4.4 Development of a clinical anatomy knowledge base for each selected problem procedure

A detailed knowledge database was developed for every problem procedure selected by Scoring option C. This was done in a standard way by means of the following headings:

1. *Indications*
2. *Contraindications/ Precautions*
3. *Step by step procedure*
4. *Materials*
5. *Anatomical pitfalls*
6. *Complications (anatomically relevant)*
7. *References*

The most recent and relevant literature was studied extensively to compile a referenced clinical anatomy synopsis for each problem procedure separately.

The result of this study is presented here for each selected problem procedure:

4.4.1 Emergency procedures

4.4.1.1 Cricothyroidotomy – (needle and surgical)

1. Indications

- The quickest, safest and easiest way to obtain an airway where intubation is difficult[1]. The advantages of a cricothyroidotomy are the speed with which the procedure can be performed and that it can be done safely outside the operating room in contrast to a tracheostomy, which should always be performed under controlled conditions in the operating room.

- Any patient requiring airway management who cannot be intubated by the oral or nasal route.

- Trauma patients whose cervical spine has a possible injury and where manipulation of the neck is contraindicated[15].

1.1 Needle cricothyroidotomy

- Temporarily for a few minutes. High-pressure jet insufflation may be used through a 14- or 16-gauge needle, which is readily available in emergency department settings. The problem is accumulation of carbon dioxide. The oxygen pressure must be at least 50 psi and intratracheal pressures should not exceed 20 cm H_2O for adult patients[17 18]. Most hospital wall outlets deliver oxygen at 50psi.

1.2 Surgical cricothyroidotomy

- Inability to intubate the trachea is a clear indication for creating a surgical airway. This may be due to:

    - Severe maxillofacial trauma.
    - Edema of the glottis and inability to visualize the vocal cords e.g. angioneurotic edema and anaphylactic shock e.g. secondary to a bee sting, snakebite, burns or toxic inhalation.
    - Severe oropharyngeal or tracheobronchial hemorrhage.
    - Unstable cervical spine fracture with contraindications for neck manipulation.
    - Fracture of the base of the skull.

    - Foreign body obstruction.

- Creating an emergency airway where equipment is lacking and where oral or nasal endotracheal intubation cannot be performed rapidly and safely.
- Technical failure to intubate[14].
- Clenched teeth[14].
- Masseter spasm following succinylcholine[14].

2. Contra-indications/ Precautions

- A less invasive method is possible to secure a patent airway, e.g. intubation.

- Patients under 5 years of age (A needle cricothyroidotomy may be done). However, a formal tracheostomy is preferred.

- Fracture of the larynx and existing pathology of the larynx[8].

- Transection of the trachea with retraction of distal end of the trachea into the mediastinum.

- Anatomical barriers like a vast hematoma or massive subcutaneous emphysema in the region, which makes palpation of the anatomical landmarks such as the thyroid and cricoid cartilage impossible.

3. Step by step procedure

3.1 Needle Cricothyroidotomy

Skill acquisition and maintenance are less complicated compared to a surgical cricothyroidotomy[15].

1. Ensure a free flow tubing of oxygen. Cut a hole towards the end of the tubing. This will allow for intermittent oxygen delivery.
2. Place the patient in a supine position with a non-twisted neck.
3. Assemble a 12 or 14 gauge over the needle catheter attached to a 5 ml syringe
4. Surgically prepare the neck using antiseptic swabs.
5. Identify the cricothyroid membrane, between the cricoid cartilage and the thyroid cartilage. Stabilize the trachea with the thumb and forefinger of one hand to prevent lateral movement of the trachea during performance of the procedure.
6. Puncture the skin in the midline with the needle attached to the syringe, directly over the cricothyroid membrane. A small incision with a #20 scalpel may facilitate passage of the needle through the skin.
7. Direct the needle at a 45-degree angle inferiorly to avoid vocal cords, while applying negative pressure to the syringe and carefully insert the needle through the lower half of the cricothyroid membrane.

8. Aspiration of air signifies entry into the tracheal lumen. This is important because it assures that the posterior tracheal wall was not penetrated (thus avoiding possible massive paratracheal emphysema) and it assures that the catheter tip is not embedded in the tracheal mucosa avoiding tracheal mucosa damage.
9. Remove the syringe and withdraw the needle while advancing the catheter downward into position, being careful not to perforate the posterior wall of the trachea.
10. Attach the oxygen tubing over the catheter needle hub.
11. Intermittent ventilation can be achieved by occluding the open hole. The ventilatory rate should be about 20/min, with the inspiratory phase lasting about 1 second. The expiratory phase should be at least 2 seconds.

3.2 Surgical cricothyroidotomy

1. Place the patient in a supine position with the neck in a neutral position. Palpate the thyroid notch, cricothyroid membrane, the sternal notch and hyoid bone for orientation. Assemble the necessary equipment.
2. Surgically prepare and anesthetize (if there is time) the area, if the patient is conscious.
3. Stabilize the thyroid with the non-dominant hand, keeping the skin taut over the thyroid notch. This is important in order not to lose the anatomical landmarks during the procedure.
4. Make a *vertical* skin incision (2cm) over the cricothyroid membrane. Locate the membrane and then carefully incise *horizontally*[14] (1.5cm) through the lower half of the membrane in order to avoid the cricothyroid arteries. Make sure only the tip of the scalpel blade enters the airway, to avoid injury to the posterior cricoid cartilage. The tracheal hook can be used to stabilize the larynx especially in the patient with a fat neck or hypermobile larynx.
5. Insert the scalpel handle into the incision and rotate it 90 degrees to open the airway. Extend the incision laterally for approximately 1 cm on each side of the midline.
6. Insert an appropriately sized, cuffed endotracheal tube or tracheotomy tube into the cricothyroid membrane incision, directing the tube distally into the trachea. The tube should always be aimed downwards in order not to injure the vocal cords above.
7. Inflate the cuff and ventilate the patient.
8. Observe bilateral lung inflation and auscultate the chest for adequate ventilation.
9. Perform suction of the trachea.
10. Secure the endotracheal tube to the patient to prevent dislodging.
11. Caution: Do not cut or remove the cricoid, or thyroid cartilages.

Alternative methods:

1. Brofeldt's rapid four-step technique[16].

This technique is simple to perform, aids comprehensive retention, lacks the need for specialized surgical equipment and may be ideal for the out-of-hospital environment.

The materials needed are a #20 scalpel, tracheal hook and a cuffed tracheostomy tube (#6 Shiley for most adults)

Step 1. Palpation

The operator is positioned at the *left* shoulder of the patient.
Palpate the cricothyroid membrane with the left hand's index finger.
The middle finger and thumb palpate the carotid pulses and stabilize the trachea.

Step 2. Incision

With the right hand, make a horizontal incision over the skin.
Make a subsequent horizontal incision into the inferior aspect of the cricothyroid membrane.
Push the scalpel through the membrane, creating a 2.5 cm horizontal incision. This eliminates the need for an extension of the incision or spreading the incision transversely as is usually recommended[22].

Step 3. Traction

Use the left hand and place the tracheal hook through the incision made into the trachea.
Turn the hook 90 degrees inferiorly and apply caudal traction to the superior margin of the cricoid cartilage with the left hand resting on the patient's sternum.

Step 4. Intubation

Insert the tube with the right hand
Remove the tracheal hook and inflate the cuff.
The hand motion during this method is similar to that of intubation, when using a laryngoscope in the left hand and inserting the tube with the right hand.

2. Method reported by Toye and Weinstein[26].

Toye and Weinstein[26] report on their success with a cricothyroidotomy device, consisting of a tube, dilator and needle. The needle is able to split after guiding the dilator through it into the infraglottic space. The tube is then percutaneously inserted over the dilator, after which the dilator is removed.

The advantage of this method is the speed of performance, less bleeding, smaller stoma scar, less assistance and fewer instruments are required.

4. Materials

- Sterile pack and gloves.
- Local anesthetic.
- #20 or #11 scalpel.
- Size 4-6 endotracheal tubes (male no 6, female no 4 or5) or size 4-6 cuffed tracheostomy tubes.

- Mosquito clamps.
- Tracheal hook if available.
- Pair of Mayo Scissors.
- 10 cc syringe.
- Adhesive tape.
- Ambubag with tubing, oxygen.
- Suction.
- For PTV (percutaneous transtracheal ventilation): Over the needle type catheter (12-14 gauge).

5. Anatomical pitfalls

5.1 Infraglottic cavity

- The infraglottic cavity is the most superficial part of the airway at the cricothyroid membrane. It can therefore easily be accessed surgically.

5.2 Cricothyroid membrane (median cricothyroid ligament)

- The cricothyroid membrane forms the first indentation inferior to thyroid cartilage, it is easily identifiable, even in obese patients. It is located immediately subcutaneously and is a dense fibro elastic membrane. The membrane is bordered laterally by the cricothyroid muscles. The area of the membrane is trapezoidal in shape.

- The membrane is specifically referred to as the median cricothyroid ligament. It is the superficial, thickened anteromedial part of the conus elasticus below the laryngeal mucosa[27]. It arises from the cricoid cartilage with ventral densely arranged fibres, which make the ligament clearly distinguishable from the anterior overlying tissues, and looser arrange collagenous fibres towards the airway lumen. It stretches superiorly to the thyroid and arytenoid cartilages with the free superior margin being the cord[35].

- The membrane may be pierced by small blood vessels, usually situated at its attachments to the thyroid and cricoid cartilages[35].

- Size of the membrane: Adult: 22-33 mm wide (beyond the cricothyroid muscles), 9-10 mm high[9]. The endotracheal tube's outer diameter should not exceed 8 mm and an inner diameter of at least 5 mm is recommended to provide good airflow[12].

- Dover *et al*[27] reported on the dimensions of the cricothyroid membrane in a study on 15 cadaveric specimens. The average width of the cricothyroid membrane between the cricothyroid muscles was 8.2 mm and the average height 10.4 mm. The average width and height were consistently smaller in females. Females: average 6.9mm(width) by 9.5mm (height). Males: 8.8mm (width) by 10.9mm (height).

- In an autopsy-based study, Bennett *et al* [19] demonstrated that the vertical measurement of the cricothyroid membrane ranged from 8-19mm (13.69mm:mean) and the width between the cricothyroid muscles between 9 and 19mm (12.38 mm: mean). They also showed that the vertical height measurement of the cricothyroid membrane is influenced by the synovial cricothyroid joint. Mobility can be limited in patients with rheumatoid arthritis.

5.3 Easily identifiable landmarks

- These are the anterior midline structures of the neck (from superior to inferior): Mandible, floor of the mouth, hyoid bone, thyrohyoid membrane, thyroid cartilage, cricothyroid membrane and cricoid cartilage. The landmarks may change due to the injury that mandated the cricothyroidotomy. The thyroid notch can however be palpated in most patients[17].

5.4 Arteries and veins

- There are no major arteries, veins and nerves in the area of the cricothyroid membrane. The blood supply of the larynx comes from the superior laryngeal artery, a branch of the superior thyroidal artery, as well as the inferior laryngeal artery branching from the inferior thyroidal artery. There is an extensive anastomosis between these two laryngeal arteries[19]. The right and left cricothyroid arteries transverse the superior part of the cricothyroid membrane, and have not been found to be clinically significant for the procedure. Bennett *et al* [19] reported a 62% incidence of an artery running transversely across the cricothyroid membrane.

- The cricothyroid artery usually arises from the superior laryngeal artery, a branch of the superior thyroid artery[29].

- Dover *et al* [27] reports on the cricothyroid artery arising from the superior thyroid artery in 93% of the 15 cases studied. In most specimens the artery crossed the upper half of the cricothyroid membrane. The artery gives off branches which penetrate the membrane and then run superiorly toward the thyroid cartilage. It is therefore recommended to make the incision in the lower half of the cricothyroid membrane[7] along the superior border of the cricoid cartilage. This will also avoid damage to the vocal cords[19]. The incision should not be made alongside the inferior border of the thyroid cartilage.
  In 54% of cases, the superior thyroid artery coursed anterior to the sternothyroid muscle and on the lateral border of the cricothyroid membrane. This underscores the important fact that the incision of the membrane should not extend laterally more than 1cm. Dover *et al* [27] also found venous tributaries of the superior and inferior thyroid veins, crossing the cricothyroid membrane. In 80% of the 15 dissections, Dover *et al* [27] found small veins from the region of the thyroid isthmus crossing the cricothyroid membrane.
  Occasionally two cricothyroid arteries anastomose in the midline to form the median descending artery supplying a pyramidal lobe of the thyroid gland.

- Lateral to the cricothyroid membrane, the thyroid and cricoid cartilages are bridged by adipose tissue and delicate connective tissue, which also forms the route for blood vessels entering or leaving the larynx[31]. Further laterally the gap between the cricoid and thyroid cartilages are bridged by the cricothyroid muscles.

5.5 Anterior jugular veins

- These veins run in a vertical fashion in the lateral aspect of the neck and should be uninvolved if one stays to the midline. Some authors recommend an initial vertical incision of the skin and cervical fascia to avoid these vascular structures laterally and ease identification of structures in difficult situations [7,11]. Thereafter the cricothyroid membrane is incised horizontally.

- Dover *et al*[27] described the presence of paired anterior jugular veins in the subcutaneous tissue, crossing the cricothyroid membrane in a vertical direction in the majority of the 15 dissections.

5.6 Esophagus

- There is a lesser chance of injuring the esophagus during a cricothyroidotomy, than with a tracheostomy due to the circumferential cricoid cartilage posterior at the level of a cricothyroidotomy[21]. There is deficient tracheal cartilage posterior (C-shaped cartilage ring) on a lower level where a tracheostomy is performed.

5.7 Vocal cords

- The cords are situated superiorly, at least 1 cm above the site of incision [7]. The tube should be aimed downwards in order not to injure the vocal cords. The vocal cords are attached to the internal anterior surface of the thyroid cartilage.

- Bennett *et al* [19] demonstrated in a cadaver study, that the distance from the upper border of the cricothyroid membrane to the vocal cords was 9.78mm.

5.8 Anterior cervical fascia

- Due to an injury of this fascial layer, soft tissue edema may develop and can make location of the cricothyroid membrane extremely difficult[10].

5.9 Children

- The thyroid cartilage in the midline (laryngeal prominence) is difficult to palpate in children for it does not develop until adolescence.

- The most prominent structures are the hyoid bone and cricoid cartilage.

- The cricothyroid membrane is situated more cephalad in children compared to adults.

- The height of the cricothyroid membrane is not as high as in the adult (3 mm in infants compared to 9-10 mm in adults). Therefore a needle cricothyroidotomy is indicated for children younger than 12 years. An endotracheal tube, which is too large, may damage the cartilage structures permanently.

- Because of difficulty in palpating the anatomical landmarks, it is better to do a formal tracheostomy than a cricothyroidotomy in children under 5 years of age.

- There may be an increased risk of damaging the only completely circumferential supporting structure (cricoid cartilage) in a child. This is also the narrowest segment of the infant airway. In adults the narrowest segment of the airway is the glottic opening.

- The airway is also narrower and more flexible than in the adult, making posterior penetration of the tracheal wall much more likely in the child and infant.

- The mucosa is more fragile, looser and softer, making edema and laceration more likely and thus cause subglottic stenosis.

- The risk of subglottic stenosis is higher in children and adolescents[20].

5.10 Vascular anomalies

- A few vascular anomalies, where a major artery crosses the neck are usually found lower in the neck. Major anomalous vessels do not overlie the cricothyroid membrane.

5.11 Cricoid cartilage

- The cricoid cartilage consists of an arch (anterior) and lamina (posterior). The cartilage is situated at level C6. It is the only complete cartilaginous ring in the larynx and trachea, serving as a stent and maintaining a patent airway following cricothyroidotomy[24].

5.12 Thyroid gland and isthmus

- The isthmus is absent in 10% of cases[13]. The thyroid gland has a pyramidal lobe in 40% of people. Others report a 60-65% incidence and regard the lobe as a normal component of the thyroid gland[33]. This lobe may extend as high as the hyoid bone and therefore may be at risk of injury when performing a cricothyroidotomy. It represents a persistent portion of the inferior end of the thyroglossal duct. The lobe is usually situated on the left of the midline. The thyroid gland descends anterior to the hyoid bone and laryngeal cartilages. The isthmus is usually 1.25 cm wide and lies anterior to the second and third tracheal cartilages[30].

- The thyroid gland may also impinge on the cricothyroid membrane, and if injured during the procedure, cause bleeding.

5.12 Recurrent laryngeal nerve

- These nerves run bilaterally between the trachea and the esophagus on the plane of the cricoid cartilage and supplies the larynx sensorically as well as all the laryngeal muscles except the cricothyroid.

5.13 Common carotid artery and internal jugular vein

- These structures lie posterolaterally to the cricoid cartilage and staying in the midline will prevent injury to these structures

6. Complications (anatomically relevant)

One needs to remember, that the complications listed are minor when thinking of the catastrophic morbidity associated with failure to secure an airway. This procedure is usually done in the Emergency Room or in the field, and therefore necessarily has a higher complication rate than if the procedure is performed electively [7,14]. However, Miklus *et al* [6] reports no serious complications in a retrospective analysis of 20 patients on which a cricothyroidotomy was performed outside of the hospital on a helicopter transport team.
Complication rates of between 6.1 and 8.6% are reported for elective cricothyroidotomies compared to 40% in the Emergency Room[14].

6.1 Incision over the thyrohyoid space

- McGill *et al* [14] found in a study of 38 cricothyroidotomies, that the most frequent complication was incorrect placement of the tube through the thyrohyoid membrane. According to them, an initial horizontal incision of the skin may contribute to misplacement of the tube through the thyrohyoid space. They argue that vertical incisions can be extended when necessary to get to the appropriate level of the cricothyroid space.
  Furthermore, proper identification of the anatomical landmarks are crucial, including the cricoid cartilage, thyroid cartilage, cricothyroid membrane and the hyoid bone. The position of the cricothyroid membrane should also be reconfirmed after the skin incision has been made.

- Incision over the thyrohyoid space should be prevented by careful identification of the anterior midline structures of the neck.

6.2 Intra- and postoperative bleeding

- Evidence from cadaver studies shows that vessels may actually complicate the procedure by bleeding more commonly than originally recognized[3]. Severe bleeding is however seldom encountered[21]. When treating a patient in severe respiratory distress rapid and effective control of the airway is the first priority and bleeding can be dealt with secondary.

