4.4.3.4 Reduction of uncomplicated forearm fractures

1. Indications

- The following uncomplicated types of fractures according to the Universal classification system[25] can be managed with closed reduction:

Type	*Fracture*	*Management*
Type I	Nonarticular, undisplaced	Cast or splint support
Type IIA	Nonarticular, displaced, stable	Closed reduction and cast
Type III	Intra-articular, undisplaced	Closed reduction and cast

2. Contraindications

- The following complicated types of fractures according to the Universal classification system [25] should be managed by an operative procedure, and not by closed reduction:

Type	*Fracture*	*Management*
Type IIB	Nonarticular displaced, unstable	Closed reduction and percutaneous pins, external fixation
Type IVA	Intra-articular, displaced, reducible	Closed reduction and percutaneous pins, external fixation, intramedullary rods
Type IVB	Intra-articular, displaced, not reducible	Open reduction (limited), external fixation, internal fixation, bone graft (unusual)
Type IVC	Complex	Open reduction (adequate), external fixation, internal fixation, bone graft (usual)

3. Step by step procedure

3.1 Colles' fracture reduction

- A Colles' fracture [33] should be reduced by correcting the following elements that characterize a Colles' fracture:
    - Impaction of the distal and proximal segments of the fracture (Shortening of the radial length). With the styloid of the radius and the ulna on the same plane.
    - The distal fragment is displaced dorsally (Dorsal displacement).
    - The distal fragment is angulated radially (Radial displacement).
    - Ulnar styloid avulsion.

Step 1. Radiographic confirmation

- An anteroposterior and lateral radiograph should be obtained. A control X-ray of the normal side should be obtained.
- Determine the radial length, the dorsal angle and the radial angle of the fracture.
- If available, radiological screening during the actual reduction is very helpful.

Step 2. Reduction

- Any rings should be removed from the fingers before reduction
- Reduction should be done under anesthesia (either general or regional anesthesia)

    Regional anesthesia[22]:

    - Prepare the skin with 2% chlorhexidine in alcohol.
    - Inject 5-10ml of 1% lidocaine without adrenaline into the periosteum at and around the fracture site. The fragments are usually impacted. Therefore infiltration around the fracture site is necessary.
    - Wait 5- 12 minutes and manipulate the fracture.

- Distract the hand and the distal fragment to disimpact the fracture. This is an important step to restore radial length.
- Apply three-point pressure to restore the dorsal angle by pressing on the distal fragment dorsally with both thumbs and counteracting the pressure with the index and middle fingers volarly.
- Apply steady pressure from radially with the thenar eminence of the doctor's hand to restore the radial angle of the distal fragment. By this action the distal radial

fragment is pushed ulnarwards to reduce the radial displacement.

- After the radius is reduced and stabilized, the radio-ulnar joint should be assessed. Anatomical reduction of the radius means that the head of the ulna is in the ulnar notch of the radius.

  There are three grades of distal radio-ulnar joint lesions[21]:
  - Type 1 – the lesion is stable clinically and radiologically. There may be a minimally displaced avulsion of the ulnar styloid, but the primary stabilizers of the triangular fibrocartilage complex are intact
  - Type 2 – Unstable distal radio-ulnar joint lesions with clinical and radiological evidence of subluxation due to a massive tear of the fibrocartilage complex and avulsion of the base of the ulnar styloid.
  - Type 3 – potentially unstable lesions, due to skeletal disruption of the joint surface at the ulnar notch or ulnar head.

  Most type 1 distal radio-ulnar lesions are successfully treated by immobilization in a cast in neutral rotation for 6 weeks[21]. Unstable radio-ulnar dislocations need percutaneous transfixation of the ulna to the radius, or operative treatment including open and arthroscopic techniques.

Step 3. Immobilization

- A plaster cast with the wrist slightly dorsiflexed and the metacarpophalangeal joints 90 degrees flexed, should be applied. A below the elbow radiodorsal plaster slab should be applied[5].

- Immobilization should be done with the forearm in a neutral position with slight ulnar deviation and in moderate supination [6, 25] and the neutral position. The wrist should not be in a flexed position [25].

- If a lot of swelling is present, apply a backslab, followed by a circular cast as soon as the swelling has diminished. A below the elbow cast should be applied.

- After 1 week, the position of the fracture should be checked radiographically to confirm anatomical reduction. If reduction is satisfactory a circumferential plaster can be applied if the swelling permits.

Step 4. Mobilization

The following exercises are described:

- Claw flexion is where the interphalangeal joints are flexed and the metacarpophalangeal joints extended.

- Tabletop flexion is where the interphalangeal joints are extended and the metacarpophalangeal joints are flexed.

- Fist flexion is where the wrist, metacarpophalnageal joints and interphalangeal joints are flexed.

- **Full extension of all the digital joints.**

- Abduction and adduction of the fingers.

- Opposition of the thumb tip to each fingertip.

- Elevation of the hand and forearm helps avoiding edema.

Step 5. Removal of the cast[24].

- Cut the plaster along its weakest or thinnest border.

- Avoid cutting through the slab where it overlies a subcutaneous border of a bone.

- Use the plaster scissors to cut through the plaster and then loosen the cast with a plaster spreader.

- In the case of a frightened child, the cast can be soaked in water for 10-15 minutes and then be removed like a bandage.

3.2 Smith's fracture

- Smith fractures occur in the same region of the radius but are associated with a palmar flexion deformity[25].
- Reverse the procedure of reducing a Colles' fracture.
- Strong supination is necessary.
- Recurrence of the deformity is common in a below-elbow cast in younger age groups. Therefore it is better to fix the arm in the supinated position by extending the cast above the elbow.
- Apply a volar cast where the plaster is moulded against the anterior aspect of the lower forearm and wrist. This prevents the fracture from slipping from the reduced position.

3.3 Other forearm fractures

3.3.1 Greenstick fracture

- A marked angular deformity is often seen that needs to be corrected. This can usually be done by rotating the forearm. In general, dorsal angulation is corrected by supination and volar angulation by pronation.
- Apply an above elbow cast.

- Retain the cast for three to six weeks, according to age.
- Watch for recurrence of the deformity while in the plaster.

3.3.2 Radius and ulna (middle third)

- Closed reduction is often possible in children but is difficult in adults
- The rotational deformity should first be corrected.
- Determine the rotation of the proximal fragment by comparing radiologically the tuberosities of the radius on the intact and fractured sides. Rotate the forearm to the correct position; apply strong manual traction with the elbow at 90 degrees and mould the cast into position.
- Apply the cast from the axilla to the metacarpal heads with the forearm still in the correct rotational position
- Keep the plaster on for twelve weeks.
- Shortening of one bone or angulation should not be accepted. If this cannot be corrected, proceed to open reduction and internal fixation.

3.3.3 Ulna (lower two thirds)

- Reduction is necessary with gross angulation or a secondary rotational deformity.
- Immobilize in an above the elbow cast

3.3.4 Ulna – upper third (Monteggia fracture dislocation)

- It is best to treat a Monteggia fracture dislocation by open reduction and fixation.
- Even a small return of angulation after reduction, permits the head of the radius to re-dislocate.

3.3.5 Proximal radius fracture in children[1]

Fractures of the radial head and neck are seen in 5-10% of fractures around the elbow. Angulation of 30-60 degrees needs closed reduction under anesthesia.

1. The patient is generally anaesthetized.
2. The humerus is stabilized and the elbow flexed 90°.
3. The forearm is held in the ipsilateral hand of the doctor and supinated as far as possible.
4. Apply pressure on the anterolateral aspect of the head of the radius.
5. Carefully rotate the forearm to a neutral position and then into full pronation.
6. The displaced and tilted radial head is rotated under pressure and reduces. This is facilitated by the lax capsule of the elbow joint in elbow flexion.
7. Confirm stability and reduction radiographically.
8. Place the arm in a posterior above the elbow plaster splint and in full supination to relax the biceps brachii muscle for three weeks.

4. Materials

- Pre- and post reduction radiographs
- Radiographic screening (ideal)
- Material to apply a cast
- Plaster scissors, plaster spreader
- 2% chlorhexidine in alcohol
- 1% lidocaine without adrenaline and 10cc syringe and needle if local anesthesia is administered.

5. Anatomical pitfalls

5.1 Colles' Fracture

- Colles[33] described the fracture in 1814 as follows: "This fracture takes place at about an inch and a half above the carpal extremity of the radius".
  The dorsal surface of the wrist presents with a considerable deformity or swelling and a depression is seen in the forearm.

- All fractures of the distal radius spanned by the pronator quadratus with a dorsiflexion deformity are considered Colles' fractures[25].

