test).

	Cocci (round)	**Bacilli** (rod)
Gram (+ve) (purple)	- *Staphylococcus* (aures, epidermidis, MSSA, MRSA). Bacteria in clumps. - *Streptococcus* (pneumoniae, viridans, pyogenes). Bacteria in chains. - *Enterococcus* (faecalis).	- *Clostridium species* (perfringens, tetani, botulinum, difficile). Spore forming. - *Bacillus species*. Spore forming. - *Propionibacterium acne* (anaerobic).
Gram (-ve) (red)	- *Neisseria* (meningitidis, gonorrhoeae).	- *Enterics* (E-Coli, shigella, salmonella, proteus, campylobacter). Gut organisms. - *Respiratory bacilli* (haemophilus influenzae, klebsiella). - *Pasteurella multocida* (animal bites). - *Eikenella corrodens* (human bites). - *Brucella species.* - *Pseudomonas aeruginosa*

❖ **Methicillin resistant Staphylococcus aures (MRSA):**
- Carries the mecA gene which encodes for penicillin binding protein which provides antibiotic resistance.
- Prevents cell wall-penicillin binding rendering penicillin ineffective in destroying the cell wall.
- Methicillin used in 1950s instead of penicillin for resistance.
- Found in the nose, throat and skin with 2% of the population colonised.
- Manage colonisation with nasal mupirocin and bath in 4% Chlorhexidine.
- Teicoplanin, vancomycin and linezolid can be used to treat MRSA infections.
- Panton-Valentine leucocidin (PVL) toxin produced by some strains of Staphylococcus aureus.
- PVL toxin is more aggressive and kills WBCs to cause severe soft tissue necrosis and bone infections.
- Methicillin sensitive Staphylococcus aures (MSSA) have a higher risk of carrying PVL gene (30% of population are carriers).

❖ **Staphylococcus epidermidis:** encapsulated organism meaning that an infected implant would need removing to cure the infection.

❖ **Clostridium:**
- Anaerobic.
- Spores are resistant to disinfectants such as alcohol and so you need to wash hands with soap.

❖ **Propionibacterium (Cutibacterium) acne:**
- Anaerobic and commonly found in the axilla.
- Typically present late with a subtle shoulder infection.
- Since it's an anaerobe, it grows slowly and therefore requires14 days to achieve a positive culture.
- Clindamycin, vancomycin and teicoplanin can be used to treat it.

❖ **Pseudomonas aeruginosa:** associated with infections in IVDU and puncture wounds to the foot.

❖ **Gram -ve bacilli group:**
- Colonise the upper respiratory tract in children.
- Identified using PCR.
- Sensitive to penicillin.
- Extended-spectrum beta- lactamases(ESBL):
  - Produced by two main bacteria being Escherichia coli(E-Coli) and Klebsiella.
  - Resistant to many penicillin and cephalosporin antibiotics.

Mechanism of action of antibiotics

❖ **Act against the cell wall:**
- **Interfere with peptidoglycans synthesis** (building the bricks)**:** Bacteriocidial
  - **Beta-lactams:**
    - **Penicillin V** and **G**, **amoxicillin**, **flucloxacillin** (penicillinase resistant) and **cephalosporins**.
    - Gram +ve.
  - **Carbapenems:**
    - **Imipenem**, **meropenem** and ertapenem
    - Used for the treatment of severe and multidrug resistant bacterial infections.
    - Increasing rates of bacteria developing resistance to carbapenems (e.g. klebsiella pneumonia).
    - Gram -ve and narrow activity against gram +ve bacteria.
- **Interfere with incorporation of glycan subunits** (insertion of bricks)**:** Bacteriocidial
  - **Glycopeptides:**
    - **Vancomycin** and **teicoplanin**
    - Used for the treatment of MRSA.
    - Orally not absorbed, therefore useful in the treatment of C.diff.

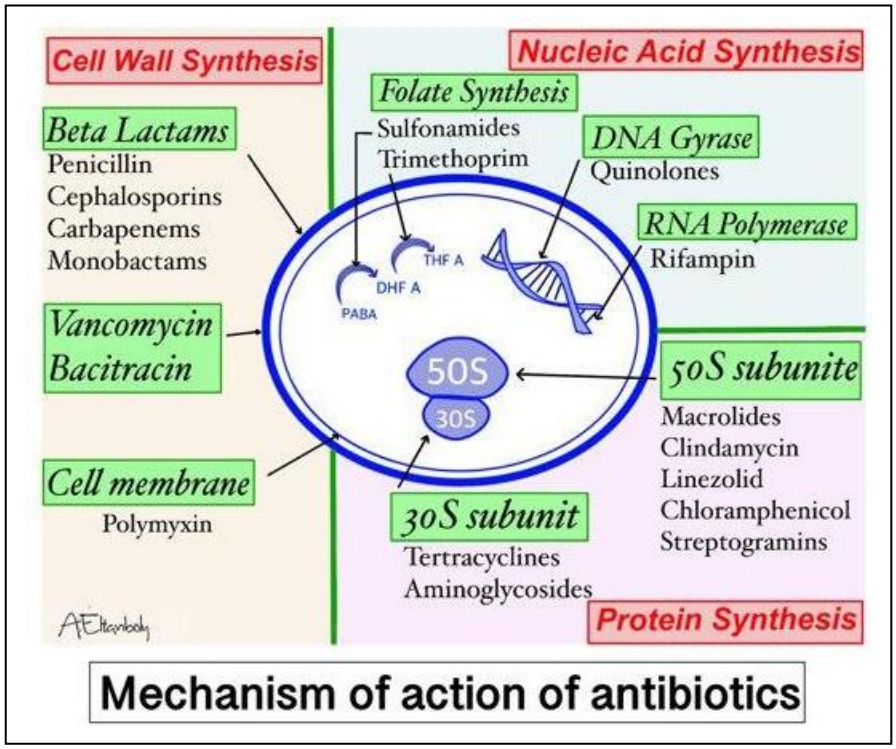
❖ **Act against protein synthesis:**

- **Interfere with the ribosome 30S subunit**:
  - **Aminoglycosides:**
    - **Gentamicin** (5mg/Kg OD).
    - Bacteriocidial against a wide range of gram -ve bacteria and only gram +ve staphylococcus.
    - Good bone penetration.
    - Nephrotoxic and associated with hearing loss.
  - **Tetracyclines:**
    - **Doxycycline**
    - Bacteriostatic against both gram +ve and gram-ve bacteria.
- **Interfere with the ribosome 50S subunit**:
  - **Macrolides:**
    - **Erythromycin**, **clarithromycin** and **azithromycin**.
    - Bacteriostatic against a wide range of gram +ve bacteria and limited against gram -ve bacteria.
    - Commonly used as a substitute for patients with a pencillin allergy.
  - **Oxazolidinones:**
    - **Linezolid.**
    - Action against a spectrum of gram +ve and anaerobic bacteria.
    - Useful in the treatment of MRSA in both oral and IV preparations.
    - Can cause myelosuppression and should not be given for more than 4 weeks with blood test check.
  - **Clindamycin:**
    - Bacteriostatic, but can be bactericidal in higher concentrations.
    - Most effective against anaerobic gram -ve, aerobic gram -ve and aerobic gram +ve bacteria (staph a. causing bone and joint infections.
    - Gives a high bone concentration but there's a risk of pseudomembranous colitis.
    - Also useful in patients with pencillin sensitivity.

❖ **Act against nucleic acid:**

- **Interfere with DNA gyrase**:
  - **Quinolones:**
    - **Ciprofloxacin**, **levofloxacin** and norfloxacin.
    - Bacteriocidial against both gram -ve and gram +ve bacteria.
    - They have a toxic effect against chondrocytes and inhibit early fracture healing.
    - Also associated with increased risk of tendinopathy and tendon ruptures (e.g. triceps, quads and achilles).
- **Interfere with DNA synthesis**:
  - **Metronidazole** (belongs to the nitroimidazole class of antibiotics).
- **Inhibit RNA polymerase**:
  - **Rifampicin**:
    - Against intracellular phagocytised staphylococcus aureus in macrophages.
    - Causes body fluid discoloration and makes urine turn orange.
    - Anti-TB drug.
- **Interfere with folate synthesis**:
  - **Sulfonamides**:
    - Bacteriostatic
  - **Trimethoprim**:
    - Bacteriostatic against both gram +ve and gram -ve bacteria.

- Mainly used in the treatment of UTIs.



Dental procedure antibiotic prophylaxis in arthroplasty

- **British society of antibacterial chemotherapy:** no routine prophylactic antibiotic is required for patients with prosthetic joints who undergo dental work.
- **Comorbidities:**
  - Immunocompromised patients.
  - Previous prosthetic joint infection.
  - Type I (insulin-dependent) diabetes.
  - Malnourishment.
  - Haemophilia.
  - HIV.
  - Malignancy.

IMMUNOLOGY

❖ **Immune response:** this is when biological structures and processes come together to protrct against disease.

❖ **White blood cells (WBCs) or leukocytes:**

- **Granulocytes:**
  - - *Neutrophils*are involved in the acute phase of trauma and also target bacteria.
  - - *Eosinophils*target parasites and are involved in allergic reactions.
  - - *Basophils*release histamine in inflammatory reactions.
- **Lymphocytes:**
  - *B- - cells*mature in the bone marrow and release antibodies.
  - *T- - cells*mature in the thymus and then stay in the blood stream ,spleen and lymph nodes.
    - Helper (CD4) T-cells - activate macrophages and B-cells
    - Cytotoxic (CD8)T-cells - induce death of infected cells.
    - Supressor T-cells - regulate B and T-cells.
- **Monocytes:**
  - Largest type of WBC and are produced in the bone marrow.
  - Circulate in the bloodstream and differentiate into macrophages when they migrate into tissues.
  - Produce protease(lytic enzymes) and cytokines(IL-1, TNF) in phagocytosis.

❖ **Innate immune system:**

- Non-specific (no memory).
- Pre-programmed to react to common broad pathogen catogories.
- Anatomic barriers such as skin.
- Inflammation.
- Complement cascade and circulating proteins.
- Chemotaxis - attract inflammatory cells.
- Opsonisation - attach to the pathogen to make it susceptible to phagocytosis.
- Lysis of cell membrane.
- Assist clearance of immune complexes by liver and spleen.

❖ **Acquired immune system:**

- Has memory.
- Pathogen and antigen specific mechanism.
- B-cells, CD4 and CD8 cells.
- Can also be classified as humoral immunity which is antibody and cell mediated.

❖ **Immunoglobulins (antibodies):**

- **Ig M**:
  - First in acute infection.
  - largest of the antibodies
  - In the foetus.
  - Rheumatoid factor is an IgM
- **Ig G**:
  - Later in acute infection.
  - Most abundant.
- **Ig E**: involved in allergic reactions and against parasites.
- **IgA**: antibody that plays a role in the immune function of mucous membranes.
- **IgD:** usually expressed with IgM but its role is not fully known.