- Bleeding is usually due to a superficial venous plexus injury. This can be prevented by incising directly over the cricothyroid membrane, and staying in the midline. The incision should not be extended too far laterally. Bleeding usually occurs from the edges of the incision. This complication is minimized if the skin incision is performed vertically [2]. McGill *et al* [14] also reports on two cases of 38 where hemorrhage required ligation due to horizontal incisions. The bleeders occurred at the margin of the incision and may be avoided in vertical incisions.

- One study done on cadavers reported a high number of small vessels in the region of the cricothyroid membrane at risk [3]. The complication of bleeding can however be present even when doing the procedure correctly, therefore one needs to be aware and treat appropriately. Caution should be taken not to incise the thyroid isthmus, which is a highly vascular structure. The thyroid isthmus is found on the level of the 2nd and 3rd tracheal rings.

- The cricothyroid artery courses through the superior half of the cricothyroid membrane. Therefore the incision should be made through the inferior half of the membrane. McGill [14] refers to a case of fatal airway hemorrhage followed by aspiration when the cricothyroid artery was disrupted.

- Fatal airway hemorrhage after cricothyroidotomy has also been reported by Schillaci *et al*[28] with laceration of the cricothyroid artery with resultant endobronchial bleeding and asphyxia. Autopsy revealed that this patient had a larger than normal cricothyroid artery coursing horizontally across the midportion of the membrane. These arteries run closer to the thyroid cartilage and the incision should therefore be made closer to the cricoid cartilage.

- Brofeldt *et al*[16] reports on bleeding from the anterior jugular veins in one patient, which was controlled without any problem.

- Bleeding from the cricothyroid arteries can be controlled by ligation of the branches of the superior thyroidal artery, which may be necessary due to the extensive collateral blood supply[28].

- Donald *et al*[34] reports a brisk persistent endolaryngeal hemorrhage probably due to one of the vessels running in the submucosal area of the larynx in the region of the cricothyroid membrane. The endolaryngeal arteries in the submucosa of the subglottic region anastomose with the cricothyroid arteries via a perforating branch.

6.3 Execution time of greater than 3 minutes.

- A cricothyroidotomy should easily be established within 2 minutes[22].

6.4 Misplaced tube resulting in endobronchial intubation

- This can occur, especially when using an endotracheal tube, which is inserted too deeply. Usually the tube goes down the right primary bronchus, which is more vertical, is shorter and has a greater diameter when compared with the left.

6.5 Subglottic stenosis

- Subglottic stenosis is believed not to be a common complication [8], even in the presence of laryngeal pathology. The most common cause of subglottic stenosis is endotracheal intubation [5]. This condition is caused by mucosal damage due to a tube eroding the mucosal surface by excessive cuff pressures, frequent tube movement and rigid tubes. This complication was more frequently seen when large bore tubes were used[19].

- It has been said that a cricothyroidotomy tube should be removed after 48 hours due to the risk of subglottic stenosis. Sise *et al* [20] showed in a prospective analysis that there is long-term morbidity associated with cricothyroidotomy. However it seems similar to that seen in tracheostomy. When comparing the complications in cricothyroidotomy and tracheostomy they are different. Subglottic stenosis due to cricothyroidotomy is most frequently reported in long-term cricothyroidotomy. It is rare in tracheostomy. But major vessel erosion and pneumothorax have been described after tracheostomy[32] and not after cricothyroidotomy[20 21]. Ger[32] describes the complications of tracheostomy and links these to the anatomy. Tracheostomies, especially those done below the isthmus level are prone to pneumothoraces (due to the pleura reaching 2.5 cm above the medial third of the clavicle) and there is a risk of possible injury to the brachiocephalic artery (especially in older patients with a short neck). Cricothyroidotomy therefore offers a distinct advantage due to its ease in performance.

- Brantigan *et al* [21] reported in 1976 no chronic subglottic stenosis in long term cricothyroidotomies, however later studies by the same author showed that the complication was prevalent, although not high[8]. This was published after the landmark paper by Jackson[23] which convinced the medical profession for nearly 40 years that the incidence of subglottic stenosis was high and the procedure should therefore be abandoned. This was appropriate in Jackson's patient population where there was a significant number of infectious laryngeal diseases such as diphtheria, tuberculosis and Ludwig's angina.

- Should a cricothyroidotomy be used for a longer period, it should only be used in patients free of acute laryngeal pathology[8]. This includes an already injured larynx due to prolonged endotracheal intubation[22]. Weymuller *et al*[25] also suggest that a cricothyroidotomy should not be used after prolonged intubation due to the high risk of subsequent subglottic stenosis.

- Usually the cricothyroidotomy stoma heals satisfactory with granulation tissue and more than 50% re-epithelialization after two weeks[22 24].

6.6 Vocal cord damage

- It is important to avoid vocal cord damage by directing the needle caudally at 45°.

6.7 Laryngeal damage

- This may occur due to an oversized tube being forced through the relatively small cricothyroid space. Injury to the vocal cords is associated with too vigorous superior traction on the thyroid cartilage[16]. This technique is suggested to expose the incision made in the cricothyroid membrane[9]. To avoid the risk of injury to the vocal cords traction can be applied to the inferior side of the incision on the cricoid cartilage[16].

6.8 Dysphonia and hoarseness

- Dysphonia and hoarseness due to damage to the vocal cords have been reported [4]. It may be the result of cutting the vocal cords, especially if the incision through the cricothyroid membrane is made close to the thyroid cartilage. It should be made alongside the superior border of the cricoid cartilage[19].

- Dysphonia can occur secondary to a tracheal cartilage fracture, usually due to the insertion of an oversized tube[14,19]. The outer diameter of the tube should not exceed 8 mm[12,14]. A number 4 Shiley tube has an internal diameter of 5 mm and an outer diameter of 8.5 mm.

- Hoarseness has been reported due to a small amount of granulation tissue below the cords secondary to cricothyroidotomy[22].

- Gleeson *et al* [4] reports a high incidence of vocal disturbance after cricothyroidotomy in patients requiring a prolonged period of mechanical ventilation. Subjective vocal changes like loss of volume, a voice that fatigues easily, deep and husky voices and limited vocal ranges have been reported. These subjective findings were found to correlate with objective analysis of laryngographs.

6.9 Pretracheal intubation

- Pretracheal intubation has also been reported[16]. This complication is more likely to occur when the incision of the cricothyroid membrane is opened by superior traction on the thyroid cartilage. This can be avoided by inferior traction on the cricoid cartilage. A large diameter tracheal hook can be used for this by placing the hook around the posterior wall of the anterior arch of the cricoid cartilage.

6.10 Aspiration

- During a needle cricothyroidotomy or PTV (percutaneous transtracheal ventilation), the airway is not protected from the aspiration of upper airway secretions, blood or emesis[15].

6.11 Tube dislodgement

- The incidence is low due to the proximity of the airway to the skin surface[21].

6.12 Massive subcutaneous emphysema[15]

- Found especially in PTV (percutaneous transtracheal ventilation). This serious complication may occur due to misplacement or dislodgment of the catheter into the subcutaneous tissue. The catheter should be securely placed.

- Subcutaneous emphysema may also develop due to leakage of air via a secondary puncture site.

- It may also occur after removal of the catheter, which can be avoided by applying digital pressure over the puncture site.

6.13 Tracheal stenosis

- Pressure necrosis of the trachea occurs due to a high-pressure balloon cuff. Therefore a low-pressure cuff should be used.

6.14 Recurrent laryngeal nerve injury

- Injury to these nerves may lead to vocal cord paralysis. The nerves lie between the trachea and the esophagus at the level of the cricoid cartilage and enter the larynx from posteriorly. Therefore, staying in the midline without injuring the posterior wall of the subglottic airway, will ensure avoidance of these nerves.

6.15 Perforated esophagus

- This is a theoretical complication[15]. So is the formation of a tracheo-esophageal fistula[6]. Care should be taken not to incise or push the needle too deeply after entering the infraglottic cavity.

6.16 Tracheo-left brachiocephalic vein fistula formation

- This complication may be due to a too high pressure in the cuff and can be prevented by using a low-pressure cuff tube.

- In children, the relative shortness of the neck places the cervical and upper thoracic structures at a higher level and the brachiocephalic vein may have a cervical rather than mediastinal position[32].

6.17 Pneumothorax, Pneumomediastinum

- These have been reported in PTV (percutaneous transtracheal ventilation) due to barotrauma[15]. The procedure should therefore be avoided in patients with emphysema.

- Mediastinal emphysema may occur with cannula misplacement posterior to the esophagus.

6.18 Thyroid cartilage fracture

- McGill [14] reports a case, where due to an oversized tube through the cricothyroid membrane, a longitudinal fracture occurred through the thyroid cartilage with consequent severe disphonia. The tube used had an outer diameter of 12 mm, which is 3 mm larger than the average height of the cricothyroid membrane of 9-10 mm[9]. Various authors[12, 14] advise that the outer diameter of the tube should not be more than 8 mm.

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4.4.1.2 Orotracheal and nasotracheal intubation

1. Indications

- Any clinical situation where a definite airway is necessary.

2. Contra-indications/ Precautions

- An unstable neck injury is a relative contraindication. Intubation could however be done without extending or rotating the neck.

- Nasotracheal intubation is contraindicated in patients with a suspected skull base fracture and severe nasal injury, as well as if acute epiglottitis[17] is suspected.

3. Step by step procedure

3.1 Orotracheal intubation

1. Assure adequate ventilation and oxygenation. Make sure suctioning equipment is immediately available in case the patient vomits.
2. Inflate the cuff of the endotracheal tube to ascertain that the balloon does not leak, and then deflate the cuff.
3. Connect the laryngoscope blade to the handle, and check the bulb for brightness
4. Have an assistant manually immobilize the head and neck. The patient's neck must not be hyperextended or hyperflexed during the procedure.
5. Hold the laryngoscope in the left hand (For left handed people the opposite is true).
6. Insert the laryngoscope into the right side of the patient's mouth, displacing the tongue to the left.
7. Visually examine the epiglottis and then the vocal cords.
8. Gently insert the endotracheal tube into the trachea without applying pressure on the teeth or oral tissues. The cuff should just disappear inferior to the vocal cords.
9. Inflate the cuff with enough air to provide an adequate seal. Do not overinflate the cuff.
10. Check the placement of the tube by auscultating the chest and abdomen with a stethoscope to ascertain tube position.
11. Visually observe lung expansion with ventilation.

12. Secure the tube. If the patient is moved, the tube placement should be reassessed.
13. If endotracheal intubation is not accomplished within seconds or in the same time required to hold your breath before exhaling, discontinue attempts, ventilate the patient with a bag-valve mask device, and try again later.
14. Placement of the tube must be assessed carefully. A chest X-ray may be helpful to assess the position of the tube, but it cannot exclude esophageal intubation.

3.2 Nasotracheal intubation

1. In suspected neck injury, leave the cervical collar in place to assist in maintaining immobilization of the neck.
2. Assure adequate ventilation and oxygenation.
3. Inflate the cuff of the endotracheal tube to ascertain that the balloon does not leak, and then deflate the cuff.
4. If the patient is conscious, spray the nasal passage with an anesthetic.
5. Have an assistant maintain manual immobilization of the head and neck.
6. Lubricate the nasotracheal tube and insert the tube into the nostril.
7. Guide the tube slowly but firmly into the nasal passage, straight posteriorly from the nostril and then backward and down into the nasopharynx. The curve of the tube should be aligned to facilitate passage along this curved course. The tube should not be directed superiorly, as expected from the external nasal anatomy, but rather straight posteriorly. The bevel of the tube should be placed to face the septum to avoid damage to the turbinates.
8. As the tube passes through the nose and into the nasopharynx, it must turn downward to pass through the oropharynx. This is the most painful part as the tube turns 90 degrees down the nasopharynx
9. Proceed with the procedure as with an orotracheal intubation, guiding the tube through the vocal cords with a Magill's forceps. It may be necessary to apply pressure on the thyroid cartilage.
10. Inflate the cuff with enough air to provide an adequate seal. Avoid overinflation.
11. Check the placement of the tube by auscultating the chest and abdomen with a stethoscope to ascertain tube position.
12. Visually observe lung expansion with ventilation.
13. Secure the tube. If the patient is moved, the tube placement should be reassessed.
14. If endotracheal intubation is not accomplished within seconds or in the same time required to hold your breath before exhaling, discontinue attempts, ventilate the patient with a bag-valve mask device, and try again later.
15. Placement of the tube must be assessed carefully. A chest X-ray may be helpful to assess the position of the tube, but it cannot exclude esophageal intubation.

Danzl *et al* [17] reports on successful translaryngeal anesthesia prior to nasotracheal intubation. During this technique topical anesthetic is injected through the cricothyroid membrane into the larynx. After aspirating air, 1.5-2.0 ml of 4% lignocaine is injected swiftly, usually causing a mild cough. Performing this technique before intubation facilitates passing a tube through the vocal cords. However, the major disadvantage of this procedure is the small time interval before intubation, where the protective reflexes are depressed and resultant aspiration can occur[17].

Advantages of nasotracheal intubation:

- The procedure minimizes neck movement and is reported by Danzl[17] to be an alternative to cricothyroidotomy and tracheostomy where the X-ray status of the cervical spine is unknown in a trauma patient.
- The procedure does not require opening of the mouth and can therefore be performed in patients with temporomandibular joint dislocation and masseter spasm.
- It is suitable for patients with a short thick neck or other anatomical characteristics that would make orotracheal intubation difficult. Also where there is inability to properly align the oral-pharyngeal-laryngeal axis because of cervical spine anomalies, ankylosing spondylitis, obstructing inflammatory processes like Ludwig's angina and a paratonsillar abscess.
- It is possible to perform the procedure with the patient in a sitting position, advantageous in patients with severe congestive cardiac disease who cannot tolerate lying flat.
- The procedure can be performed blindly. In this case breathing sounds are used to guide the tube towards the vocal cords. If the breathing sounds diminish, the tube is deviating away from the glottis and if the sounds increase in loudness and clarity, the tube is moving closer to the glottic opening[40].

4. Materials

- Laryngoscope.

- Endotracheal tubes with high volume low-pressure balloon. Adult men: 7.5 to 9.0mm, women: 7.0 to 8.0 mm. For nasal intubation a slightly smaller tube is chosen.

- In children a formula of: tube size = (4+ age (years))/4, is used. Easier to assess using the width of the fingernail of the little finger of the child. Children under 8 years, are intubated with an uncuffed tube, therefore adequate tube size is essential to prevent aspiration.

- 20 cc syringe.

- Scissors.

- Magill's forceps.

- Suction.

Preintubation checklist in optimal circumstances:

- Monitors connected: Blood pressure, O_2 saturation, ECG

- IV Line connected
- Necessary drugs drawn up
- Bag-valve mask connected to oxygen source
- Stylet ready to be inserted in tracheal tube if necessary
- Check integrity of the balloon
- Have tape ready
- Check laryngoscope light
- Check oral suction device
- Remove patient's dentures
- Check optimal head positioning: neck slightly flexed, and head extended on the neck.

5. Anatomical pitfalls

5.1 Arytenoid cartilages[23]

- These are paired cartilages forming the posterior aspect of the laryngeal inlet, articulating on the posterior shoulders of the cricoid cartilage.

5.2 Nasopharynx

- The nasopharynx extends from the posterior aspect of the nasal cavity to the soft palate. The nasotracheal tube is passed via the nasopharynx.

5.3 Oropharynx

- The oropharynx extends from the soft palate to the superior edge of the epiglottis.

5.4 Laryngopharynx

- The laryngopharynx extends from the epiglottis to the inferior border of the cricoid cartilage and proximal esophagus.

5.5 Vallecula

- The vallecula or pit is a space at the base of the tongue, bordered posteriorly by the epiglottis. The tip of the blade of the laryngoscope is inserted in this space to lift the tongue and epiglottis forward in order to visualize the vocal cords.

5.6 Laryngeal inlet

- The laryngeal inlet forms the opening to the larynx, bordered anterior and superior by the epiglottis, laterally by the aryepiglottic folds and posteriorly by the arytenoid cartilages.

5.7 Piriform fossae

- The piriform fossae are spaces on both sides of the laryngeal inlet, separated from the larynx by the quadrangular membranes.

5.8 Quadrangular membranes

- These membranes run from the lateral sides of the epiglottis to the arytenoid cartilages posteriorly, with the aryepiglottic fold as the superior free edge and the false vocal cords or vestibular folds as the inferior free edge. The aryepiglottic folds can close from both sides to protect the glottic inlet from foreign bodies. The aryepiglottic folds have both muscular and ligamentous components. The posterior part of each aryepiglottic fold are characterized by the presence of the corniculate and cuneiform cartilage. Closure of the aryepiglottic folds occurs under neural control[33].

5.9 Glottis

- The glottis constitutes the space between the vocal cords, both false and true as well as the glottic opening. It acts as a closed valve protecting against aspiration[26].

5.10 Nasal septum and cavity[26]

- The nasal septum may be deviated, which may cause nasal obstruction, and complicate nasotracheal intubation.

5.11 Inferior turbinate (inferior concha)

- A nasotracheal tube passing the inferior turbinate may fracture the concha[26].

5.12 Pharynx[26]

- The pharynx is a U-shaped fibromuscular tube extending from the base of the skull to the cricoid cartilage at the entrance of the esophagus.

5.13 Additional cartilages

- Corniculate cartilage. These cartilages are found in the posteromedial portion of the arytenoid cartilage just anterior to the arytenoid cartilages in the ary-epiglottic fold.

- Cuneiform cartilage. These cartilages form the anterolateral prominence of the arytenoid cartilage slightly anterior to the corniculate cartilage.

5.14 Anatomical factors predicting a difficult intubation [1]:

5.14.1 Adults

It has been estimated that inability to successfully manage difficult airways, has been responsible for as many as 30% of deaths totally attributable to anesthesia[27]. The following anatomical factors play a major role in difficult intubations:

- Prominent upper incisors.

- Limited ability to extend at the atlanto-occipital joint.

- Poor visibility of the pharyngeal structures with tongue extension (Mallampati classification[4]) and limited ability to open the mouth[5].

  Class 1 predicts an easy intubation and Class 4 a difficult intubation[4].

