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CHAPTER ONE: INTRODUCTION

1.1 THE IMPORTANCE OF DIAGNOSING CERVICAL SPINE INJURY

Due to the mobility of the cervical spine, it is also the part of the spinal column that is most likely to cause further and very serious complications for the patient if immobilisation is not rigidly enforced in the presence of an unstable injury. (ACS, 1997: p218*)*.

Cervical spine injuries are "potentially the most devastating and life-altering of all injuries compatible with life." (Hu S et al., 2000; p223) yet they are the most commonly missed severe injuries (Demetriades et al., 2000). The cost of a missed cervical spine injury, for the patient and the clinician, is large (Clancy, 1999). It is both a personal and a financial cost since an unstable cervical spine injury can cause paralysis and death. Zabel et al., (1997) described cervical spine injury with resultant neurological sequelae as "a catastrophe". The lifetime cost of caring for a quadriplegic patient has been estimated at €850,000 - €4.2million. Some of the highest monetary indemnifications in medical litigation cases are made to patients who are quadriplegic because of cervical spine injury (Clancy, 1999; Kaneriya, et al., 1998; Berlin., 1996) yet Davis et al., (1993) report a rate of 4.6% of patients whose diagnosis of cervical spine fracture was delayed or missed.

1.2 THE IMPORTANCE OF STRICT IMMOBILISATION

The ACS' protocol for the effective management of trauma patients is known as the Advanced Trauma Life Support protocol, commonly referred to as the ATLS protocol. It is followed in a significant number of trauma centres internationally and is therefore quite influential. It states quite clearly that "spinal protection should be maintained until a c-spine injury is excluded". (ACS, 1997, p228*)*. Despite this there is an alarming reported incidence of patients who arrive in the emergency department neurologically intact, who develop deficits during the course of their care.

Davis et al., (1993)	10%	Patients who arrive in the emergency department neurologically intact but develop deficits during hospital care
Davis et al., (1993) Drainer et al., (2003)	3% - 25%	suffer unnecessary manipulation in the emergency department or delays in diagnosis, with resultant exacerbation of their existing injuries, causing paralysis and even death.
ACS, 1997: p217	5%	patients who experience the onset of neurological symptoms or exacerbation of existing ones while in the care of the Emergency Department.
Ross et al., (1987)	10%	patients who experience the onset of neurological symptoms or exacerbation of existing ones while in the care of the Emergency Department.

Table 1.1. Reported percentage of patients who arrive in the Emergency Department neurologically intact and subsequently develop deficits

Missed cervical spine injury is understandably referred to as “an unacceptable disaster” (Ross et al.,1987). Consequently, there is a great responsibility on all the members of the multi-disciplinary trauma team, to identify and treat accordingly, any cervical spine injury, therefore, until the neck has been deemed to be free of injury, the immobilisation must be rigidly enforced. This usually takes the form of a rigid cervical collar, sandbags at either side of the neck and the patient’s head taped to the trolley to enforce the immobilisation. (ACS, 1997: p228).

However, there are drawbacks to long-term immobilisation by collar. Therefore, removal of the immobilisation at the earliest opportunity can be as important as enforcing it initially.

1.3 THE IMPORTANCE OF REMOVING THE IMMOBILISATION

Where the cervical spine cannot be cleared by a combination of clinical examination and imaging techniques, the immobilisation must be maintained, however, there are many disadvantages. Immobilisation is applied in the form of a rigid cervical collar, which limits neck movement but not sufficiently (Demetriades et al., 2000), thus

- the potential for exacerbation of injury increases with the length of time that the collar is left on.
- they can also give a false sense of security (Webber-Jones et al., 2002).

There are complications of long-term collar use.

1. Skin damage. 55% of patients with a collar on for more than five days will develop a full thickness ulcer beneath it. The areas most likely affected will be the pressure points, - the chin, occiput, ears, shoulders, laryngeal prominence and sternum.
2. Swallowing, breathing, coughing and vomiting limitations which have the potential to cause aspiration.
3. Spinal cord injury from exacerbation of an existing injury due to neck movement in 3%-25% of patients.
4. Marginal mandibular nerve palsy with long-term sensory compromise. This causes drooping of the lower lip, drooling and decreased absent skin sensation of the affected side.
5. A potential increase in intra-cranial pressure, which is particularly unfortunate as it is proven that between 10-20% of head-injured patients have a cervical spine injury. This is also acknowledged in the ATLS student manual, which states that approximately 5% of head-injured patients have a cervical spine injury and 25% of patients with a spinal injury have at least a mild head injury. ATLS guidelines clearly state that any injury above the clavicle should always prompt a search for a cervical spine injury, plus, in any patient with multiple trauma a vertebral column injury must be suspected and ruled out (ACS, 1997; p217: Papadopolous et al.,1999).
6. A possible delayed extubation or difficulty weaning from the ventilator

7. General immobility causes skin breakdown at sacral pressure points as well as heels and elbows. There is also increased risk of DVT, pneumonia, ileus etc. (Clancy,1999; Webber Jones et al., 2002; Ross et al.,1987; ACS, 1997; p217).

In addition, there are other complications with using collars for immobilisation, as in the case cited by Papadopoulos et al.,. (1999) where application of a collar to a patient with ankylosing spondilitis exacerbated an existing injury, eventually causing the death of the patient from complications. Clancy (1999) further states that continued immobilisation risks a delay in detection and treatment of an unstable injury.

Clearly, immobilisation by collar has disadvantages, therefore clearance of the spine or stabilisation of the injury is the goal of the trauma team. Within this team, the role of the radiographer is vital, as without adequate, diagnostic images, in most cases, the spine cannot be "cleared".

1.4 VISUALISATION OF THE CERVICO-THORACIC JUNCTION

The ATLS protocols demand that the area from the occiput to the first thoracic vertebra be seen on the lateral projection (ACS, 1999: p225). However, this is not straightforward. Visualisation of the cervico-thoracic junction has long been a problem for radiographers and physicians. Difficulty in clearing the cervical spine specifically because of non-visualisation of the lower cervical region is an ongoing problem for emergency physicians and radiologists and is the subject of much discussion in the literature (Ross et al., 1987; Davis, 1989; Vanden Hoek & Propp., 1990; Ireland et al., 1997; Jenkins et al., 1999; Jelly et al., 2000). Ross et al.,(1987) found a 25% rate of non-visualisation; there have been many other reports ranging from 13% to 37% (Ireland et al., 1997; Kaneriya et al., 1998; Zabel et al., 1997; Tan et al., 1999). Lateral cervical spine films are rejected and repeated at twice the rate of images of any other part of the body (Cocks et al., 1999; p38).

1.5 PREVALENCE OF INJURY AT THE CERVICO-THORACIC JUNCTION

This rate of non-visualisation is all the more unacceptable because of the prevalence of injury in this region. Difficulties in demonstrating the spinal column clearly are more prevalent at the junctional areas and the majority of missed injuries occur at the cervico-thoracic junction (Grech, 1981, pp143-167). In the mid and lower cervical spine the fracture patterns are similar but there is a greater occurrence of injury at the lower levels. This is probably due to the approaching fixation point with the thoracic spine combined with a lever effect from the middle and upper cervical spine (Cusick & Yoganandan., 2002).

Kaneriya et al., (1998) state that 18% of all cervical spine injuries occur here, and various other researchers state figures between 9% and 18% (Jenkins et al., 1999; Jelly et al., 2000).

Davis, (1989) refers to "the significant risk of injuries below the C6 level" while a study by Shatney et al.,(1995) found the following;

	Most Common Site Of Injury	**2nd Most Common Site Of Injury**	**3rd Most Common Site of Injury**
Patients With Definite Spinal Cord Injury	C6 (33%)	C5 (32%)	
Patients With Osseous Disruption But No Neurological Deficit	C5 (26%)	C2 (21%)	C6 (18.5%) C7 (18.5%)

Table 1.2. Most common sites of cervical spine injury reported by Shatney et al.

This finding of 18% injury at the lower levels concurs with the other studies.

The importance of visualising these vertebrae clearly enough to outrule any injury cannot be emphasised enough. The width of the spinal canal is less at the level of C6 than in the upper regions of the spine. Consequently, the potential for injury from swelling of the cord and impingement from osseous disruption is much greater, as is the potential for resultant neurological sequelae (Cusick & Yoganandan, 2002).