- Mechanism of injury[27]

  - It is widely accepted that distal radius fractures are caused by a fall on the outstretched arm with the hand in either dorsal flexion or volar flexion. Dorsal displacement of the distal fragment result when the hand is in dorsal flexion (Colles' fracture) and volar displacement of the distal fragment when the hand is in volar flexion (Smith's fracture) during the fall.

- The following elements characterize a Colles' fracture:

  - Impaction of the distal and proximal segments of the fracture (Shortening of the radial length). With the styloid of the radius and the ulna on the same plane.
  - The distal fragment is displaced dorsally (Dorsal displacement).
  - The distal fragment is displaced radially (Radial displacement).
  - Ulnar styloid avulsion.

5.2 Wrist[25]

- At the wrist the radius and ulna are closely related to a concentration of tendinous, neural and vascular structures, which are situated in narrow channels. During a fracture these structures are at risk of injury. They may be excluded from the original injury but may be included due to compression, swelling and secondary scar formation.

5.2.1 Radiocarpal joint

- The distal radius articulates with both the scaphoid and lunate bone of the proximal row of carpal bones. The distal joint surface of the radius is more curved for articulation with the scaphoid compared to the lunate[31].

5.2.2 Radio-ulnar joint

- The distal radio-ulnar joint should always be considered with the proximal radio-ulnar joint for they form a functional unit. The distal and proximal radio-ulnar joints form the 'forearm joint', with the ulna being the stable and weight bearing part and the radius rotating in pronation and supination.

- The distal ulna has cartilage over its most dorsal, volar and radial surfaces. It articulates with the ulnar or sigmoid notch of the radius.

- The forearm rotates about 150° at the distal radio-ulnar joint. The radius and the hand rotate around the ulnar head [7].

- The curvature of the ulnar notch has a radius, which is 4-7 mm larger than that of the ulnar head. Pronation and supination is therefore a combined rotation and sliding movement and the volar and dorsal radio-ulnar ligaments as well as the joint capsule are of great importance for the stability of the joint. The ulnar head has an inclination of 20° relative to the long axis of the ulna. This is also the case with the ulnar notch of the radius[18].

- The radio-ulnar joint is stabilized by the interosseous membrane, the pronator quadratus muscle, the radio-ulnar joint capsule and the triangular fibrocartilage complex (TFC) between the distal radius and ulna, which includes the volar and dorsal radio-ulnar ligaments.

- Innervation of the radio-ulnar joint: Lourie *et al* [3] demonstrated in 24 cadaver dissections, that the dorsal sensory branch of the ulnar nerve gives off a transverse branch in 80% of cases innervating the distal radio-ulnar joint and overlying skin.

- Articular disc and triangular fibrocartilage complex (TFC)

    - There is no contact between the ulna and the carpal bones. An articular disc separates the radiocarpal joint from the distal radio-ulnar joint[31]. A perforation in the articular disc joins the radiocarpal and radio-ulnar joint cavities in 25% of cases[27].
    - Kauer[31] points out that the articular disc is in fact an extension of the deep layer of the antebrachial fascia. The antebrachial fascia stratifies at the level of the distal radio-ulnar joint. The fact that the articular disc and the

extensor carpi ulnaris muscle are situated within the deep layer of the antebrachial fascia provides mobility to the ulna on the radius during pronation and supination of the hand. This allows for pronation and supination in every position of the hand and forearm[19].

- The articular disc has several extensions as reported by Kauer[31]: An extension to the base of the ulnar styloid process, to the ulnar styloid process, to the triquetral bone and to the hamate and base of the 5th metacarpal bone. The articular disc should be regarded as a complex fibrous system that links the radius to the ulna and the radius to the carpal joint. The complex attaches to the ulnar aspect of the lunate fossa of the radius[7]. This whole complex is therefore often referred to as the triangular fibrocartilage complex (TFC). The triangular fibrocartilage complex is contributing significantly to stabilizing the radio-ulnar joint[7]. Its anatomy allows the independent movement of the radio-ulnar and radiocarpal joints[19].

- The triangular fibrocartilage complex is a ligamentous and cartilaginous structure suspending the radius and carpal bones from the distal ulna[7]. The complex includes the dorsal and volar radio-ulnar ligaments, the meniscus homologue, the articular disc and the extensor carpi ulnaris sheath.

- The **articular disc** plays an important stabilizing role in both the distal radio-ulnar and radiocarpal joints. It is part of both joints and allows independent movement in each joint[19].

- The disc is a fibrocartilaginous semicircular biconcave structure[20]. The distal surface of the disc forms one quarter of the proximal articular surface of the radiocarpal joint. The radius forms the other three quarters[27].

- The tendon of the extensor carpi ulnaris keeps the TFC under tension and helps with the stability of the joints[19].

- **Specific tests for the distal radio-ulnar joint[8]:**

  - **A stability test:** The radius and ulna are fixed between the thumb and index finger of the examiner. The bones are moved up and down to detect joint laxity as compared to the contralateral side. The test is positive if the ulna can be subluxed.

  - **The forearm rotation test**. The patient is asked to pronate and supinate the wrist to a maximal range. The test is positive if pain is present with or without limited movement.

  - **The forearm rotation compression test**: The patient is asked to pronate and supinate the forearm while the examiner compresses the distal radio-ulnar joint. The test is positive indicating instability in the presence of pain and/or subluxation of the ulnar head.

5.3 Distal radius[27]

- The distal radius is formed of cancellous bone covered by a thin layer of cortical bone. It has a carpal articular surface for articulation with the lunate and scaphoid bones and an ulnar notch for articulation with the head of the ulna. Both these joints have thin capsules, which are strengthened by ligaments.

5.4 Ligaments[27]

- There are dorsal and volar radiocarpal and ulnarcarpal ligaments. The volar ligaments are constantly found. The volar radiocarpal and ulnarcarpal ligaments combine to form the volar arcuate ligament. The dorsal ligaments are not always present. To provide for its unique range of movement, the wrist has no collateral ligaments[31].

5.5 Movement around the wrist

- The wrist allows for dorsal and volar flexion and radio-ulnar adduction and abduction and combinations of these movements. Rotation of the hand is excluded from the wrist. To allow for this movement the wrist has no collateral ligaments, but other stabilizing factors[31]. The extensor carpi ulnaris on the ulnar side and abductor pollicis brevis and extensor pollicis brevis on the radial side are dynamic collaterals to the wrist joint[31]. The flexor carpi ulnaris, extensor carpi radialis longus and brevis, flexor carpi radialis and abductor pollicis longus also play a role in stabilizing the wrist. The important apparatus of ligaments joining the carpals and the scaphoid and lunate to the radius play an important stabilizing role.

5.6 Interosseous membrane[17]

- The interosseous membrane has a distal tract (8 mm wide, 31 mm long and 1 mm thick), which inserts on the dorsal capsule of the distal radio-ulnar joint and some deep fibers attach to the triangular fibrocartilage complex, which influence the joint. This tract strengthens the dorsal capsule of the distal radio-ulnar joint. The interosseous membrane joins the radius and ulna together to form a syndesmosis. A fracture of the distal radius is therefore usually associated with an ulnar fracture as well. Fractures can occur to the ulnar shaft, head and styloid process.

5.7 Distal radio-ulnar joint capsule[16]

- The distal radio-ulnar joint capsule is separate from the triangular fibrocartilage complex and accommodates the rotation of the distal ulna. This capsule may play an important role in the limited pronation and supination movement of patients who suffered fractures of the distal radius.

5.8 Structures in relation to the wrist joint[27]

- **The extensor tendons** lie dorsally in their tunnels deep to the extensor retinaculum.

- **The flexor tendons** are somewhat protected from a distal radius fracture by the pronator quadratus muscle. The flexor tendons run in the carpal tunnel.

- **The median nerve** accompanies the flexor tendons in the carpal tunnel. It is prone to injury with distal radius fractures.

- **The ulnar nerve and artery** are less prone to injury since they are situated under superficial parts of the volar carpal ligament on the radial side of the flexor carpi ulnaris muscle. They may however be injured with fractures due to the insertion of the volar carpal ligament on the ulna.

- Both the ulnar and median nerves are not in contact with the volar surface of the radius and ulna[29].

5.9 Surface anatomy of the distal wrist crease[32]:

- The distal wrist crease is situated over the proximal row of carpal bones. The radiocarpal joint is on average 13.5 mm proximal to the distal wrist crease, and the center of the radio-ulnar joint is on average 21.1 mm proximal to the distal wrist crease. The base of the ulnar styloid is on average 11.7 mm proximal to the distal wrist crease. Bugbee *et al* [32] found the lunate consistently proximal from the distal wrist crease.