❖ **Immunological hypersensitivity reactions:**

- **Type I**:
  - Immediate anaphylactic reaction.
  - Associated with allergy.
  - Mediated by IgE antibody.
  - Activation of mast cells and basophils
- **Type II**:
  - Antibody dependent hypersensitivity.
  - Mediated by IgG and IgM antibodies.
- **Type III**:
  - Immune complex - antigen bound to antibody.
  - Mediated by IgG and IgM antibodies.
- **Type IV**:
  - Delayed reaction which is cell-mediated hypersensitivity.
  - Mediated by T-cells, monocytes and macrophages.
  - Take several days to develop.
  - Examples include Mantoux test(tuberulosis skin test).
  - Response to metallic orthopaedic implants.

INFLAMMATION

❖ This is the biological process in which the body responds to pathogens, damaged cells and/or irritants.

❖ **Acute:**

- Red, hot, pain, swelling and loss of function
- In response to pathogens as macrophages and histiocytes release inflammatory mediators.
- These cause vasodilatation and leakage of fluids from capillaries.
- Outcome is either resolution, scar tissue or chronic inflammation.

❖ **Chronic:**

- Prolonged inflammatory response.
- Get simultaneous destruction and healing.

SKIN GRAFT AND FLAPS

❖ Avascular graft used to cover deep structures and form a bacterial barrier and prevent joint contracture.

❖ **Indications:**
- Primary wound closure can't be achieved.
- Wound healing with problematic scarring.

❖ **Contraindications:** Wounds with exposed bone, tendon, nerves, or blood vessels.

❖ **Partial/split thickness:**
- Perfused wound bed with good vascularisation over muscle or subcutaneous tissues.
- Nutrition obtained by diffusion from wound bed, imbibition followed by inosculation.
- Glabrous (lacks hair follicles).
- Donor sites e.g. anterolateral thigh.

❖ **Full thickness:**
- Volar hand wounds and fingertips.
- Contain full thickness of dermis and epidermis, which contains hair follicles and sweat glands.
- Donor sites e.g. proximal forearm and hypothenar eminence of hand.
- Better innervation and sensation.
- Less scar contracture.
- More durable and resistant to shear stresses.

❖ **Technique:**
- Hand held or electric dermatome.
- Liquid paraffin.
- Skin under tension.
- Meshed graft to provide a greater surface area and lower incidence of haematoma formation and infection.
- Immobilise site to protecrt against shear forces.
- Leave donor site undisturbed for two weeks until it's not painful as newly formed epithelium will rip off with the dressing.
- Mepilex dressing can be removed with less risk of damaging the wound.
- Prevent infection.

❖ **Flap:**
- Unit of tissue transferred from the donor site to a recipient site while maintaining its own vascular supply.
- Pedicle is the vascular portion of transferred tissue which contains one artery and one or more veins.
- Indications is when there is a soft tissue injury with exposed bone, tendons, cartilage or orthopaedic implant.
- **Classification by tissue type:**
  - *Cutaneous*include skin and subcutaneous tissue.
  - *Fasciocutaneous* include fascia with overlying skin.
  - *:Muscle*
    - Usually requires additional transfer of skin graft to cover the muscle.
    - May be transposed as part of a musculocutaneous flap (composite).
    - If the motor nerve is not preserved then the flap will atrophy to 50% of its original size.
  - *Vascularised bone graft:*this involves harvesting a segement of bone with a vascular pedicle .
  - *Composite*: consists of multiple tissue types.
- **Classification by mobilisation type:**
  - *Local flap:* tissue transferred from an area adjacent to the defect.
  - *Rotational, advancement or transposition* (Z-plasty) e.g. sural flap.
  - *Distal/regional flap:* transfer of tissue to non-contiguous anatomic site.

- *Free tissue transfer:* local tissue is not sufficient.

- **Complications:**
  - Flap failure in which vasospasm often leads to thombosis at the anastomosis.
  - Donor site morbidity pain and cosmesis.
  - Non-union of a vascularised bone graft.

ADVANCED NON-OPERATIVE THERAPIES

Extracorporeal shockwave therapy (ESWT)

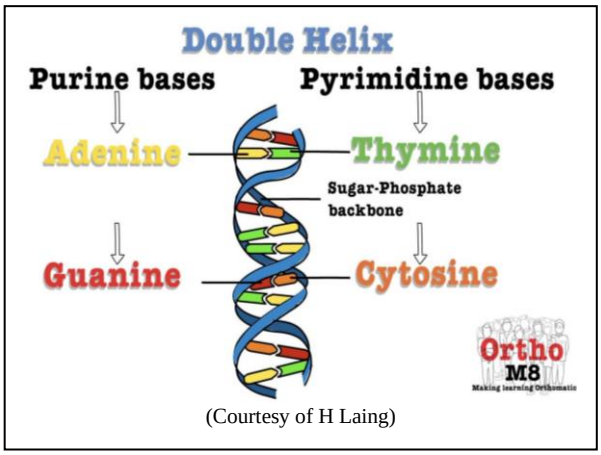
- ESWT has increasingly been used in the treatment of musculoskeletal disorders over the last two decades.
- Works on the principle of using low frequency sound waves under water to generate shockwaves.
- In orthopaedics these are used to induce neovascularisation at the osteotendinous junction.
- This happens through the release of growth factors (endothelial nitric oxide synthase, VEGF and proliferating cell antinuclear antigen), which enhance local blood supply and cell proliferation.
- ESWT has the advantage of being non-invasive with no associated pain.
- **Indications:** in the treatment of refractory and chronic MSK conditions such as:
  - .Plantar fasciitis
  - Greater trochanteric bursitis.
  - ,Achillespatellar ,elbow and rotator cuff tendinopathies.
- **Contraindications:**
  - Pregnancy.
  - Directly over major neurovascular structures.
  - Pacemaker.
  - At sites of DVT.
  - Infection and open wounds.
  - Over joint replacements.

Platelet rich plasma (PRP)

- PRP involves centrifugation of patient's own blood and harvesting the plasma component since this will contain a concentration of platelets and growth factors.
- Calcium chloride it then added to initiate platelet This pure sample is then injected directly into the site starting an inflammatory cascade and promoting soft tissue healing.
- **Clinical applications:**
  - Currently there's limited supporting literature for PRP use in soft tissue injury healing, OA, fracture healing, ACL reconstruction, meniscal repair, rotator cuff repair and insertional achilles tendinopathy.
  - There is potential benefit for PRP use in the management of tennis elbow.

GENETICS

- Each cell nucleus contains 46 chromosomes (23 pairs with 22 autosomal and 1 sex) which are long DNA molecules
- **Deoxyribonucleic acid (DNA):**
  - Double helical structure comprising of two chains, which are linked by hydrogen bonds.
  - Code for genes.
  - Nucleotide bases are thymine (T), adenine (A), guanine (G), and cytosine (C).
- **Ribonucleic acid (RNA):**
  - Single strand molecule.
  - Messenger RNA(mRNA) is a type of RNA, which carries information about a protein for its synthesis by the ribosomes.
  - Nucleotide bases are uracil (U), adenine (A), guanine (G), and cytosine (C).



(Courtesy of H Laing)

- **Allele:**
  - One version of a gene, which occupies a specific position on a specific chromosome.
  - Homozygous is when both alleles are idential.
  - Heterozygous is when the two alleles differ and one can be more dominant than the other or contain mutations.
- **Genome:** is the complete DNA sequence of an organism.
- **Genotype:** is the genetic make up of an organism.
- **Phenotype:** is the observed characteristics of the genotype.
- **Penetrance:** percentage of individuals who express the phenotype of the dominant allele.
- **Variable penetrance:** is when the individual may not demonstrate the phenotype although they have the genotype.
- **Mitosis:** growth and division of somatic cells.
- The somatic cell cycle consists of four phases: the initial growth (G_1), DNA replication/synthesis (S), gap (G_2) and mitosis (M).
- **Meiosis:** growth and division of sex cells.
- **Apoptosis:** is the programmed cell death but this physiological function is lost in some cancers.
- **Tumour suppressor genes:**
  - Inhibit cell proliferation and prevent neoplasia.
  - Absence leads to unregulated cell growth.
- Metabolic conditions are most likely to be recessive whilst structural conditions and most likely to be dominant.
- **Haploid:** is the presence of a single set of chromosomes such as in a human egg or sperm cell (contains half the amount of DNA found in a diploid, which is a normal cell).
- **Anticipation:** disorders that present earlier and more severely in affected subjects compared to their affected parent.
- **Aneuploidy:**
  - Describes the loss or gain of a whole chromosome.
  - Monosomy is the loss of one chromosome e.g. Turner syndrome (XO).
  - Trisomy: is the presence of an extra chromosome e.g. Down's syndrome (Trisomy 21).
- **HLA system:**
  - Found on chromosome 6.
  - Has the genes which form cell surface antigen presenting proteins.
  - B27 (ankylosing spondylitis & psoriatic arthritis).
  - DR1 & DR4 (RA).

❖ **PCR test:**
- This can be used in prenatal diagnosis of sickle cell anaemia.
- It works by generating many copies of DNA sequences rather than needing to culture foetal cells.

❖ **Genetic counselling:**
- For inherited conditions
- Consequences and nature of disorder.
- Probability of transmitting it.
- Options in management and family planning.

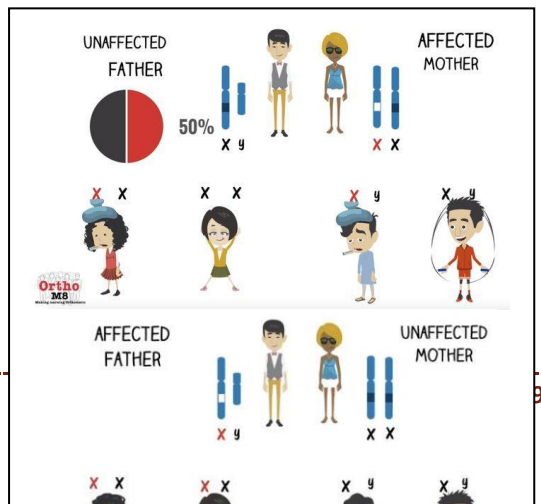
Genetic aberrations

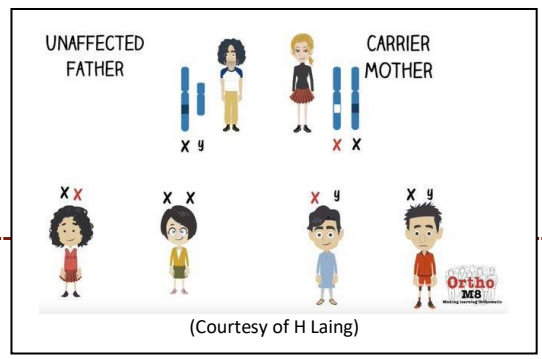
❖ **Chromosomal:**
- Structural: deletion or translation of DNA material.
- Numerical: Trisomy(e.g. Down's syndrome) or monosomy(e.g. Turner's syndrome).