1.6 AETIOLOGY OF CERVICAL SPINE INJURY

1.6.1. Typical mechanisms of injury

The main causes of cervical spine injury from trauma are

- High speed motor vehicle accidents
- Jumps and falls from a height greater than 4 metres
- Pedestrian/motor vehicle accidents
- Recreational high-risk sports such as snowboarding, skiing, skating,
- Diving related accidents
- Assaults
- Gunshot wounds

(Ross et al., 1987; Davis et al., 1993; Shatney et al., 1995; Tan et al., 1999; Blackmore et al., 1999; Jelly et al., 2000; Takhtani & Melhem., 2002; Drainer et al., 2002; Mann et al., 2003).

The mechanism of injury is a reliable indication of cervical spine trauma with high-energy impacts being the most prevalent cause of known cervical spine fractures (Blackmore et al., 2001).

1.6.2. Typical age patterns of the injured

These are the types of injuries that are suffered predominantly by young males. Indeed, all studies show that trauma victims are predominantly male and young (Shatney et al., 1995; Tan et al., 1999; Jelly et al., 2000; Daffner, 2000; Hu S et al., 2000; p223). Tan et al.,(1999) refers to "the relatively young age of the trauma population" and gives an average age of 44 years.

Others quote average ages of

- 29 years (Shatney et al., 1995),
- 35 years (Jelly et al., 2000),
- 39 years (Daffner, 2000).

1.7 ANATOMY OF THE CERVICO-THORACIC JUNCTION

1.7.1 General characteristics of any vertebra

A vertebra consists of two distinct parts, an anterior solid segment (vertebral body) and a posterior segment or arch. The arch (neural arch) is formed of two pedicles and two laminae supporting seven processes - four articular, two transverse and one spinous process. The vertebral bodies are stacked on each other forming a solid column which supports the trunk and the head. The arches form a solid protective, tunnel, running the full length of the column, through which the spinal cord passes safely. The vertebrae are connected to each other by the articular processes and the inter-vertebral discs. The transverse and posterior spinous processes serve the attachment of muscles and between each pair of vertebrae are openings through which the nerves pass as they leave the spinal cord.

1.7.2 Cervical Vertebrae

The cervical vertebrae are smaller than those in any other part of the spinal column and are distinguishable by the foramen in the transverse process which does not exist in the transverse process of any other vertebrae. The spinous process is bifid to allow a greater surface area for attachment of ligaments and muscles.

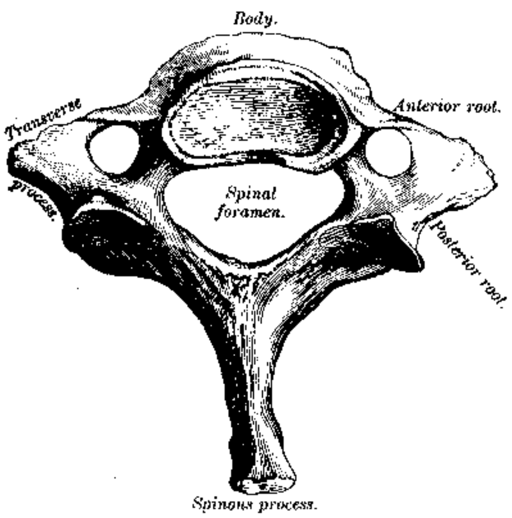


Figure 1.1. Seventh cervical vertebra:

Taken from: Gray's Anatomy, 1977, p38

The seventh cervical vertebra or C7 has a distinctively long, prominent spinous process that is thick, almost horizontal and unlike the typical cervical vertebral process, it is not bifurcated (Figure 1.1.). The lower end of the ligamentum nuchae is attached to it.

1.7.3 Thoracic Vertebrae

The thoracic vertebrae increase in size as they descend and at the extreme ends resemble those of the region of the vertebral column adjacent to them. They each have either a full facet or a demi-facet on both sides of the body to facilitate the relationship with the ribs.

Both the last cervical vertebra and the first thoracic are described as atypical. As junctional vertebrae each one has features of the adjoining group, making them similar to each other while still distinctly of their anatomic group.

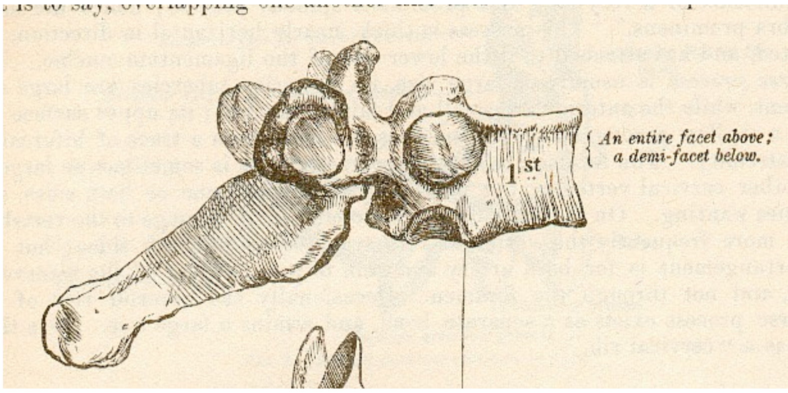


Figure 1.2. The First Thoracic Vertebra

Taken from: Gray's Anatomy, 1977, p40

The first thoracic vertebra, has, on each side of the body, a single, entire articular facet for the head of the first rib and a demi-facet for the upper half of the second rib. The body is like that of a cervical vertebrae being wider than it is long. The spinous process is thick, long and almost horizontal. (Grays Anatomy, 1977, pp34-36)

1.7.3 Musculature

The musculature of this region is quite complex as there are a number of different movements of the head, neck and shoulder joint. However, the main muscle implicated in the difficulties which arise with visualisation of C7 and T1 in radiography is the trapezius, although the deltoid can sometimes contribute. These are also the muscles most implicated in the contra-indications of the Swimmers projection.

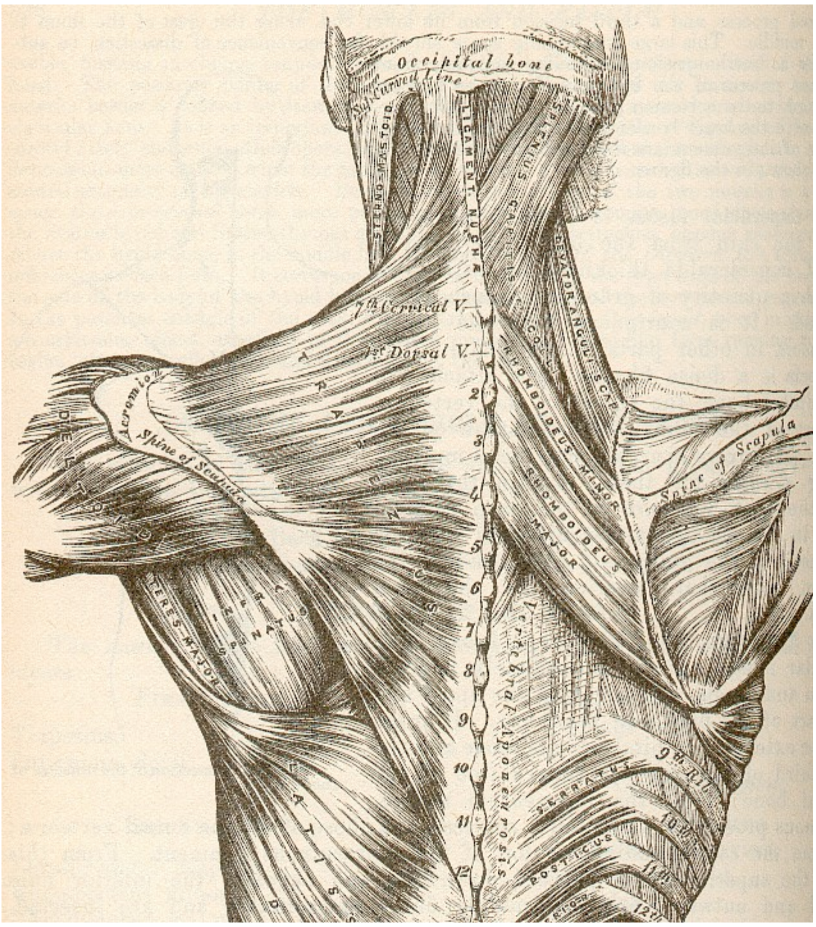


Figure 1.3. Trapezius.