  Class 1: soft palate, uvula, fauces and tonsilar pillars visible.
  Class 2: soft palate, uvula, fauces visible.
  Class 3: soft palate, base of uvula visible.
  Class 4: Only hard palate visible.

  The classification is based on the clinical sign used to predict a difficult intubation, which is the concealment of the palatoglossal and palatopharyngeal arches as well as the uvula by the posterior third of the tongue, with it maximally protruded.
  If the base of the tongue is disproportionately large, it overshadows the larynx as well as the faucal pillars and uvula, complicating visualization. Mallampati argues that because of the fact that it is impossible to measure the volume of the posterior third of the tongue, the size should be predicted by how much it masks other structures. The tongue is the single largest structure in the mouth affecting direct laryngoscopy.

- A short distance from the thyroid notch to the chin with the neck in extension. Matthew *et al*[6] showed that patients with a thyromental distance < 6 cm (distance from the thyroid notch to the mental prominence with the neck extended) and a horizontal length of the mandible < 9 cm (distance from the angle of the mandible to the symphysis menti) showed a good correlation with Grade 3 and 4 according to the Mallampati classification[4]. Therefore, if present, intubation is likely to be difficult.

- A difficult intubation may also be expected if the distance from the anterior point of the chin to the hyoid bone in an adult is less than 3 fingerbreadths when the head is extended. Patients with a shortened distance may have a poorly developed mandible or a short thick neck. The larynx is then usually situated anteriorly, and one may need to use the straight laryngoscope blade as well as cricoid pressure.

- Previous surgery in the oral cavity, or any swelling, neck tumors, burns etc. that cause distortion of the anatomy and thus complicate intubation. Care should be taken in patients with tumors in the neck region, for it may point to a possible difficult intubation. Wakeling *et al* [25] reported a case with large goiter, where the larynx was found to be pushed over to the other side.

- Patients with ankylosing spondilytis, Down's syndrome or a hypoplastic mandible are difficult to intubate due to neck rigidity and displacement of the tongue.

- Radiographic indicators for the ease of intubation include the mandibular length to height ratio[2] and the distance from the spinous process of the atlas to the occiput[3]. White and Kander[28] compared the lateral, postero-anterior and submentovertical skull radiographs of a group of patients where difficult laryngoscopy was experienced with a control group. The most significant factor for ease of direct laryngoscopy was the posterior depth of the mandible. This measurement was taken from the alveolus immediately behind the third molar tooth to the lower border of the mandible. An increase in this measurement is thought to hinder displacement of the soft tissues by the laryngoscope blade.
  Van der Linde *et al* [38] showed in a similar study that a combination of anatomical factors determine the ease of intubation for e.g. the distance of the occiput to the spine of C1 and ratios expressed to either the maxillary length or effective mandibular length.
  These are however of no use in the emergency situation.

- Benumof [27] elaborates on three extremely easy-to-perform, no-cost pre-intubation examinations, that predict subtle anatomic causes for intubation difficulty:

  i) **Relative tongue/pharyngeal size:** The size of the tongue relative to the oral cavity can be simply graded by looking into the patient's mouth. Grading is done according to Mallampati's classification[4] earlier described.

  ii) **Atlanto-occipital joint extension** – It is known that flexion of the neck on the chest with extension of the head on the neck, brings the oral cavity, pharynx and larynx in a more straight line, which may ease intubation[30]. The natural tendency to extend the neck actually makes intubation more difficult. No other study has however improved on Magill's[30] clear description. In this position less of the tongue will obscure the view of the larynx. Examination of the extent of this movement can be done at the bedside. Movement of 35 degrees of extension is usually possible. This examination is obviously absolutely contraindicated in the patient presenting in the emergency room with a suspected neck injury.

  iii) **Mandibular space** – This space is expressed as the distance from the hyoid bone or thyroid cartilage to the mandible, by means of fingerbreadths. This distance will determine how easily the larynx will fall in line with the pharyngeal axis when the atlanto-occipital joint is extended. A thyromental distance of more than 6 cm, strongly suggest that laryngoscopy will be relatively easy.

Benumof [27] recommends that all patients for elective intubation, should have these three anatomical points examined: the ability to open their mouth widely for examination of oral cavity structures, size of the mandibular space and ability to extend the head with the neck held in flexion.

5.14.2 Children

Children have some anatomical factors which make intubation more difficult:

- Infants have a proportionately larger head, which naturally extends the head and flexes the neck. The head may be floppy and the larynx may be positioned posteriorly making visualization of the cords difficult. This may be overcome by putting a towel under their shoulders. The use of a pillow under the head to align the airway axes is not necessary and makes visualization of the glottis more difficult [26].

- Children have an increased tongue-to-oropharynx ratio, a shorter neck, which makes forward movement of the tongue more difficult, and a long U-shaped epiglottis, which makes visualization of the glottis difficult [26]. These factors make the use of a straight blade necessary.

- The infant's larynx is situated higher and more anterior (level of C2, C3, compared to the C4-C6 level of the adult)[26].

- The vocal cords are concave upwards, with the anterior attachment lower than the posterior. This may effect ventilation. The vocal cords of an adult are horizontal[26].

- The relatively short trachea in children increases the risk of primary bronchus intubation. This may be prevented by following the formula for correct placement in children: Depth (cm) = age/2 + 12 [26].

- The airway diameter is smaller and is smallest at the cricoid ring. Therefore, trauma with the laryngoscope and tubes is a risk. Cricoid pressure may cause complete airway obstruction and an endotracheal tube may be able to pass through the vocal cords, but not the cricoid cartilage ring just inferior to the level of the vocal cords. If this happens, the next smaller tube should be used [26].

- Children have a smaller residual lung capacity. Therefore they can become hypoxic more rapidly than an adult. Prolonged periods without ventilation should therefore be avoided.

- Teeth in children are easily knocked out and aspirated.

- Children have large palatine and pharyngeal tonsils (adenoids). These structures may obscure visualization of the vocal cords and when performing a nasotracheal intubation cause excessive bleeding, with possible airway obstruction [26].

5.15 Superior laryngeal nerve

- The superior laryngeal nerve is a branch from the vagus nerves and divides into an internal and external branch. The external branch supplies the cricothyroid muscles and the internal branch pierces the thyrohyoid membrane and innervates the laryngeal mucosa from the upper surface of the vocal folds to the base of the tongue. The superior laryngeal nerve can be anesthetized to perform intubation while the patient is awake. During this procedure, anesthetic solution is injected midway between the thyroid cartilage and hyoid bone, deep to the thyrohyoid membrane into the paraglottic space[32]. The disadvantage of this procedure is the unprotected airway from the time of injection until intubation has been successfully completed.

5.16 Trachea

- The average adult trachea has an external diameter of 20mm and length of 11cm. Whiffler *et al* [37] measured the transverse tracheal diameter of the tracheal air space on 200 postero-anterior chest X-rays. The average measurement of this internal diameter was 17 mm.

6. Complications (anatomically relevant)

6.1 Inability to visualize the vocal cords

- Cormack *et al* [5] reports three main factors contributing to a difficult intubation:
  a) Forward displacement of the larynx
  b) Forward displacement of the teeth
  c) Backward displacement of the tongue.

  This may be the case in the absence of any pathology, due to a normal anatomical variation.

- May be due to **incorrect initial placement** of the laryngoscope blade. The blade should slide alongside the right side of the tongue, therefore displacing the tongue to the left side. If the blade is placed initially over the middle of the tongue, the tongue will fold over the lateral edges of the tongue and obscure the airway.

- The **laryngeal aperture** may be seen in different grades, as discussed by Benumof [27]. Grade 1 is the visualization of the entire laryngeal aperture, Grade 2 only the posterior portion of the aperture is seen, Grade 3 is visualization of only the epiglottis and grade 4 the visualization of only the soft palate. The grade 3 and 4 views will often lead to an impossible intubation. The incidence of a grade 3 laryngoscopic view is 1-4% and that of grade four 0.05 to 0.35 %[27].

- After the blade of the laryngoscope has reached the posterior one third of the tongue, sliding into the vallecula, the laryngoscope should be lifted upward and forward at a 45-degree angle. The epiglottis should become visible and continuation of anterior elevation will expose the vocal cords. Bending of the operator's wrist may lead to dental injury.

- If the blade tip is pushed too deeply into the vallecula, the epiglottis is pushed down and obscures the laryngeal inlet[4].

- When using a straight blade, the tip of the blade is placed posterior and slightly beyond the epiglottis, thus directly lifting it anteriorly. Too deep placement may result in the entire larynx being lifted anteriorly and thus out of the field of vision.

- Head positioning - The extended head, with the neck flexed, allows for the shortest distance and straightest line between the teeth and the vocal cords. The line from the upper incisors through the pharynx to the larynx is almost a straight line. By flexing the neck and extending the head, this line is converted to a straight line[38]. In suspected neck injuries this position is absolutely contraindicated. Alexopoulos *et al* [24] has demonstrated that extension of the head does not necessarily make intubation easier, and one should be aware of restricting circulation through the vertebral arteries to the brain in patients already having some circulatory impairment by hyperextending the head.

- Difficult intubations in obstetric care are more common, due to the more frequent grade 3 airway, in which the epiglottis can be visualized, but not the vocal cords[5]. The laryngoscope blade tends to depress the epiglottis and therefore hide the vocal cords.

- Cricoid pressure – This maneuver, called Sellick's maneuver, is done to displace the larynx posteriorly in order to visualize the vocal cords. This maneuver should always be used to intubate obstetric patients to prevent regurgitation of stomach content and to stabilize the larynx[39].

6.2 Esophageal intubation

- The only way to prevent esophageal intubation is to ensure that the tube is seen passing through the vocal cords [20,26].

- Absent or diminished breathing sounds, vocalization, increased abdominal size and gurgling sounds over the epigastrium, are clinical signs of esophageal placement.

- The problem is that esophageal placement is not always obvious. Normal breathing sounds may be heard in the midline. Therefore auscultation of both lung fields in the lateral axillary line is mandatory[34].

- Fog formation inside the tube with each breath, suggests correct endotracheal placement.

- Observation of chest rise and fall with positive pressure ventilation also suggests correct endotracheal placement.

- Correct placement can also be assessed by means of a fibreoptic scope. The fibreoptic scope may be passed down the endotracheal tube. Visualization of the tracheal cartilage rings confirms correct placement as well as placement within the trachea.

6.3 Too deep placement

- A major complication of endotracheal intubation is accidental migration of the tip of the endotracheal tube into a primary bronchus[20]. This may lead to hypoxemia and collapse of the contralateral lung with possible resultant tension pneumothorax.

- Asymmetrical breathing sounds, suggest a primary bronchus intubation: the tube has been inserted too deeply. Most frequently the right primary bronchus is intubated due to its vertical alignment with the trachea, wider diameter and shorter length when compared with the left primary bronchus[26]. The cuff should be deflated and the tube withdrawn until equal breath sounds are present.

- Bloch *et al* [13] reports correct tube placement in children as follows: After hearing equal breathing sounds in both lungs, the tube is withdrawn 2 cm in children under 5 years, and 3 cm in older children.

- After the cuff has passed through the vocal cords, it should not be advanced more than 3 cm. The tip of the tube should desirably lie between 3 and 7 cm above the carina, according to Conrardy *et al* [8].

- Owen *et al* [12] reported in a study involving more than 500 patients the following lengths, representing the distance between the tip of the tube to the upper incisors in adults of average size:
  Tracheal tube depth (cm) = 21 cm in females.
  Tracheal tube depth (cm) = 23 cm in males.
  Owen *et al* [12] reported that the measurement of the tube beforehand, to be more reliable than auscultation to determine the correct position of placement.

- Reed *et al* [15] reported the optimum distance from the external nose to the tip of the nasotracheal tube to be about 28 cm in males and 26 cm in females. This is to ensure adequate positioning of the tip of the tube being at least 2cm above the carina.

- Auscultation is essential, not only anteriorly but also laterally for the right middle lobe and lingula on the left. Midline auscultation only may lead to an erroneous impression of tracheal placement when the tube is actually in the esophagus.

- Radiographic confirmation

  - **Adults**

    On a radiograph, the tip of the endotracheal tube should ideally be 5 cm ±2 cm above the carina in a neutral head and neck position. The carina overlies the 4th, 5th or 6th thoracic vertebral body.
    The carina is situated more superior in children, consistently aligned between the

3rd and 5th thoracic vertebral body.

- **Children**

Blayney and Logan[9] reported that T1 is the sole best reference point to be used to assess the tip of the endotracheal tube in children. The tip of the tube should not lie below T1 vertebral body. Previously the medial ends of the clavicles were used to determine correct placement, but the position of the clavicles is highly variable. Cole[10] and Morgan *et al* [11] developed a formula to determine the proper depth of tube placement with lengths representing the distance from the tube tip to the upper incisors in children. Tracheal tube depth (cm) = age (years)/2 +12.

Kuhns *et al* [35] proposes that a 9-cm distance should be marked on the operator's index finger for tube length of infants. For 1-year old infants 2 cm should be added and for very small infants 2 cm should be subtracted. This method is more practical in the emergency situation where formulae are impractical.
The average length of the infant's trachea is 5.7 cm.

6.4 Cervical strain

- Cervical strain, subluxation/ dislocation of cervical vertebrae may occur. This is especially the case in the emergency patient and patients with rheumatoid arthritis [20,26].

6.5 Aspiration

6.5.1 Aspiration of gastric content

- Cricoid pressure or Sellick's maneuver[39] is essential for all emergency intubations, including general anesthesia for emergency procedures and obstetric procedures to help prevent gastric content from entering the airways.

6.5.2 Aspiration on extubation

- Before extubation, a substantial amount of fluid may accumulate above the cuffed endotracheal tube, which may consist of secretions, blood or gastric contents. This must be aspirated before extubation. To prevent this, proper suction is necessary before extubation, a cuffed endotracheal tube with the largest diameter for the individual patient should be used to reduce dead space above the cuff, and a gauze pack can be used in the laryngopharynx[36].

6.6 Oral cavity injury

- Soft tissue injury of the oral cavity resulting in abrasion and hemorrhage, which may involve the lips, tongue, soft and hard palate, buccal mucosa and pharynx [20,27].

6.7 Vocal cords

- Spasm, avulsion and laceration may occur due to the passing of the endotracheal tube. Laryngeal injury is however very rare[26].

- Pediatric patients are far more prone to laryngospasm[7]. This occurs when the vocal cords are stimulated, e.g. when touching them with the endotracheal tube. Consequently the adductors of the cords contract, which may prevent passing of the tube. The tube should not be forced, due to possible permanent damage to the cords.

- Laryngospasm usually occurs due to inadequate anesthesia. If laryngospasm is prolonged a muscle relaxant may be necessary.

6.8 Piriform fossae

- These fossae may be perforated resulting in a pneumothorax and pneumomediastinum[26].

- Injury to upper airway structures greatly increases in the case of a difficult intubation. Benumof[27] stated that in patients where multiple attempts at laryngoscopy were made, the incidence of upper airway complications increased dramatically.

6.9 Malpositioning of the tube due to head movement

- Conrardy *et al* [8] has shown in a controlled study that the endotracheal tube moves on average 1.9 cm towards the carina with flexion of the neck and 1.9 cm away from the carina with extension. It moves 0.7 cm away from the carina with lateral head rotation. Therefore head movement may lead to inadvertent extubation or endobronchial intubation.

- Bosman *et al* [34] documented that head movement in infants is an important factor of both malpositioning and displacement of the endotracheal tube. This may be both endobronchial intubation and accidental extubation. The reason for this is the short distance of the glottis to the carina in infants. It is not less than 4cmand movement not greater than 1,8cm. Therefore, Bosman *et al* [34] advises to mark the tube in adults 22 cm from the tip, and to fix the tube when this mark has reached the vocal cords. Fixation of the tube to the lower lip, rather than the upper lip is advised.

6.10 Cardiovascular

- The laryngeal reflex is perhaps the body's most potent reflex. Endotracheal intubation, which involves the advancing of a foreign body through the larynx, may evoke either a sympathetic (usually) or parasympathetic (more often in younger patients) reflex [20,26].

- Sympathetic – The sympathetic reflex usually results in hypertension, dysrhythmia and tachycardia. Cerebral hemorrhage, left ventricular failure and cardiac ischemia or arrhythmias have been reported[17].

- Parasympathetic – The parasympathetic reflex usually involves a bradycardia and even asystole. This is due to pharyngeal and laryngeal stimulation (pharyngeal plexus of which the vagus nerve forms part). Prolonged pharyngeal stimulation may also result in laryngospasm, bronchospasm and apnea.

6.11 Dental injury

- Loose teeth may be aspirated[27]. Therefore an avulsed tooth not found in the oral cavity makes a chest X-ray necessary. McGovern *et al* [14] found broken teeth to be the most common complication of laryngoscopy.

6.12 Injury to the arytenoid cartilages

- Dislocation and avulsion of these cartilages may occur[26]. This may cause impaired movement of the cricoarytenoid joint with hoarseness and immobility of the vocal ligament after endotracheal intubation. Paulsen *et al* [23] demonstrated in 30 unfixed cadaver larynges, that intubation trauma may damage the cricoarytenoid joint, especially the large synovial fold, which after hemarthrosis of the joint may lead to cricoarytenoid joint dysfunction. Anatomically the cricoarytenoid joint is a diarthrodial joint supported by a wide joint capsule lined with synovial membrane and a strong posterior cricoarytenoid ligament. The joint allows two principle types of motion: A rotating movement around the axis of the joint, and a linear glide on the shoulders of the cricoid cartilage. This allows for abduction, adduction and changing the length of the vocal cords. Damage to the cricoarytenoid joint may consequently lead to vocal fold immobility and hoarseness. Care should be taken, not to damage the laryngeal inlet with the endotracheal tube or laryngoscope when intubating.

6.13 Rupture of the trachea

- Although rare, reckless movement of intubated patients may cause rupture of the trachea in its membranous part, which is susceptible to tearing in the elderly [20]. This may be caused by overinflation of the tube, for the pilot balloon does not accurately reflect the degree of tube inflation Signs and symptoms pointing to this complication are subcutaneous and mediastinal emphysema, dyspnoea and hemoptysis[36].

6.14 Dysphonia and aphonia (traumatic laryngitis)

- This is found in up to 50% of intubated patients. The reason for this is temporarily epiglottic and arytenoid edema[20].