❖ **Single gene:** Mendelian inheritance.

❖ **Polygenic**: multifactorial conditions such as DDH and CTEV.

❖ **Mendelian inheritance:**
- Traits inherited by genes located on autosomal or sex chromosomes.
- **Autosomal dominant:**
  - Only need to get the abnormal gene from one parent to inherit the phenotype.
  - Structural.
  - 50% of the off-spring affected.
  - E.g. Achondroplasia, Marfan, Ehlers- Danlos, multiple hereditary exostosis(MHE) osteogenesis , imperfecta(types I and IV).
- **Autosomal recessive:**
  - Two copies of the abnormal gene must be present to develop the disease.
  - Associated with enzyme/physiological deficiencies.
  - Affected phenotype are homozygous.
  - Carriers are heterozygous.
  - E.g. sickle cell anaemia, Friedreich' s ataxia, OI(types II and III).hypophosphatasia ,
- **Sex-linked dominant:**
  - Most of the sex-linked traits are on the X-chromosome.
  - E.g. hypophosphataemic rickets (the only x-linked dominat orthopaedic condition).
- **Sex-linked recessive:**
  - Affects males because only a single recessive gene on the affected X-chromosome is required.
  - Therefore carrier mothers transmit to50 %oftheir male children .
  - E.g. haemophilia, Duchenne muscular dystrophy, Becker's muscular dystrophy, Hunter's syndrome.





(Courtesy of H Laing)

ORTHOTICS

❖ **Orthosis** is a device, which is externally applied or attached to a body segment that facilitates or improves function by supporting, correcting, or compensating for skeletal deformity or weakness.

❖ **Ideal orthosis:**
- Biomechanically effective.
- Lightweight.
- Durable.
- Cosmetically pleasing.
- Easy to apply and take off.
- Rapid provision and replacement.
- Inexpensive.
- Washable.
- Adjustable.
- Comfortable.
- Free of pressure areas.

❖ **Functional characteristics:**
- Provision of support.
- Limitation of motion.
- Correction of deformity.
- Motion assistance.
- Miscellaneous e.g. feeling of warmth
- Combination.
- Static versus dynamic.

❖ **Principle of application:**
- At least 3 points of pressure.
- Joint must be maintained in optimal anatomical position.
- Principal force applied at joint.
- Opposed by two forces, one proximal and one distal.
- The sum of all applied forces must be zero to achieve equilibrium.

❖ **Types:**
- Static - rigid with no moving parts.
- Dynamic - allows joint movements.

❖ **Biomechanical concepts:**
- Newton's 3rd law (for every action, there is an equal and opposite reaction).
- Gait patterns (may require a gait lab).
- Ground reaction force (GRF).

- If not passing through the centre of the joint, it will create either a clockwise or anticlockwise moment.
- Midstance:
  - GRF posterior to the hip causes clockwise extension moment, resisted by the anterior capsule.
  - GRF anterior to the knee causes an anticlockwise extension moment, resisted by the posterior capsule.
  - GRF anterior to the ankle causes an anticlockwise dorsiflexion moment, resisted by the gastrocnemius-soleus complex.
- Pre-swing:
  - GRF posterior to the knee causes clockwise flexion moment.

- Coupling: is when one joint is affected by the position of another e.g. knee extension and ankle plantarflexion.
- Apply free body diagrams when resolving forces about a joint with an orthosis and draw as you talk.
- Controls moments about a joint:
  - Three-point fixation using a rigid frame, straps and pads.
  - Charnley principle for fracture immobilisation.
  - Only prevents movement in one plane and one direction.
  - E.g. hinged knee orthosis for medial collateral ligament injury.
- Control of translational forces across a joint:
  - Four-point fixation to prevent translation.
  - E.g. Jack knee orthosis for PCL injury.
- Control of axial forces across a joint:
  - Load sharing device.
  - E.g. exoskeletons for arthritic joints.
- Controlling the line of action of GRF:
  - Modifying the point of action and the line of action of the GRF.
  - E.g. lateral heel wedge for medial knee OA.

❖ **Materials:**

- Leather - used in shoes.
- Rubber - used for padding and shock absorption.
- Plaster of paris.
- Metal - rigid and adjustable.
- Thermosetting plastics:
  - Moulded into a permanent shape.
  - Liquid plastic undergoes irreversible polymerisation to form a rigid form.
  - A high temperature is required to mould and its difficult to fabricate.
  - Durable and used for making prosthesis and orthosis, which are under great stress.
- Thermoforming plastics:
  - Undergoes reshaping when heated and this is a great advantage.
  - Based on moulding temperature.
  - High temperature of 120-190°C for polyeythlene or polypropylene:
    - Ideal for high stress activities.
    - Variability in molecular weight, tensile strength, fatigue resistance and mouldability.
  - Moderate temperature of 100-120°C:
    - Can be applied to the patient as it cools (low conductivity of heat) and allow for moulding.
  - Low temperature of <80°C for polymers such as polyisoprene and polycaprolactone:
    - Can be warmed in a hot water bath and easily applied.
    - Less rigid and durable.

- Easily used as hand therapy splints.
- Modified by hair dryer or heating in water.

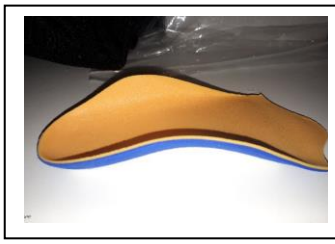
- Self generating polyurethane foam:
  - Allows shaping on the patient and hardens after application.
  - Used to make corsets and braces.
  - Also used to make moulded cushions for wheelchair.

❖ Functional classification of orthoses

- Orthosis can be classified as corrective or accommodative according to function.
- **Corrective**
  - Tend to be hard.
  - They limit joint motion and stabilise flexible deformities.
  - An example is the rocker sole that can lessen the bending forces on an arthritic or stiff midfoot during the midstance as the foot changes from accepting the weight-bearing load to pushing off. It is also useful in treating metatarsalgia and hallux rigidus.
- **Accommodative**
  - Tend to be soft to allow them to shock-absorb and to accommodate fixed deformities
  - Examples are various pressure-relieving insoles that are used to dissipate local pressures over bony prominences to treat diabetic feet.
- Sometimes the same orthotic can be used for support and/or correction:
  - The thoracolumbar sacral orthosis (TLSO) can be supportive in the case of fractures or corrective in the case of idiopathic scoliosis.
  - AFO can be supportive for weak muscles in polio and corrective in cerebral palsy.

❖ Foot orthoses:

- **Insoles**:
  - Simple: are off the shelf and fabricated without casting but can have poor contact and provide little control.
  - Total contact: are made from the imprint of the patient's foot.
  - Functionally the foot is held in a corrected position when the cast is taken.
  - It's a corrective insole when it corrects the patient's flexible deformity.
  - It's an accommodative insole when the patient has a fixed deformity.
- **Shoes:**
  - *External:*
    - Heels can have flared medial or lateral sides (resists eversion and inversion), wedged medial to promote inversion, lateral to promote eversion, extended for support and elevated for leg length discrepancy or equinus deformity.
    - Soles can have rocker bars, metatarsal bars, wedges or flares.
  - *Internal:*
    - Heels can be cushioned to provide comfort and have a rigid plastic inert with high posterior, medial and lateral walls to provide a deep cup e.g. **University of California Biomechanics Laboratory (UCBL)** insert. This is used to control hindfoot valgus and midfoot pronation (found in adult acquired flatfoot, PTTD, flexible pes planus and plantar fasciitis).
    - Soles can have metatarsal pads, inner sole excavations and arch supports.



❖ Ankle-foot orthoses (AFO):

- Used to prevent or correct deformities and reduce weight bearing.

- Ankle position affects knee stability.
- Shown to reduce energy of ambulation (spastic diplegia in CP, post polio syndrome, CVA related spastic hemiplegia).
- Consists of shoe insert, calf shell, a heel retaining strap and calf strap.
  - Posterior leaf spring - used to compensate for weak ankle dorsiflexors and excessive equinus at heel strike.
  - Solid AFO holds the ankle and foot position in all directions.
  - Hinged AFO is set to a desired ankle position e.g. prevents plantarflexion but allows dorsiflexion.
  - Ground reaction AFO (GRAFO) provides knee support for patients with weak quadriceps and gastrosoleus complex. The solid anterior tibial strap prevents excessive tibial forward progression (this would normally be controlled by eccentric contraction of gastrosoleus complex) by generating an extension moment to counteract the flexion moment of the GRF. But this requires there to be full knee extension, ankle dorsiflexion to neutral when the knee is extended and no significant rotational deformity in the tibia or foot.
  - Dynamic AFO (DAFO) or Tone-reducing AFO (TRAFO) are inhibitive casting and reduces tone in muscle groups in CP.

❖ **Knee ankle-foot orthoses (KAFO):**

- This is an extension of the AFO with a joint at the knee.
- Used in patients who are unable to maintain knee stability.

❖ **Trunk-hip-knee ankle-foot orthoses:**

- Extends to the spine.
- For paraplegic patients.

❖ **Miscellaneous:**

- Weight bearing orthoses such as the patella tendon bearing orthosis (PTBO for diabetic ulcers).
- Charcot restraint orthotic walker (CROW) for off-loading in charcot feet and diabetic feet.
- Boots can be either simple walking boots with Velcro straps or air cast boots, which are air inflated by little pumps to create a snug fit.

- Fracture orthosis (e.g. Sarmiento humeral brace) uses the principles of hydrostatic compression forces of the surrounding soft tissues.
- Angular and deformity orthosis e.g. Dennis-Brown orthosis used in the management of club foot after Ponseti casting.
- Hip orthoses such as the Pavlik harness for paediatric disorders.
- Boston brace:

- Is used to treat paediatric scoliosis.
- It is custom made and works on the principle of three-point fixation.
- The bottom part is fixed around the pelvis and the top part has raised sides for improved sideways support to avoid lateral shift of the spine.

- Fracture functional bracing:
  - This was advocated by **Sarmiento** from the USA.
  - In a *review paper he published in the BJJ in 2006* he described his technique.
  - He believed that rigid immobilisation of long bone fractures is non-physiological, and instead movements and continued functional activities encouraged local blood flow and osteogenesis.
  - The principle is to stabilise the fracture while allowing weight bearing and joint movements.
  - Motion at the fracture site is prevented through circumferential compression of the soft tissues.
  - The triangular shape proximally covers the medial flare of tibia and patellar tendon making it patella tendon bearing, thus limiting rotation at the knee but allowing flexion and extension.

❖ **Complications:**

- Psychological.
- Physical:
  - Due to compression phenomena.
  - Heat and water retention.
  - Patient orthosis interfacial effects at the junction between the orthosis and patient.
  - Patient intrinsic factors such as paralysis, neuropathy and PVD.
  - Extrinsic factors such as bony prominences and thin subcutaneous tissue.
- Avoided by:
  - Proper contouring to increase the contact surface area.
  - Good mechanical design
  - Reduce shearing.
  - Adequate padding.