Taken from: Gray's Anatomy, 1977, p338

The trapezius has it's origins in the external occipital protuberance, the superior nuchal line of the occipital bone and the ligamentum nuchae, which attaches it to all the spines of the cervical vertebrae. It is directly attached to the spinous process of the seventh cervical vertebra and the spinous processes of all the thoracic vertebrae. Its insertion is into the spine and the acromion process of the scapula and into the posterior border of the lateral one third of the clavicle. Its actions include shoulder elevation, extension and rotation of the neck and movement of the scapula (Dean & West, 1987. pp 216, 220; Gray, 1997 ed. p337; Cash, 1999. p48). It lies on the shoulder at the base of the neck. If it is very developed, it's density obscures the lower cervical and upper thoracic vertebrae from the lateral projection.

Consequently, the cervico-thoracic junction lies midway between the humeral heads, the first ribs and the left and right trapezius muscles, making imaging of this region more difficult.

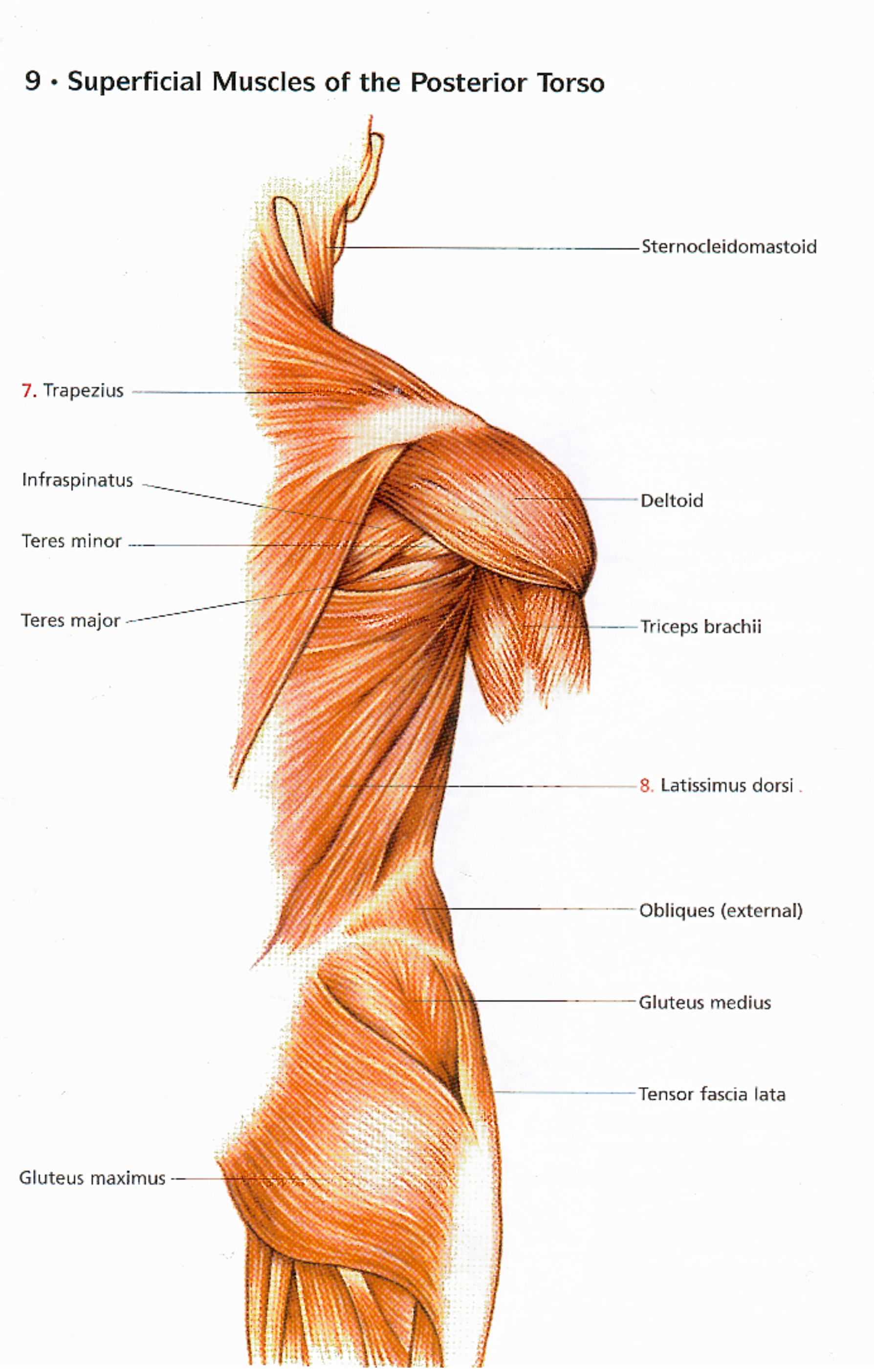


Figure 1.4. Posterior muscles of the torso showing the Deltoid
Taken from: Cash, 1999, p25

It can also be obscured by the deltoid muscle. The deltoid is situated laterally at the shoulder joint. The anterior part draws the arm forward, inwardly rotates it and abducts it. This part has its origin in the lateral clavicle. The lateral part has its origin in the acromion process of the scapula and the origin of the posterior part is the spine of the scapula. All parts are inserted into the deltoid tuberosity of the humerus (Cash, 1999, p50). If the deltoid is very developed, as it can be in young males, or if the patient's body habitus is such that the shoulders do not slant, then the deltoid can overshadow the cervico-thoracic region from the lateral projection.

1.8 IMAGING OF THE CERVICO-THORACIC JUNCTION

1.8.1 Problems with visualisation of this region

In the particular population of trauma victims who are at high risk for cervical spine injury there is also a predominance of well-developed trapezius muscles and consequently much less chance of seeing the lower cervical and upper thoracic region on the first lateral projection. Tan et al., (1999) mention body habitus as one reason for the lack of visualisation of C7/T1 in addition to muscle spasm. This is common in cervical spine trauma and makes the lower cervical region technically difficult to x-ray (Kaneriya et al., 1998).

A review of the literature did not yield any study which examined the visibility of the cervical spine in all requests for radiography, not just trauma, but the overall incidence of non-visualisation of C7/T1 would probably be much lower if non-trauma cervical spine films were considered. Blackmore et al., (2001) acknowledge this when they say that more inadequate examinations occur in trauma patients. Non-trauma patients are radiographed in the erect position, in expiration, coupled with voluntary depression of the shoulders, or handheld weights cause forced depression of the shoulders. Neither of these techniques are applicable in trauma radiography where the patient is supine and immobilised. The use of weights as traction is contraindicated in trauma due to the potential for exacerbation of injury (Davis, 1989; McGill & Yingling, 1999). There is the added disadvantage of the possibility of non-cooperation due to the patient being unconscious, or combative. Consequently, the imaging of the cervico-thoracic junction must rely on techniques that are external to the patient.

1.8.2 The Production of High Quality, Diagnostic Images

The primary role of the trauma radiographer is to use imaging technology to demonstrate the patient's condition as in the presence, or absence, of any traumatic anatomical disruption and to do it quickly, safely, clearly and unambiguously.

- *Quickly* means that time should not be wasted. According to ATLS principles, "x-rays should be used judiciously and should not delay patient resuscitation". (ACS, 1997, p34)
- The word "*safely*" has two meanings for the radiographer

1. To cause no unnecessary movement of the patient which might result in an exacerbation of an existing condition, this is particularly relevant in cases of suspected spinal injury. Cervical spine injury is present in 2 % - 3% of all trauma patients, with the potential to cause morbidity or mortality if precautions are not taken (Jelly et al., 2000). Within this group it is estimated that between 3% and 25% suffer unnecessary manipulation in the emergency department or delays in diagnosis, with resulting worsening of their injuries, paralysis and even death (Davis et al., 1993; ACS, 1997: p217). It is not stated how many of these unnecessary manipulations occur during imaging but there is one published case study which describes exacerbation of an unstable injury during positioning for the Swimmers projection (Davis, 1989).
2. The second meaning of *safely* is to achieve the most diagnostic images using the least amount of radiation. This is known as the ALARA principle (As Low As Reasonably Achievable). This principle causes much debate in the case of diagnosis of cervical spine injury. With the advent and increasing availability of computerised tomography scanning (CT), the diagnosis of cervical spine fractures and other injuries has improved considerably but it is known that CT is a high dose procedure in comparison to plain film radiography (Rybicki et al.,.., 2002). Within the confines of plain film radiography, the radiographer has opportunities for dose reduction.

- Focus-film distance

  Distance is very important in matters of radiation dose because of the inverse square law. Long focus-film distances (FFD) deliver smaller doses (Meredith & Massey, 1977: p10).