6.15 Subglottic edema and stenosis

- This is especially dangerous in children. Due to the relatively small internal cross section of the larynx in children, minor swelling of the mucosal layer can cause airway obstruction [20]. This is more dangerous in the subglottic region, where the cricoid forms a circumferential ring of cartilage and forms the narrowest part of the airway.
- Children have a higher risk of developing subglottic stenosis compared to adults[31].
- Subglottic stenosis develops due to pressure from the airway to the loose connective tissue and submucous blood vessels against the nonresilient cartilage. This may cause edema and necrosis, leading to scaring[31].
- The main reasons for subglottic stenosis are too large a size of airway tubes, traumatic technique and prolonged intubation.
- Most pressure is exerted on the cricoid lamina in an intubated patient positioned with the head bent backward. This pushes the cricoid lamina against the tube.

6.16 Laryngeal granulomas, polyps and ulcers.

- These laryngeal conditions may develop after endotracheal intubation[17]. Patients present with hoarseness, and a sore throat[20].

6.17 Paresis of the hypoglossal and or lingual nerves

- Blanc[20] points to this possibility due to pressure of a laryngoscope blade in the retrolingual region.

6.18 pecific complications related to nasotracheal intubation

Danzl *et al* [17] reports a complication rate of 3% for nasotracheal intubation. It is an easily mastered skill with a low complication rate.

6.18.1 Nasal injury

- Mild to moderate bleeding is the most common complication[18].

- Epistaxis – Danzl *et al* [17] reports that severe epistaxis was encountered in only 5 of 300 cases. Four required pharyngeal suctioning. Tintinalli *et al* [18] reported 1 case of severe epistaxis in 71 patients and less serious bleeding in 12 others.

- Nasal septum injury occurred when too much force was applied[18].

- Other complications as described by Taryle *et al* [19] and Blanc *et al* [20] are the following: concha fracture, intracranial placement through skull base fracture and retropharyngeal laceration or dissection.

- Brodman *et al* [29] has reported on a method to pass the endotracheal tube through the nose with minimal damage. A suction catheter is placed through the endotracheal tube and being soft, thin and pliable, easily moves through the nasopharyngeal curve into the nasopharynx. The endotracheal tube is then threaded over the catheter. After reaching the oropharynx the catheter is removed and the endotracheal tube inserted through the vocal cords under direct vision. They have not experienced epistaxis and other injury to the nasal cavity.

6.18.2 Misplacement of the tube in blind intubation:

- Van Elstraete[16] reported a less than 50% success rate of blind nasotracheal tube placement within the first attempt in the operating room. Four potential locations may then be considered for the tip of the tube to lie: 1) in the vallecula, 2) on the arytenoid cartilage or vocal cord, 3) in the piriform fossae and 4) in the esophagus.

- In blind nasotracheal intubation, breathing sounds are used to guide the tube towards the vocal cords. If the breathing sounds diminish, the tube is deviating away from the glottis and if the sounds increase in loudness and clarity, the tube is moving closer to the glottic opening. By listening carefully at the proximal end of the tube, the tube can be rotated to the point where the breathing sounds are heard loudest. At this point the tube can be inserted through the vocal cords during inspiration[40].

6.18.3 Sinusitis

- Sinusitis[20] is a frequent complication and may be an unrecognized source of sepsis as reported by Deutschman *et al* [21]. They report on paranasal sinusitis secondary to prolonged nasotracheal intubation. The diagnosis should be suspected in case of sepsis of undetermined origin. The major factor in precipitating sinusitis is the blockage of sinus outflow via the nasal openings. Simply moving the tube to the oral route or performing a tracheostomy seems to solve the problem[21]. In addition to the maxillary sinus draining into the middle meatus at the semilunar hiatus[26], all the sinuses drain into the nasal cavity.

6.18.4 Mediastinitis

- Seaman *et al* [22] reports on a rare complication of mediastinitis following a retropharyngeal abscess due to nasotracheal intubation. The abscess dissected into the mediastinum through the retrovisceral space. A retropharyngeal abscess should be considered a medical emergency[18].

6.18.5 Damage to the tube cuff with the Magill forceps.

6.18.6 Intracranial penetration

- Several cases have been reported associated with attempted blind nasotracheal intubation[17]. It is therefore a contraindication to intubate a patient via the nasal route in a suspected head injury.

6.18.7 Transient bacteremia

- Patients with known heart valve lesions need to be given prophylactic antibiotics[17].

6.18.8 Otitis media

- This may occur during prolonged intubation especially in neonates and resultant obstruction of the opening of the auditory tube[17].

6.18.9 Retropharyngeal laceration

- Retropharyngeal laceration and subsequent dissection is rare. This space is bordered, anteriorly by the pharyngeal wall, prevertebral fascia and carotid sheath. It extends from the skull base down to the posterior mediastinum.

- Loss of flow of air from the tube, once the tube has passed the turbinates, indicates that the tip of the tube is abutting the pharyngeal mucosa. Slight pressure at this point may lead to retropharyngeal perforation. A suspicion of the occurrence of this complication is important.

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4.4.1.3 Lumbar puncture

1. Indications

1.1 Diagnostic

- Suspected central nervous system (CNS) infection.
    - High index of suspicion in infants younger than 12 months of age, they may have no meningeal signs or even fever. Most common signs in a child between 3 months and 3 years: irritability and vomiting, uncomfortable fever of unknown origin, alteration in consciousness and meningeal signs
    - Patients with AIDS infection with unusual organisms like Cryptococcus, Toxoplasma and Listeria, and a fever of unknown origin.
- Possibility of CNS infection with the exception of brain abscess.
- Suspected spontaneous subarachnoid bleeding – Finding blood in the cerebrospinal fluid (CSF).
  CT scan is the first line investigation and not lumbar puncture[21]. If the scan is negative a lumbar puncture is necessary to examine the CSF.
- Neoplasia – diagnostic cells may be found in patients with leukemia or carcinomatous meningitis.
- Performance of a myelogram by introducing contrast fluid (Nowadays since MRI seldomly performed).
- Diagnosis of Guillain-Barré syndrome or multiple sclerosis.
- Despite the redundancy of lumbar puncture since the emergence of CT and MRI, suspected purulent or viral meningitis is still an indication for lumbar puncture[12].

1.2 Therapeutic

- Spinal anesthesia: intrathecal or epidural.

- Chemotherapy and palliative pain management – drugs may be administered via the epidural or spinal route.

2. Contraindications

- Raised intracranial pressure from a space-occupying lesion. Especially in the case of a brain abscess. Caution should be taken when signs of herniation are present, for example a unilateral third nerve palsy with altered level of consciousness. Tentorial or cerebellar coning may be precipitated. It is important to examine the fundi to establish the presence of papilloedema before performing a lumbar puncture. If present a lumbar puncture should be avoided. A careful history and clinical examination should provide adequate information whether increased intracranial pressure is present or not[32].

- Absolutely contraindicated in patients with infection near the site of insertion.

- Coagulopathies, unless essential when platelet infusion should be given beforehand.

- Spinal cord compression. Removal of CSF in this situation may drastically alter fluid dynamics and may impair bladder function[32].

3. Step by step procedure

3.1 Position: Lateral recumbent position:

The patient should be positioned in the lateral recumbent position with the back flexed as far as possible. Ask the patient to try to touched the flexed knees with his/her chin[26]. One pillow under the head and one between the knees for support. Neck maximally flexed. There is no need for the patient's knees and neck to be forcibly flexed. The back should be at right angles to the floor with one hip exactly above the other. The needle is passed horizontal to the floor. This ensures that the needle stays in the midline[33].

Upright position:

The patient is seated with the neck and back fully flexed. Flexion facilitates the course of the needle through the widened gaps between adjacent lumbar spinous processes.

3.2 Wash hands

3.3 Clean skin – Prepare the area with an antiseptic solution.

3.4 Determine site of insertion: A line joining the posterior superior iliac crests (most cephalad part of both iliac crests) will intersect the midline at L4/L5 interspace (Tuffier's line)[15,26]. The space above L4 is therefore L3/L4 and below L4/L5. Both these spaces are below the termination of the spinal cord at L1/L2 in the majority of adults[26]. In a small percentage of people, the spinal cord may extend down to L2/L3. The exact space used influences the segmental anesthetic level.

3.5 Infiltrate skin and deeper subcutaneous tissue with anesthetic solution – Solution may also be deposited in the area of the interspinous ligament and even deeper in a vertically fanning distribution on both sides of the spinous process. This anesthetizes the recurrent spinal nerves innervating the muscle and interspinous ligament.

3.6 Insertion of needle:

i) Use index and thumb to hold the skin taut, push the lumbar needle through the skin, exactly in the midline[26].

ii) The puncture may be performed through the L3-4 or L4-5 interspace in adults.
Insert the needle at the superior aspect of the spinous process that lies inferior to the space to be entered. Aim for the umbilicus (15 degrees cephalad) if the L4/5 interspace is used[19]. The spinal cord ends at L3 in children. Therefore it is recommended that L4/5 or L5/S1 is used in children.

iii) The bevel should be in the sagittal plane so as not to cut the longitudinal fibres of the dura mater, diminishing injury to the dura mater by separating the fibres of the dura, rather than cutting through them. This will reduce leakage of CSF.

iv) Pass the needle through the supraspinous ligament, which connects the spinous processes and the interspinousal ligaments which connect adjacent borders of spinous processes.

v). Pass the needle through the ligamentum flavum – feel a 'pop' as it is penetrated. In older patients the ligament may provide significant resistance since it is often calcified. The resistance of the ligamentum flavum is felt at a depth of 4-7 cm.

vi) After entering the ligamentum flavum, remove the stylet at each 2mm interval of needle advancement to check for flow of CSF.

vii) A second 'pop' represents penetration through the dura mater into the subarachnoid space.
If bone is encountered – withdraw the needle partially to the subcutaneous tissue. Repalpate the back to make sure the needle is in the midline. If bone is encountered again, slightly withdraw the needle and re-angle with point angling more superiorly.

viii). Clear fluid will appear if the subarachnoid space is penetrated. If not, it is worth rotating the needle through 90 degrees as the opening at the end of the needle may be obstructed by a nerve root[32].

ix). The subarachnoid space will be entered well below the spinal cord. The needle will push isolated nerves of the cauda equina to the side during advancement.

3.7 Connect the manometer and read the pressure while holding the manometer tube perpendicular to the spinal needle. A normal value for a relaxed patient is 80-200 mm CSF. This can be slightly higher in an anxious patient, but values above 200mmCSF are abnormal. Manometer readings can only be performed in the lateral decubitus position. The zero-mark is at the level of the spinal needle.

3.8 Caveat: Do not have more than 3 attempts in any single interspace before either obtaining assistance from a senior colleague or proceeding to another interspace. Never try to aspirate CSF. This may have serious neurological consequences[32].

3.9 Removal of the spinal needle. It has been said that reinserting the stylet before needle removal helps prevent post spinal headache. This reduces the risk that a frond of arachnoid will be pulled out and prevent closure of the dural puncture defect[19].

Alternative method: Lateral approach

This method may be used in case of calcification of the supraspinous ligament in older persons, complicating a midline approach. The needle is inserted in the paramedian line and is angled horizontally and not towards the umbilicus.
The needle passes through skin, superficial fascia, fat and dense posterior layer of the thoracolumbar fascia and erector spinae muscles, ligamentum flavum, epidural space, dura and enters the subarachnoid space.
In this way the supraspinous and interspinous ligaments are bypassed.

4. Materials

- Sterile gloves.
- Antiseptic solution.
- Skin-marker pen.
- Spinal needle (atraumatic needle 20-gage needle in adults, 22-gage or smaller in children).
- Three way stopcock, manometer.
- 4 specimen tubes.
- Local anesthetic solution and needles.
- Sterile drapes.

5. Anatomical pitfalls

5.1 Needle pierces in order:

- Skin, subcutaneous tissue, supraspinous ligament, interspinous ligament, ligamentum flavum, epidural space with posterior intervertebral venous plexus, dura, arachnoid and eventually the subarachnoid space.

5.2 Lumbar vertebra

- Spinous process, lamina, superior articular process, inferior articular process, lamina and facet joint. The needle may be stopped by these bony structures if the needle is not placed exactly in the midline. The spinous processes of lumbar vertebrae project horizontally backwards, in contrast to those in the thoracic vertebrae.

5.3 Tuffier's line[15]:

- A line joining the posterior superior iliac crests (most cephalad part of both iliac crests) will intersect the midline at L4/L5 interspace.

5.4 Lumbar lordosis[19]

- The normal lumbar lordosis narrows the interspace between adjacent spinous processes and laminae. To overcome this the patient is positioned in a fetal-like position with the hips and knees flexed as well as the vertebral column. In the sitting position the patients leans forward with the head flexed. These positions open up the interspaces between the spinous processes and laminae to facilitate spinal needle advancement.

5.5 External vertebral venous plexus

- The posterior part of the external vertebral venous plexus is located in the epidural space and may be involved in a bloody tap. The internal vertebral venous plexus forms a ring around the cord.

5.6 Nuchal rigidity

- This sign is seen in children older than 3 years and involves the posterior group of longitudinal neck muscles. This sign is distinguished from primary pain in the cervical muscles by the usual preservation of lateral movement in meningeal irritation.

5.7 End of spinal cord

- **Adults:** The vertebral level at which the spinal cord terminates varies widely from T12 tot L3/L4 intervertebral disc[24]. The spinal cord extends to the L1-2 disc in 51% of people and to the L2-3 disc or below in 12%[15]. Reimann *et al* [24] studied the termination of the spinal cord in 129 cadavers which became the standard reference for the vertebral level of the termination of the spinal cord: The mean level of the spinal cord lies opposite the disc between the first and second lumbar vertebra. One sacral cord is described by Reimann *et al* [24]. In a recent MRI study including 136 adult scans, MacDonald *et al* [28] showed that the median level of termination of the spinal cord for both males and females was the middle one-third of the first lumbar vertebra, a higher level than usually stated. This ranged from the middle one-third of T11 to the middle one-third of L3. It is important to note that only 25% of cords ended below the disc between L1 and L2, compared to the 49% of cords below this level in the cadaver study done by Reimann[24]. Due to the great enhancement of the understanding of human anatomy by MRI, and the problems of shrinkage and as most cadavers are those of elderly patients, this new modality is widely recognized as the gold standard for demonstrating the anatomy of the lumbosacral region. The advantages of MRI are the fact that the anatomy of live healthy subjects can be studied, the age range is wider and the spinal cord can be studied in the supine position[28].

- Puncture may be performed from L3/L4 interspace to L4/L5 interspace[27]. The conus medullaris can be as low as L2 and L3, even as far as midway along the body of L3. Therefore it is recommended that the L3/4 or L4/5 interspace are used as the entry site[19].

- **Infants**: The spinal cord ends at L3. Needle placement should therefore be at L4/5 or L5/S1.

The differences in adults and children are due to longitudinal growth of the spinal canal and cord growth not keeping up to this.

5.8 Height of anesthesia

- The height of anesthesia is related to the level of lumbar puncture. An anesthetic level as high as T1 may be reached with intradural anesthesia where the L2-3 interspace is used, but only up to T6 when performed at L4-5 level[25].

5.9 Meninges

- **Dura mater** – The dura mater lines the spinal canal to the level of S2. MacDonald *et al* [28] found in their MRI study, that the median level of termination of the dural sac was the middle one-third of S2. The upper one-third of S2 was the median level for males and the middle one-third of S2 for females. They determined a range extending from the upper border of S1 to the upper border of S4.

- **Arachnoid mater** – The arachnoid mater lines the dural sac to the level of the middle one-third of S2[28].

The subarachnoid and epidural spaces are related to the meninges and also continue down to S2 at the level of the posterior superior iliac spine (PSIS) also called the dimple of Venus.

- **Pia mater-** The pia mater leaves the spinal cord at the conus medullaris to form the filum terminale, traversing the subarachnoid space and terminating on the periosteum of the coccyx, after penetrating the dura and arachnoid at level S2.

5.10 Lumbar cistern

- This cistern represents the expansive portion of the subarachnoid space inferior to the spinal cord, where the spinal needle can be safely introduced[19]. Within the cistern run the dorsal and ventral roots of L2 to Co1 (coccyx 1) as the cauda equina, before exiting the vertebral canal through their respective intervertebral foramen.

5.11 Epidural space

- There is debate in the literature whether the epidural space is an actual or potential space. Parkin *et al* [31] concludes in a cadaver-based study that the use of the term space is meaningless and confusing as it implies that there is an open space where there does not exist one. A space is only artificially created when the dura is separated from the vertebral canal by solutions as local anesthetics. Newell[29] refers to the space as a potential space lined by a mesothelial layer, which can be easily opened without tissue damage. It contains the internal venous plexus, epidural fat and bands of fibrous tissue connecting the dura to the vertebral canal. Routine diagnostic MRI studies indicate the space to be completely filled with tissue with a signal matching that of fat[29].

5.12 Cauda equina

- The cauda equina represents the anterior and posterior roots of the lumbar and sacral nerves.

5.13 Ligamentum flavum

- The ligamentum flavum forms a strong elastic yellow membrane. It can be up to 1 cm thick in the lumbar region and covers the interlaminal space between adjacent vertebrae. It helps the paraspinous muscles to maintain an upright position. Fibres are stretched in the flexed position and can be more easily crossed by the spinal needle. If the needle is exactly in the midline, it will go between the two ligaments, which spans the space between the laminae of adjacent vertebrae.

  In a flexed spine, the extent of the ligamentum flavum that is exposed is much greater compared to the extended spine[26].

5.14 Children

- Beware of a too long a period of flexion of the neck while positioning the child, for this may produce dangerous airway obstruction.
- Positioning is best accomplished by an assistant overlying the child and maintaining the spine maximally in a flexed position by holding the child behind the shoulders and knees. Make sure to maintain the airway.
- Newborn and premature babies may experience severe hypoxia, so a sitting position is preferable[2].

6. Complications (anatomically relevant)

6.1 Traumatic tap

- A traumatic tap usually occurs due to too lateral placement of the needle. The posterior external vertebral venous plexus in the epidural space may be involved in a bloody tap. A traumatic tap is defined as a tap containing macroscopic blood[14].
- A traumatic tap should be distinguished from a subarachnoid hemorrhage. Fluid generally clears after the first and second tubes in a traumatic tap. The presence of a clot in one of the tubes strongly favors a traumatic tap. Clotting does not occur in a subarachnoidal hemorrhage due to defibrinated blood being present in the CSF.
- Entry of the internal or external vertebral venous plexi, poses a slight risk of neurological symptoms, as clots may compress the spinal nerve roots or nerves[19].