❖ **Principles to minimise orthotic-limb interface pressures:**

- Maximise the lever arm.
- Maximise the contact surface area.
- Maximise conformity.
- Protect bony prominences.
- Have moist absorbent lining.

❖ **When you are asked to describe an orthosis**

- This can be anything!
- It could be something you have never seen but this doesn't really matter because the chances are that the examiner also didn't know before the start of the exam.
- Stick to the below principles and you will impress any examiner.
- Start describing the part of the body it supports such as AFO, KAFO etc.
- Described by the joint or region of the body it encompasses.
  - *Upper limb:* shoulder (S), elbow (E), wrist (W), hand (H).
  - *Lower limb:* hip (H), knee (K), ankle (A), foot (F).
  - *Spine:* cervical (C), thoracic (T), lumbar (L), sacroiliac (S).
- Then describe whether it is corrective or accommodative.
- Describe whether it is static or dynamic.
- Finally describe the materials it is made from.

PROSTHETICS

❖ **Definition:**
- A device or artificial substitute designed to replace the function or appearance of a missing body part
- Aim to maximise the patient's functional independence.

❖ **Outcomes dependant on:**
- Patient:
  - Pre-morbid level of activity.
  - Level of amputation.
  - Ability to learn new skills.
  - Pathology of contralateral limb.
  - Static and dynamic balance.
  - Sufficient trunk control and upper-limb strength.
  - Other co-morbidities.
- Prosthesis:
  - Comfortable to wear.
  - Well suspended with minimal pistoning movement.
  - Easy to put on and take off.
  - Appropriate components.
  - Lightweight, durable and reliable.
  - Cosmetically pleasing.
- Teamwork:
  - MDT - surgeon, rehab physician, prosthetist, specialist physio, occupational therapist and psychologist.
  - Pre-amputation assessment with rehab team where possible.
  - Early rehabilitation and MDT approach.
  - Joint decision for any operation with the stump fashioned with the prosthesis in mind.

❖ **Prostheses classification:**
- Level of amputation - this determines the amount of energy consumption above baseline:
  - Syme (ankle diarticulation) = 15%.
  - Long BKA (unilateral) = 10%.
  - Short BKA (unilateral) = 40%
  - Average BKA (unilateral) = 25%.
  - BKA (bilateral) = 20-40%.
  - AKA (unilateral and traumatic) = 60-70%.
  - AKA (unilateral and vascular) = 100%.
  - AKA (bilateral) >200%.
  - Hip diarticulation = 200%.
- Structure:
  - Exoskeleton - rigid outer shell with hollow prosthesis.
  - Endoskeleton - modular internal strut covered in soft external cosmesis.

❖ **Principles of a good stump:**
- **Length:**
  - In relation to the knee, the stump length needs to be 12-18cm from the medial joint line.
  - Use 1 inch/foot height rule.
  - Transfemoral is 2/3rd of the femoral length.
  - Transtibial is 1/3rd of the tibial length.

- **Soft tissue & scars:**
  - Should never be under tension.
  - Adequate muscle/tissue covering of bone ends (myoplasty).
  - Too much tissue is good for cushioning but makes fitting difficult.
- **Bone ends** must be bevelled.
- **Neurovascular:**
  - Haemostasis is crucial.
  - Nerves must be cut sharply and high up so that they can retract and not form neuromas at the socket site.

❖ **Common elements of a prosthesis:**

- **Socket:**
  - Connection between prosthesis and residual limb.
  - Protects residual stump and transmits force.
  - Manufactured after using a plaster mould or computer assisted mapping of the stump.
  - May need to be serially adjusted to the volume of stump as it changes.
  - Silicon is commonly used as it provides airtight seal between prosthesis and amputated stump.
  - Weight bearing areas for the socket include the heel pad, trans-tibial, patellar tendon, lateral tibial flare, medial tibial flare, trans-femoral, and Ischial tuberosity.
- **Suspension:**
  - Attaches the prosthesis to the stump:
    - Easy to apply and remove.
    - Minimal pistoning.
  - Classified as:
    - Anatomic or self-suspension, which grips the bulbous stump.
    - Belts, straps or sleeves.
    - Roll-on locking liners (liner on the stump has a pin at the end for locking).
    - Suction suspension (look for a valve on the prosthesis).
- **Link (shank):**
  - Connects the socket with the terminal device.
  - Made from metal or cabon-fibre.
  - May include an articulation.
  - May include a dynamic device for shock absorption.
- **Terminal device:**
  - Weight bearing (foot) - energy storing or non-energy storing.
  - Function providing (hand).
  - Static (cosmetic).
  - Dynamic (functional).

❖ **How is the load transferred from the prosthesis to the limb?**

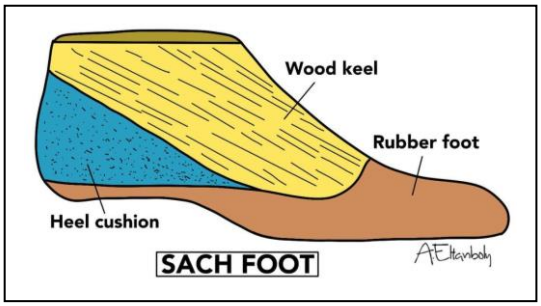
- Load transfer can be both direct and indirect.
- **Direct load transfer or end- weight bearing**occurs when there is a knee or ankle disarticulation (Syme). Intimacy of the prosthetic socket is necessary only for suspension.
- **Indirect load transfer** is when an amputation is performed through a long bone (BKA or AKA) and the end of the stump does not take all the weight, but the load is transferred indirectly by the total contact method. This requires an intimate prosthetic-socket fit.

❖ **What are the different types of knee joint mechanism?**

- **Single axis:**
  - Polycentric with four-bar linkage and a moving centre of rotation provides controlled flexion during the gait cycle, which is good for longer residual limbs.
  - Advantage of being light weight.
- **Hydraulic knee:**
  - This allows variable cadence via a piston mechanism, which is suitable for shorter residual limbs in patients with higher activity levels.
- **Manual locking knee:**
  - A constant friction knee hinge that is locked in extension.
  - Manually unlocked to allow function when sitting.
  - This is primarily used when patients have weak musculature, balance issues, just learning to use prosthetics or have visual impairment.
- **Micro-processor-controlled knee:**
  - This new design is a micro-processor-controlled knee with a motor.
  - Battery life, weight and cost are significant limiting factors.

❖ **Different types of foot prosthesis**

- **Solid Ankle Cushioned Heel prosthesis (SACH)**
  - Non-energy storing device.
  - Used for patients with low activity levels.
  - It's lightweight, cost effective and requires little maintenance.
  - It can lead to overload on the non-amputated limb. And has therefore been replaced by a **single-axis foot**, which has an ankle hinge that provides dorsiflexion and plantarflexion.



- **Energy storing non-articulating foot prosthesis:**
  - Made of carbon fibre.
  - Components are compressible, which provides some energy return.
- **Energy storing articulating hydraulic prosthesis:**
  - Allows inversion, eversion and rotation of the foot.
  - Useful for walking on uneven surfaces.
- **Motor powered ankle:**
  - Rechargeable batteries and controlled by a micro-processor.
  - Reduces the energy requirements of walking.
  - Heavy and expensive.

❖ **Types of upper limb prostheses** - these can be cosmetic, functional or myoelectric:

- **Cosmetic:** passive with no moving parts but can have some function such as turning a light on. They also improve gait.
- **Functional**: are body powered and activated by shoulder movements via a harness and cables. These tend to have poor cosmesis.
- **Myoelectric**:
  - Electrodes attached to residual muscles send electrical signals to the prosthesis.
  - These signals are magnified and passed to a microprocessor to operate the terminal device.
  - These prostheses are heavy and therefore best suited for trans-radial amputations.
  - They also require maintenance and training.

- Provide better cosmetic appearance and tend to be more functional with better movements.
- The terminal device can be a split hook powered by body or a powered device.

❖ **Prosthetic complications**

- **Pistoning** (most common complication):
  - Can occur during the swing phase due to ineffective suspension.
  - Can occur during the stance phase due to poor socket fit or due to stump volume changes.
  - The shear forces from pistoning can cause skin damage and can make the prosthesis feel heavier.
- **Skin damage, blistering and ulcers**:
  - Avoid these by using plaster of paris mould.
  - The prosthetist is able to mark out the pressure areas,
  - These are considered when fashioning the prostheticto minimise the pressure through unprotected bony prominences.
  - Computer-assisted technology is being used to map the stump.
  - Maximise the surface area through which the forces are applied to the skin.
  - Maximise the conformity between the orthotic and the underlying limb.
  - The material at the interface should be moisture absorbent to avoid skin maceration.

STATISTICS

Types of data

❖ Data is the observation of variables.

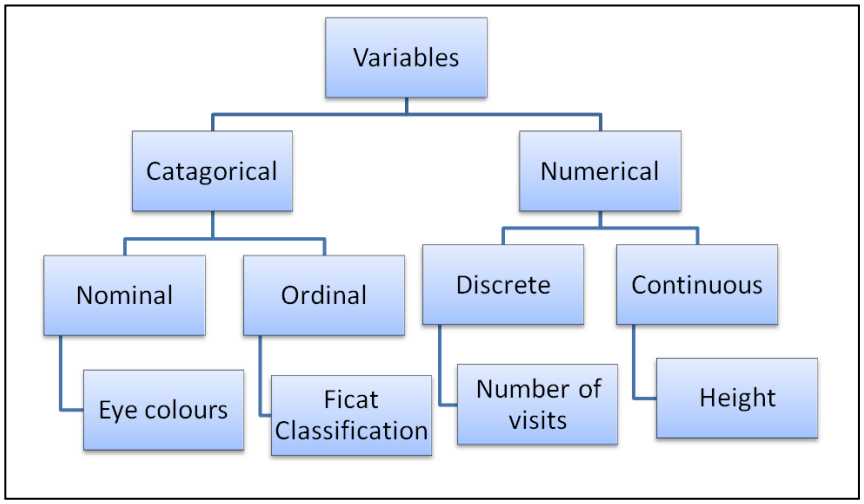
❖ **Categorical** (words): objects are grouped into categories:

- **Ordinal:**
  - Ordered
  - Disease severity such as mild, moderate and severe or e.g. Ficat stages.
- **Nominal:**
  - Unordered with eah category being equal.
  - E.g. gender, eye colour and type of prosthesis.
- Displayed in bar or pie charts.

- Analysed using **Chi-squared** or **Fisher exact** (used when there's <5 values in any one cell of the 2x2 contingency table).

❖ **Numerical:**

- **Continuous:**
  - Can take any value
  - E.g. include weight, height and BP.
  - Use parametric tests such **Student t-test**.
  - Unpaired data is when you get observations from separate subjects.
  - Paired data is when you get observations relating to the same subject.
- **Non-continuous (discrete):**
  - Whole numerical values such as number of children.
  - Use **Mann-Whitney U test** or **Wilcoxon test**.
- Displayed in a histogram, scatter plot graph or box-whisker plot.
- Described using mean, median, mode and interquartile range.