- Use/non-use of an anti-scatter grid

  The first lateral is performed without a grid, a technique which has been proven in other studies to reduce the dose to the patient by half (Bell et al., 2003). If this lateral is not successful in showing C7 and T1, then the next attempt will be Swimmers projection. Swimmers is always performed with an anti-scatter grid because of the amount of scattered radiation produced. There is a marked increase in the density of the cervico-thoracic region compared to the middle and upper cervical regions. This increase in density requires an increase in the penetrating power of the beam (kV), thus causing more photons of scattered radiation to reach the film and having a deleterious effect on image contrast and quality. An anti-scatter grid is necessary to absorb these but this leaves mainly primary photons reaching the film which necessitates an increase in mAs, and consequently dose, to ensure adequate film blackening. Thus the use of a grid increases contrast and also patient dose (Meredith & Massey, 1977: p248).

- Collimation of the primary beam

  The amount of scatter produced is the single greatest cause of a reduction in contrast on the film and the major factor in determining this is the volume of tissue irradiated. Tight beam collimation reduces scatter production by irradiating a much smaller area and is one of the most effective ways of increasing the visibility of image detail on the film while minimising the irradiation of the patient. Less tissue irradiated means less interaction of the primary beam with the tissues resulting in less scatter produced, less photons present to be absorbed by the tissues and a consequent reduction in patient dose (ibid, 1977: p248/9). The improvement in image detail increases the chance of producing a high quality film first time with a lessened risk of repeat films.

- The use of an optimum kV

  The choice of tube kV is a balance between quality of film produced and patient dose. The radiographer must use a kV that is low enough to limit the effects of scatter yet high enough to keep the dose within ALARA principles (ibid, 1977: p249). In the United Kingdom, the National Radiological Protection Board (NRPB) have cautioned against “over-zealous reductions in patient dose” resulting in a decrease in image quality and make recommendations on quality assurance that each department should implement to ensure that this does not occur (NRPB, 1992). With the milliamperage/sec (mAs) values that are needed to give adequate film density in the radiography of the cervico-thoracic region, there is a very real risk that kV values above optimal level will be used, in an attempt to keep the patient dose as low as possible.

- *“Clearly and unambiguously”* means that the radiographer must ensure that the quality of the image is such that injuries are identifiable. This principle is fundamental to trauma radiography. The finding of a fracture or other anatomical disruption on a lateral cervical spine film is an important finding that will change patient management and impact immensely on the outcome for the patient, but a film which is inadequate or negative for injury cannot be used to exclude cervical spine injury (ACS, 1997, p34).

Just as important as demonstrating injury is demonstrating truly that there is no injury. For example, the presence of a visible artefact that mimics a fracture line, results in the patient undergoing CT scanning, which has the potential to significantly increase the radiation dose and delay the patient in the diagnostic imaging department (DID).

In all cases where a combination of clinical examination and radiography cannot clear the cervical spine, CT scanning will be used if available, due to its high sensitivity for fractures. This is recommended protocol according to ATLS principles (ACS, 1997, p226) and many papers have been published which also make this recommendation (Tan et al., 1999; Barba et al., 200; Kaneriya et al., 1998).

It must be remembered that “the purpose of diagnostic imaging in the setting of spinal trauma is to obtain the maximum information with the minimum of risk to guarantee the most adequate treatment according to the severity of the spinal injury” (Buitrago-Tellez et al.,1996: pp59-91).

When the patient is conscious and alert and has no distracting injuries that may mask neck pain, the clinical examination is highly accurate in predicting cervical spine injury. However, in the unconscious patient with multiple injuries, the clinician must rely heavily on imaging to assess the status of the neck (Jelly et al., 2000; Ullrich et al., 2001). Consequently, the images produced by the radiographer must be of a standard that will allow a definitive decision to be made (Berlin, L. 1996).

There are two accepted ways of defining quality in radiography; they are resolution (sharpness) and noise. The ideal image has high resolution and low noise. Both of these factors are influenced by the speed of the image receptor.

1. Resolution

“Resolution is the ability to image two separate objects and visually detect one from the other”(Bushong, 1993, p267).

High contrast resolution is in evidence in cervical spine lateral projections where there are two structures of very differing densities side by side, the bony vertebrae and the prevertebral soft-tissues. It is necessary for the diagnosing clinician to be able to see both of these accurately, as perceived changes in either one can signify traumatic injury (Hu S et al., 2000: p229).

In the cervico-thoracic region this is an even greater problem as the transition from neck to transthoracic area is sudden and varies hugely in density, the shoulder region being the widest, densest part of the body, especially in males. The challenge for the radiographer in this instance is to demonstrate the vertebrae above the shoulders for purposes of identification, while also demonstrating clearly all parts of the vertebrae below the trapezius muscle and between the humeral heads, as well as their associated soft tissues anteriorly. This requires excellent resolution. The inherent unsharpness of anatomical structures due to their tendency to have a rounded edge is also a factor in the resolution of the image. (Meredith & Massey, 1977, p267). This is particularly relevant in the imaging of the vertebrae.

2. Noise

Noise results in a fluctuation in the optical density of the image and has three main causes:

a. Graininess of the film

due to the size and distribution of the silver halide grains in the structure of the emulsion of the film.

b. Structure mottle

which is the equivalent graininess of the light-emitting phosphor of the intensifying screens in the cassette.

c. Quantum mottle

which is the mottled appearance present on the radiograph due to the speed of the system (Bushong, S, 1993 p266).

The first two are not usually the choice of the individual radiographer, however, the third factor in noise, quantum mottle, can be controlled somewhat by the exposure factors chosen by the radiographer. The speed of the film/screen system available is a contributory factor but can be combated by the use of exposure factors suitable not only to the area under investigation but also taking into account the speed of the system, the likelihood of quantum mottle and balancing this with considerations of dose.

One other thing that is essential for the accuracy and clarity of the radiographs is removal of clothing (Zabel et al., 1997). This is often done by the radiographer in the x-ray room but it is essential to realise, that in a semi-conscious state removal of clothing and some life saving interventions, are perceived by the patient as an assault on the body and add even more to the trauma (Mohta et al., 2003). Removal of clothing can also induce hypothermia in the traumatised patient with implications for the recovery (Schinco & Tepas, 2002). Despite this, there must be no overlying shadows from clothing, or other artefacts, which will obscure or mimic a fracture. In a 1997 study, one fracture was not seen on the lateral view because of an overlying shadow (Zabel et al., 1997).

1.8.3 Adequate number of appropriate radiographic projections

This is an inherent part of demonstrating the patient's condition and as such is a primary function of the radiographer.

1.9 METHODS OF DEMONSTRATION OF THE CERVICO-THORACIC JUNCTION

1.9.1. "Clearing" the cervical spine

The aim of cervical spine radiography in trauma is to enable the emergency physicians and radiologists to "clear the spine". When the cervical spine is deemed to be "cleared", the clinician has taken into account the history, clinical examination and other investigations and is satisfied that there is negligible risk of an important injury being present. (Clancy, 1999).

There are several imaging modalities in use for demonstration of the cervical spine. The following algorithm shows the usual decision rule using all the currently available modalities:

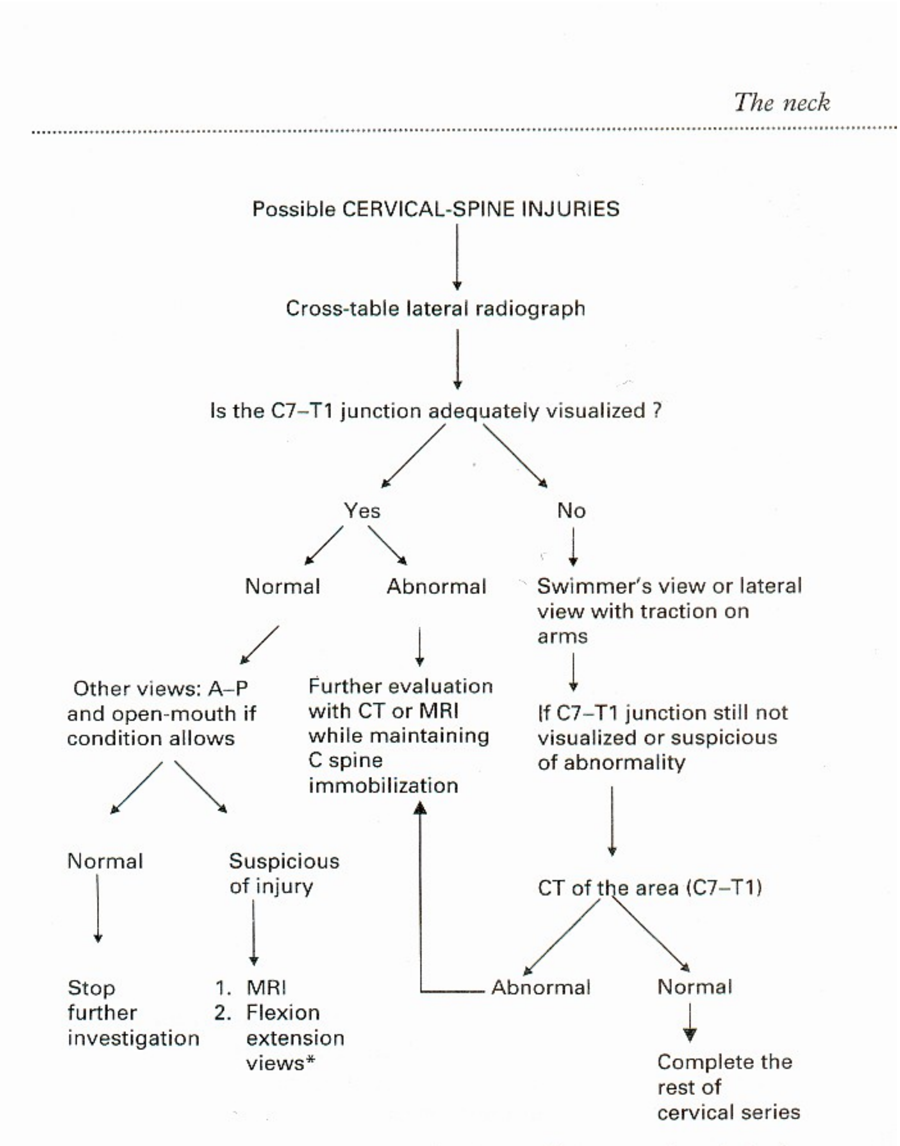


Table1.1. Algorithm for deciding on cervical spine imaging:

Taken from: Cocks et al., 1999, p117

1.9.2 Plain Film Radiography.

This is sometimes referred to as conventional radiography.

Advantages

It is possibly the most cost-effective and the most readily available means of imaging. In some second-care centres it is the only available means of imaging. There are over 130,000 disabled survivors of spinal injuries per year in the European Union, the vast majority of whom had their initial radiographs taken in community hospitals (Imhof & Fuchsjager, 2002). This indicates that plain film radiography is still predominantly, the modality on which the initial diagnosis of spinal injury is based. It is readily accessible, quickly available and mobile, which means it can be used in the resuscitation room of the emergency department. It allows the optimum overview of the cervical spine and is often “specific and definitive” (Cocks et al., 1999; p104). It gives the best information on dislocation, shows the facet joints and the prevertebral soft-tissues well, enabling visualisation of soft-tissue swelling, which is indicative of a disruption of the anterior longitudinal ligament. It can also be performed in provocation, which is essential for diagnosis of ligamentous laxity (Holtas et al., 1995)

Disadvantages

The results of numerous studies show that not all fractures are visible on plain films. Barba et al., (2001) reported that plain film radiography failed to demonstrate 31% of fractures (4 out of 13) despite being deemed adequate for diagnosis. However, these patients did not have AP projections and studies have proven that the lateral alone is not adequate. An AP projection can demonstrate traumatic tilting which is not visible on the lateral projection (Hu S et al., 2000; p185). Blackmore et al., (1999) state that 5%-8% of lateral views do not demonstrate fractures. However, Ross et al., (1987), Woodring & Lee (1992) and Bach et al., (2001) all showed that in combination with conventional tomography, a three view radiography series can compare favourably to CT. In addition, Ireland et al., (1997), showed that a five view radiography series is an excellent tool for diagnosis of cervical spine fracture. It has the same sensitivity for fracture as MRI but when all injuries including cord injuries are taken into account MRI is superior, depicting 79% of all injuries compared to 23% for radiography (Katzberg, 1999). Inability to show the spinal cord has always been one of the limitations of radiography and images oriented in the axial plane are necessary for this due to the protective design of the vertebral body.

1.9.3 Traction

Advantages

Distraction of the shoulders by pulling the arms distally is the most commonly used method for increasing the number of vertebrae seen on the lateral view. It has been proven to be mildly effective in the clinical setting by Ohiorenoya (1995). This study proved that distal shoulder distraction was only useful if the upper one-third of C7 was already on the lateral without traction but none of the disadvantages of traction were considered. It has also been proven to be of significant use in the laboratory setting, where application of known loads to fractured porcine cervical spines gave considerably better visualisation of known fractures of the cervical vertebrae.

Disadvantages

However, in the same study, application of traction also increased the size of the fracture's radiolucent gap and the authors concluded that the use of traction in the laboratory is recommended but they "acknowledge the need for extremely judicious use of traction in the trauma imaging clinic". (McGill & Yingling, 1999). According to Davis (1989) there is significant distraction of the vertebrae during arm traction in patients with fractures and ligamentous injuries. There are other disadvantages.

- It is uncomfortable for the already traumatised patient and has the potential to result in unwanted movement of the neck.
- It is also possible to damage axillary vessels during arm pull (Ireland et al., 1997).
- It is not possible in patients in whom an associated distracting painful injury (DPI) of the upper extremities is present and there is a high incidence of DPI in patients who have been subjected to high energy trauma, mostly involving the upper and lower extremities (Ullrich et al., 2001; Shatney et al., 1995). These are also the patients most at risk for cervical spinal injury.
- It does involve some dose to the physician too and considering the liberal use of cervical spine radiography the cumulative dose to the physician has the potential to be significant. A figure of 3000 cervical spines per year for one institution, is quoted in one paper (Blackmore et al.,1999).

Along with all those disadvantages, it is still not a successful way of demonstrating the cervico-thoracic junction, as the lateral view may still be incomplete (Zabel et al., 1997, Clancy, 1999; Ohiorenoya et al., 1996).

1.9.4 Swimmers

Incidence of use

The most common method of demonstrating the lower cervical region when laterals fail to do so, is the projection known as "Swimmers". It is used in 89% of Accident Departments in Ireland and the UK (Jenkins et al., 1999) with a moderate degree of success and it retains a role in assessing vertebral body alignment and integrity (Ireland et al., 1997). Woodring & Lee (1992) found it very useful in assessing alignment but not fractures. Its use is widespread and longstanding and despite disadvantages it is regularly used by clinicians to inform their decision on the presence or absence of injury at the cervico-thoracic junction.

Method

To position the patient for Swimmers, the radiographer must abduct the patient's arm anteriorly and rotate it through 180^0 until it rests against the ear, as in back crawl swimming. With the supine patient it is more difficult to extend the shoulders in the cranial and caudal direction so that the humeral heads are separated from the lateral aspect, but it is necessary for clarity of C7/T1. The central ray is projected horizontally and centred just above the shoulder remote from the film and so the x-ray beam must pass through the torso at the level of C7/T1, which is the widest part, especially in men.

Hazard and risk

This positioning involves movement of the patient, which is not recommended in spinal trauma as arm raising has been found to cause ipsilateral flexion and rotation of the upper thoracic vertebrae (Theodoridis & Ruston, 2002). There is one documented case of an exacerbation of an unstable injury due to positioning for Swimmers (Davis, 1989). The hazardous nature of Swimmers in the presence of an unstable cervical spine injury is acknowledged by other authors (Cocks et al., 1999; p38; Morris & McCoy., 2004) so Swimmers clearly has the potential to cause neurological sequelae of an unstable cervical spine injury and is not without risk. However, there continues to be a great number of Swimmers projections performed without report of detrimental effects, so, it seems the level of risk is low and this is why radiographers and clinicians continue to use it for diagnosis.

ALARA principles dictate that the use of radiation for diagnosis is kept at a level "as low as reasonably achievable" because of the risk attached. Swimmers projection needs higher exposure factor settings and often requires repeat projections which increases the cumulative dose. The reasons for repeats of this projection most often are

- the inability of the patient to cooperate when they are intoxicated, neurologically impaired or have any injury of the arm or shoulder (Kaneriya et al.,. 1998).
- body habitus which dictates the exposure factors needed (Ireland et al.,1997)

- difficulty due to arm movement (Ireland et al.,1997)

Daffner (2000) reports a 41% repeat rate for Swimmers, it was the projection most likely to need to be repeated and the most difficult for the radiographer to acquire; 22% of cervical spine views needed to be repeated because they were too dark and half of these were Swimmers. Of the 14% which were too pale, 57%, more than half, were also Swimmers. This highlights the fact that it is not easy for the radiographer to assess the exposure needed for this projection.