6.2 Dry tap

- A dry tap is usually due to incorrect positioning of the patient and misdirection of the needle. The needle is often advanced onto bony structures. This is often due to a too cephalad direction of the needle, with obstruction by the lamina or spinous process of the superior or inferior vertebrae. If the needle is directed too laterally, an inferior or superior articular process may provide obstruction. A too lateral approach may also injure the spinal nerve root in the intervertebral foramen[19].

- The back may also not be fully flexed, with the gaps between the lumbar spinous processes not widened[26].

- If only one iliac crest is used to locate L4, 30% of needles are misplaced at L2-3. This high misplacement figure is diminished to 4% if Tuffier's line is used to determine L4[15], as determined by a cadaver study. By physically defining Tuffier's line, too high placement of the needle will be avoided, decreasing the risk of injuring the spinal cord.

- If bony resistance is encountered, remove the needle to the subcutaneous layer, change the angle, make sure to be in the midline and readvance. If no CSF emerges, rotate the needle 90 degrees, as a nerve root may be lying across the end. If there is still no fluid, replace the stylet and advance the needle a millimeter or two.

If firm resistance is encountered, do not force the needle, as it may be against the bone or an intervertebral disc.

- A low pressure may indicate that flow in the spinal canal is impaired. This is the case in spinal lesions or with cerebellar tonsillar impaction. No attempt should ever be made to aspirate CSF. This may cause neurological damage[32].

6.3 Difficulty to find landmarks

- Difficulty in finding the landmarks may be experienced in obese patients and in patients with osteoarthritis where osteophytes may impede access to the spinal canal. This may also be the case in patients suffering from ankylosing spondylitis and kyphoscoliosis[26].

6.4 Headache

- Headache is the most common complication of lumbar puncture[8].

- Headache occurs in 5-30% of spinal taps[4,17]. Usually it starts 48 hours after the procedure[20] and may last up to 1 to 2 days and even two weeks. The headache starts with rising and disappears in the recumbent position. The longer the patient is upright the longer it takes before the headache subsides[20]. Head shaking and jugular vein compression worsens the headache. A frontal, occipital or diffuse headache may occur, but the typical localizations are occipital, at the vertex, or posterior to the eyes[8].
  Most patients recover in a week's time.
  Sometimes it is accompanied by nausea, vomiting, vertigo, tinnitus, diminished hearing and blurred vision.

- The reason for the headache is due to leakage of CSF through the dural puncture site into the epidural and paravertebral spaces faster than the production rate of CSF[5,8]. The incidence of headache after lumbar puncture is directly related to the size of the needle and therefore the dural puncture site[5]. This leads to low CSF pressure and traction on pain sensitive structures in the cranial cavity, especially the pain sensitive basal dura. Dura mater is richly innervated with adrenergic, cholinergic and peptidergic fibres[20].
  Another postulate is that the headache is due to an absolute reduction of CSF volume below the cisterna magna decreasing the supportive cushion of the brain[20]. The result is downward movement of brain tissue with stretching of pain sensitive structures, like meninges and vessels. The loss of CSF causes a compensatory dilatation of the cerebral vasculature[8]. Relief in the recumbent position is due to upward movement of the weight of the brain.
  A decrease in CSF volume leads to labyrinth changes, which may account for the diminished hearing, tinnitus and vertigo occasionally associated with the headache[20].

- The following risk factors for a post lumbar puncture headache are listed: female, lower body mass index, young age, large needle size, beveled needle type compared with pencil-point needle of same size, bevel of needle cutting longitudinal dural fibres[7] and multiple punctures.

- The pencil-point needle separates, rather than cuts through the dural fibers, giving a lower incidence of post lumbar puncture headaches[18]. The pencil point needle (22-25 gauge) is indicated for spinal anesthesia, but not for diagnostic use, as they do not allow free flow of CSF with resultant difficulty to obtain sufficient fluid.

- The size of the needle used and therefore the dural rent seems to correlate with the frequency of post lumbar puncture headaches[5, 7]. The incidence of headache is smaller if a thinner needle is used. Headache is also milder when the thinner needle is used. The thinner needles make manipulation of the needle tip more difficult because of intermittent obstruction by nerve root filaments[5].

- Position during performance of the procedure was not found to influence the incidence of the headache[6]. Brocker[7] however reported in a controlled study of 894 patients that the incidence of post lumbar puncture headache is reduced from 36.5% to 0.5% by having patients lie in a prone position for 3 hours after the puncture. This, according to him, causes hyperextension of the spine and disrupts alignment of the holes in the dura and arachnoid and releases the tension on the dura. Brocker[7] convincingly shows that the dura migrates cephalically during extension and comes in closer contact with the bony elements and therefore obliterates the epidural space.

Prevention:

- The smallest possible atraumatic needle with a stylet should be used and multiple punctures should be avoided.
  Prolonged bed rest does not reduce the incidence of post lumbar puncture headache [6,17]. This was the finding in a randomized study of 110 patients, where the effect of immediate mobilization with 4 hours bed rest was compared to agroup with prolonged bed rest after a first diagnostic lumbar puncture. There was no significant difference between the groups.

- An epidural blood patch can be placed, stopping the CSF leak and increasing the CSF pressure[8] by compressing the spinal dura. This has become the most rapidly effective measure for terminating post lumbar puncture headache. 10-20 ml autologous blood is injected epidurally and spreads over nine spinal segments, six upward and three downward[20]. The needle is placed at the same level as the previous lumbar puncture into the epidural space. Patients may suffer transient paresthesias in their lower extremities after the blood injection. Accidental injection of blood in the subarachnoid space may cause a chemical meningitis. Blood usually clears in 1-4 weeks from the CSF and usually has no major neurological complications[8].

- Adequate hydration may reduce the incidence of post lumbar puncture headache [20].

- It has been suggested that the incidence of post lumbar puncture headache may be reduced by removing the needle when the patient is prone in Trendelenburg's position. The hydrostatic pressure in the lumbar subarachnoid space is negative in this position. Therefore, when removing the needle, there is inversion of the dural puncture site instead of eversion. Maintaining the patient in this position for 60 minutes ensures sealing of the dural hole[20,23].

6.5 Herniation syndromes

- Large pressure gradients exist between the cranial and lumbar compartment in supratentorial mass lesions. By lowering the pressure in the spinal compartment by performing a lumbar puncture transtentorial and foramen magnum herniation may occur[22]. Duffey[10] reported on 30 patients with post-lumbar puncture herniation syndromes of which half lost consciousness immediately after the lumbar puncture. The role of lumbar puncture in the subsequent deterioration was not clear. Other studies report very low complication rates. Zisfein *et al* [11] report 38 patients with CT documented intracranial lesions (distortion of ventricles, cisterns or sulci by hematomas, abscesses, subdural collections and tumors), who underwent lumbar puncture, with low complications. They conclude that lumbar puncture carries little measurable risk to most patients with CT-documented intracranial mass lesions. Pre-existing tentorial herniation is however a contraindication for the performance of a lumbar puncture. This can easily be diagnosed by findings of pupillary and oculomotor fixation, quadriparesis, posturing and respiratory changes.

- **Anatomy of herniation**

  The decrease of pressure in the lower spinal segment precipitated by performing a lumbar puncture and removing CSF, will cause downward movement of the transtentorial and tonsillar structures[12]. Therefore anybody is at risk of herniation during a lumbar puncture. Gower *et al* [12] points out that those with a pressure gradient between the intracerebral and intraspinal CSF are at a greater risk of herniation.

  i) Uncal herniation – expanding lesions in the temporal cranial fossa shift the medial temporal lobe medially over the notch of the tentorium and compress the midbrain, peduncle and third cranial nerve. The third cranial nerve and posterior cerebral artery are caught between the swollen uncus and the free edge of the tentorium. The earliest sign is a slightly dilated pupil unilaterally. Impaired consciousness is not consistently present.
  ii) Tonsillar herniation – The cerebellar tonsils compress the medulla at the foramen magnum.
  iii) The anterior cerebral artery may be compressed against the falx and increases ischemia and edema.
  iv) Posterior midline displacement compresses the deep great cerebral vein.
  v) Compression of the posterior cerebral artery at the tentorial notch can produce occipital infarction.

vi) Kinking of the aqueduct may interfere with CSF drainage.
vii) Transtentorial herniation displaces the brain stem inferiorly, stretching the medial perforating arteries of the basilar artery, which produces brainstem ischemia.
viii) Transient unilateral or bilateral sixth nerve palsy may be caused by stretching of the abducent nerve as it crosses the petrous ridge of the temporal bone.

- **Prevention:** A CT-scan should first be performed if there is any indication or history suggesting raised intracranial pressure[12].
  A careful neurological examination should precede any lumbar puncture.

- The decision to perform a lumbar puncture is based on risk-benefit analysis. Failure to perform a lumbar puncture in the case of meningitis may be fatal if there is delay for example waiting for CT- results. It may be difficult to distinguish between herniation and bacterial meningitis, as the latter can produce similar signs. If either condition cause herniation this may result in papilledema, pupil inequality, stupor, seizures and focal neurological deficits.

- No more than 3-6 ml of CSF should be collected[12].

- **CT findings suggesting raised intracranial pressure :**

  - Lateral shift of midline structures (septum pellucidum and third ventricle). Gower[12] points out that asymmetry of the lateral ventricles alone, may not give an accurate assessment as ipsilateral ventricle dilatation may occur secondarily to a stroke or there may be coaptation of a frontal horn which may be a normal anatomical variant.

  - Loss of suprachiasmatic and basilar cisterns. Loss of these cisterns, reflect symmetrical supratentorial pressures higher than infratentorial pressure.

  - Obliteration of the fourth ventricle. This is strongly suggestive of a posterior fossa mass, which if present is the strongest contraindication to perform a lumbar puncture. Removal of a small amount of CSF from the spinal compartment may result in the cerebellar tonsils moving into the foramen magnum and causing tonsillar herniation. The posterior fossa and foramen magnum are difficult to visualize with CT. Therefore obliteration of the fourth ventricle should be regarded as highly suspicious of a posterior fossa mass.

  - Failure to visualize the superior cerebellar and quadrigeminal plate cisterns with sparing of the ambient cistern. These findings suggest upward herniation.

6.6 Pain referred to the lower limb

- If the patient complains about a shooting pain down a leg during the procedure, a nerve may have been hit. The needle was probably angled away from the midline towards the side of the pain. If this happens, the needle should be withdrawn completely and the procedure started again.

- Do not withdraw the plunger of a syringe if it is attached to the needle or when injecting anesthetic solution. The negative pressure may pull a spinal nerve root against the needle tip and produce paresthesia, pain or injury[19].

6.7 Infection

- It is very difficult to distinguish between spontaneous meningitis and lumbar puncture induced meningitis. The risk for lumbar puncture induced meningitis is higher in the presence of a bacteremia in children under one year of age[9]. A lumbar puncture must however be performed on any child in whom meningitis is suspected, due to its mortality and sequelae.

6.8 Subdural hematoma

- In elderly people, the removal of a large volume of CSF may result in a tear or avulsion of a perforating vein.

6.9 Backache

- Transient sensory symptoms due to irritation of individual nerve roots of the cauda equina are common and present as a shooting pain. The patient may feel momentary discomfort, but the nerve root will be pushed away by the point of the needle and is not damaged.

- Disk herniation has been reported due to the needle passing beyond the subarachnoidal space into the annulus fibrosis, with resultant rupture of the nucleus pulposus[30, 32].

- Multiple attempts may lead to paraspinal muscle spasm, presenting as backache.

6.10 Retroperitoneal abscess

- One case of a retroperitoneal abscess is reported, produced by dural laceration in a patient with meningitis[13]. The patient developed a psoas abscess due to extravasation of infected CSF into the retroperitoneal space.

6.11 Unexpected abnormal raised CSF pressure

- If an abnormally high pressure is encountered, collect the fluid from the manometer and withdraw the needle. Obtain intravenous access in case it may be necessary to give mannitol and contact expert neurological help.
  Jugular compression (Queckenstedt test) should not be performed for it is dangerous[16].

6.12 Hypoxia and ventilation-perfusion mismatches in children

- Gleason *et al* [3] demonstrated that performing a lumbar puncture on an ill, premature baby using the traditional recumbent position with neck flexion, may result in significant respiratory ventilation-perfusion imbalance leading to hypoxemia. They recommend that the neck should not be flexed, but extended or the infant should be in the upright position[3].

- One cause of clinical deterioration is compression of the diaphragm during flexion rather than upper airway obstruction. This could also be avoided by performing the procedure in either the sitting position or with the neck in extension[21].

- Weisman *et al* [2] compared the grade of hypoxemia in three different positions. The sitting and lateral position without knees-to-chest position experienced less hypoxemia than those in the lateral knees-to-chest position. The neck should be kept in the neutral position.

6.13 Interspinal epidermoid tumor

- This complication usually arises due to the failure to use a stylet[1]. This tumor constitutes a mass of desquamated cells containing keratin, causes by viable epithelial cells introduced into the spinal canal by the spinal needle. Skin tissue can easily be excised by a hollow needle and then implanted into the subarachnoid space. The stylette should not be removed until the needle tip has passed the skin[1]. Congenital lesions are rare, and arise from epithelial tissue becoming sequestrated at the time of closure of the neural groove in week 3 to 5. Unstyletted lumbar puncture needles should be avoided[21].

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4.4.1.4 Central venous catheterization (subclavian and internal jugular vein)

1. Indications[29, 45]

- Emergency care patients needing fluid status monitoring after initial fluid resuscitation.
- Severely injured patients for venous access.
- Patients needing central venous pressure monitoring.
- Patients needing various infusions of fluid, medication, chemotherapy or temporary pacemakers
- Patients needing intensive care with regular blood specimens and blood transfusions.
- Patients needing total parenteral nutrition.
- Route to obtain vascular access once peripheral sites are exhausted, especially in children[35].

2. Contraindications

- Distortion of local anatomy or landmarks.
- Suspected injury to the superior vena cava with penetrating wounds of the thorax.
- Bleeding diathesis or anticoagulation therapy.
- Pneumothorax or hemothorax on the contralateral side.
- Previous radiation therapy to the clavicular area.
- Subclavian route not recommended in small children.

- Relative contraindication: Left side catheterization due to the thoracic duct on the left side which if punctured may cause a chylothorax with high morbidity.

- Cervical trauma with distortion of the anatomy at the entry site or swelling.

- Lack of experience.

- Presence of apical bullous disease or patients with emphysematous lungs[15].

3. Step by Step procedure

3.1 Subclavian vein [13, 14, 15, 43]

1. Place the patient in a supine position, at least 15 degrees head down (Trendelenburg's position), to distend the neck veins and prevent air embolism. Only if the cervical spine has been cleared radiographically can the patient's head be turned away from the puncture site[59].
2. Clean the skin surgically and drape the area. Sterile gloves should be worn during the procedure.
3. Use a local anesthetic if the patient is awake.
4. Introduce a larger caliber needle attached to a syringe, 1 cm below the junction of the middle and medial thirds of the clavicle.
5. Direct the needle medially and slightly superiorly to stay on the inferior border of the clavicle, in the direction of the suprasternal notch where the index finger of the other hand is placed.
6. Slowly advance the needle until its tip comes in contact with the inferior border of the clavicle[12], while gently withdrawing the plunger of the syringe.
7. It is then gently advanced on the inferior border of the clavicle until the vein is entered. When free flow of blood appears, remove the syringe and occlude the needle with a finger to prevent air embolism. With newer catheter packs, the guidewire can be inserted via a separate port and the needle does not need to be removed.
8. Insert the guidewire and remove the needle. Then insert the catheter over the guidewire.
9. Remove the guidewire and connect the catheter to the intravenous line.
10. Fix the catheter in place. Subcutaneous fixation is easier to perform in the pectoral region than in the neck region[8].
11. Attach the central venous pressure set-up to the intravenous tubing and adjust the manometer to level zero with the level of the patient's right atrium.
12. Obtain a chest X-ray to identify the position of the tip of the catheter and a possible pneumothorax.
13. Obtain free flow intravenous fluid with gravity and flow of blood through the catheter tubing on lowering the intravenous fluid bag below the level of the patient.

3.2 Internal jugular vein [43]

1. Place the patient in the supine position, 15 degrees Trendelenburg's position, to distend the veins of the neck and thus preventing air embolism. Only if the cervical spine has been cleared radiographically can the patient's head be turned away from the puncture site[59], not more than 30° to the opposite side[14].
2. Clean the skin around the puncture site and drape the area. Sterile gloves should be worn during the procedure.
3. Use a local anesthetic if the patient is awake.
4. Locate the carotid artery by palpation in the space between the trachea and sternocleidomastoid muscle. Thereafter do not palpate the carotid pulse again[14]. The vein is located immediately lateral to the carotid pulse[56]
5. Introduce a large caliber needle attached to a syringe into the center of the triangle formed by the sternal and clavicular heads of the sternocleidomastoid muscle and the clavicle.
6. Direct the needle inferiorly, parallel to the sagittal plane, 30-45 degrees posterior with the frontal plane. The needle should be advanced inferiorly and slightly laterally towards the anterior end of the first rib behind the clavicle.
7. Slowly advance the needle while gently withdrawing the plunger of the syringe.
8. When free flow of blood appears, remove the syringe and occlude the needle with a finger to prevent air embolism.

   Alternative method[32]: Find a point one-third of the distance along the line between the sternal head of the clavicle and the mastoid process, just lateral to the sternocleidomastoid muscle[32]. At this point the external jugular vein (which should not be used due to its valves) crosses over the sternocleidomastoid muscle. Introduce the needle and cannula at an angle of 30 to 40 degrees to the skin, deep to the sternocleidomastoid muscle and advance inferiorly and medially towards the suprasternal notch until entering the internal jugular vein at a depth of 2 to 3 cm[12, 15]. The needle is hence advanced through skin, superficial fascia, platysma muscle and deep cervical fascia.
9. Insert the guidewire and remove the needle. Then insert the catheter over the guidewire.
10. Remove the guidewire and connect the catheter to the intravenous line.
11. Fix the catheter in place.
12. Attach the central venous pressure set-up to the intravenous tubing and adjust the manometer to level zero with the level of the patient's right atrium.
13. Obtain a chest X-ray to identify the position of the tip of the catheter and a possible pneumothorax.
14. Obtain free flow intravenous fluid with gravity and flow of blood through the catheter tubing on lowering the intravenous fluid bag below the level of the patient.