5.10 Anatomical classification of distal radius fractures

5.10.1 Frykman classification[27]:

Type 1 – extra-articular radius fracture
Type 2 – extra-articular radius fracture plus an ulnar fracture
Type 3 – fracture into the radiocarpal joint
Type 4 - fracture into the radiocarpal joint plus an ulnar fracture
Type 5 – fracture into the radio-ulnar joint
Type 6 – fracture into the radio-ulnar joint plus an ulnar fracture
Type 7 – Fracture of both joints without an ulnar fracture
Type 8 – Fracture of both joints with an ulnar fracture

5.10.2 Universal classification system[25]:

Type	*Fracture*	*Management*
Type I	Nonarticular, undisplaced	Cast or splint support
Type IIA	Nonarticular, displaced, stable	Closed reduction and cast
Type IIB	Nonarticular displaced, unstable	Closed reduction and percutaneous pins, external fixation
Type III	Intra-articular, undisplaced	Closed reduction and cast
Type IVA	Intra-articular, displaced, reducible	Closed reduction and percutaneous pins, external fixation, intramedullary rods
Type IVB	Intra-articular, displaced, not reducible	Open reduction (limited), external fixation, internal fixation, bone graft (unusual)
Type IVC	Complex	Open reduction (adequate), external fixation, internal fixation, bone graft (usual)

Type I and IIA are regarded as uncomplicated.

5.11 Anatomical measurements of reduction of a Colles' fracture[5, 23]

5.11.1 Dorsal displacement:

- **Dorsal angle (Lateral radiograph)**
  The dorsal angle is the angle between a line perpendicular to the long axis and the articular surface. The first line is drawn in the long axis of the radius and the second is a line joining the volar and dorsal margins of the articular surface. The dorsal angle is illustrated in Fig 1.

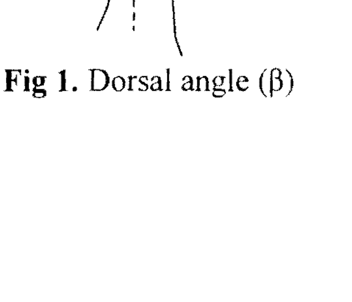

Fig 1. Dorsal angle (β)

- **Dorsal shift (Lateral radiograph)**

Dorsal shift is the difference in the distance from the long axis to the most dorsal point of the distal end of the bone. Dorsal shift is illustrated in fig 2.

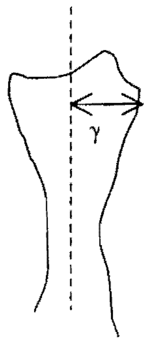

Fig 2. Dorsal shift (γ)

5.11.2 Radial displacement:

- **Radial angle (Antero-posterior radiograph)**
  The antero-posterior view is used to determine the radial angle. The radial angle is between a line perpendicular to the long axis of the distal third of the radius and a line through the tip of the radial styloid process and the most distal part of the radius at the radio-ulnar joint. The radial angle is illustrated in fig 3.

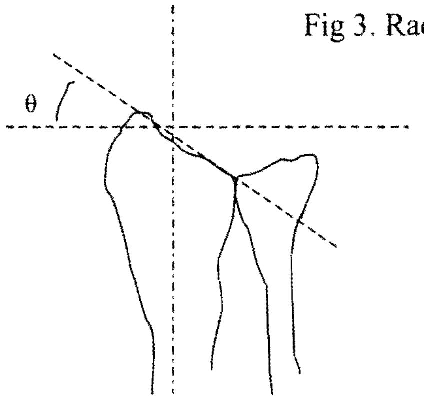

Fig 3. Radial angle (θ)

- **Radial length (Antero-posterior radiograph)**
  Radial length is defined as the projected distance between the radial styloid process and the distal articular surface of the ulna on an antero-posterior radiograph. Measurement of the radial length is illustrated in fig 4.
  A wrist with a small dorsal angle tends to show considerable shortening.

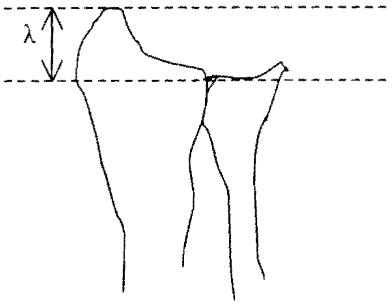

Fig 4. Radial length (λ)

- **Radial shift (Antero-posterior radiograph)**

  Radial shift is the increase in distance from the long axis to the most radial point of the styloid process. Radial shift is illustrated in fig 5.

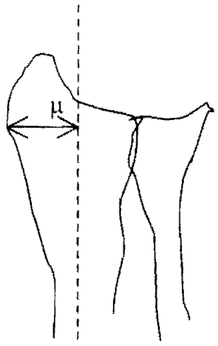

Fig 5. Radial shift (μ)

- Displacement according to Van der Linden *et al* [23], can be adequately described by two measurements, one for **dorsal displacement** and one for **radial displacement.**
  He also showed that restoration of the dorsal angle result in the diminishing or disappearance of radial shortening.
- The dorsal and radial angles are independent from each other. Therefore during reduction, both these angles need to be reduced. The distal fragment needs to be pushed dorsalward and ulnarward. If both angles are restored, the radial length will also be restored. Radial length is however also restored by the initial disimpaction of the fracture.
- Reduction is the key to a good outcome. According to Van der Linden *et al* [23], the technique of immobilization plays a less important roll in the final outcome.

5.11.3 Successful anatomical reduction.

- Reduction is considered satisfactory when the position on the post-reduction radiograph meets the criteria for an excellent anatomical grade[5].

- The criteria for an excellent, good, fair and poor anatomical grade are illustrated in the following table by Stewart et al [5]:

Dorsal angle	Neutral	1-10	11-14	15+
Loss of radial lenght	0-3	3-6	7-11	12+
Loss of radial angle	0-4	5-9	10-14	15+
Score	**0**	**1**	**2**	**4**

An excellent grade = 0, good = 1-3, fair = 4-6 and poor = 7-12

- A **severely displaced fracture** is classified as follows:
    - Dorsal angle of more than 40°.
    - Radial shortening of 10 mm or more.
    - Loss of the radial angle of 15° or more when compared to the normal side.

- Boszotta *et al* [10] states the following indications for surgical repair of Colles' fractures:
    - Radial shortening of over 3mm
    - A dorsal angle of more than 10°
    - Presence of a dorsal debri zone and avulsion of the distal radio-ulnar joint.

5.12 Brachioradialis muscle

- The brachioradialis muscle tends to deform the Colles' fracture, however this is least likely in supination. The brachioradialis muscle is the only muscle attached to the distal fragment of the fracture[26]. Sarmiento *et al* [6] find an increased number of unsatisfactory anatomic results in fractures that were immobilized in pronation, due to the muscle-deforming force of brachioradialis when the arm is in a pronated position.

6. Complications (anatomically relevant)

- Cooney *et al* [4] reports on the complications seen in 565 patients with Colles' fractures.
  Complications are usually due to repeated attempts for reduction, incorrect application of the cast, poor mobilization of the joint and fingers and inadequate

rehabilitation.

- Cooney *et al* [4] reports a 31% complication rate with the following distribution:
  - Persistent neuropathies of the median, ulnar or radial nerves (45 cases)
  - Radiocarpal or radio-ulnar arthrosis (37 cases)
  - Malposition and malunion (30 cases)
  - Pain dysfunction syndrome (20 cases)
  - Unrecognized associated fractures (12 cases)
  - Finger stiffness (9 cases)
  - Tendon rupture (7 cases)
  - Volkmann's ischemia (4 cases)

6.1 Inadequate reduction

- Anatomical reduction is usually possible to obtain even in elderly people if the bone is of good quality and if there is no excessive comminution. Reduction is difficult in the presence of osteoporosis and severe comminution.

- Linscheid *et al* [25] reports that an operative approach is seldom needed and the best possible reduction should be sought. The degree of anatomical reduction significantly affects the final result.

- Insufficient traction is the most common problem associated with inadequate reduction. This may be due to soft tissue being entrapped, making reduction impossible. Muscle relaxation greatly assists in reducing a fracture.

- If reduction cannot be maintained, percutaneous Kirschner wire fixation or open reduction and internal fixation are necessary.

- Loss of reduction leads to shortening of the radius, an abnormal radial angle and dorsal displacement and incongruence of the distal radio-ulnar joint. Various functional complications may be the result. Functional complaints include loss of wrist and forearm motion, weakness of the wrist, finger stiffness and possible loss of dexterity.

- A bad result due to fixation in an abnormal position (wrist flexion, pronation and ulnar deviation) is the stiff claw hand, extension contracture of the metacarpophalangeal joints, flexion contractures of the PIP joints and flexion contracture of the wrist joint.