1.9.5. Supine (or trauma) obliques

Advantages

These are the projections which follow Swimmers in 6% of cases in the survey done by Jenkins et al., (1999). They are lower dose than Swimmers; Ireland et al., (1997) found that they need 1.6mGy per pair compared with 7mGy for a single Swimmers view. There is no movement of the patient and they are superior to Swimmers projection in showing the posterior elements of the vertebrae, important because of the greater potential for instability and impingement on the spinal cord from a posterior disruption (Ireland et al., 1997; Jenkins et al., 1999). Supine oblique projections were found to reduce the need for CT scanning by 48% (Kaneriya et al., 1998).

Disadvantages

However, there are some disadvantages. Visualisation of the lower cervical and upper thoracic spine in supine obliques, seems to vary from one institution to another. Jelly et al., (2000) found visualisation excellent with these projections, showing down to T2 in 100% of cases, yet Ireland et al., (1997) had the same failure rate as Swimmers, 38% and Kaneriya et al., (1998) report a rate of 13% of non-visualisation of C7/T. Similar to Swimmers projection, supine obliques can present technical difficulties for the radiographer and add to the time that the patient is delayed in the X-ray room (Kaneriya et al., 1998). Ireland et al., (1997) found a 26% repeat rate, Ross et al., (1987), was not impressed with them, describing them in the same way as he described Swimmers “technically inadequate and generally unhelpful”. The most disadvantageous aspect of these projections has to be interpretation. Several authors have discussed the rate of misinterpretation in plain film radiography of the cervical spine. 94% of errors were fundamental according to Davis, (1993) and misinterpretation was one of the two types of fundamental error made. Clancy (1999) also gives alarming figures for misinterpretation that warrant attention and states with certainty that the misinterpretation rate is worse with inexperience and recommends that all doctors ordering cervical spine radiography should be competent at interpretation. Supine obliques distort the anatomical image because of the extreme angulation of the X-ray tube. They may show the posterior elements well in the hands of an expert but are difficult for the inexperienced junior doctor working in the emergency department. There is much anecdotal evidence to suggest that this is the main reason they are not in common use despite their superiority to Swimmers. It is also difficult for the radiographer to critically evaluate them with regard to adequacy of diagnostic information, unless specialised training is given. These points are important, given Davis's (1993) findings, Clancy's (1999) comments on interpretation and Berlin's (1996) statement that "a radiologist's accuracy can be no greater than the quality of radiographs presented for interpretation". In the paper by Ireland et al., (1997) where supine obliques were introduced, a twelve-week training period was set up for everyone concerned, to eliminate a learning curve and enable participation in the study.

1.9.6. Conventional Tomography

Advantages

Two studies have shown this to be a good diagnostic tool for detection of atlanto-occipital dislocations, subluxations of vertebral bodies, fractures of lateral masses and articular processes. Both these studies show that alone it is not as effective as CT but in combination with radiography it compares very favourably (Woodring et al., 1992; Bach et al., 2001).

Disadvantages

Non-availability of conventional tomography during on-call hours, the inferiority of detection, longer imaging times and unsafe positioning of the patient are the disadvantages of conventional tomography (Ross et al., 1987; Van Goethem& Biltjies., 1996). Consequently, CT scanning has replaced conventional tomography in every centre where CT is available.

In most centres today, it is not used for diagnosis of cervical spine injury but still remains an strong option where CT scanning is not available (Bach et al., 2001). Therefore, for the radiographer, radiologist and emergency physician working only with clinical findings and radiography, there is evidence in the literature to suggest that despite the drawbacks, the cervical spine can safely be cleared without the use of advanced technology (Ross et al., 1987; Bach et al.,. 2001).

1.9.7. CT scanning

Advantages

There is no doubt that the advent of CT scanning has revolutionised the diagnosis of spinal injury. Non-visualisation of the cervico-thoracic junction is no longer a problem in those centres where CT scanning is available, due to the acquisition of the images in the axial plane.

It gives clear and definitive information where:

1. the area in question is not adequately seen
2. an injury is definitely identified on radiography
3. where an injury is suspected on radiography (Table 1.1.)
4. where there is a negative film but clinical indications of injury (ACS, 2000; p226; Kaneriya et al.,. 1998; Barba et al., 2001; Daffner, 2000; Van Goethem & Biltjies,1996).

With a diagnostic capability of 100%, as reported in several studies, the high sensitivity of CT in diagnosing osseous and some non-osseous injuries has dramatically decreased the potential for a missed cervical spine injury (Jelly et al., 2000, Barba et al., 2001; Lee et al., 2003). Ross et al., (1987) found that *all* of the CT studies included in his research were adequate for interpretation. It is superior to plain film radiography for demonstrating osseous anatomical disruption such as burst fractures of the vertebral bodies; it shows quite clearly fractures of the posterior elements of the vertebrae and any osseous impingement into the spinal canal (Woodring et al., 1992; Chiles & Cooper, 1996; Kaneriya et al., 1998).

It is understandable therefore, that CT is a desired method of investigation for actual and suspected injuries of the cervical spine, given the difficulty of demonstration the cervico-thoracic junction and the capacity for producing suboptimal images of this area, more than any other (Ireland et al., 1997).

Disadvantages

There are, however, disadvantages to the use of CT scanning, especially in cases of multiple trauma.

Despite reports of high sensitivity and 100% detection of fractures, not all injuries are seen on CT. (Bach et al., 2001; Ross et al., 1987; Woodring et al., 1992). Morris & McCoy, (2004) in their review of the literature involving cervical spine injury in unconscious polytrauma victims, acknowledge that CT is not foolproof for detection of all injuries and therefore recommend a combination of directed CT and plain films for increased accuracy. "Computerised tomography detects more fractures, plain films detect more malalignment and the two modalities are complimentary" The fractures missed by CT are mostly those in the axial plane, which are oriented in the same direction as the CT section. Slice thickness of 5mm or 10mm will reduce the sensitivity for fracture and certain other injuries are often missed (Lee et al., 2003). Fractures of the pedicle, the articular processes, the spinous processes and the dens do not always show on CT, nor do dislocations, subluxations and ligamentous injuries. MRI and plain film radiography are superior for these. (Bach et al., 2001; Cohen et al., 2003).

<u>Comparison films for follow up investigations</u>

Many follow-up treatments involve imaging, starting with orthopaedic and neurological interventions which use fluoroscopy as a guide and pre-treatment plain film images are necessary for comparison (Mann et al., 2003).

<u>Undesirable movement of the patient</u>

The patient has to be lifted off the trolley and onto the CT table for scan. In the case of a suspect spinal injury, this lift must be carried out "as one piece" so as to maintain anatomic alignment of the vertebral column. (ACS,1997: p241). This requires several trained staff, all of similar height and is often difficult to do correctly and time-consuming in an out-of-hours service, due to the lack of availability, or lack of immediate availability, of suitable staff. This movement of the patient onto the scanner table is not recommended, as movement should be minimised; transportation of a patient with an injured spine is hazardous (Chiles and Cooper, 1996).

Cost-effectiveness

Jelly et al., (2000) found just one significant injury picked up by routine scanning of C6-T2 and concludes that the normal protocol of three-view radiography supplemented by targeted CT would have detected all of the injuries and would therefore be more cost-effective. Kaneriya et al., (1998) also found that routine use of CT for cervical spine injury had a rate of 88% of scans with no abnormal findings. They recommended "bilateral oblique radiography" as a cost-effective protocol compared with CT.

Cumulative dose

The important issue of radiation dose is mentioned infrequently but Mann et al., (2003) state that due to the much greater radiation dose involved in sequential CT scanning that screening CT for detection of spinal injuries should only be used when helical CT with multi-planar reconstruction is available. The author states that helical CT carries much less risk of radiation hazards than the older incremental scanners but does not give a figure for the actual dose involved in helical CT.

A recent study found that in imaging of the cervical spine, the dose to the thyroid was 14 times greater for CT than that for plain film radiography. The figure given for the thyroid dose in this study was 26mGy for CT, 1.8mGy for radiography. They recommend the judicious use of CT for patients with suspected cervical spine injury (Rybicki et al., 2002).