Data distribution

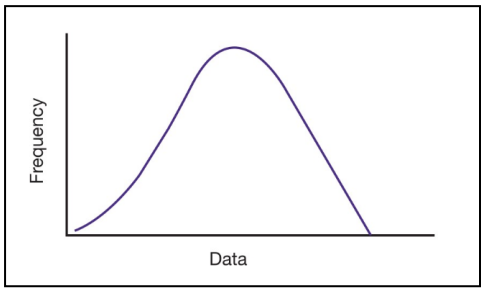
❖ **Normal distribution (Gaussian):** bell-shaped curve with symmetrical data spread.

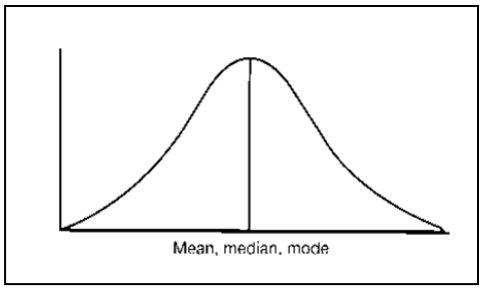
❖ **Skewed distribution:**

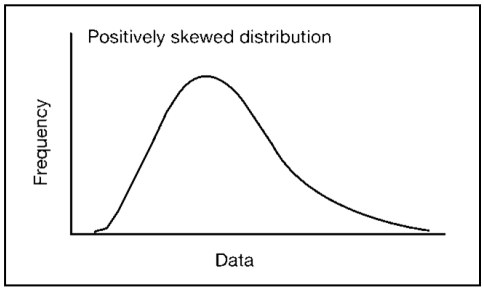
- **Postively skewed**: has the graph tail towards the higher value end
- **Negatively skewed**: has the graph tail towards the lower value end.
- It's always best to test for whether the data is normally distributed since this has implications for which tests are used.
- **Transformation** is the method by which data can be normalised in order to allow for parametric testing.

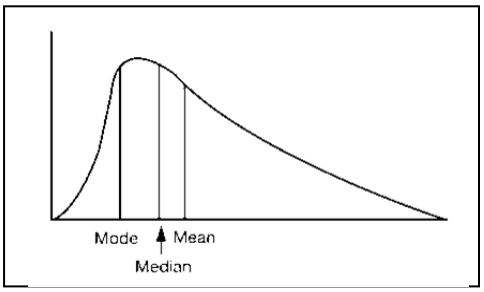
❖ **Measures of central tendency:**

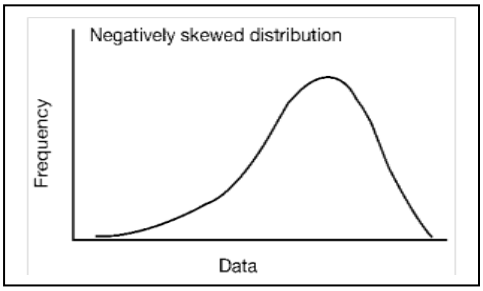
- **Mode**: value which occurs most frequently and is used with categorical data.
- **Median**: middle value when all data is arranged in order. This is used when the data is skewed.
- **Mean**: is the average value and used with normally distributed data (parametric).
- For normally distributed data, the mean, median and mode are the same.

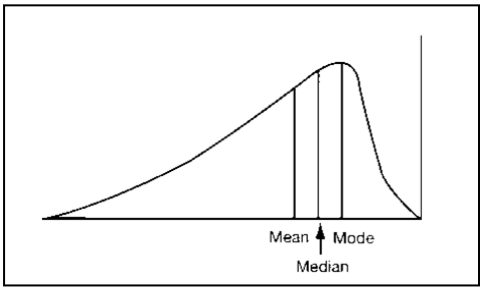






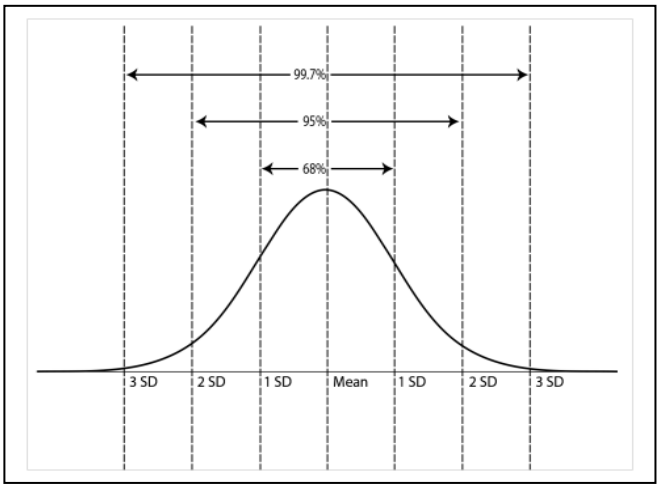


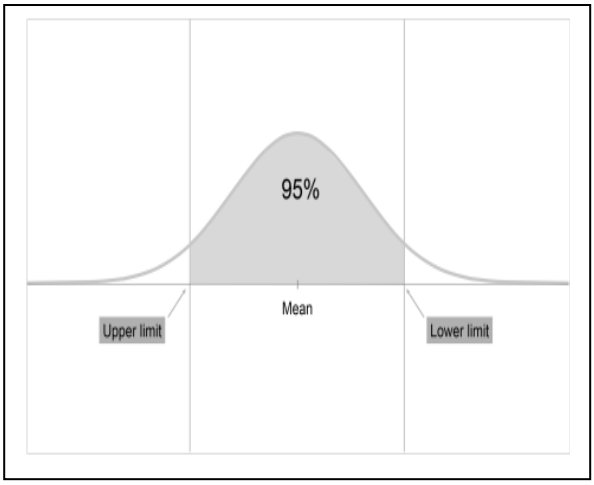




Measure of data spread / variability

- **Range:** the lowest and highest data values.
- **Percentiles:** groupings of data into brackets of 1%, 10% or more commonly 25% (known as quartiles).
- **Variance:** is the average of the corrected sum of squares about the mean. Two data sets can have the same mean but the data spread can be very different.
- **Standard deviation (σ):** this is the square root of the variance. The use of square root gives the same dimension as the data. It is a measure of deviation of individual values from the mean.
- For reasonably symmetrical bell-shaped data, one standard deviation (SD) accounts for roughly 68% of the data, two SD represents roughly 95% of the data and three SD contains around 99.7% of the data.
- **Confidence interval (CI):**
  - Interval that includes values with a specified probability (e.g. 95%), 2 SD either side of mean.
  - Measure of variation and describe where results are likely to be.
  - Widens when there's increased uncertainty from reduced number of data points.
- **Effect size:** difference in outcome between the intervention and control groups divided by the standard deviation.





Data interpretation

- All good studies test hypotheses.
- **Null hypothesis:** assumes that any difference seen between two groups occured purely by chance.
- **P-value:**
  - Probablity that results occurred by chance.
  - If < 0.05, then the null hypothesis is rejected.
  - The smaller the p-value, the stronger the evidence against the null hypothesis.
  - Orthopaedic surgeons are usually willing to accept a 5% probability that the difference seen was due to chance (when the p-value is set to 0.05).
- **Errors:**
  - **Type I (α) error:**
    - False positive.
    - Incorrectly rejecting the null hypothesis.
    - Occurs due to confounding factors (other causes) or using too many tests.
  - **Type II (β) error:**
    - False negative.
    - Incorrectly accepting the null hypothesis.
    - Occurs due to small sample size with inadequate power.
- **Power analysis:**
  - Method of determining the number of subjects (sample size) needed to have a reasonable chance of showing a difference if it exists.
  - Factors affecting power analysis:
    1. Size of the difference between the means - the larger the difference the easier it is to detect a difference and greater the power.
    2. Spread of the data - the larger the spread, the less likely a difference will be detected.
    3. Acceptable level of significance - relates to the p-value that is set.
    4. Sample size - power increases with increasing sample size.

5. Variability in observations - the larger the variability the lower the power.
6. Experimental design - e.g. within subjects versus between subjects.
7. Type of data - parametric versus non-parametric.

- Usualy accept 80% power for a 20% type II error.
- **Power = 1 - (probability of a type-II error)**.

❖ **Pearson correlation r value:**

- Measures the relation between two variables which are normally distributed.
- Ranges from -1 to 1.
- Positive value means that the association is positive i.e. if X increases then Y increases.
- E.g. recurrent falls and number of fractures.

❖ **Spearman correlation test:** used for the association between two variables when the data is ordinal.

❖ **Regression analysis:**

- To estimate the association between two variables.
- Independent variable causes change in the dependent variable.
- Graph plotted with data concentrated along an imaginary straight line.
- Shows correlation between the variables.

Study designs

❖ **Observational:** the investigator observes rather than alters events (PE after THR).

❖ **Experimental:** the investigator applies an intervention and then observes the outcome (heparin versus placebo for DVT prophylaxis in THR).

❖ **Study timelines:**

- *Retrospective study:* the outcome of interest has already occurred.
- *Prospective study:* follows the patient or cohort forward in time.
- *Cross-sectional study:* examines patients or events at one point in time without follow-up.

Significance testing

❖ Think about the following when testing for statistical significance:

- What type of data has been used in the study?
- What is the sample size?
- Are the groups distributed normally?
- Does the data need to be transformed so that we can make the normality assumption?
- Are the groups interdependent and require a paired test?
- Is a single or two-tailed P value necessary? Two-tailed test are most common, though if looking for a unidirectional association then a single-tailed test may be used.

❖ **Tests can be parametric or non-parametric:**

Parametric tests	Non-parametric tests
- Assumes data were sampled from normal population. - Observations must be independent. - Populations must have the same variance. - Can use absolute difference between data points. - Increased power for a given sample size.	- No assumptions made about data origin. - No limitiations on data type. - Rank order of values. - Less likely to be significant. - Decreased power for a given sample size.

❖ **Paired t-test:**

- This should be used when there is a pair of observations on a single subject e.g. BP before and after application

of a tourniquet.

- If there are multiple observations, then **analysis of one-way variance (ANOVA)** should be used.

❖ **Unpaired t-test:**

- This can be used to compare two random unrelated samples provided they both follow a normal distribution.