- Inadequate reduction can be changed by closed methods up to 3 weeks after the injury and open methods up till 6 weeks after the injury.

- Stoffelen *et al* [8] concludes that a dorsal angle of more than 5°, a radial shortening of 4 mm or more and a lateral shift of 2 mm or more, contribute to a poorer result with restriction in supination.

- Associated styloid fractures result in poorer functional results due to the involvement of the distal radio-ulnar joint.

- Dorsal angle of more than 20° result in poor functional outcome.

- There is a rough correlation between the anatomy of the fracture at 6 weeks and the function at three months [5, 6].

- Loss of reduction means the fracture is unstable and should be referred. This is usually the case in great comminution, marked displacement of fragments and interposition of soft tissue.

- Adequate reduction means that the full dorsal length of the radius is restored. Full and adequate reduction has been shown to benefit the outcome of Colles' fractures[5]. These benefits are good early function and, less risk of developing carpal tunnel syndrome.

- Dias *et al* [35] has shown in a prospective radiographic assessment of patients above 55 years that during a 13-week period following the injury and reduction, the deformity progressively recurred, even after the plaster cast had been removed. Radial length and angle disturbance return to their position before reduction. They conclude that the initial injury determines the radiological and therefore anatomical result. This view is challenged by Stewart *et al* [14] and Van der Linden *et al* [23] by pointing to the definite correlation between the completeness of the reduction and the final anatomical result also in the elderly.

6.2 Nerve injuries[25]

- Frykman[27] reports an incidence of 3.2% of nerve injuries in a series of 430 patients with Colles' fracture. The median nerve was involved in 2.3% of all the cases and the ulnar nerve in 0.9% of cases. The most frequent clinical symptom was numbness in the field of innervation of the nerve. Only exceptionally, numbness was experienced in the entire field of innervation.

- Frykman[27] reports that the involvement of an intra-articular fracture was a common etiological factor in all the cases he studied with nerve injuries. Intra-articular fractures and peri-articular hematoma and swelling lead to increased pressure in the carpal tunnel.

- Volar fracture segments, excessive callus formation, persistent hematoma and localized swelling may compress on both the ulnar and median nerve.
- Force of reduction, positioning of immobilization contribute to neuropathies.

- Aro *et al* [12] reported a 12% rate of late compression neuropathies after conservative management of 166 Colles' fractures. The incidence of median nerve compression

was 8% and that of ulnar nerve compression 4%. Median nerve compression was associated with malunion with radius collapse and dorsal angle deformities. Ulnar nerve compression was associated with malunion with radius collapse or volar subluxation of the ulnar head.
Anatomical malalignment of Colles' fractures therefore play an important role in late compression neuropathies.

- The symptoms of nerve compression usually diminish after reduction of the fracture. Persistent symptoms can be treated with median nerve decompression[27].

- The nerves can also be injured by the bony fragments. This is best treated by reduction and immobilization of the fracture. If the nerve irritation is persistent, an exploration needs to be done.

- Nerve injuries may involve the roots of the nerves of the brachial plexus up to the digital nerves. This is due to possible associated fractures.

- The most common nerve injured is the median nerve at the site of the injury. Ulnar nerve injuries and injury to the branches of the radial nerve occur, but are less common.

- Simultaneous injuries to both the median and ulnar nerves are rare[27].

- Median nerve compression is usually easily recognized, but radial and ulnar nerve compression may be difficult to diagnose if not specifically looked for[4].

6.2.1 Median nerve

- The median nerve is usually entrapped in the carpal tunnel and the ulnar nerve in Guyon's canal due to bleeding in the region and swelling after the injury. Entrapment of the median nerve is much more common than that of the ulnar nerve due to the intimate relation of the median nerve to the distal radius[27].

- Progressive edema and hematoma formation in the carpal tunnel after the initial injury and fracture reduction are responsible for acute median nerve compression.

- The wrist should not be immobilized in the flexed position, for this position can produce nerve irritation[25].

- Lynch *et al*[28] report 3.3% incidence of median nerve compression in 600 cases.

- The use of local anesthesia for reduction of the fracture may be associated with median nerve compression[4].

- Abbot *et al*[29] classified median nerve injuries in the following categories: 1) Primary injury after fracture (very rare), 2) Secondary injury after fracture due to the bony fragment, bleeding or callus formation, 3) late or delayed involvement and 4) injuries associated with immobilization in palmar flexion.

- Primary injury necessitates immediate exploration. Atrophy of the thenar muscles is an absolute indication for surgery.

- There may be two reasons why the median nerve is prone to injury during immobilization of the wrist in flexion[29]. 1) The median nerve runs from deep to superficial just proximal to the wrist and is therefore not amenable to displacement with flexion, and 2) the transverse carpal ligament has a sharp proximal edge close to the anterior border of the radius. In palmar flexion, impingement may occur on this edge.

- Robbins[30] pointed out that with acute volar flexion of the wrist, the anterior part of the lunate bone rotates to point volarwards. This reduces the volume of the carpal tunnel especially in the presence of displaced bony fragments and bleeding.

- Median neuropathy is associated with reduction of the fracture under local anesthesia, where the local anesthetic solution is injected into the fracture hematoma. This increases the pressure as well as scar and fibrosis formation, which are responsible for nerve compression [4, 13].

- Callus formation may compress the median nerve proximal to the carpal tunnel.

- Elderly patients and patients where reduction has a poor anatomical result are more likely to develop carpal tunnel syndrome. This is especially true if there is dorsal angle disturbance at the fracture site. Carpal tunnel syndrome carries the highest morbidity in Colles' fracture[5].
  Stewart *et al* [11] studied 209 patients with Colles' fractures for six months and reported a 17% incidence of carpal tunnel syndrome after three months and 12% after six months. Older patients and those with higher degrees of dorsal angle disturbance were most at risk.

6.2.2 Ulnar nerve

- Ulnar nerve injuries are less common due to the anatomical relation of the ulnar nerve which is on the ulnar side of and superficial to the carpal tunnel. Dislocation of the ulnar head is known to cause ulnar nerve injuries. The diagnosis may be difficult if only the deep motor branch of the ulnar nerve is involved and the patient is not presenting with radiating pain to the 4th and 5th digits.

- Aro *et al* [12] reports that CT examination may demonstrate volar dislocation of the ulnar head in patients with symptoms of ulnar nerve compression.

- Entrapment of the ulnar nerve between a dislocated ulna facing to the palm and fragments of the radius requires immediate treatment. Sensory function of the ulnar nerve and the motor function to the intrinsic hand muscles deteriorate quickly.

- Ulnar neuropathy may also occur due to cast compression, especially at the elbow.

- Clarke *et al* [15] reports three cases of ulnar nerve palsies following distal radius fractures. All three cases had dense scar tissue around the nerve, with one ulnar nerve being displaced dorsally due to a dislocated radio-ulnar joint. Clarke also performed an anatomical study to try to explain the lower incidence of ulnar nerve compression compared to median nerve compression. Anatomically, this may be due to the greater excursion and mobility of the ulnar nerve compared to the median nerve, which runs through a confined space in the carpal tunnel. He made a transverse incision over the radio-carpal joint through all the structures in six cadaver wrists. The proximal stumps of the median and ulnar nerves were then assessed regarding their mobility in three directions: longitudinal traction, radial displacement and ulnar displacement. The ulnar nerve had greater mobility and therefore escapes injury in most cases.

6.2.3 Radial nerve

- Radial neuropathy can occur with improper cast immobilization. It is usually due to direct pressure on the radial styloid region, dorsum of the thumb and metacarpal region of the index finger compressing the superficial branche of the radial nerve on the bony structures.

- If an above-elbow cast is used, the cast should extend up to the axilla or it may compress the radial nerve in the radial groove of the humerus.

6.3 Missing the diagnosis[25]

- Falls on the outstretched hand are common and fractures can easily be missed. The diagnosis should be made in the presence of a history and tenderness over the bone. The fracture line may only become apparent days after the injury. Although not displaced these fractures can result in complications, due to radius shortening and consequent radio-ulnar joint involvement.

6.4 Associated skeletal injuries[25]

- Due to the mechanism of injury, the entire upper limb is involved. Associated injuries at the elbow, humerus and clavicle are therefore not uncommon. These regions should be examined and if necessary also radiologically evaluated. Due to the syndesmosis between the radius and ulna, the ulna is usually involved as well.

- The proximal row of carpal bones can also be involved as well as the triangular fibrocartilage complex. Scaphoid fracture, radial head fracture, Bennett's fracture and intercarpal ligament injury can occur simultaneously with the Colles' fracture due to the same mechanism of injury. These injuries may not be obvious just after the injury.

- A fracture of one bone with appreciable shortening is usually accompanied by dislocation of one end of the other bone. It is therefore important to always check the elbow and wrist radiologically.