Advantages:

- Slightly fewer complications compared to the subclavian route, but a slightly higher incidence of failure[13, 30].
- Chest compressions during CPR can continue.
- Bleeding complications are more easily detectable and compression can be applied.

The internal jugular vein is compressible at the insertion site whereas the subclavian vein is not.

- Less risk of a pneumothorax.
- Malpositioning is rare (almost a straight course to the superior vena cava on the right).

4. Materials

- Sterile pack with gloces.
- Lignocaine 1%.
- 25-ga needle with 5cc syringe.
- Central intravenous fluid set.
- Central venous catheter and insertion set.
- Nylon sutures.
- Needle holder.
- Suture scissors.

5. Anatomical pitfalls

5.1 Subclavian vein

- The subclavian vein has a large diameter (1 to 2 cm) and stays patent even in the case of hypovolaemia. This is due to the connective tissue around it, attaching it to surrounding structures[3, 60]. The vein is 3-4 cm long in the adult[29, 45]. The problem with this vein is its association with immediate intrathoracic complications and close relation to the subclavian artery and brachial plexus, which are just posterior to the anterior scalene muscle[43]. Furthermore in the case of bleeding, controlling the bleeding is a problem due to the overlying clavicle.

- The vein lies posterior to the medial third of the clavicle. No valves are found in the vein. The subclavian vein joins the internal jugular vein to form the brachiocephalic vein posterior to the sternoclavicular joint. The angle of the subclavian vein joining the internal jugular vein is 90 degrees or greater[44].

- Anterior to the vein are the clavicle and subclavius muscle. Posteriorly lie the anterior scalene muscle, subclavian artery and brachial plexus. Inferior is the first rib and the apical portion of the pleura. Sometimes the subclavian vein appears to be sunken into the apex of the pleura. Before it is joined by the internal jugular vein to form the brachiocephalic vein on both sides, the external jugular vein drains into it and the right lymphatic duct on the right and thoracic duct on the left[60].

5.2 Internal jugular vein

- The internal jugular vein is most frequently used for central venous catheterization[60].

- Its surface anatomy is represented by a straight line connecting the mastoid process and the medial end of the clavicle.

- Posterior to the vein are the transverse process of the atlas, medial and anterior scalene muscles and cervical plexus in the upper neck. More inferiorly the phrenic nerve, thyrocervical trunk and first part of the subclavian artery are found posterior to the internal jugular vein.

- Medially lie the common carotid artery and vagus nerve.

- Anterior lie the sternocleidomastoid muscle in the mid-neck and the omohyoid muscle crosses the vein in the base of the neck.

- The internal jugular vein has a large diameter, is easy to locate and has a short straight route to the superior vena cava, especially on the right. The problem with this vein is its connection with intrathoracic complications and its close relation to the common carotid artery. It has an anterolateral relation to the common carotid artery throughout its course[14]. As the vein approaches the supraclavicular junction with the subclavian vein, it takes a more medial position in the triangle between the two heads of the sternocleidomastoid muscle.

- The brachial plexus is separated from the internal jugular vein by the anterior scalene muscle. The phrenic nerve is anterior to the anterior scalene muscle and the stellate ganglion lies anterior to the lower brachial plexus.

- The vessel is more distensible than the subclavian vein, which is shown by narrowing of the diameter of the vein with prolonged palpation of the carotid pulse[36]. The diameter of the internal jugular vessel is greatest below the cricoid cartilage, where it may reach 2 to 2.5cm[14].

- A head-down tilt of 14 degrees (Trendelenburg position) causes significant distension of the vein. Both extensive palpation of the neck and rotation of the head increases the difficulty to cannulate the vein. Extensive palpation of the carotid artery, may distort the anatomy. Therefore, Bazaral *et al* [14] recommends that after locating the artery, palpation should be discontinued.

- The internal jugular vein is more collapsible compared to the subclavian vein[52]. This may complicate catheterization. The advancing needle may press the anterior wall of the vein against the posterior wall. This may result in passing the needle through both walls without locating the lumen. If no blood is found after advancing the needle at a depth of 2.0-2.5 cm, the needle should be withdrawn and therefore reestablishing a lumen by drawing the anterior wall from the posterior wall.

- The right internal jugular vein is preferred due to its straight course into the superior vena cava and right atrium, which facilitates successful and correct placement of the catheter[60].

5.3 Patient position

5.3.1 Subclavian vein

- **Turning of the head** – Turning the head should only be done if a possible neck injury has been excluded. Anatomical studies have not confirmed that a head turned away from the site of insertion is beneficial to the insertion of a catheter, either by increasing the diameter of the vein or by influencing the relation of the subclavain vein to the clavicle[44]. Turning of the head may however decrease the risk of contamination and patient anxiety during the procedure[13]. One author states that the acuteness of the angle of the subclavian-internal jugular vein is increased by turning the head [44].

  In a very well performed study, Jesseph *et al* [44], showed by means of anatomical dissection and MRI, that the traditional recommendations of positioning the patient with the shoulders retracted and the head turned away, actually distort the anatomy of the subclavian vein, making successful cannulation of the vein more difficult. They suggest a position of lying supine with the head and shoulders in a neutral position. This is a favorable position considering the fact that many patients needing a central venous catheter in the emergency department have suspected neck injuries where manipulation of the head is totally contraindicated.

  The angle of the subclavian vein with the internal jugular vein is more or less 90 degrees[44], and increases when the head is turned to one side. This suggests that turning the head away from the side of the puncture may in fact promote malpositioning in the internal jugular vein. Turning the head towards the site where the procedure is performed may prevent the advancing catheter from moving into the internal jugular vein.

- **Retraction of the shoulders** - Retracting the shoulders by placing a sand bag or rolled towel between the scapulae of a patient, decreases the space between the clavicle and the first rib, making catheterization of the subclavian vein more difficult[13, 29]. It is therefore better to keep the shoulders in the neutral position.

- The patient should be positioned in the Trendelenburg position. This facilitates filling of the vein and decreases the risk of air embolism[60].

5.3.2 Internal jugular vein

- Rotation of the head will not change the size of the internal jugular vein significantly. Full neck extension also reduces the diameter of the vein considerably. Armstrong *et al* [36] demonstrated in a study of 35 people, that the mean size of the internal jugular vein in the normal position is 11.5mm. There was poor correlation between neck size and diameter. The vein was located lateral to the common carotid artery in most cases, but was anterior to the artery in two cases and anterolateral to the artery in 12 cases. The anterolateral position of the vein to the artery increased to 25 cases when the head was turned to the opposite side.

- Head position has been found to alter the relative position of the internal jugular vein but not the size of the vessels except for full neck extension where the diameter of the vein is reduced considerably. Use of the Trendelenburg position and the Valsalva maneuver both increased internal jugular vein size[36]. The Valsalva maneuver had greatest effect on the vein diameter due to its increase of intrathoracic pressure.

5.4 Direction of the needle

5.4.1 Subclavian vein

- 1cm below and 1 cm lateral to the junction of the middle and medial thirds of the clavicle. The needle is advanced toward the tip of the opposite index finger, which is placed deeply in the suprasternal notch. The direction of the needle is now aligned with the central axis of the subclavian vein, minimizing the risk of puncturing the subclavian artery, pleura or apex of the lung[29]. By keeping the needle in a horizontal plane, the risk of arterial or pleural injury is minimized[60].

- On its course the needle goes through skin, superficial fascia, the subclavius muscle, clavipectoral fascia and subclavian vein.

5.4.2 Internal jugular vein

- The needle is inserted at the apex of the triangle formed by the sternal and clavicular heads of the sternocleidomastoid muscle. The apex is situated approximately 5 cm superior to the clavicle. The vein lies at a depth of 1.0-1.5 cm below the skin between the sternocleidomastoid muscle and the cervical pleura. The needle should be directed in a caudal direction at an angle of 30- 45 degrees to the frontal plane, keeping the needle parallel to the sagittal plane. This ensures that the needle is directed along the central axis of the vein[52].

- Bazaral *et al* [14] suggests a needle insertion at or above the cricoid cartilage. The needle should be inserted at a 30-40 degree angle to the skin, expecting the internal jugular vein 1-2 cm inferior to the cricoid cartilage ring at a depth of 1-1.5 cm. The head should not be extremely rotated, which may cause the sternocleidomastoid muscle to overlie the vein.

5.5 Phrenic nerve

- The phrenic nerve runs on the anterior surface of the anterior scalene muscle. It lies medial to the attachment of the anterior scalene muscle to the scalene tubercle on the first rib, in contact with the postero-inferior side of the subclavian vein at the junction of the subclavian and internal jugular veins[29]. The nerve may be injured if the needle is advanced too deeply. The internal thoracic artery runs in close relation to the phrenic nerve after branching from the subclavian artery[45].

5.6 Subclavian artery

- The subclavian artery runs posterior to the anterior scalene muscle, and has a superior and more posterior course than the subclavian vein[29].

5.7 Thoracic duct

- The thoracic duct drains into the left subclavian vein, in the angle where the left subclavian vein joins the left internal jugular vein, after running across the anterior scalene muscle[29]. The danger of left cannulation is injury to the thoracic duct, which is a rare complication[34]. However it is associated with high morbidity[48]. Shimada *et al* [59] reports on several branching patterns of the terminal thoracic duct. The most common type drains into the venous angle between the internal jugular and subclavian veins (38%), followed by the type draining into the external jugular vein (28%) and internal jugular vein (27%) and a complex drainage pattern in 7%. The thoracic duct is therefore at risk of injury in both the subclavian and internal jugular routes for central venous catheterization on the left side.

5.8 Right lymphatic duct

- This duct drains into the right subclavian vein, in the angle where the subclavian vein joins the internal jugular vein on the right, also running across the anterior scalene muscle[29] behind the internal jugular vein[45].

5.9 Apex of the lung

- The apex of the right pleura is usually lower than the left[13], making the right side the preferred side (with the thoracic duct found on the left side). If subclavian catheterization fails, first attempt the ipsilateral internal jugular vein, before considering the left side.

5.10 The cervical pleura

- The cervical pleura is covered by the supra-pleural membrane (Sibson's fascia) with surface markings from the junction of the medial and middle thirds of the clavicle to the sterno-clavicular joint. Its highest point can be as high as 2.5 cm above the clavicle[12]. The apical pleura is in contact with the postero-inferior surface of the subclavian vein[29, 45]. Therefore, if a needle is advanced through both walls of the subclavian vein, the parietal pleura, pleural space and lung may be penetrated with a resulting pneumothorax. A concurrent laceration of a blood vessel, will result in a hemothorax.

5.11 Brachial plexus

- All the roots of the brachial plexus (C5-T1) run posterior to the subclavian artery[29, 45].

5.12 Common carotid artery

- The common carotid artery usually lies medial to the internal jugular vein[43], but the position of the vein to the artery varies considerably in children[42] and with the turning of the head to the opposite side[36].

5.13 Correct placement of catheter tip

- The catheter tip should be placed 3-4 cm above the junction of the superior vena cava and the right atrium [1].

5.14 Vagus nerve

- The vagus nerve is located in the carotid sheath, usually behind the internal jugular vein.[29] On a lower level, the vagus nerve lies postero-medial to the jugulosubclavian junction[45].

5.15 External jugular vein

- The external jugular vein crosses over the sternocleidomastoid muscle at a point one third of the distance along the line between the sternal head of the clavicle and the mastoid process. It is separated from the sternomastoid by the cervical fascia and often has one or more sets of valves in its course through the neck [12, 34, 60].

5.15 Anterior scalene muscle

- This muscle is attached to the scalene tubercle of the first rib, with the subclavian vein anterior to it and the subclavian artery and brachial plexus posterior to it[29]. This muscle is approximately 10 to 15 mm thick in the adult and 5 to 8 mm in children[45]. Thus venipuncture of the subclavian vein has less risk of injuring the subclavian artery which lies directly posterior to the anterior scalene muscle and the brachial plexus which lies posterior to the subclavian artery.

5.16 Fascial layers of the neck

- These layers predispose to subcutaneous emphysema and hydromediastinum after both subclavian or internal jugular vein catheterization. Air dissects in the pretracheal fascial layer down into the mediastinum.

5.17 Sternocleidomastoid muscle

- The sternal and clavicular heads of the sternocleidomastoid muscle form an apex where they meet. This apex forms the site of needle insertion for the internal jugular vein[43].

- An alternative insertion site is found at a point one third of the distance along the line between the sternal head of the clavicle and the mastoid process.

5.18 Suprasternal notch

- This is the anatomical landmark towards which the needle is aimed when performing a subclavian vein cannulation[43, 29].

5.19 Superior vena cava

- This central vein varies in length, from 3 to 10 cm, depending on the length of the patient[45]. The junction of the superior vena cava with the right atrium is one-third the distance from the suprasternal notch to the xiphoid process[45]. The tip of the central venous catheter should normally be positioned not more than 3-4 cm superior to the junction of the superior vena cava and the right atrium[1].

5.20 Children

- Cobb *et al* [34] studied the anatomy of the subclavian and internal jugular veins on several autopsies, by measuring the angles of vessels to each other, the distances of the vessels to bony and muscular landmarks, and their diameters.
  In the infant the right and left subclavian veins entered the central venous system at an acute angle. The left brachiocephalic vein joined the right brachiocephalic vein at a right angle. After one year of age, these angles become less acute and have a similar configuration than adults. This may be the reason for the relative ease of cannulating the subclavian vein in older patients, but misplacement of the catheter upwards into the internal jugular vein is often found. This is more often found on the right due to the acute angle of the subclavian vein joining the internal jugular vein, and consequently some authors prefer to use the left hand side[53]. The danger of left cannulation is injury to the thoracic duct, which is a rare complication[34]. However it is associated with high morbidity[48].

- The internal jugular vein however, enters the superior vena cava almost in a straight line. Cobb *et al* [34] suggests that using the internal jugular vein in infants is a safe and reliable route to use for gaining central venous access. There was no significant difference in diameter between the internal jugular and subclavian venous system. The external jugular vein can also be used in children, but Cobb *et al* [34] identified several sets of valves in its curved and nonfixed course. The internal jugular vein may, on the basis of anatomical relationships, be the site of choice in children.

- Mallison *et al* [37] pointed out in an ultrasonographic anatomical study on the position of the internal jugular vein in children, that the internal jugular vein varies in position. In a series of 25 patients, the internal jugular vein was anterior to the common carotid in 14 cases, in 1 anterolateral and in 10 lateral to the common carotid artery at the level of the apex of the two heads of sternocleidomastoid. These relations differed at the level of the cricoid cartilage. This anatomical fact is the reason for a high failure rate of cannulating the internal jugular vein in children, despite the correct identification of anatomical landmarks and palpation of the common carotid artery. Mallison *et al* [37] argues that due to the considerable variation in the position of the internal jugular vein in children, the routine use of ultrasound guidance, if only to locate the vessels, may be sensible. They found a portable ultrasound easy to use and requiring little training.

- Alderson *et al* [42] studied the possible variations of the internal jugular vein, which could account for some of the difficulties during landmark-guided percutaneous cannulation of the internal jugular vein. In 50 patients under 6 years, they found an antero-lateral position of the vein to the common carotid artery in 82% of cases, 10% anterior to the artery, 4 % in the same position as the artery, 2 % widely lateral to the artery and 2% that could not be seen. Eighteen percent of their population group therefore had anatomical factors, possibly complicating a landmark-approach to the internal jugular vein. They also showed that the diameter of the vein correlated poorly with age, weight and height.

- Due to the fact that the subclavian vein in neonates, run more cephalad than in older patients, the needle should be directed midway between the sternal notch and the chin, or 1cm above the sternal notch[35]. The course of the vein becomes less cephalad with an increase in age and weight. The needle should therefore be directed towards the sternal angle in adults.

6. Complications (anatomically relevant)

There are different opinions concerning the complication rate of subclavian and internal jugular vein approaches for central venous access. Moosman[29] holds that the supraclavicular route is more likely to be associated with complications. Other studies show the contrary[13].
The complications for central venous catheterization are summarized in Table 1, a modified version of Hegarthy's classification[27].

6.1 Pneumothorax

- A pneumothorax is the most common complication of subclavian vein cannulation and may be partial, total, bilateral or under tension. It occurs with an incidence of 30% of all complications[45].

- Damage to the parietal pleura due to the surface anatomy of the pleura, 2.5 cm above the first rib. A pneumothorax can usually be avoided if correct technique is used, especially the correct direction of the needle. However, repeatedly deep unsuccessful probings after failure to obtain venous blood clearly raises the chances of injuring the pleural space and producing a pneumothorax. Chest X-ray is mandatory after the

procedure is performed.
Maggs *et al* [15] was one of the first to report on fatalities due to tension pneumothorax, bilateral pneumothorax and combined hemopneumothorax.

- The pleura is only 5 mm directly posterior to the subclavian vein beyond the protective edge of the first rib[46].

- **Prevention:** Adhere to the proper line of needle advancement. If the needle is placed too far posteriorly, the pleural cavity may be entered and the lung lacerated[45]. Abandon the procedure after two unsuccessful attempts. If the puncture and catheterization fails on one side, radiographic exclusion of a pneumothorax is advisable before attempting the other side. Clinical bedside examination may fail to pick up a slowly developing pneumothorax.

  It is important that doctors who perform this procedure should be able to perform an immediate tube thoracostomy if necessary[15]. The major factor in keeping the incidence of a pneumothorax low, is the experience of the person behind the needle. Holt *et al*[50] reports that in a retrospective survey of over 600 subclavian venepunctures, serious traumatic complications occurred in seven patients, six of them in the hands of inexperienced operators (staff who have performed less than 12 supervised cannulations).

6.2 Arterial puncture[27,29]

- Arterial puncture usually involves the **subclavian artery** posterior to the anterior scalene muscle on the first rib. The subclavian artery is intimately located posterior to the subclavian vein[28]. This is the second most common complication of central venous catheterizations (20%). In subclavian vein catheterization the subclavian artery is punctured if the needle is directed too far laterally and posteriorly[45]. It is said to be easily recognized and without sequelae[54].