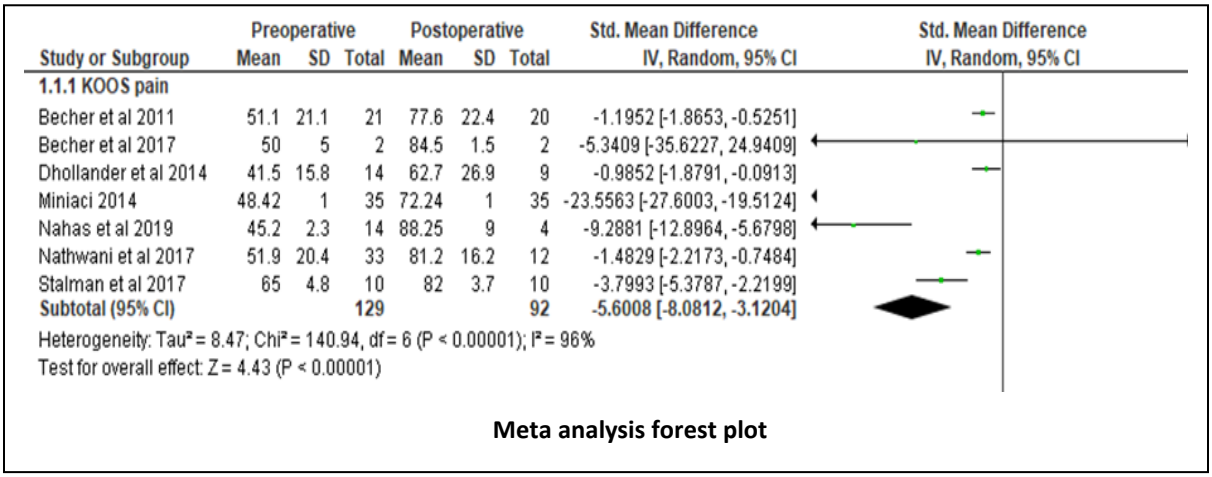
❖ **Chi-squared test:**

- This is used for qualitative data.
- The test is unreliable if any of the expected values is < 5, in which case apply the **Fisher exact test** instead.

Levels of evidence

❖ **Meta-analyses (quantitative):**

- Statistical analysis that combines the results of multiple scientific studies that address the same question.
- The results are usually presented in the form of a **forest plot**.
- The left-hand column includes the studies reviewed and the right side displays the effect size of each study with a CI.
- The area of each square indicates the weight of the study, i.e. fatter squares are from bigger studies.
- A vertical line indicates the line of no effect with an odds ratio = 1. So if the CI for a study crosses this line, it means that it demonstrated no significant effect.
- An overall effect size is denoted by a diamond, the size of which is determined by the overall 95% CI.



Meta analysis forest plot

- **Heterogeneity:** is a problem that can arise when attempting to undertake a meta-analysis.
- Ideally, the studies whose results are being combined in the meta-analysis should all be undertaken in the same way and to the same experimental protocols.
- Study heterogeneity is a term used to indicate that this ideal is not fully met, for example we can combine apples of different colours but we couldn't combine apples and oranges.
  - Low heterogeneity = 0-25%
  - Medium heterogeneity = 25-75%
  - High heterogeneity >75%

❖ **Systematic reviews (qualitative):**

- Systematic and explicit methods to identify, select and critically appraise relevant research.
- The data from these analysed studies is not combined due to high degrees of heterogeneity.

❖ **Randomised controlled trials:**

- Groups of patients are randomised to either receive or not receive an intervention and the outcomes are compared in a prospective manner.
- **Study design features:**
  - Randomisation: ensures that all prognostic variables, both known and unknown will probably be distributed equally among the treatment groups. This avoids bias in treatment assignment.
  - Types of randomisation:
    - *Simple*: computer-generated tables (days of the week). This method may not be appropriate in small or multicentre trials as it doesn't ensure that each group has the same demographics.
    - *Stratified*: ensures equal distribution between treatment groups in which only two or three variables (age, sex etc) are stratified. Stratification is practical only in large trials and should be performed by each centre in multicentre trials.
    - *Block*: treatment is allocated by blocks of set size. This ensures that an equal number of patients are assigned to each treatment e.g. if the block size if six, then three receive treatment A and three receive treatment B.
- **Bias:**
  - Flaw in impartiality that introduces systematic error into the methodology that has potential to affect the results of a study.
  - Bias can be reduced by randomisation, masking (previously known as blinding) and meticulous attention to the study protocol.
  - Types of bias:
    - *Selection bias:* an individual may or may not be included in the study if the investigator believes that one particular treatment would favour the individual over the other. This can be overcome by allocation concealment.
    - *Ascertainment bias:* knowledge of the intervention (by the researcher of the participant) may distort the results, if a belief is held that one treatment is better than the other. This can be overcome by masking/blinding.
    - *Recall bias:* a person's recall may change based on the presence of disease. This is best overcome by prospective data collection and/or biological measures where possible to validate results.
    - *Publication bias:* higher publication success amongst those studies with positive findings.
    - *Systematic bias:* incorrectly calibrated instruments.
    - *Observer bias:* assessor, placebo effect, use of validated PROMS.
- **Confounding factors:**
  - When a variable is independently associated with both the outcome and the exposure.
  - This results in false conclusions being reached.
  - E.g. that grey hair is associated with OA, which of course is confounded by age since age is associated with grey hair and OA.
  - Confounding can be reduced by matching or measuring (e.g. statificiation can be done to look at patients at different ages with or without grey hair and its association with OA).
- **Masking/blinding:**
  - Protects against ascertainment bias.
  - Blinding can be single (only patient is blinded), double (both patient and investigator are blinded) or triple (the statisticians are also blinded).

❖ **Cohort studies:**
- The best available scientific method for measuring the effects of a suspected risk factor.
- In a prospective cohort study, the researchers raise a question and form a hypothesis about what might cause a disease.
- The cohort is then observed over a period of time, which may take several years.
- Problems with cohort studies:
  - Lengthy follow-up i.e. a disease may only become apparent after many years following exposure.
  - Expensive
  - Difficulty in examining rare diseases and outcomes as the practicalities of the study will limit the initial size of the cohort.
  - Not randomised.

❖ **Case-control studies:**
- Studies where individuals with a certain outcome (cases) are compared to individuals without the outcome (controls).
- A historic (retrospective) analysis of exposures (i.e. the things that may have triggered the disease outcome) is made.
- These studies are quick and cheap to conduct. If carried out carefully, can yield clinically relevant information e.g. odds ratios.
- They are particularly useful in trying to identify the causes of uncommon diseases.
- These studies commonly have many methodological biases.

❖ **Case series:**
- The outcomes of a group are reported but there is no comparison group.
- They usually act as a stimulus for more powerful studies.

❖ **Expert opinions:** an expert in the field presents their opinion on a given subject.

Phases of clinical trials

❖ **Phase 0:**
- First in-human trials.
- Sub-therapeutic doses of drug given to small number (10-15) of subjects to gather pharmacodynamic (what drug does to the body) and pharmacokinetic (what the body does to the drug) data.

❖ **Phase 1:**
- Researcher test experimental drug or treatment on a slightly larger group of subjects (20-80).
- Evaluating safety, determine the safe dosage range and identify side effects.

❖ **Phase 2:**
- Experimental treatment given to a larger group of subjects (100-300).
- Assess effectiveness and further evaluate safety.

❖ **Phase 3:**
- Treatments given to large group of subjects (1000-3000).
- Aim to confirm effectiveness, monitor side effects and compare to commonly used treatments.

❖ **Phase 4:** post marketing studies delineate information, including treatment risks, benefits and optimal use.

How to conduct a trial

1. Identify a problem to study and put together a hypothesis.
2. Identify the gold standard from literature search.
3. Design the study:
   a. Population

b. Randomisation
c. Inclusion/exclusion criteria.
d. Comparison.
e. Methodology.
f. Observational (observe daily practice).
g. Experimental
h. RCT, cohort, case-control or cross-sectional.

4. Study timeline
5. Power analysis to work out how subjects required.
6. Ethical approval (Integrated Research Application System).
    a. The ethical committee is formed of university professors.
    b. The application must include:
        i. Study details and protocol.
        ii. Co-investigator details.
        iii. Study sponsor.
        iv. Does the chief investigator personally gain financially from this funding?
        v. Study insurance.
        vi. Details of the procedures to which humans will be subjected.
        vii. Potential benefits to subjects and/or society.
        viii. Potential risks to subjects and precautions taken to minimise risk.
        ix. Alternative procedures, if any, available to subjects.
        x. Will participants receive payment/reward for participation in the study?
        xi. Information on previous ethics applications
        xii. Funding.
7. Collect data.
8. Analyse results to draw conclusions.
9. Write up and publish the work to add to the literature.

Structure of a research paper

❖ **Abstract:**
- Background.
- Objectives.
- Setting.
- Design & methods.
- Patients.
- Outcome measures.
- Results.
- Conclusion.

❖ **Introduction:**
- Problem.
- Incidence.
- Current treatments.
- New treatments.
- Consequences.
- Current practice in my workplace.

❖ **Aims and objectives**

- **Methodology and design.**
- **Results:** What did we find?
- **Discussion:**
  - Interpretation study results.
  - Correlation between study results and results reported in the literature.
  - Complications associated with other treatments.
  - Advantages of new treatment.
  - Limitations of study.
  - Conclusions.
- **References.**
- **Appendices.**

Publications

- The Impact factor (IF) is a measure of citations in science and social science journals over a 2 year period.
- Used as a proxy for importance of the journal to its field.
- BJJ has an IF of 4.306 (2019) and Journal of Arthroplasty has an IF of 4.757 (2022).
- PubMed is a platform providing access to Medline.

Critical appraisal of a published paper

- Does the study address a relevant clinical question?
- Null hypothesis stated in which two interventions are equally effective and any difference occurs by chance.
- Is the research question complete and includes study design? Use the acronym PICO:
  - *Population*: What is the inclusion and exclusion (eligibility) criteria.
  - *Intervention*.
  - *Comparison* with a control group.
  - *Outcome*.
- **Aim of the study?**
- **What type of study is it?** (Level of evidence).
- **Design of the study?**
  - Observational (descriptive).
  - Experimental.
- **What is the study time-line:** retrospective, prospective or cross-sectional?
- **What type of research is it?**
  - Quantitative - Objective, RCT, categorical, hypothesis (Interventional or observational).
  - Qualitative - Subjective, interview/questionnaire, open-ended questions and no hypothesis.
- Validated primary and secondary outcome measures used:
  - Have high inter-observer and intra-observer reliability and reproducibility.
  - Primary outcome measure decides success/failure of intervention?
  - Validity is the extent to which the test actually measures what it's meant to measure.
- Supported by high quality research studies.
- **Reliability** is that it demonstrates consistent measurement.
- **Where was study performed?** Multicentre increases external validity.
- **Details of how procedures were done.**
- **Any bias?**
- **How was the sample size determined?**
  - Large enough to detect significant treatment effect if it exists.

- But not too large to waste resources and have unnecessary number of patients receiving inferior treatment.

❖ **What are methods of data collection?**

- Randomised:
  - Stratified by age, gender etc.
  - Minimises selection bias and facilitates blinding.
- Controlled:
  - To prevent type I error (false +ve) caused by confounding factors.
  - Confounding variables other than the one studied that can cause or prevent the outcome.
- Blinded to avoid assessment bias.
- Hawthorne effect - behaviour changes when the participants have knowledge that their behaviour is monitored.