6.5 Vascular injuries[25]

- Vascular injuries may occur during unusual displacement of a distal radius fracture. Exploration is necessary if a vascular injury is suspected.

Volkmann's ischemia

- This may be due to an undiagnosed constricting cast.

- Compartment syndrome is also seen in the forearm. Pain especially on stretching the muscles and swelling are reliable signs. The flexor compartment of the forearm is most frequently involved. Decompression of the cast, skin and fascial layers is necessary. Monitoring of the arterial blood flow is important.

6.6 Radio-ulnar dissociation

- Knowledge of the anatomy and biomechanics of the joint is very important in the treatment of distal radius fractures[18]. With a distal radius fracture, the distal segment of the radius angulates dorsally or radially and therefore the ulnar notch of the radius is no longer congruent with the ulnar head. The radio-ulnar ligaments, which are part of the triangular fibrocartilage complex, may tear.

- Wrist disabilities after distal radius fractures are most commonly caused by injury to the distal radio-ulnar joint[21]. Early recognition of injury to the joint may allow proper anatomical reconstruction of the bony components, joint surfaces and ligaments of the distal radio-ulnar joint. Some instability of the radio-ulnar joint is present in every displaced distal radius fracture.

- Ekenstam[18] reports on three important anatomical aspects of the distal radio-ulnar joint. He found that 10° of radial compression and a dorsal angle of 40° is enough to cause subluxation of the distal radio-ulnar joint. A fractured styloid process seen on X-Ray reveals a disrupted TFC. Restoring stability to the distal radio-ulnar joint is crucial for normal function of the forearm and wrist. Because radius compression due to a Colles' fracture has such an important impact on the TFC, it is crucial to disimpact the fracture during closed reduction.

- Altered anatomy of the distal radius and ulnar styloid fractures lead to dysfunction of the distal radio-ulnar joint[8]. Stoffelen *et al* [8] evaluated the involvement of the distal radio-ulnar joint in 272 distal radius fractures. At one-year follow-up, 13 patients had instability of the joint, nine had pain with simple forearm rotation, 51 had instability during compression and 130 had loss of strength in forearm rotation. He concludes that impaired function due to altered anatomy in distal radius fractures can be explained by distal radio-ulnar joint dysfunction.

- Injury to the lateral aspect of the elbow is associated with instability of the distal radio-ulnar joint[2].
  Various fractures of the elbow and wrist are associated with radio-ulnar dissociation. A disrupted interosseous membrane is presumably the cause for this problem. Both the interosseous membrane and the triangular fibrocartilage complex stabilize the radio-ulnar joint. Imaging of the interosseous membrane is unhelpful in the difficult diagnosis of radio-ulnar dissociation. MRI may be promising.

6.7 Mal-union

- Mal-union usually occurs due to inadequate reduction seen in unstable and comminuted fractures. If reduction cannot be obtained by closed manipulation, patients should be referred for surgical reduction.

- McQueen *et al* [36] has shown that mal-united Colles' fractures have significant functional deficits. The wrist is weak, deformed, stiff and sometimes a painful joint. The author concludes that is essential to strive for an anatomically accurate result to ensure minimal functional deficit.

6.8 Radiocarpal or radio-ulnar arthrosis

- Arthrosis is diagnosed in the presence of any painful motion of the wrist and forearm or mechanical obstruction of motion.

- This complication is more often seen in Frykman [27] VI, VII and VIII, where the articular surfaces are also involved and where either an internal or external pin-fixation was used.

- Radiocarpal arthrosis usually develops if an adequate anatomical reduction cannot be obtained. Two common problems with reduction are:
  - Radial deviation with dorsal angle disturbance of the distal radial component.
  - Poor restoration of radial length to maintain the distal radio-ulnar joint.

6.9 Pain dysfunction syndrome[25] (Shoulder-hand-finger syndrome, Sudek's atrophy)

- The characteristic of this syndrome is the inhibition of function due to pain. It is exacerbated by caution, panic, anxiety and other psychological attitudes.
  As active movement is inhibited, swelling occurs which limits even passive movement. The skin is very sensitive and typically has a shiny appearance.

- This syndrome may be secondary to median nerve neuropathy [4, 28].

- Shoulder pain is commonly associated and the syndrome is therefore sometimes referred to as shoulder-hand-finger syndrome.

- Inactive patients are more prone to the syndrome[27]. Active exercise of both the shoulder and fingers should immediately commence to prevent contracture formation and the circulation.

- The condition should be identified early and appropriate measures initiated.
  A range of six exercises are described:

  - **Claw flexion** is where the interphalangeal joints are flexed and the metacarpophalangeal joints extended.
  - **Tabletop flexion** is where the interphalangeal joints are extended and the metacarpophalangeal joints are flexed.
  - **Fist flexion** is where the wrist, metacarpophalnageal joints and interphalangeal joints are flexed.
  - Full extension **of all the digital joints.**
  - **Abduction and adduction** of the fingers.
  - **Opposition** of the thumb tip to each fingertip.

- Elevation of the hand and forearm helps avoiding edema.

6.10 Tendon rupture

- Rupture of the extensor pollicis longus, index flexor digitorum profundus or flexor pollicis longus has been reported[4]. Tendon rupture occurs due to displaced bony fragments that wear through the tendon during the subsequent weeks and months.

- The extensor pollicis longus tendon is at greatest risk from initial injury at the dorsal fracture edge. It may also be due to cramping of the tendon in its fibro-osseus tunnel due to callus formation around the fracture site with devascularization and eventual rupture of the tendon.

- Frykman[27] reports 3 cases with rupture of the extensor pollicis longus tendon in a series of 430 patients with Colles' fracture.

- The extensor digiti minimi and extensor digitorum to the little and ring finger can rupture through rubbing over a subluxated ulnar head.

6.11 Subluxation of the ulna

- Colles[33] first described ulnar subluxation which is evident if the surgeon finds that the end of the ulna may be moved readily forwards and backwards.

- The ulna often subluxates in a dorsal direction and sometimes in a palmar direction. The ulnar nerve may as a result be injured. A high index of suspicion should be maintained for this injury which may become apparent with clinical examination and radiographic observation. The ulna must be reduced into the ulnar notch of the radius.

6.12 Immobilizing the hand in palmar flexion (Cotton-Lodor position)

- Immobilizing the hand in the so-called Cotton-Lodor position where the hand is immobilized in palmar flexion, is very undesirable. In the palmar flexion position, the hand is in a position of nonfunction. The digits cannot be flexed properly, especially in the presence of swelling. The tension in the extensor tendons created by a palmar flexion position, results in compression of the dorsal surface of the articular fragments and acts adversely on maintaining reduction. Dorsal angle disturbance is the primary displacement.

- The palmar flexion position also increases the risk of entrapment of the median and ulnar nerves[25].

6.13 Immobilizing the wrist in ulnar deviation

- According to Linscheid[25], ulnar deviation increases the compressive stresses and radius shift of the radiocarpal articulation, which may aggravate radius translocation. He prefers the wrist to be in a neutral position with slight ulnar deviation and moderate supination.

- The hand should not be immobilized in pronation, for this increases the already unstable distal radio-ulnar joint.

- The forearm should be immobilized in moderate supination and if the length of the radius cannot be maintained, the patient should be transferred for fixation.

6.14 Uncoordinated function

- Loss of coordination and strength occur in all patients in the early months after the fracture.

6.15 Cast related complications[24]

- Pressure necrosis. This can result from localized pressure on bony prominences. The sequence of events is often as follows: The patient complains of persistent discomfort which is ignored. The pain disappears and sloughing occurs with staining of the overlying cast. A window should be cut at the suspected site. When ulceration is present a dressing should be applied.

- Edema distal to the plaster cast. Edema usually disappears after 2-3 days with elevation of the limb. If the edema does not disappear, the cast is too tight and should be split along its full length.

- Skin blistering and dermatitis.
The skin becomes scaly and the epithelial layer is discarded. Dermatitis may develop especially in hot weather.

- Loss of vascular function.
This is usually due to injury to the vascular supply during the initial injury. Capillary circulation should be checked both before and after the application of the cast. This will avoid gangrene or Volkmann's contracture.

- Compartment syndrome.
Compartment syndrome may develop especially in the flexor compartment. If a compartment syndrome is suspected the cast should be removed immediately.

- Neuropathy of the superficial sensory branches of the radial, ulnar, median and musculocutaneous nerves are frequent complications of pressure within or at the edges of the cast. Release of pressure is necessary[25].

6.16 Triangular fibrocartilage complex (TFC) tears[25]

- The TFC is usually injured with marked displacement of the ulnar head. The TFC may be torn from its medial attachment, from its insertion on the base of the styloid process and/or from its foveal insertion. Avulsion of the ulnar styloid process result in tearing of the TFC.