In the UK, CT accounts for just 4% of all requests for imaging but 40% of the dose to the public from medical x-rays (Hart and Wall, 2002). These figures were published soon after two articles in the American Journal of Roentgenology which raised concerns about the link between adult cancers and paediatric CT dose. Consequently, there is much concern about CT dose generally (Rogers, 2001; Sandrick, 2003; Ringertz, 2003).

On the road to recovery, the patient with multiple injuries will have many diagnostic and therapeutic procedures involving radiation and Tan et al., (1999) say that given "the relatively young age of the trauma population" and the high associated rate of morbidity of these injuries over time, CT of inadequately visualised C7/T1 appears to be cost-effective. This author fails to mention that multiple injuries will necessitate a high number of interventions involving radiation, therefore cumulative dose must also be a consideration.

Observed/unobserved medical emergency

Once in the scanner the patient is left alone in the room due to the potential for a high radiation dose to staff who stay in the room. Therefore, the potential for an unobserved medical emergency is greater than in the X-ray room and this could be potentially life-threatening to the patient.

Hypothermia

There is a concern too regarding hypothermia, as patients are undressed for clinical examination and the temperature in a CT scanning room is very closely controlled at a maximum of 24ºC. This is too cold for an exposed, traumatised patient and can lead to recovery complications (Schinco & Tepas, 2002).

Unequal access to technology

CT scanners are much more costly to purchase, install and maintain and consequently they are not always available in “second-care hospitals” (Bach et al.,. 2001). In Ireland, in 2004, 27 hospitals accept multi-trauma patients and of these, four do not have a CT scanner (Ambulance Service, 2004; Murphy, 2004), this is 85% access to CT. In practice, many of the CT scanners are only operational during daytime hours so this figure of 85% access decreases during on-call hours.

Expertise in interpretation of the images

The CT images require training in interpretation and consequently must be read by a radiologist, who is an expert in the field of diagnosis. No other medical personnel interpret them.

1.9.8 MRI Scanning

Advantages

Magnetic Resonance Imaging (MRI) has several advantages over other types of imaging.

- It has the best low-contrast resolution
- It is non-invasive
- No use of ionising radiation
- No bone or air artefacts

- Capable of multi-planar imaging (Bushong S, 1993; p450)

These are particularly good assets in imaging of the traumatised cervico-thoracic spine. It shares some of the advantages of CT with respect to the cervico-thoracic junction.

- Acquisition of images in the axial plane
- Superiority of soft tissue differentiation compared with radiography. (Bach et al., 2001).

In fact, it is in soft tissue injuries of the spine that MRI succeeds above all other modalities and is of increasing utility, having been described as the definitive method of demonstrating soft tissue injuries (Katzberg et al.,1999; Van Goethem & Biltjies,1996). Where MRI is used as “a standard frame of reference”, post-traumatic spinal cord compression is demonstrated in just 33% of cases by CT (Takhtani & Melhem, 2002).

Disadvantages

Movement of the patient

The patient must be moved onto the MRI table and this is contraindicated in trauma where movement must be kept to an absolute minimum. (ACS, 1997; p217).

Demonstration of fractures and bony abnormalities

MR imaging is not as successful as other forms of imaging, in demonstrating bony injuries, such as fractures of the vertebrae and in particular, fractures of the posterior elements, which may be the cause of spinal instability. In this instance, CT scanning and plain film radiography are the superior method of demonstration (Takhtani & Melhem, 2002; Chiles & Cooper, 1996).

Access for all of the life-support equipment

The multi-traumatised patient needs “continuous haemodynamic monitoring and respiratory support”(Takhtani & Melhem, 2002). However, the amount of equipment needed for continual monitoring of the patient’s vital signs and the materials and functioning of this equipment, prohibits entry into the “tunnel” that is the MRI scanner. This has been circumvented in some places by the use of extra long fluid lines, oxygen lines and electrical leads, which mean that the monitoring equipment can stay in the control room where it can be watched closely. The patient though, is not easily accessible and in an emergency situation, any delay in accessing the patient is contraindicated; time is of the essence and the hazards and delays in an emergency situation are similar to those in CT.

<u>Artefacts and heating effects</u>

The use of monitors and fixation devices in the vicinity of the scanner is associated with artefacts and risks, due to interference with the magnetic field. However, it is now possible to have monitors that operate at frequencies outside the radio-frequency spectrum of the MRI scanner or have effective radiofrequency shielding and cervical orthotic devices that are made from MR compatible materials such as aluminium, plastic and graphite. These reduce the image-degrading artefacts and risks such as heating effects and induction of electric currents. (Takhtani & Melhem, 2002). They are, however, expensive and until this safer equipment becomes commonplace, interference from the necessary monitors and immobilisation devices remains problematic.

Expertise in interpretation of the images

Katzberg et al.,(1999) say that they cannot emphasise strongly enough, the importance of training in interpretation of the images. Consequently, these cannot be read by a junior doctor in the emergency department and must therefore await the expertise of the radiologist.

Unequal access to technology

There may be increasing availability of MR scanners in the USA, yet in a 1999 survey of all the A/E departments in Ireland and the UK, very few departments had access to MRI (Jenkins et al.,1999). From the Irish perspective, the increasing availability of MRI scanners may be a future trend but not a present one. There are presently only seven MRI scanners in public hospitals in Ireland, therefore of the 27 hospitals that accept major trauma cases, at least 20 have no emergency access to MR Imaging (Higgins, 2004).

1.10 MOTIVATION

Adequate demonstration of the cervical spine in a multi-trauma patient can be a source of much difficulty for the diagnostic radiographer. The trauma radiography team in our institution noted that delays in imaging were always as a result of difficulty in demonstrating the cervico-thoracic junction. Non-visualisation of C7/T1 on the lateral cervical spine film, is reported as occurring in 13%-37% of all patients. (Ireland et al., 1997; Kaneriya et al., 1998; Zabel et al., 1997; Tan et al., 1999). Cervical spine radiography for trauma victims is requested approximately 115 times per month (1400 cases per year). (CUH Statistics, 2002). Consequently there are approximately 13 - 37 patients per month, (approximately 7 per week, 1 per day), in whom the cervico-thoracic junction is not adequately demonstrated. These patients require specialised projections of the area and present the radiographer with varying degrees of difficulty (Cocks et al., 1999).
It was the ongoing difficulty of Swimmers that prompted this research.
A technical or radiographic solution to this problem on non-visualisation was needed, or an alternative way of demonstrating the cervico-thoracic region radiographically. It was hoped that as this had been a problem for so long that there would be a solution in the literature.
This led to the overall research question which is;

Can visualisation of the cervical spine in trauma patients be improved without increasing patient dose?

Through discussion, a tightly collimated true lateral of the cervico-thoracic area was proposed and piloted. With exposure modifications, it proved successful but required further research to ensure widespread acceptance and investigation of radiation dose issues.

1.10.1 The Coned True Lateral Projection (CTLP)

- The patient remains supine with both arms by his side.
- The x-ray tube is brought in to a focus-film distance of 100cm

- The central ray is directed at a point externally which overlies the C7/T1 joint space internally. In most patients this is in line with the External Auditory Meatus (EAM) at the level of the palpable bony prominence of the acromion process. Where the cervical collar worn by the patient is too large or too small, causing hyper-flexion or hyper-extension of the neck, this point may be more anterior or posterior than the line of the EAM.
- The cassette is supported at the patient's side distal from the x-ray tube, centred at the level of the acromion process, so that the central ray is directed to the centre of the film.
- No grid is used.
- The exposure settings needed are approximately 5kV more than that used for the lateral projection and double the mAs value of the lateral projection for an average sized patient.
- Due to the tight collimation, the lateral projection is occasionally needed in conjunction with this film, for identification of the vertebral levels.

Advantages

The advantages appear to be

- non-movement of the trauma patient
- smaller exposure factor settings at the generator than those used for Swimmers
- grid-free technique

This led to the first hypothesis which is:

The proposed CTL projection is of lower dose than Swimmers projection.

This new projection demands no movement of the patient at all. Consequently, there is no bone overlying the image of the vertebrae on the final film and the facet joints and spinous processes appear to be more visible than on the Swimmers projection, as do the prevertbral soft tissues anteriorly. The patient is more comfortable and less likely to move therefore the risk of movement unsharpness is minimal. This observation gave rise to the second hypothesis which is:

The proposed CTL projection is of better quality than the Swimmers projection in demonstrating the cervico-thoracic junction in trauma patients.

Disadvantages

- Visualisation of all of the anatomical features can be impaired due to the tight collimation needed and this can cause difficulty with identification of the vertebral levels.
- Assessing the exposure needed for this projection is easier than for the Swimmers projection but it is still variable and repeat films are needed on occasion because of inaccurate exposure factors.