❖ **Were appropriate statistical tests used?**

❖ **Were all patients who entered the study accounted for at the end?**

❖ **Was Intention-To-Treat (ITT) analysis performed?**

- Patients who dropped out were still analysed in their original group.
- Minimises non-responder bias.
- Or was it as per-protocol analysis.

❖ **Are conclusions justified by the results?**

❖ **Can the results be generalised to my practice?**

Screening tests

❖ To identify unrecognised disease in people without signs or symptoms.

❖ Must have very **high sensitivity & specificity**

❖ **WHO guidelines:**

1. There should be treatment for the condition.
2. Facilities for diagnosis and treatment should be available.
3. There should be latent stage of disease.
4. Test should be acceptable to the population.
5. Natural history of the disease adequately understood.
6. Should be an agreed policy on whom to treat.
7. Cost of finding a case economically balanced with medical expenditure.
8. Treatment started early is of more benefit than started later.

❖ **Results:**

- Reproducible with low Interobserver error.
- K (kappa) score measures interobserver error and ranges from 0-1.
- **Sensitivity:**
  - Probability that test results will be positive in patients with the disease.
  - True +ve/All patients with the disease.
  - Sensitivity = TP / (TP + FN).
  - Sensitive tests are useful for screening.
- **Specificity:**
  - Probability that the test result will be negative in patients without the disease.
  - True –ve/All people without the disease.
  - Specificity = TN / (FP + TN).
  - Useful for confirmation as they don't result in treatment of an unaffected individual.
- **Positive predictive value (PPV):**

- Probability of patient having the disease when the result is positive.
- PPV = TP / (TP + FP).

▪ **Negative predictive value (NPV):**
- Probability of patient not having the disease when the result is negative.
- NPV = TN / TN + FN.

▪ **Accuracy:**
- Tells about how often the test is correct.
- Number of correct diagnoses (positive and negative) as a proportion of the total number of diagnostic results recorded.
- Accuracy = TP + TN / TP + FP + TN + FN.

		Condition		
		Positive	**Negative**	
Test	**Positive**	True +ve	False +ve (Type I error)	**PPV**
	Negative	False –ve (Type II error)	True –ve	**NPV**
		Sensitivity	**Specificity**	

▪ **Incidence:** percentage of new causes in a defined population during a given period of time.
▪ **Prevalence:** percentage of the population who suffer from disease at a given point in time.
▪ **Number needed to treat (NNT):**
- The number of patients treated to achieve one positive outcome.
- Expresses effectiveness of the intervention.

▪ **Number needed to harm (NNH):**
- The number of patients needed to be exposed to a risk factor before one comes to harm.
- Refers to the detrimental effect of a risk factor.

▪ **Absolute risk:**
- Probability that an individual will experience a specified outcome during a specific period.
- Usually 0-1 or expressed as a percentage.
- If the absolute risk of developing a condition is very low (e.g. 0.001%) and even if the relative risk is large, the risk is still very small if factor present.

▪ **Relative risk (RR):**
- Ratio between the incidences of outcomes from two cohorts.
- Calculated by dividing the risk in those exposed (experimental group) by risk in those not exposed (control).
- If it is >1, then the risk of disease is higher when exposed to the factor investigated.
- If the RR is > 5, the individual is five times more likely to develop the disease if exposed to the factor investigated.
- Used in cohort studies and tells you about the association between exposure and outcome.

▪ **Odds ratio (OR):**
- The likelihood of someone with the disease being exposed to the factor compared to someone without the disease and not being exposed to the factor.
- Likelihood of a positive outcome in the study group / likelihood of a positive outcome in the control group.

- Displayed as a forest plot graph with the square representing the size of population.
- Used with case-control (retrospective) studies.
- Tells about the strength between exposure and outcome.
- OR > 1 means there's an increased frequency of exposure among the study group.
- OR < 1 means there's a decreased frequency of exposure among the study group.

▪ **Relative risk reduction (RRR):**
- The difference in the event rates between the intervention group and the untreated group, expressed as a proportion of the event rate in the untreated group.

▪ **Box and whisker plot:**
- Used to display information about range, median, interquartile, central tendency and spread.
- Used for numerical data.
- Horizontal line in box represents the median value.
- Interquartile range indicated by the box.
- Whiskers represent the upper and lower values with outliers plotted as dots.
- Horizontal dotted line indicates the mean value.

▪ **Bar chart:** used for ordinal, nominal or discrete numerical data

▪ **Histogram:**
- Illustrate distribution of continuous numerical variable data.
- Unlike bar charts, histogram bars touch each other to illustrate that data is continuous.

Survival analysis

❖ Study in which the outcome of an intervention is plotted over time allowing for variable dates of entry and different lengths of follow-up

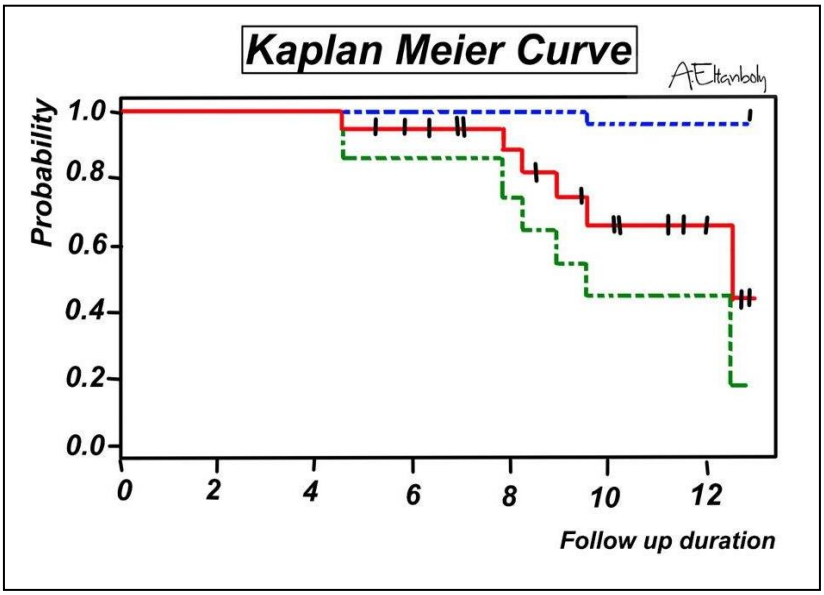
❖ **Data can be analysed at:**
- **Actuarial life-table method** has fixed intervals
- **Kaplan-Meier product limit method** uses time to failure.

❖ The definition of failure must be clear from the outset.

❖ **How to construct a life table for joint replacements?**
- The endpoint needs to be defined e.g. revision.
- The number of joints being followed up and the number of failures is determined for each year after surgery.
- For each time period, the number of patients at risk, number of failures and number of withdrawals are recorded.

❖ **Kaplan–Meier survival analysis:**
- Life table analysis of continuously analysed data at pre-determined intervals and at times of failure.
- Outcome of intervention plotted over time.
- Looking at cumulative probability of survival.
- Allows variable dates of entry and follow up over different lengths of time.
- Need to have start and end dates e.g. THR and revision.
- Dip (step) in the graph can e.g. represent a revised joint or patient death.
- The percentage failure rate for each period is determined from by dividing the number of failures during the interval by the number of patients at risk. The percentage success rate can then be calculated.
- **X-axis** shows the time elapsed.
- **Y-axis** indicates the survival percentage from the study population.
- **Dotted lines** are CI:
  - Widens over time as the number of patients decreases (less reliable data towards the right of the plot).
  - The upper line assumes that all have survived and the lower line assume they have all failed.
  - Important to compare between 2 implant types and can tell the difference if there is no overlap.

- **Censored (lost) patients:**
  - Identified by little vertical marks.
  - Marks those subjects that have either dropped out, lost to follow-up or died before the end of the study
  - This ensures that all patients are accounted for but do not count as failures.
  - Must not extrapolate the results beyond the defined time periods and only specific hard endpoints must be used.



OUTCOME SCORES

❖ Patients are asked to fill out pre- and post-procedure questionnaires regarding the outome of an intervention.

❖ **Why do we need it?**

- Research
- Quality improvement
- Audit
- Economic evaluation

❖ **Which scores to choose?**

- Reliability: the consistency of a measure.
- Validity: the accuracy of a measure.
- Prior use in studies with similar patient demographics.

Types

❖ **Patient reported outcome measures (PROMs)**

- Patient specific:
  - Subjective
  - Short
  - Self completed questionnaires, which measure symptoms, function and QoL from the patient's perspective.
  - E.g. **McMaster Toronto Arthritis Patient Preference Questionnaire (MACTAR).**
- **Disease specific:**
  - *Harris Hip Score* (0-100, with 100 being the best), looks at pain, function, activities and clinical examination.
  - *Western Ontario and McMaster Universities Arthritis Index (WOMAC)* looks at pain, stiffness and physical function.
- **Generic:**
  - *EQ-5D)EuroQoL (*measures the general quality of life looking at the five dimensions of mobility, self-care, usual activities, pain/discomfort and anxiety/depression.
  - *SF- 36(short-form survery)* comprises of 36 questions covering eight domains of health exploring the person or population's quality of life:
    - Limitations in physical activities.
    - Limitations in social activities.
    - Limitations in usual role activities due to physicial health problems.
    - Limitations in usually role activitities due to emotional problems.
    - Bodily pain.
    - General mental health.
    - Vitality.
    - General health perceptions.
  - *SF- 12*uses the same eight domains of the SF-36 but is a shorter version reducing the burden of responses.
- **Region specific:**
  - *Oxford Hip Score (OHS)* comprises of 12 questions with a 0-48 score and <20 indicating severe hip OA:
    - Severity of pain, night pain, any sudden pain.
    - Limping, walking distance, stairs, putting on socks, stiffness.
    - Getting in/out of car, washing, shopping and work.

- *Oxford Knee Score (OKS)* comprises of 12 questions with a 0-48 score and <20 indicating severe knee OA:
  - Severity of pain, night pain, any sudden pain.
  - Limping, walking distance, stairs, kneeling, stiffness.
  - Getting in/out of car, giving way, shopping and work.
- *Knee Society Score* (originally published in 1989 but then changed in 2011) is composed of five components and rates the knee prosthesis function and patients' functional ability following a TKR:
  - Patient demographics
  - Objective knee score out of 100 points (completed by the surgeon).
  - Patient expectations score out of 15 points (completed by the patient).
  - Patient satisfaction score out of 40 points (completed by the patient).
  - Functional knee score out of 100 points (completed by the patient).
- *Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire*
  - Comprises 30 items that look at a patient's ability to perform certain upper extremity activities.
  - Score ranges from 0-100.
  - Higher scores indicate a greater level of disability.
- *Constant-Murley shoulder outcome score*
  - Introduced to determine the functionality following treatment for a shoulder injury.
  - Divided into four subscales of pain (15 points), activity of daily living (20 points), strength (25 points) and range of motion (40 points).
  - The maximum Contant score is 100 with a higher score meaning higher quality of function.

❖ **Clinician-reported outcome measures:** these are dependent and based on the clinician's judgement and reports on observed behaviours and signs. E.g. is **pain rating scale**.