- Tearing of the TFC is found clinically by localized pain in the ulnocarpal sulcus. Depression of the ulnar head and forced ulnar deviation accentuate the pain.

6.17 Mechanical constraint of finger movement

- The metacarpophalangeal joints, proximal and distal interphalangeal joints should be free of mechanical constraints. It is important that the metacarpophalangeal joints are free to move since they are most prone to stiffness. The little and ring fingers are most at risk of an extension contracture. Care should be taken that the cast does not immobilize the metacarpophalangeal joints. These joints should be frequently flexed past 60° to prevent contrature formation of the collateral ligaments.

- This may be a severe complication with considerable pain particularly of the proximal interphalangeal joint. This is commonly associated with incorrect application of the cast. Early finger motion after cast application is essential to prevent stiff fingers.

6.18 Poor movement ability

- Hove *et al* [9] showed in a prospective study of 26 patients with Colles' fractures with secondary displacement after immobilization and subsequent remanipulation that the total pronation and supination movement five years after the Colles' fracture correlated with the initial radial length and dorsal angle disturbance. Total movement in all directions correlated well with the initial radial length.
  Initial radial shortening is therefore an important factor in a Colles' fracture and needs to be corrected for a good functional result.

6.19 Hand complications

- Stewart *et al* [14] studied the hand complications of Colles' fracture in 230 patients. He found an incidence of 17% of carpal tunnel syndrome after three months and 12% at six months. These patients were significantly older and the amount of dorsal angle disturbance of their fractures was significantly greater. The nerve tissue of older patients tolerates pressure relatively poorly. It is accepted that the final anatomical result is related to the completeness of the reduction. This is especially true for proper reduction of the dorsal angle with regards to hand complications.

- The incidence of Dupuytren's disease was 11%. These patients were also significantly older.

6.20 Pathological fracture

- With a pathological fracture the preexisting lesion should be established. Biopsy of the lesion may be necessary.

6.21 Pain

- Subluxation of the radio-ulnar joint is a common cause of residual pain after a Colles' fracture.

- Frykman[27] reports that at least 25% of patients with a distal radius fracture have some complaints one year after the injury. Most of these complaints are referred to the distal radio-ulnar joint[18].

6.22 Infection[25]

- Infection and gangrene are uncommon complications. If present, thorough surgical debridement is of great importance as well as aggressive antibiotic treatment.

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4.4.4 Imaging Procedures

4.4.4.1 Obstetric ultrasound examination

1. Indications[6]

Antenatal screening

- Estimation of fetal age
- Earlier detection of twins
- Amniocentesis for lung maturation evaluation

16-20 weeks

- fetal age: Uncertain clinical dates
    - Indicated induction of labor
    - Repeat elective cesarean section
- Significant discrepancy between uterine size and clinical dates
- Detect multiple gestation
- Suspected fetal death
- Follow-up examination of placental position
- Suspected placenta previa or abruptio placentae
- Determination of presenting fetal part
- Estimation of fetal weight in premature rupture of membranes, premature labor, and a fetus that is large for gestational age
- To assist amniocentesis
- History of congenital abnormalities
- Review maternal and fetal anatomy
- Confirming a breech presentation at 36 weeks by physical examination.
- Ultrasound guided amniocentesis for fetal lung maturity testing.
- Vaginal bleeding of undetermined cause during pregnancy
- Suspected ectopic pregnancy
- Suspected polihydramnios and oligohydramnios
- Evaluation of fetal condition in late registrants
- Evaluation of a pelvic mass
- Suspected uterine abnormality

- Suspected hydatiform mole

Serial examinations in the second and third trimester can be used to screen for intrauterine growth retardation.

2. Contraindications

No contra-indications are reported except for inappropriate use which are listed under complications.

3. Step by step procedure[5]

Step 1. Meet patient and establishes rapport.

Step 2. Perform an abdominal examination and the fundal height should be measured.

Step 3. Use a mechanical sector transducer for visualization. This transducer scans in an arc and produces a pie-shaped image. First obtain an orientation of the transverse and longitudinal views.

Step 4. The following are easy guidelines for obstetric ultrasound [7, 8]:

First trimester

- Location of the gestational sac
- Identify the embryo and record the crown-rump length
- Report on the presence or absence of fetal life
- Record the fetal number
- Evaluate the uterus and cervix and adnexal structures

Second and third trimester

- Record the presence or absence of fetal life
- Record the fetal number
- Document the fetal presentation
- Give an estimate of the amniotic fluid (normal, increased or decreased)
- Record the placental position and its relation to the internal os of the cervix
- Assessment of gestational age: Biparietal diameter
  Femur length
- Fetal growth assessment: Abdominal circumference
- Fetal anatomy:
  - cerebral ventricles,
  - four chambers of the heart and the heart's position in the thorax,
  - spine,

- stomach,
- urinary bladder,
- umbilical cord insertion on the anterior abdominal wall and
- renal region

Step 5. Compare these findings with possible previous scans

The following need to be mastered: assessment of gestational age and fetal growth, survey of fetal anatomical structures to detect abnormalities and examination of the placenta, amniotic fluid, uterus and adnexal structures[6].

Anatomy not seen with the one mode, can often be seen more clearly with the other.

4. Materials[6]

Ultrasound machine

- Screen – video monitor
- Hardware and software
- Tranducers – Mechanical sector – scans in an arc and produces a pie-shaped image
  - Linear array – produces a rectangular shaped image

5. Anatomical pitfalls

5.1 Embryology

The ovum starts dividing after feritilization into the morula and blastocyst which implants in the endometrium at about one week after ovulation.
The gestational sac is surrounded by the trophoblast which is seen as a hyperechoic rim and will develop into the placenta.
At 6 weeks the fetal pole can first be seen, however the anatomy only becomes visible after the second gestational month[10].
Fetal heart activity can be seen after 5 weeks gestation.

5.2 Gestational age determination[6]

Gestational age is measured in weeks and days from the onset of the normal menstrual period (conception date plus 15 days)[10]. Others refer to the term gestational age extending from fertilization to birth[20]. Sometimes it is then referred to as fertilization age. The first mentioned calculation is usually used in obstetric ultrasound measurements, but does not solve the problem mentioned by O'Rahilly[20], that the word gestational used in two different meanings, has lost scientific value.

All measurements done to determine gestational age are done in millimeters.

This determination becomes less accurate later in pregnancy with as much as a 3-week deviation in either direction at 30 weeks gestation.
The most accurate time to determine gestational age is between 10 and 12 weeks. During this period the fetus is experiencing linear growth and the crown-rump length estimation at 6-12 weeks is very accurate.
Anatomical landmarks are best found from 17-23 weeks gestation.
Crown-rump length at 6-12 weeks and biparietal diameter at 17-23 weeks have a 95% confidence interval of being close to 10 days of conception.
After 23 weeks there is more variation in growth.

Croft *et al* [22] has shown very little difference in ultrasound measurements in a study comparing aging in preserved fetuses and live fetuses. There was also no significant difference between manual and ultrasonographical measurements.

5.3 Anatomy visualized in the first trimester

- **Gestational sac**

The embrio is seen within the amniotic cavity. The yolk sac is still present. The trophoblast can be seen as a hyperechoic rim. The extra-embryonic coelom is directly external to the amniotic sac. The amniotic membrane can also be seen.

- **Crown-rump length (CRL)**

This is the longest length of the embryo, excluding the limbs and the yolk sac[11]. CRL gives an excellent correlation between length and age at a phase where the embryo is rapidly growing and minimally affected by pathology. A longitudinal view of the embryo should be obtained. The measurement is done from the outer edge of the cephalic pole and the outer edge of the fetal rump. The average of three measurements is used. This measurement at 7 to 10 weeks is predictive of the menstrual age with an error of three days. The error increases to 5 days between 10 and 14 weeks gestation. The range of error is dependent on the biological variation in fetal size, variation in maturity and therefore fetal size, individual differences in the timing of ovulation and fertilization as well as errors made concering measurement technique.
The CRL is related to tables based on reliable menstrual data[21].

As pregnancy advances, most measurements are subject to increased biological variation.

- **Cardiac activity** – presence or absence of fetal life
- **Somatic activity**
- **Placental location**
- **Pelvic anatomy**

- **Fetal number**

5.4 Anatomy visualized in the second and third trimester

5.4.1 Estimation of gestational age

- **Biparietal diameter (BPD)**[4]

The BPD's accuracy is best between 17-23 weeks but can be done between 12 and 28 weeks gestation. The BPD as measured before 28 weeks forms a standard method of ultrasound dating[17].
The BPD should be measured by standard consensus at the level of the thalami. Measurements rostral to the thalami, result in underestimation of the BPD and therefore of the gestational age.
The BPD measurement is done at a standard reference level, which includes the cavum septum pellucidum and both thalami. Head circumference is measured at the same level as the BPD.
The measurement is done from the outer table of the proximal skull to the inner table of the distal skull (as seen on the ultrasound screen)[12, 13]. The same landmarks should be used throughout pregnancy.