- Embolization to the carotid and basilar vessels can occur from the subclavian artery. Hurwitz *et al* [28]even reported two patients developing fatal cerebral infarctions after subclavian vein catheterization associated with inadvertent arterial puncture.

- The **common carotid artery** medial to the internal jugular vein in the neck may also be punctured. This artery is punctured in 0.6%-30% of internal jugular vein catheterizations[7]. Usually it responds well to local pressure[45].

- **Ascending aorta.** One study reported the puncturing of the ascending aorta[5], within the pericardial reflection causing a fatal hemopericardium. The patient reported by Childs *et al* [5] had gross abdominal distension, causing superior movement of the intrathoracic structures and therefore change in the classical anatomical landmarks.

- **Pulmonary artery.** Puncturing of this vessel has also been documented[6].

6.3 Hemothorax [27,29,46]

- Due to puncturing a vessel as well as the pleural membrane. A hemothorax usually occurs due to injury to the subclavian vein and direct infusion of blood into the pleural space. A tube thoracostomy is usually required[45].
  Holt *et al* [50] reported a case where an apical branch of the pulmonary artery was lacerated, with resulting hemothorax and requiring a thoracostomy.

6.4 Venous air embolism [27,29,17]

- Venous air embolism can occur with negative air pressure in the thorax with inspiration. If the site of insertion is vertically higher than the level of the heart an air embolism may result[45]. Air moves as a bolus to the heart where it lodges at the pulmonary valve, which may break up due to ventricular contractions and enter the pulmonary circulation, cause tissue hypoxia and lowered cardiac output[55]. Symptoms of tachipnoea, elevated jugular venous pressure (JVP), chest pain and hypotension may be found. The mortality rate is high.

- Flanagan *et al* [17] reports on the fatal outcome of venous air embolism, pointing out that a 14-ga needle can transmit 100 ml of air per second with a 5-cm pressure difference across the needle. It seems that hypovolemic patients are at higher risk of developing air embolism.

- Prevention: Position the patient in the Trendelenburg position. Check catheter equipment, catheter ports, connections etc. There is a higher risk with central catheters due to the connective tissue around the central veins connecting it to surrounding structures. This is especially true for the subclavian vein. The veins therefore stay patent even in hypovolaemia and have a higher risk of air embolism occuring than the peripheral veins which collapse[3]. The needle should be occluded in the interval between removal of the syringe and threading of the guide wire or catheter[27].
  New central venous catheters make this step unnecessary due to the fact that the guide wire is advanced through the syringe.

6.5 Brachial plexus injury[27,29,46]

- With the subclavian and internal jugular vein catheterization the brachial plexus may be injured when the correct technique is not followed and the needle is not directed correctly. The brachial plexus is posterior to the subclavian artery behind the anterior scalene muscle on the first rib. Therefore, a brachial plexus injury is usually also associated with a subclavian artery puncture.
  The brachial plexus with the subclavian artery cross the first rib only 2 cm lateral to the subclavian vein[46].

- Usually the problem is caused by placement of the needle too far laterally and deeply,

injuring the roots of the brachial plexus with consequent motor and sensory deficits of the shoulder, arm or hand[45].
Extensive neurological damage has been reported with internal jugular vein catheterization[31]. This includes damage to a phrenic nerve, the sympathetic chain on the left, the IX, X, XI and XII cranial nerves and the anterior branches 2nd, 3rd and 4th cervical nerves[31].

- Paschall *et al* [32] comments on upper root brachial plexus injury after internal jugular vein cannulation. The patient complained of sensory loss over C5/C6 distribution and loss of motor function of the muscles around the shoulder joint.
  The upper trunk of the brachial plexus (C5, C6) lies at the level of the cricoid cartilage, close to the puncture site of the internal jugular vein. The upper trunk lies in the posterior triangle of the neck and the internal jugular vein in the anterior triangle. Therefore, when using the posterior access route to the vein at the junction of the middle and lower thirds of the sternocleidomastoid muscle, aiming at the suprasternal notch, the upper trunk of the plexus may be injured if the needle is slightly posterior when entering the posterior triangle[32].
  This complication is however rare, but one should be aware of the possibility of injury to the upper trunk of the brachial plexus when using the posterior approach.

- Smith[46] reports on a case with brachial plexus injury where the injury consisted of motor function deficiencies to the shoulder, elbow, and hand as well as sensory loss to the lateral upper arm.

6.6 Malpositioning of catheter tip

- The correct position of the catheter tip is in the superior vena cava, not more than 3-4 cm above the junction of the superior vena cava and the right atrium[1]. If a saline filled catheter tip is, for example, in the superior vena cava, 5 cm above the reference point which is on the mid right atrial level, the recorded pressure would be 0.3 cm H_2O too low, which is clinically insignificant due to the consistent nature of the error in successive readings[33].

- Sheep *et al* [20] and Greenall *et al* [4] argue that the tip of the catheter should lie in the proximal superior vena cava above the reflection of the pericardium and therefore above the level of the ascending aorta. Collier *et al* [19] argues for a point at least 2 cm above the junction of the superior vena cava and the right atrium. The pressure at this point is within 1 mm Hg of that in the right atrium[57].

- Malpositioning is least likely with the internal jugular approach, but approximately 5% will not lie within the superior vena cava or the right atrium[53].

- Most malpositioned catheters occur in the following locations: Internal jugular vein (43,4%), contralateral brachiocephalic vein (11.2%) and right atrium (9.8%)[2].

- Deitel [47] reports on catheters inserted via the subclavian route entering the internal jugular vein and passing up into the neck. Pressure applied above the clavicle or lateral rotation of the head in the direction of the operator while the catheter is advanced may inhibit its passage into the neck.

- Subclavian vein catheters that are misplaced into the internal jugular vein are more common on the right (15%) when compared to the left (2%)[10]. The reason for this is shown by the more acute angle of the right subclavian vein with the right internal jugular vein when forming the right brachiocephalic vein when compared to the less acute angle on the left. This was confirmed on coronal magnetic resonance image (MR) studies of the two angles[11].
  Complications of a malpositioned catheter may result in a hydrothorax, hemothorax, ascites[24], chest wall abscesses[25] (reported in a patient with long term catheterization and administration of total parenteral nutrition), chest pain[26], embolization to the pleural space[27] etc.
  Unusual chest pain syndromes may indicate central venous catheter malposition[26]. Webb *et al* [26] described this phenomenon in three incidents involving cannulation of the left internal thoracic vein.

- Malpositioning of catheters via the internal jugular vein appears to be more common via the left. This is due to the brachiocephalic vein on the left being longer and oblique in its course. Furthermore the left brachiocephalic vein has frequent small tributaries e.g. the left internal thoracic vein, pericardiophrenic vein[21,40] and left superior intercostal vein[26].

6.7 Failure to locate the internal jugular vein

- Locating the internal jugular vein becomes more difficult after common carotid arterial puncture because of vein compression by hematoma formation from blood leaking out of the artery[36].

- The anterior wall of the vein may also, due to the collapsible nature of the vein, be pushed against the posterior wall by the needle. The needle may therefore puncture both walls without reaching the lumen. Withdrawal of the needle at this point, may draw the anterior wall away from the posterior wall and with aspiration the lumen of the vein may so be encountered[52].

6.8 Cardiac tamponade[27,29]

- Cardiac tamponade occurs due to perforation of the superior vena cava, right atrium or right ventricle. The pericardium inserts on the base of the heart over the superior vena cava, ascending aorta and pulmonary trunk[20]. The catheter should therefore not lie too deeply, certainly not in the right atrium or ventricle[47]. Furthermore, the catheter should lie parallel to the wall of the superior vena cava. One study reports a mortality rate of 87% in patients developing cardiac tamponade [4]. Collier *et al* [19] reports that cardiac tamponade develops due to prolonged contact of the rigid catheter with the myocardial wall. Sheep *et al* [20] showed that cardiac tamponade is more often the result of injury to the right atrium than the right ventricle. He reports on a case of cardiac tamponade following superior vena cava perforation after using rather rigid Teflon catheters on the left hand side. It is thought that direct contact with the constantly moving vessel wall and subsequent erosion, eventually cause perforation by the catheter.

- Van Haeften *et al* [21] reports on cardiac tamponade resulting from a misplaced central venous line in the pericardiophrenic vein. These veins drain to the brachiocephalic veins on both sides. However they are more likely to be cannulated via left sided internal jugular vein catheterization. This can be prevented by preferential use of the right internal jugular vein, routine use of a J-tipped guide wire and roentgenographic control. Van Haeften *et al* [21] argues that this malpositioning is probably more common and deserves more attention due to a resultant potentially fatal cardiac tamponade.

- Cardiac tamponade is clinically described by Beck's triad [62] : Elevated central venous pressure, decreased blood pressure and absent heart sounds. Patients may complain of chest pain (stretching of the pericardium which is innervated by the phrenic nerve), nauseousness (referred via the vagus nerve), abdominal pain (referred pain via the splancnic nerves) and shortness of breath (pulmonary edema). Unexpected hypotension with venous distension in a patient with a central venous catheter, should be regarded as being due to cardiac tamponade until proven otherwise[20]. A high degree of suspicion should exist because the diagnosis is often delayed because of similar findings in other more common post-operative problems[19].

- Cardiac tamponade is prevented by using soft poly-urethrane catheters, measuring the desired length of the catheter beforehand, securing the catheter tightly to the skin and confirming the position of the catheter with a Chest X-ray[4,19,20,55] Catheters with beveled edges are unacceptable.

- Perforation of the superior vena cava is more likely to occur via the left sided internal jugular vein approach compared to the right due to the circuitous course of the catheter. First it bends in one direction to accommodate the brachiocephalic vein on the left and then in the opposite direction into the superior vena cava. The path of a catheter inserted via the right internal jugular vein is however straight[20,21]. Sheep *et al* [20] therefore pleads for avoiding the use of the left internal jugular vein for catheterization.

- Due to the serious nature of cardiac tamponade caused by central venous catheters, especially when the tip of the catheter is located in the right atrium, periodic radiographs are necessary to confirm correct catheter placement[47].
  Aslamy *et al* [41] argues convincingly that the absence of normative data to determine the dimensions of central venous vasculature and relationships of venous structures with radiographic landmarks, complicates confirmation of the location of the catheter tip. It is proposed that the caudad margins of the clavicles correspond with the origin of the superior vena cava [4], or the intervertebral disk between the fifth and sixth

thoracic vertebrae, would show the upper limit of the superior vena cava. Greenall *et al* [4] suggests that the tip of the catheter should lie no more than 2 cm below a line drawn below the lower surface of each clavicle. None of these have been anatomically correlated and may well be of limited value due to the effects of parallax and radiographic technique. However, new MRI studies of the central venous anatomy, have revealed better anatomical correlates to determine catheter position on a radiograph. MRI provides an opportunity to gather normative information on anatomic relationships, allowing imaging in transverse, sagittal and coronal planes. In studying the MR anatomy of the central venous system of 101 patients, Aslamy *et al* [41] showed that the level of the right tracheobronchial angle would always be within the cephalad portion of the SVC. Their data suggest that placement of the catheter tip < 2.9cm caudad to the right tracheobronchial angle as seen on a normal chest radiograph, avoids intracardiac placement in most patients[41].

- Abduction and adduction of the arm, rotation of the trunk and flexion of the neck can change the position of the tip of the catheter over a distance of several centimeters[21]. This may explain the development of cardiac tamponade after several days. Krog *et al* [58] examined catheter movement in a cadaver based study and found that catheters inserted correctly via antecubital veins, advance up to seven cm with elevation and abduction of the arm. Displacement of catheters via the subclavian or internal jugular vein was approximately two centimeters.

6.9 Dysrythmias

- If the tip of the catheter is too deeply placed into the right atrium or ventricle, it can irritate the wall of the heart chambers and cause dysrythmias [29].
  During internal jugular vein catheterization it may also be due to stimulation of the carotid sinus in the neck where the common carotid artery bifurcates.
  Dysrythmias are prevented by correctly measuring the catheter beforehand and confirming correct positioning of the tip of the catheter by a chest X-ray [55].

6.10 Catheter related infection.

- The catheter is a foreign body and may carry bacterial agents into the vein, which may lead to bacterial endocarditis. This complications is the most common complication of central catheters used long term[61].

6.11 Chylothorax [8,27,29]

- A chylothorax mostly occurs on the left hand side. The thoracic duct drains into the subclavian vein where it is joined by the internal jugular vein to form the brachiocephalic vein. The smaller right lymphatic duct on the right hand side is however also at risk and puncturing can also lead to a chylothorax[9].
  The right lymphatic duct crosses the anterior scalene muscle to enter the superior margin of the subclavian vein near its junction with the internal jugular vein.
  Therefore placing a needle above or behind the vein or penetrating both walls could

injure the right lymphatic duct.

- It is however rare when compared to the left hand side. Vellani *et al* [8] reports one case where the thoracic duct was injured via the left subclavian vein. The chylous discharge however stopped after four days.

- Even on the left this complication is extremely rare[34]. Hinckley[48] reports on a bilateral fatal chylothorax secondary to a thrombus surrounding a central venous catheter with occlusion of the thoracic duct. Although this complication may be rare according to the literature, the morbidity associated with it is high. Tachypnea and hypotension progressing to sudden death due to a chylothorax is described. Shock develops after a latent period of lymph collection in the extrapleural space, then rupturing through the pleura. A chylothorax may be resolved by ligating a leaking thoracic duct, or spontaneously through development of adequate collateral circulation[48].

6.12 Accidental mediastinal entry

- Albertson *et al* [39] reports on two cases of cannulation of the left internal jugular vein with mediastinal entry, and warns of the need for extreme caution when using this vein. This may be explained by a venous anomaly: The most common variant of systemic venous drainage is a persistent left superior vena cava. It occurs in 0,3% of persons with otherwise normal hearts, and in 4.3% of patients with congenital heart disease[38]. It may also be due to cannulation of the left pericardiophrenic vein, and subsequently entering the mediastinal space as reported by Weeden *et al* [40].

6.13 Hydrothorax[27,29]

- This complication develops when both the intrathoracic vein and pleura or pleura alone are perforated by the catheter. The intravenous fluid leaks out into the pleural space and gives the picture of a pleural effusion. Again this complication is seen in too deeply placed catheters[55]. The hydrothorax may be bilateral because of the presence of congenital or acquired interpleural communications[20]. Allsop *et al* [24] reports a case of actual cannulation of the pleural space. This should be recognized at the time of insertion by failing to aspirate blood as the cannula is advanced and by lowering the whole infusion set below the level of the patient to observe the reflux of blood.

6.14 Hydromediastinum

- This is a rare complication, but has been documented by Adar *et al* [16]. In their case, the movement of the catheter relative to the fixed subclavian vein, caused the tip of the catheter to perforate the brachiocephalic vein with resultant leakage into the mediastinum. The negative pressure in the mediastinum during inspiration, would encourage continuous leakage.

6.15 Phrenic nerve injury

- Both Drachler *et al* [22] and Obel[23] reported on phrenic nerve damage after subclavian vein catheterization, with a resulting paralysis of the hemidiaphragm. This can be fatal in a patient whose respiratory function is compromised.

- The phrenic nerve runs on the anterior scalene muscle, immediately behind the subclavian vein at the puncture point[23]. It is therefore surprising that this nerve is not injured more frequently. The nerve may also be anaesthetized by the local anesthetic injected at the site of catheter insertion. In this case, rapid recovery of diaphragmatic movement will occur.

6.16 Horner's syndrome

- Damage to the sympathetic chain is possible as it has a close relation to the subclavian artery. Briscoe *et al* [31] have reported a patient with a lesion of the cervical sympathetic chain after internal jugular vein cannulation.

6.17 Catheter embolization

- This especially happens in catheter through needle devices. A high mortality is reported and Propp *et al* [18] points out various complications following embolization of a catheter such as arrhythmias, venous thrombosis, myocardial perforation and pulmonary embolism. Transvenous techniques are used to retrieve the catheter, or otherwise surgery may be necessary.

- Physical damage to the catheter can result in a small piece of catheter embolizing in the blood stream. Predisposing factors include the use of a catheter through needle device. The sharp point of the needle can easily damage the catheter, especially when the catheter is withdrawn slightly [55]. A catheter through cannula device should always be used. A poorly fixed catheter may also predispose to catheter embolization. Signs and symptoms suggesting catheter embolism include shortness of breath, palpitations and dysrythmias on ECG.

6.18 Hoarseness

- Theoretically the vagus nerve may be injured when both the internal jugular and subclavian vein is cannulated, by injuring the vagus and therefore the recurrent laryngeal branch posterior to the internal jugular vein[29].

6.19 Massive subcutaneous air development

- The development of subcutaneous air may be severe enough to cause respiratory distress[45]. Smith *et al* [46] reported two patients who needed a tracheostomy due to a compromised airway after subclavian vein catheterization.

6.20 Thrombosis

- Thrombosis may occur, due to intimal damage caused by the catheter, which acts as a foreign body in the vein. Thrombosis is more commonly seen in longterm catheterizations. Brown *et al* [61] reports on a case of superior vena cava thrombosis in a patient with a longterm central venous line for parenteral nutrition.

6.21 Laceration of the internal thoracic artery

- Larsen *et al* [49] reported on lacerating the internal thoracic artery from an attempt to catheterize the subclavian artery, with resulting bleeding in the mediastinum requiring a sternotomy.

6.22 Laceration of the ascending cervical artery

- Laceration of the ascending cervical artery with massive hemothorax was reported by Wisheart *et al* [51] after the internal jugular approach.

6.23 Prevention of complications

To keep complications to a minimum, the following basic factors need to be observed[27]:

- The indications for central venous catheterization should be carefully considered.

- Thorough acquaintance of the clinical anatomy of the subclavian and internal jugular vein as well as their neighboring structures. Meticulous technique should be followed.

- There is no substitute for experience. Most complications are found in the hands of inexperienced operators.

- Awareness of the complications, their frequency and reason for occurrence is very important. The reason for the complications can in almost every instance be explained by the regional anatomy.

7. References.

7.1 Scientific papers

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Table 1. Complications for central venous catheterization, modified from Hegarthy's classification[27].