❖ **Observer-reported outcome measures:** these are based on observation made by a third party other than the patient or clinician. These are usually done by non-clinical individuals such as a patient's family member and an example is an **assessment of a patient's cognition**.

Quality adjusted life year

❖ Used to assess whether a medical intervention is value for money.
❖ Measures quality and quantity of life lived.
❖ Used in cost-effectiveness analysis with lower cost to QALY ratio being preferred.
❖ Used by NICE since 2013.
❖ Threshold for cost-effectiveness is £30000 per QALY
❖ THR is second best to cataract surgery.

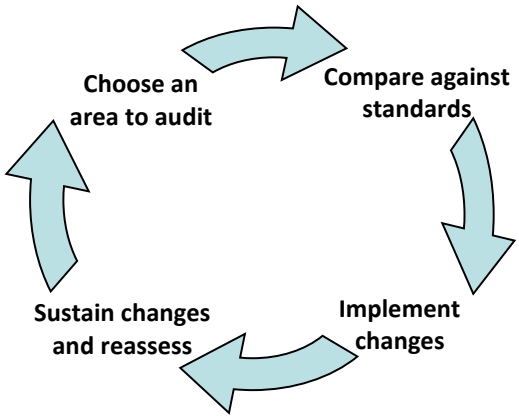
CLINICAL GOVERNANCE

❖ Clinical governance is a framework through which NHS organisations are accountable for continuously improving the quality of their services and safeguarding high standards of best practice care through a patient centred approach in which clinical care can also flourish.

Pillars of clinical governance

❖ **Clinical risk management**
- Assessing risk and devising measures to minimise it.
- Aim to provide a safer environment for both staff and patients e.g manual handling courses.
- New patients reviewed by consultant within 24 hours.
- Review complications rates.
- Comply with health and safety legislations.

❖ **Clinical audit**
- Continuous cyclical quality improvement process.
- Aims to improve patient care and outcomes
- Carrying out a systematic review, implementing change and rechecking for improvement.
- Aimss to save money whilst Improving patient care



❖ **Staff management**
- Ensuring adequate and appropriately trained staff e.g. improving working life.
- Yearly appraisals and PDP.

❖ **Continuous professional training and development**

❖ **Patient's involvement**
- Use of information about the patients' experience and outcome.
- Patients Advise and Liaison Service (PALS).
- Complaints management.
- Patients' surveys.
- Public consultation on changes to hospital services.
- Reports from incidents.

❖ **Evidence based practice**
- Integration of clinical expertise and research knowledge to provide the best possible care.
- Conscientious and judicious use of current best evidence to make decision about treatment:

- NICE
- Cochrane
- Clinical guidelines

▪ **Get it right First Time (GIRFT):**

- National review of adult elective orthopaedic services in England.
- Now active in 35 specialities including T&O.
- Looking objectively at the quality and efficiency of the orthopaedic services.
- Aims:
  - Reduce unnecessary variations in clinical care.
  - Quality improvements.
  - Subsequent savings.

❖ **Information governance**

▪ Don't use patient-identifiable information unless necessary.
▪ Access on strict need to know basis.
▪ Research and development.

CONSENT

- This is a two-way process, which needs to start when the patient is 1st seen in clinic.
- **Elements of a valid consent:**
  - Has to be voluntary.
  - The patient has to have capacity.
  - Appropriate information is given to the patient.
- **Consider the following:**
  - Is the right person giving consent?
  - Explain the diagnosis.
  - Explain the procedure.
  - Aim of proposed procedure.
  - Alternatives including non-surgical.
  - Risks.
  - Approach.
  - Post op information on likely time spent in hospital and the length of the recovery.
- **Questions.**
- **Information sheets.**
- Reminder that the patient can change their mind at any time.
- When the patient attends for surgery the whole process is repeated to ensure that they fully understand.
- Only the patient can consent, with the following exceptions:
  - Incapacitated patient with temporary factors like fear and panic may destroy a person's capacity to decide.
  - Unconscious patient
  - Non-Gillick competent child usually under the age of 16 years requires a parent or guardian to consent.
  - The mother has automatical parental responsibility.
  - The father has parental responsibility if:
    - Married to the mother now or at time of birth.
    - Agreement by court order.
    - Named on the birth certificate.
- **Legal guardian is appointed by court.**
- **Who should obtain consent?**
  - The person providing the treatment such as the consultant.
  - The task can be delegated to a suitably trained individual who understands the procedure and can assess the patient's ability to give valid consent. This doesn't delegate accountability.
- Jehovah witness: Look for an advanced directive (usually in written on a card). If this isn't available then contact the legal services department.
- **Mental Capacity Act (2005)**
  - Must always assume a person has capacity unless it's proved otherwise.
  - Must take all practical steps to enable the patient to make their own decisions.
  - Must not assume incapacity if someone makes an unwise decision. As long as they understand the consequences, they are entitled to make their own decisions.
  - Always make decisions in patients' best interest.
  - Carefully consider actions to ensure the least restrictive option is taken.
  - Assessing capacity:
    - Is there any impairment or disturbance in the function of mind or brain (permanent or temporary)?
    - If yes, is the patient able to understand the information provided?
    - If no, are they able to retain the information long enough to decide and weigh up the risks and benefits

and able to communicate the decision?
- If the answer is NO to any of these, then the person does not have capacity under MCA 2005.

❖ **Gillick competency**

- The right of a child under 16 years of age to consent for medical examination or treatment if they had sufficient maturity and intelligence to understand the nature and implications of that treatment (Gillick v West Norfolk 1986).
- There are no defined questions to assess Gillick competency but the professionals need to consider:
  - The child's age, maturity and mental capacity.
  - Their understanding of the issues including advantages, disadvantages and potential long-term impact.
  - Their understanding of the risks, implications and consequences that may arise from their decision.
  - Their understanding of advice and information given.
  - Their understanding of any available alternative options.
- Young adults (16 and 17-year olds) are presumed to have sufficient capacity to decide on their own medical treatment unless there is significant evidence to suggest otherwise.
- Medical professionals need to consider Gillick competency if a young person under the age of 16 wishes to receive treatment without their parents' or carers' consent or knowledge.
- A Gillick competent child can go against their parent(s) if they can make judgement and balance the risks and benefits of treatment.
- If the young person has made their choice but the parents do not agree with it, treatment can still proceed if the child has been assessed as Gillick competent.
- Refusal to give consent for a treatment by a child up to 18 years deemed to be non-Gillick competent may be over-ridden by their parents if the treatment is considered in their best interest.
- Competent child cannot refuse a treatment thought to be in his/her best interest in England and Wales. Parental consent will be needed but it is best to go through Court of Protection in this situation.
- For the unborn child, only the pregnant mother can consent to any form of medical treatment or procedure.

❖ **Other factors to consider when taking consent:**

- Advanced directives also called a living well, must be in writing and clearly state that the refusal stands even if it will place the individual's life at risk.
- Lasting power of attorney: is when a patient had already chosen someone to act on their behalf when they lack mental capacity to make decisions.
- Ward of the court is someone placed under protection of a legal guardian or court because they are a minor or incapacitated adult.
- Independent mental capacity advocate (IMCA): is an independent individual trained in the Mental Health Act who is appointed to act on the patient's behalf if they lack capacity.
  - In serious medical treatment or emergencies, decisions are made by paid staff when an adult lacks capacity and has no one who can speak for them.
  - Legal safeguard for people who lack the capacity to make specific important decisions.
  - NHS body has a duty to involve an IMCA when a vulnerable person (adult with dementia or learning disability) who lacks mental capacity needs to decide about serious medical treatment.

❖ **Montgomery ruling**

- Duty to give the patient all the facts, risks and benefits so they can make an informed consent.
- A patient should be told whatever they want to know, not what the doctor thinks they should be told
- Subjective risks:
  - Patient specific with individualised risks.
  - If a patient attaches significance to it.
  - Or we think a patient would want to know.

ETHICS

❖ **Medical ethics is based on four key principles:**

- Autonomy: individuals have a right to be self-governing.
- Non-maleficence: the patient should not be harmed.
- Beneficence: the patient should be promoted.
- Justice: patients should be considered equally e.g. ITU bed for a terminally ill patient.

❖ **What would you do if you have any concerns about another employee's fitness to work?**

- Under the Health and Safety at Work Act 1974 all staff have a responsibility to take care for the health, safety and welfare of themselves and others who they work with.
- Significant concerns about a practitioner may relate to any of the following areas:
  - Poor clinical performance.
  - Mis-treating patients.
  - Unacceptable behaviour such as harassing or unlawfully discriminating against staff or patients.
  - Breaching sexual or other boundaries with patients or staff.
  - Poor teamwork that compromises patient care.
  - Personal health problems leading to poor practice.
  - Not complying with professional codes of conduct.
  - Poor management or administration that compromises patient care.
  - Suspected fraud or criminal offence.
- Considerations:
  - Patient safety: must protect patients from risk of harm posed by another colleague's conduct, performance or health.
  - Duty of care to the colleague with consideration to arrange of suggest an occupational health referral.
  - Training: need for potential retraining and education.
  - Duty of care to the hospital: keep accurate records and inform the clinical director.

❖ **How would you deal with an abusive or racist patient?**

❖ First ensure that the patient is compos mentis and behaviour is not due to his/her underlying medical condition.

❖ Trusts have a policy governing racist behaviour.

❖ Racist behaviour is considered an assault on a member of staff.

❖ Explain to the patient that their behaviour is unacceptable and explain the expected standards of behaviour.

❖ Continued behaviour after a formal warning will lead to immediate exclusion from the trust premises by the security staff and/or police.

❖ Exclusion from trust premises doesn't mean that they would not receive care but alternative arrangements need to be put in place for them to receive treatment.

❖ **GMC guidance:**

- If your religious or moral beliefs affect the treatment or advice you provide, then you must explain this to the patient and ensure arrangements are made for another suitably qualified colleague to take over their care.
- All patients are entitled to care and treatment, which meets their clinical needs.
- You must not refuse to treat a patient because their medical condition may put you at risk. If a patient poses a risk to your health or safety then you should take all available steps to minimise the risk before providing treatment or make suitable alternative arrangements for treatment.
- The college's Invited Review Mechanism (IRM) is an external service to Medical Directors if there are concerns about the surgical practice within a unit or of an individual.

❖ **Caldicott Guardian:**
- This is a senior person in the organisation who is responsible for ensuring patient data is protected.
- Also known as the patient data protection officer.

❖ **Medical negligence**
- Failure to provide the expected standard of health care resulting in medical injury.
- Elements:
  - Duty: to provide care of equal standard of what is ordinarily expected of surgeons in same the specialty.
  - Breach of duty: when the action or failure to act deviates from the standard of care.
  - Causation: is when failure to meet standards directly causes a patient's injury.
- **Bolam test**: If a doctor has acted in accordance with a practice accepted as proper by a responsible body of medical opinion then he/she is not negligent.