Some fetal heads are elongated and flattened giving an artificially decreased BPD. This condition is called dolichocephaly and is especially the case in fetuses that have premature rupture of membranes[15].
In the presence of premature rupture of membranes in the third trimester, the BPD measurement is smaller than expected and consequently the gestational age of the fetus is underestimated[15]. This may be due to distortion of the fetal skull due to decreased amniotic fluid. To verify this the cephalic index should be determined. The cephalic index is the ratio of the BPD divided by the occipitofrontal diameter. The normal range of the cephalic index is 0.75 to 0.85[14]. If the cephalic index is close to either limit, the BPD should not be used for gestational age determination.

Due to growth disturbances and individual variation, which affect the size of the head, the BPD should not be used after 28 weeks gestation[16].

The following should be seen on the plane where the BPD is measured:
The paired thalami are seen posterior to the cavum septum pellucidum. Anterior to the cavum septum pellucidum the falx cerebri can be seen. Laterally a curvilinear structure can be seen representing the insula. The frontal and occipital lobes as well as the choroid plexus in the anterior horn of the lateral ventricle can also be seen.
The coronal suture and lambdoid suture of the calvarium can sometimes be seen at this level. The posterior fossa with vermis and lateral lobes of the cerebellum can be seen, with the cisterna magna posterior to the cerebellum.

- **Head circumference**

Head circumference is less influenced by growth disorders than the BPD. It is not influenced by dolicocephaly or brachycephaly[17]. The head circumference is measured at the same plane as the BPD. The longest anteroposterior length (occipitofrontal diameter, OFD) is obtained and the head circumference determined according to the following formula:
Head circumference = (BPD + OFD) * 1.62
Ott[17] has shown that the head circumference may more accurately predict gestational age when compared to BPD. Head circumference has an distinct advantage over BPD where the head shape is altered as in breech presentation or transverse lie.

- **Femur length[18]**

The femur length can be measure from 10 weeks onward. The measurement is done from the most proximal portion to the distal end of the shaft. The femoral head and the distal epiphysis are not included in the measurement.
Acoustical shadowing from other bones or the other femur can decrease the visible length of the femur.

Technique[25]: The long axis of the fetus is first identified. The traducer is then turned 90° to produce a cross sectional image of the trunk. The tranducer is now moved downward to the fetal pelvis. The femur is usually flexed. Therefore the transducer must be rotated 30°- 45° toward the abdomen of the fetus to visualize the femur.
Tangenital sections should be avoided for it will result in a too short measurement.
The ilium, ischium and distal femoral epiphyses should be avoided for they artificially increase the measurement.

Measurements are easy to perform. O'Brien[26] was unable to perform the measurements of 18 fetal femur lengths in more than 1000 examinations. These were breech presentations, were the fetal lower limbs were positioned deep in the pelvis. The pelvic bones obscured the visualization of the fetal femurs.

Fetal femur length accurately portrays gestational age up to 24 weeks.

- **Abdominal circumference[24]**

The BPD (biparietal diameter) is sometimes difficult to obtain due to head position. Abdominal circumference can easily be performed in the third trimester. The measurement is done on the level of the umbilical vein - ductus venosum complex and/or the fetal stomach as anatomical landmarks.
The measurement should not be performed on an oblique image of the abdomen for it will reflect a larger measurement than the actual circumference.

This measurement is used for fetal weight determination as well as to rule out intrauterine growth retardation by using the head circumference: abdominal circumference ratio. The ratio can distinguish assymetrical intrauterine growth retardation from symmetrical growth retardation[19].

This measurement is very sensitive to variations in fetal growth.

5.4.2 Fetal anatomy

- Visualization of fetal anatomy improves with increasing gestational age. The need for transvaginal ultrasound, steadily decreases with increasing gestational age. The optimal gestational age to examine fetal anatomy in the first trimester is at 13 weeks[2].

- The following fetal organs can be visualized by means of a transabdominal and transvaginal ultrasound. Fetal organs are better visualized by transvaginal sonar compared to transabdominal ultrasound, and even better with both transabdominal and transvaginal ultrasound[1].
  The following are stated as criteria for adequate visualization in a study done by Braithwaite *et al* [1] at 12 to 13 weeks of gestation:

  Head: Complete cranium, septum pellucidum, thalami. choroid plexi, cerebellum and ventricles

  Face:
  The face starts developing in the second month.
  Correct position of the mandibles, maxillae and orbits, lenses, nostrils, filtrum and ears.

  Heart: Four-chamber view, symmetrical ventricles and atria

  Diaphragm: Hypoechoic interface between abdomen and thoracic cavities

  Stomach: Single hypoechoic structure in the left upper abdomen

  Abdominal wall: Normal cord insertion and abdominal wall

  Kidneys: Visualisation of cortex and pelvis of both kidneys

  Bladder: Hypoechoic structure anteriorly in the midline of the pelvis

  Spine: Complete vertebrae seen in both transverse and coronal planes with normal overlying skin

  Extremities: visualization of long bones, correct posture of hands and feet.

- **Spine**

The spine starts to ossify at the tenth week of gestation. Three different ossification

centers form each vertebra, one central and two posterolateral ossification centers. The central ossification center forms the vertebral body and the two posterolateral centers the spinous process, laminae, pedicles, transverse processes and articular processes.
Spina bifida can be evaluated between 16 to 20 weeks gestation with splaying of the paired posterolateral elements.
A coronal image demonstrates the developing vertebrae.
The vertebral bodies of the lumbar spine can be seen as unpaired hyperechoic blocks along the midline with paired hyperechoic segmental blocks representing the developing posterior laminae, which will develop into the pedicles and laminae. The distance between the paired posterior laminae should be relatively constant throughout the thoracolumbar spine. A widening between the paired posterior laminae may be due to a posterior fusion defect. A slight widening can be due to the ultrasound image passing through on this level. In the thoracolumbar region, the iliac wings can also be seen. There is a normal widening of the posterior elements in the cervical region. A sagital section shows the hyperechoic vertebral bodies with between them the developing intervertebral discs.

- **Heart – chamber size and number, rate and rhythm, aortic arch and descending aorta as well as valves**

The anatomy of the heart and the kidneys are difficult to visualize in the first trimester. The four-chamber view is best seen at 13 weeks gestation, and at earlier gestations, there is an increasing incidence of artifacts, which may give a false impression of a ventriculoseptal defect[2].

At four weeks gestation, the two-chambered heart divides into the four-chambered configuration. This happens as a result of the formation of the endocardial cushions and the septum primum. The interventricular septum forms from the apex of the heart. The interatrial septum forms after the formation of the septum primum, ostium secundum, septum secundum and foramen ovale. The interatrial septum separates the atria except for the foramen ovale which close postnatally.
The normal right ventricle is more anteriorly situated and trabeculated. It also contains the visible moderator band extending from the interventricular septum to the apex of the heart.
The left ventricle is thick-walled and is associated with the apex. The interventricular septum can be seen. The echogenic fullness extending from the interventricular septum to the right ventricle is the moderator band. The posterior part of the septum is very thin and represents the membranous part of the septum.
The atrioventricular canals can be seen at the membranous part of the septum, with the mitral and tricuspid valves. The left and right atrium can be seen on the other side of the atrioventricular canals.
The interatrial septum can be seen with the patent part which represents the foramen ovale.
The descending aorta can be seen posterior to the left atrium.

- **Abdomen**

The gastrointestinal tract is formed from an endodermal midline tube. The abdominal cavity can not contain the developing gastrointestinal tract with its organs and is therefore located extra-abdominally, forming a normal physiological umbilical hernia which can be seen sonographically at 10 to 11 weeks. After the 11^{th} week, the midgut returns to the abdominal cavity for further development.
The kidneys start functioning at the second month of gestation and a fluid –filled bladder can be seen between 11 and 14 weeks gestation.
A transverse section of the upper abdomen may illustrate the insertion of the umbilical cord to the anterior abdominal wall. Two linear hypoechoic structures represent the paired umbilical arteries. There are various normal cross-connections between the two umbilical arteries[23]. These connections are called Hyrtl anastomosis after Hyrtl who described them in 1870. They occur in 96% of placentas and are usually found near the cord's insertion to the placenta. The anastomosis secures an even blood distribution over the surface of the placenta. There are normally two arteries and one vein in the umbilical cord. The umbilical vein can also be seen in the three-vessel cord.
The length of the cord varies greatly with a mean length of 59 cm. Excessively long cords are associated with fetal death due to entangling or twisting. Extremely short cords are associated with certain fetal anomalies like osteogenesis imperfecta.