Minor	**Major**
Failure to puncture the vein Failure to advance the catheter Catheter dislodgement Subcutaneous infusion Subcutaneous infection	Damage to structures in the proximity of the puncture site: Pleura - Pneumothorax Subclavian artery Brachial plexus Thoracic duct Other vessels: Common carotid artery Internal thoracic artery Ascending cervical artery Other nerves: Phrenic nerve Sympathetic chain Recurrent laryngeal nerve
	Damage to structures away from the puncture site: Superior vena cava Right atrium Blood vessels: Ascending aorta, pulmonary artery Mediastinum Pericardium, pericardial space
	Functional Overtransfusion Air embolism Dysrythmias Catheter embolism Thrombosis
	Infection Bacterial Fungal

4.4.1.5 Pericardiocentesis

1. Indications

- Cardiac tamponade may present as an emergency, for example after a knife stab wound of the thorax. Many stab wounds of the heart can be treated initially by means of a single or multiple pericardiocenteses[10]. This procedure is done to relieve pressure in the pericardial sac on the heart, while arranging to perform a thoracotomy[17]. The risk of recurrence is high and the procedure should be considered before a patient can get to theatre. Cardiac tamponade, or compression of the heart by fluid or blood in the pericardial sac, may develop rapidly after heart injury[10]. It will temporarily improve the patient's hemodynamic situation[2]. This is illustrated in a case report by Eisenman *et al* [17] where a pericardiocentesis was performed on a patient with an acute hemopericardium secondary to cardiac rupture after a myocardial infarction, with resultant hemodynamic improvement. After performance of the pericardiocentesis, the patient was transferred to the operating room. It should not delay the performance of a thoracotomy and there should be a readiness to proceed to surgery. When done correctly, the procedure can be performed at a low risk[11].

- Rapid collection of pericardial effusion. Diagnostic and therapeutic pericardial effusion drainage should be done with echocardiographic guidance[19].

- Diagnostic – In an elective situation under sonographic guidance.

2. Contra-indications

- Facilities for cardio-respiratory resuscitation should ideally be available.
- Trombocytopenia and anticoagulant therapy are relative contraindications[3].

3. Step by step procedure

Occasionally drainage of cardiac tamponade is done with the subxiphoid approach as a matter of great urgency and a large bore needle is used[10]. However, usually there are a few minutes to perform a complete and controlled aspiration[7]. If possible, echocardiographic demonstration of fluid in the pericardial space, to confirm the clinical diagnosis, should be considered before performing the procedure[13].

1. Monitor the patient's vital signs, CVP and ECG before, during and after the procedure. Send a blood specimen to the laboratory for blood grouping.
2. The defibrillator should be ready.
3. Surgically prepare the xiphoid and subxiphoid areas and locally anesthetize the area if time permits. Position the patient in a supine position.
4. Use a 16 to 18-ga, 15 cm long catheter over a needle device, attached to a 20 cc syringe. Connect the chest terminal (V) of the ECG using a crocodile clip.
5. Assess the patient for any mediastinal shift that may have caused the heart to shift significantly.
6. The needle is inserted into the angle between the xiphisternum and the left costal margin at about 45° to the anatomical transverse plane[7], directing the needle towards the left shoulder.
7. Carefully advance the needle and aim toward the tip of the left scapula. After advancing the needle to the inner aspect of the rib cage, the needle is cautiously advanced 5 to 10 mm until fluid is reached. A distinctive 'give' may be sensed when the needle penetrates the parietal pericardium. The needle should be advanced slowly with continuous negative pressure created by the syringe.
8. If the needle is advanced too far, an injury pattern (e.g. extreme ST-T wave changes or widened and enlarged QRS complex) appears on the ECG monitor[6]. If this appears, withdraw the needle until the previous baseline ECG tracing reappears[24]. This occurs secondary to irritation of the ventricular myocardium. Should the injury pattern persist, withdraw the needle completely. PR segment elevation is present with atrial contact[8].
9. When the needle tip enters the pericardial sac, withdraw as much nonclotted blood as possible. Advance the catheter and withdraw the needle.
10. After aspiration, remove the syringe and attach a stopcock. Secure the catheter in place.
11. Should the cardiac tamponade persist, the stopcock may be opened and the pericardial space aspirated again.

With an acute traumatic cardiac tamponade, aspiration of as little as 10-50 ml may greatly relieve cardiac output.

4. Materials

- ECG (electrically isolated machine)
- 16 to 18-ga 15 cm long catheter over a needle device, 18-ga spinal needle with obturator
- 20 cc syringe
- Defibrillator at hand
- Ready theatre and surgeon / speedy arrangement for transferring patient

5. Anatomical pitfalls

5.1 Subxiphoid approach.

- The needle is inserted into the angle between the xiphisternum and the left costal margin at about 45° to the anatomical transverse plane[7,15,20,21], directing the needle towards the left shoulder.

- The needle advances about 6 to 8 cm from the skin in an adult and 5 cm or less in children before reaching the pericardium[10].

- This approach has been critized by some authors for causing greater number of injuries, usually to the right atrium. Instead an echocardiographic-directed pericardiocentesis has been proposed in the intercostal space near the apex of the heart[19]. A cadaver study demonstrated greater safety with a parasternal approach in the fifth intercostal space[5]. There are however studies showing a greater risk of a pneumothorax when parasternal and intercostal approaches are used[5]. During a so-called blind pericardiocentesis, the subxiphoid approach is recommended. A blind pericardiocentesis means that the needle is not echocardiographically directed.

- This approach enters the fibrous pericardium, where it is in direct contact with the chest wall, and not covered with pleura due to the pleural recess (cardiac notch)

- The needle pierces through the skin, superficial fascia, anterior rectus sheath (as it comes off the costal cartilage) and the left rectus abdominis muscle. Thereafter it pierces the posterior rectus sheath (transversus abdominus muscle) and over the dome of the diaphragm and through the fibrous and parietal serous pericardium[18].

- In the supine position, most of the fluid/blood in the pericardial space is located laterally, inferior and posterior to the heart. The safest access route is therefore the subxiphoid route. Furthermore, this approach holds very little risk of injuring the lung[10].

5.2 Parasternal approach

- The needle is placed perpendicular to the skin in the 5th intercostal space medial to the border of cardiac dullness. This route is not advised due to the risk of injuring the internal thoracic artery[3], as well as causing a pneumothorax[5]. Lung inflation brings the edge of the lung closer to the needle.

5.3 Apical approach

- A less commonly used approach is where the needle is placed 1cm outside of the apex beat in the intercostal space, within the area of cardiac dullness. The needle is directed to the right shoulder[7]. If the apex beat is not palpable, insert the needle through the skin just inside the area of cardiac dullness. This area is close to the lingula and left pleural space and is therefore more likely to result in a pneumothorax, although there is a bare area over the cardiac apex where pleura is usually absent[23]. The pericardial sac is superficial here and has a relatively large transverse diameter. There is therefore minimal risk to injure the pleura, myocardium, liver or lung[3]. Theoretical arguments are held for this technique, such as there are smaller sized vessels near the heart apex[7] and the thicker wall of the left ventricle that can seal off if punctured. However, piercing the left ventricle has a higher incidence of ventricular fibrillation[11]. The arteries are however by no means invulnerable. Clarke *et al*[3] advises the puncture site to be identified ultrasonically. They regard the apical approach as the best site of insertion, with the patient in the left posterior oblique position to allow fluid to accumulate around the apex of the heart. This may be done in elective patients, but is not indicated in the emergency situation.

5.4 ECG changes

- There is an obvious change in the ECG when the needle touches the myocardium. The purpose of using an ECG is to prevent ventricular puncture. An injury pattern can occur when touching the ventricular wall. - e.g. extreme ST-T wave changes or widened and enlarged QRS complex[6]. Careful attention should also be paid to the PR segment as well as the ST segment during the procedure[8]. The appearance of these changes is a signal to withdraw the needle[24].
- If ST segment elevation or PR segment elevation are seen, this may signal contact between the needle and an intact pericardium immediately overlying the heart with no fluid in the pericardial sac. If however bloody fluid is obtained from the needle in the absence of these ECG changes, it signifies that fluid has been obtained from the pericardial sac and not from the chambers of the heart[24].

- If the needle touches the ventricle, marked ST segment elevation[24] or ventricular ectopic beats can be seen[7].

- Contact with the atrium can cause atrial dysrrhythmias, change of P-wave morphology, elevation of the PR segment, atrial arrhythmias or atrioventricular dissociation[8]. Previous myocardial injury may obscure the current generated by the needle touching the myocardium[9]. Sobol *et al*[9] reported a case where a myocardial laceration occurred without electrocardiographic recording, due to the needle entering a metastatic tumor, which is electrically silent.

- ECG monitoring should only be used with fully isolated electrical equipment. Currents may be responsible for ventricular fibrillation during the procedure[7].

5.5 Ultrasound guided insertion

- Blind performance is reported to cause possible perforation of the heart and can lead to death[13]. Therefore, elective pericardiocentesis is currently done with ultrasound fluoroscopic guidance[12] minimizing cardiac injury by visualizing the relation of the tip of the needle to the surrounding organs.

- Ultrasound guided pericardiocentesis has the advantage that fluid depth and quantity can be assessed and fluid location can be detected[3]. The site of entry can be determined where the fluid or blood is closest to the chest wall and where the needle track avoids any underlying vital structures[19].

- However this high technology equipment is not available in an emergency department. Therefore, the complication rate of the procedure will naturally be higher.

5.6 Xiphoid process

- The xiphisternum articulates with the posterior aspect of the body of the sternum, occasionally making palpation difficult[7]. However with the easily identifiable costal margin, the position of the xiphisternum can be predicted. Deep palpation in the area may be uncomfortable.

5.7 Pericardium

- The distance from the skin to the pericardium is 6 to 8 cm in an adult and 5 cm or less in a child[10].

- The pericardium can stretch to accommodate 2-3 liters of fluid. If the increase in fluid occurs over a long period of time, there will be a very gradual increase in intrapericardial pressure.
  However, less than 100 ml of fluid or blood accumulating rapidly may sharply increase intrapericardial pressure and may be fatal. The patient presents with shock (arterial hypotension) distended neck veins and diminished or absent heart sounds. This is also referred to as Beck's triad[22]. The liver is normal in size due to the fact that in the acute situation there is no time for it to enlarge. The same is true for the development of ascites and subcutaneous edema. Cardiac output may drop acutely, even when arterial pressure stays at reasonable levels. Venous pressure is therefore regarded as a better indicator for cardiac tamponade[10].

- The pericardium is extremely sensitive due to its extensive innervation by the phrenic nerve. Therefore, when touching it with the needle pain is experienced. This may also reassure the operator that he is in the correct space[7].

5.7 Coronary vessels

- These vessels may be injured if the needle after piercing the pericardium is not drawn slightly backward until the injury current disappears from the ECG. The operator should be aware that due to motion of the heart the needle can still touch the myocardium from time to time.

- Lying in the anterior interventricular sulcus are the anterior interventricular artery and vein.
- **Marginal artery**

The marginal artery courses on the acute angle of the right ventricle, where the pericardium reflects to become the diaphragmatic pericardium. It is at risk of being injured during the procedure[7].

5.8 Liver

- An angle of below 45 degrees may let the needle enter the peritoneal cavity and injure the liver and stomach[18]. Entering at 45 degrees the needle enters the pericardium at the angle at which it becomes the diaphragmatic pericardium. It thus avoids the diaphragm and enters the fibrous pericardium and parietal serous pericardium.

- The left lobe of the liver is situated in close relation to the xiphisternum, especially in the presence of hepatomegaly[7].

5.10 Right ventricle

- The needle enters the pericardial sac more or less where the pericardium reflects acutely to become the diaphragmatic pericardium. In this angle lies the margin of the rather thin walled right ventricle[7].

5.11 Right atrium

- Because of its thin wall, it is extremely dangerous to enter the right atrium with the needle. This is more likely to happen if the needle is directed towards the right shoulder[5] instead of the tip of the left scapula[6].

5.14 Direction of needle

- Aim towards the tip of the left scapula[6]. Other recommendations include directing the needle to the right shoulder, the left shoulder and even the sternal notch[7]. One anatomical study demonstrated that the subxiphoid approach is likely to injure the right atrium when aiming at the right shoulder[5]. Aiming for the left shoulder directs the needle to either the right or left ventricular wall.
  If the needle is directed towards the tip of the left left scapula it is more likely to pierce the right ventricle. If it were to pierce the left ventricular wall, there is a higher incidence of ventricular fibrillation[11].

6. Complications (anatomically relevant)

- Anatomically, both the amount and the location of pericardial fluid or blood are important. Most complications of the procedure are due to the needle either touching or penetrating the heart. Therefore the more fluid or blood there is between the myocardium and pericardium the less chance of a complication. In an echographic study, Wong[11] found that the width of the anterior clear space as seen with an echocardiogram (reflecting the amount of pericardial fluid) correlates significantly with the increase of complications.

6.1 Cardiac muscle perforation.

- Most perforations occur in the right ventricle[8]. Authors differ on the adverse effect of ventricular puncture[2]. Most right ventricular perforations are without adverse effect[11], but some are fatal[12, 13, 16]. The right ventricle is usually punctured on its inferior surface. Due to the lower pressure in the ventricle, bleeding is not as severe when compared to the left, but is more vulnerable to laceration due to the thinner ventricular wall.

- Cardiac puncture with hemopericardium is the prime risk, which can occur despite the use of an ECG.

- Preis *et al* [4] demonstrated the development of an intrapericardial thrombus developing in 24 hours, by slow-motion analysis of a two-dimensional echocardiogram, after a needle has penetrated the right ventricular myocardium.

- Duvernoy *et al* [12] reported complications in 352 cases where a pericardiocentesis was performed. They found three cardiac perforations which were regarded as major complications. A total of 23 (6.5%) accidental cardiac perforations occurred.

- Accidental cardiac perforation with a fine needle seems to be a minor complication, as long as the needle is directed towards the anterior diaphragmatic border of the right ventricle. Due to the contractility of the myocardium, the canal produced by a fine needle soon closes after withdrawal of the needle.

6.2 Cardiac arrhythmias

- Arrhythmias may also occur as a result of the cardiac tamponade itself[12].

- Ventricular fibrillation – Due to puncture of either the right or left ventricle. Inadvertent right ventricular puncture is less hazardous than left ventricular puncture. This may require DC cardioversion. Premature ventricular contractions occur most commonly. The incidence of ventricular and atrial dysrrhythmias is rare[11].

- Krikorian *et al* [13] describes one series of 123 patients presenting during 6 years in a specialized unit where one episode of ventricular tachicardia was observed. This episode was reverted with intravenous lignocaine.

6.3 Puncture of coronary arteries

- The right coronary artery is more at risk of injury than the left coronary artery[12].

- One study reports the injury of a coronary vessel with a subsequent hemopericardium[13]. Lacerations have also been reported in human cadaver studies[5, 14].

- Duvernoy *et al* [12] reports a case where the posterior descending branch of the right coronary artery was injured. To avoid injury to this artery, the needle should be directed towards the tip of the left scapula and the anterior diaphragmatic border of the right ventricle.

- Brown *et al* [5] reports in an autopsy-based study of 20 cases, where the subxiphoid approach was used aiming at the left shoulder, injury to the distal or marginal branches of the right coronary artery was found in 3 cases.

6.4 Pneumothorax

- Pericardiocentesis can lead to a pneumothorax because of the close relation of the pleura and the pericardial spaces.

- Duvernoy *et al* [12] reports in a series of 352 patients only two cases with the complication of a pneumothorax. These were both children. Since the subxiphoid approach was used, it seems that this is a safe route in adult patients as far as the risk of a pneumothorax is concerned.

- The approach makes it unlikely for the lung or pleural tissue to be injured due to the reflection over the cardiac notch, however this can occur[1]. A Chest X-ray should be performed after the procedure. Most pneumothoraces that were reported have been without clinical consequences.

6.5 Hypotensive episodes.

- This is due to vagal stimulation, which is inevitable during the procedure[13]. These episodes can be associated with bradycardia in which case appropriate administration of atropine, intravenous fluid and elevation of the legs if necessary.

6.6 Puncture of right atrium

- Puncturing the atria is a major complication and great care should be taken to avoid it. The atria have a thin and poorly contractible myocardium[12]. A canal caused by a needle is therefore unlikely to close after withdrawal of the needle.

6.7 Pain after piercing the pericardium.

- Patients that are awake may complain of chest pain as the needle goes through the pericardium. This is due to the sensory innervation of the pericardium by the phrenic nerve on both sides.

6.8 Dry tap

- If most of the pericardial fluid or blood is situated posteriorly or laterally, it will not be reached via a subxiphoid approach[4].

- Wong *et al* [11] has found four false negative periocardiocenteses in a study of 52 patients. Two had a loculated posterior hemopericardium and could not be reached by the anterior subxiphoid approach.

- The needle may have injured the pleura to cause a pneumothorax, the myocardium or coronary vessel to cause a hemopericardium or the peritoneum to cause a pneumoperitoneum.

6.9 Hemothorax

- A hemothorax may develop secondary to arterial injury as well as injury to the pleura[3].

6.10 Arterial bleeding

- Duvernoy *et al* [12] reports arterial bleeding from the diaphragm and the left internal thoracic artery. Laceration of this artery cannot always be avoided with the subxiphoid approach, but the risk of injuring the internal thoracic artery is higher when the parasternal approach is used as the artery is more prominent proximally and runs on the lateral side one finger breadth of the sternum.

- The vascular structures of the diaphragm include the inferior phrenic artery.
- Aiming the needle at the tip of the left scapula avoids the diaphragmatic vessels as well as the right coronary artery. Arterial injury may lead to hemopericardium, hemothorax or arteriovenous fistulae[3].

6.11 Abdominal and shoulder pain

- Abdominal pain and referred shoulder pain are caused by irritation of the diaphragm via the subxiphoid approach[12].

6.12 Infections

- This is a very rare complication, which can lead to costochondritis, pericarditis and septicemia[12].

6.13 Stomach or colon penetration

- Due to the close relationship of the stomach and the transverse colon in the epigastrium to the subxiphoid placement of the needle, these structures may be injured[18].

6.14 Liver injury

- The left lobe of the liver is closely related to the subxiphoid region and puncturing the liver may lead to leakage of blood or bile[3].

- Brown[5] reports in an autopsy based study on four liver punctures using the subxiphoid approach aiming at the tip of the left shoulder.

- The risk of injuring the liver is higher if the needle is inclined below the suggested 45° to the transverse plane of the patient[18].

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