The liver can be seen as an inhomogeneous structure occupying the ventral portion of the abdominal cavity. A cross sectional view of the fetal abdomen shows the stomach as well as the kidneys.

Care should also be taken not to confuse the adrenals in the first trimester with the kidneys. The adrenals have a dense medulla in contrast to the kidneys[2].

- **Central nervous system**

Most structures of the central nervous system are visible at 12 to 13 weeks gestation. The corpus callosum is completely formed at 3½ months gestation. The septum pellucidum and the cavum septum pellucidum are now also visible. The biparietal diameter (BPD) can be measured at this stage. The BPD should include the cavum septum pellucidum.
The cerebellum starts developing in week 11 to 12. Posterior to the cerebellum , the cisterna magna is found, which contains cerebrospinal fluid. Absence of this cistern, is indicative of Arnold-Chiari malformation.

5.4.3 Nonfetal anatomy

- Maternal bladder and cervix. Filling of the maternal bladder is not necessary from 12 to 13 weeks gestation onwards where adeqate visualization is possible[1].
- Placenta – position and grade
- Amniotic fluid volume
- Uterus and adnexae
- Maternal gallbladder if visible

5.5 Time of appearance of various anatomical structures[6] (Transabdominal ultrasound)

Gestational sac	5 weeks
Crown rump length	6-12 weeks
Fetal movement	7 weeks
Cardiac activity	7 weeks
Placenta	8 weeks
Yolk sac	7-11 weeks
Embryological period ends	10 weeks
Heart is fluid filled	12-13 weeks
Biparietal diameter	12-13 weeks
Abdominal circumference	12-13 weeks
Femur	12-13 weeks
Stomach	20 weeks
Lateral ventricles appear	12 weeks, characteristic appearance at 20 weeks
Choroid	20-24 weeks
Kidneys	17-22 weeks
Bladder	20 weeks
Heart valve motion	20 weeks
Majority of neurologic abnormalities present	24 weeks
Genitalia	25 weeks

Many of these structures can be visualized with a transvaginal ultrasound at an earlier gestational age.

5.6 Placenta

The position of the placenta before the third trimester may differ considerably from that at birth. This is due to the enlarging lower segment of the uterus, with resultant change in the placental position.

5.7 Position of the uterus.

Reichler *et al* [3] showed in a study that uterine fundal pressure in a bimanual fashion, significantly enhanced the visualization of lower limbs, head, upper limbs, kidneys, spine, gender, face and four chamber view of the heart in transvaginal ultrasounds. By applying fundal pressure, the fetus is more closely approximatd to the transvaginal transducer. As the maternal weight increases, fundal pressure becomes more ineffective.

5.8 Amniotic fluid

Ultrasound guided late pregnancy amniocentesis to determine lung maturity is done by identifying pockets of amniotic fluid which are not covered by the placenta, are free of the umbilical cord and away from the fetal face. Sometimes it is impossible to get a pocket. In such cases an assistant can elevate the fetal head abdominally and then perform the tap suprapubically. The needle is then inserted between the fetal head and the endocervix.

5.9 Fetal biophysical profile[6]

This is an objective scoring system to evaluate fetal wellbeing. It includes breathing movements, muscle tone, placental grade, amniotic fluid volume and heart rate activity. This data can be captured while doing the biometry and fetal anatomy survey.

5.10 Vaginal ultrasound[6]

This route places the tranvaginal tranducer closer to the pelvic anatomy and will display fetal anatomy about 1 week earlier than the abdominal route.

5.11 Umbilical versus paraumbilical window

Davidoff *et al* [27] demonstrated in a study of 68 patients that the umbilical window to visualize the gravid uterus is better than the paraumbilical window. He compared the two windows regarding the thickness of the tissue to the amniotic cavity, clarity of the imaged part and noise produced.
The paraumbilical tissue had a mean thickness of 18 mm, whereas the umbilical tissue thickness had a mean measurement of 11 mm. Improvement of the image clarity was not statictically different when the umbilical and paraumbilical window were compared. The clarity was however improved by 60% in patients where there was a difference in tissue thickness of more than 6 mm between the umbilical and paraumbilical tissue thickness.
In a small number of patients the clarity of the image was worse through the umbilical window. This may be due to dense fibrous tissue within the umbilicus.
There was relatively less noise through the umbilical window.
The umbilical window is therefore particularly useful in obese patients.
The umbilicus consist of skin, fibrous tissue and no fat.
The paraumbilical window consist of skin, subcutaneous fat of variable thickness, fibrous tissue and rectus abdominis muscle of variable thickness. The difference between the two windows can clearly be seen on a CT scan of the abdomen.
Histologically the umbilicus consists of epidermis, dermis and connective tissue. The paraumbilical window consits of epidermis, dermis, hypodermis, a variable amount of fat and muscle.
The rectus abdominis muscle also contains connective fibrous tissue and three pairs of tendinous intersections. The tendinous intersections are situated at the xiphoid level, umbilical level and midway between those levels.
The signal returning to the transducer is dependent on the transmission of the ultrasonic waves. Various tissues in the path of the ultrasonic beam affect the strength of the signal.

In the first trimester, bowel may intervene with the ultrasonic beam when the umbilical window is used due to the relative small size of the uterus.

Another limitation of the umbilical window is the relatively small size of the umbilicus compared to the relatively large transducer.

6. Complications (anatomically relevant)

6.1 Poor visualization

Poor visualization[1] for transabdominal ultrasound in women with a high body mass index (BMI) and retroverted uterus. A transvaginal ultrasound is indicated in these patients.

6.2 Inappropriate use[6]

- It is inappropriate to do an obstetric ultrasound examination for gestational age before 10 weeks or after 20 weeks. Morphometric features are not clearly visible before 10 weeks, and after 20 weeks gestational age determination by dates is as accurate[9].
- Routine screening of all pregnancies.
- Determination of fetal sex unless sex-linked abnormalities are suspected.
- Casual non systematic evaluation.

6.3 Incomplete anatomical survey[6]

Due to factors as fetal position, maternal factors and gestational age, the anatomical survey may be incomplete. The average success rate for visualization of individual organs range from 70% to 90%.
Only 1% to 2% of fetuses have an anatomical anomaly.

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4. Results (Cont.)

4.5 Development of a clinical anatomy training program

A multimedia CD-ROM based on a PowerPoint® platform was developed for the reasons mentioned earlier in 3.4. This provides a stimulating environment for study with an innovative combination of learning resources regarding clinical anatomy for procedures relevant to general practitioners in South Africa. Appropriate use was made of new learning technologies to facilitate teaching and learning.

The emergency procedures and two office procedures were chosen as a realistic starting point illustrating the principles and philosophy of designing a novel self directed teaching aid for practical procedures. The aim is to progress in incorporating all 15 selected procedures, but for the sake of the PhD it was decided to limit these to 8.

The program was developed in what is called a Virtual Procedures Clinic **(Attached as CD-ROM)**. This virtual clinic environment introduces the student to various rooms in a virtual clinic.

The following rooms are accessible in a non-linear format:

Orientation room

This room provides a quick overview of all the procedures that are covered in the program.

Clinical anatomy laboratory

This room provides the visual representation of the anatomical pitfalls and complications of all the procedures. These sections can be accessed in a non-linear way for every procedure.

Simulation room

A simulation of all the procedures can be visualized in this room. They are represented as animations on prosections. All the simulations can be accessed in a non-linear way.

Clinical background room

This room provides background information for every procedure regarding the following aspects: Indications, contraindications, materials necessary for the performance and a step by step way to perform the procedure.

Library

The library contains the full text papers of all the procedures as well as all the references used to compile this clinical anatomy knowledge base.

The following media were used in an interactive manner:

- Text with hypertext where relevant.
- High resolution images of dissections of relevant anatomy.
- Animations on the prosections created in PowerPoint®.
- Audio clips.
- Simulations of the performance of the procedure was done on prosections and created in PowerPoint®.
- Short video clips.

All these media were hyperlinked where relevant to ensure the creation of clinical anatomy correlations as well as a non-linear way of accessing the data.

The CD-Rom is available on the front page of this document and can be loaded in the following way:

System requirements: Powerpoint 2000
100 MHz Computer 32MB
CD-ROM drive facility

Loading instructions:

Turn the computer on and go to the "My Computer" selection.
Select the CD-ROM drive.
Select the Virtual Procedures Clinic file.
This will open the Virtual Procedures Clinic in PowerPoint®.