Further recommendations regarding these may follow from this research.

CHAPTER TWO: METHODOLOGY

2.1 ETHICS COMMITTEE APPROVAL

Ethical approval was granted by the Clinical Research Ethics Committee of the Cork Teaching Hospitals.

A submission was made to the ethics committee for permission to carry out this prospective investigation and was granted with a stipulation that all patients give written consent. This decision was appealed on the grounds of the inability to write of a number of multi-trauma patients, due to physical injury or a change in their neurological status and the consequent threat to validity if the study was limited to only those who could write. The appeal was accepted and permission granted. The submission form, letters of permission and letter of appeal form Appendix X of this study.

2.2 PILOT STUDY

A pilot study of 20 cases was carried as an initial assessment of the usefulness of this particular projection in the trauma setting and to indicate changes that would need to be made to the design of the prospective study, before the actual investigation began. (Bailey, 1997).

The first 20 trauma patients who presented during full-service hours for radiography of the cervico-thoracic junction, were imaged using the coned true lateral projection as a first preference. For the pilot study it was decided to exclude those patients who presented during on-call hours when there is a reduced staffing level. As the majority of suitable cases present during this time, the time frame for the pilot study extended from September 20th, 2001 to January 4th, 2002, due to the smaller number of suitable cases presenting during daytime hours (SHB, 2001).

2.2.1 Method

The first 20 patients who needed radiography of C7/T1 were imaged using the collimated true lateral projection. The radiographer recorded :

- Patient identification details for retrieval of the films at a later stage
- Exposure factors used

- How many vertebrae were seen on the first lateral projection.
- How many projections and of what type
- Success or failure of the projection

2.2.2. Results of the pilot study

Success rate

The proposed projection was passed by the radiographer and accepted as adequate by the emergency physician in 9 out of 20 cases, deeming it 45% successful. In 50% of cases (n=10), it was discarded and swimmer's projection was used successfully. In 5% of cases, (n=1), neither projection succeeded in demonstrating the cervico-thoracic junction.

Number of vertebrae visible on the first lateral

In 7 of the 10 cases where more than 6 vertebrae had been visualised on the first lateral projection, the CTL successfully completed the imaging of the cervical spine laterals. It was unsuccessful in every case where less than C6 was imaged on the first lateral.

2.3 CALIBRATION OF THE THERMO-LUMINESCENT DOSIMETERS

The patient doses during the study were measured using Thermo-luminescent dosimeters (TLD), a DAP meter was not available. The particular TLDs used were chips of lithium fluoride. TLDs take account of the radiation backscattered from the patient during exposure and due to this are the recommended dosimeter for patient dose measurement. They are also recommended because of their small size, unobtrusive nature and ability to measure doses in the diagnostic range with reasonable accuracy (NRPB 1992).

The room was calibrated using a Unfors meter, Mult-o-Meter Model 531, which measures exposure parameters in kVp, mAs, time in milliseconds and dose in milliGray. This is the meter used for quality control tests, which are carried out routinely on this tube. The tube output was seen to be consistent and within acceptable tolerance levels of +/- 10%.

The TLDs were calibrated according to the instructions given in the Owners manual of the Harshaw Model 5500 Automatic TLD Reader (2000) and in line with the recommendations of NRPB (1992).

2.3.1 Preparation of Dosimeters

The TLDs were pre-annealled in the TLD oven to remove any residual dose which may have been present. The oven heats up over a period of one hour to a maximum temperature of 400^{o}C. This temperature is maintained for a period of 12 hours followed by 80^{o}C for two hours, then dropping to room temperature. After this, the TLDs were stored at room temperature, in a radiation free and subdued UV environment.

2.3.1. Sensitivity ordering

As all thermo-luminescent dosimeters of identical material and size do not react to radiation in an identical manner, it was necessary to first ascertain the strength of reaction of each chip. Consequently, the TLDs were subjected to a known radiation dose, each one receiving an identical dose, which was ascertained by the use of the Unfors radiation detection meter. Firstly, a set of factors was chosen as representative of the range of exposure factors which would be used in the study. These factors were as follows:

100cms FFD
6.5cm X 6.5cm field size
81kV
20mAs
100milliseconds
Fine focus.

The detector was centred in this field and the exposure was made a total of three times, the dose readout in mGy was recorded for each exposure and from these, the average dose was ascertained.

The TLDs were housed in two identical plastic holders, in a grid of 5 X 5 compartments that measured 4cm^2. Each group of 25 were then exposed three times to these exposure factors and consequently, the known dose, as described above.

2.3.2 Setting the Time/Temperature Profile (TTP)

The TTP was now chosen. This is the heating conditions within the reader during dose readouts. The parameters chosen were:

Preheat: 135 ºC for 10seconds
followed by
Acquire temperature of 25 ºC per second to a maximum of 270 ºC for 13 $^{1}/_{3}$ seconds
followed by
Anneal: 70 ºC for 5 seconds.

These are the parameters currently used in the dosimetry service of the Medical Physics Department in which this TLD reader is in use. All 50 exposed TLDs were then put into the Harshaw 5500 TLD Reader and the readout, in nCoulombs of light emitted, was recorded for each individual chip. These readings, along with the TLD position in the carousel (TLD holder), were then rearranged from lowest to highest reading and this gave the order of sensitivity of the batch of TLDs.

2.3.3 Generating Calibration Dosimeters

The first, middle and last dosimeters were removed from the carousel to become the calibration dosimeters. These three were the least sensitive, of medium sensitivity and the most sensitive of the dosimeters and as such represented the average sensitivity of the batch. These were named 1A, 1B and 1C. The other 47 chips were numbered 1-47 in order of sensitivity and from this point, this identification was retained and carefully maintained.

All dosimeters were then annealled in the oven, using the heating profile as previously described.

2.3.4 Applying an Element Correction Coefficient to the calibration dosimeters

The three TLDs, chosen to be calibration dosimeters, 1A, 1B and 1C, were again exposed to a known dose, exactly as described above.

These dosimeters were then put in the reader and heated using the relevant TTP. An acceptable ECC was applied, upper and lower limits of 0.96 and 1.04 were chosen, which gave a range of +/- 4% deviation from the mean. Element Correction Coefficients (ECC) for each of the three calibration dosimeters were then generated. All three were accepted as calibration dosimeters.
All dosimeters were then annealled in the oven.

2.3.5 Calibrating the Reader

The TLD reader must also be calibrated to maintain the integrity of the results it generates, in spite of high voltage changes, repairs, dirt accumulation or long-term drift. The reader calibration factor (RCF) converts the raw charge data from the photomultiplier tubes (in nanocoulombs) to units of dose, in this case milligray (mGy) so that all future TLD readings will be stated in milligray. The two factors, ECC and RCF, are applied to the data using the formula;

$$\text{Exposure} = \frac{\text{ECC} \times \text{Charge(nC)}}{\text{RCF}}$$

The three calibration dosimeters, now known as 1A, 1B and 1C, which are representative of the response of the batch of TLDs, were now used to determine the reader calibration factor which was applied during all future readings which use this particular time-temperature profile.
Calibration dosimeters were exposed to the identical exposure factors used previously and then transferred to the reader, the appropriate TTP applied and the reading started. The known dose to which they were exposed was entered into the software along with the unit of measurement, milligray. From this the RCF was generated.
The calibration dosimeters were annealled in the oven.

2.3.6 Calibrating the field dosimeters (generation of ECCs for the field dosimeters)

This process applied the Reader Calibration Factor (RCF) to the reading of the field dosimeters, thereby generating an individual Element Correction Coefficient (ECC) for each one.

The field dosimeters were now exposed to the identical exposure factors as before and put into the reader. The appropriate time-temperature profile was applied and the dosimeters read. The dose used to irradiate the dosimeters was entered into the software and an acceptable element correction coefficient range was entered. In this case the values used were 0.90 and 1.10 which gave an acceptable range of +/-10% deviation from the mean of the calibration dosimeters, which was considered the acceptable range for the field dosimeters. This information was then applied, generating individual ECCs for all of the field dosimeters.

Application of these individual ECCs makes the sensitivity of all the field dosimeters virtually equal to the mean thermo-luminescent efficiency (sensitivity) of the calibration dosimeters, making the entire dosimeter batch virtually equal in response.

2.3.7 Testing

All of the 47 field dosimeters were then exposed again to a known dose, using the same factors as before and put into the reader, the appropriate TTP and ECCs applied and the readings, now in mGy, scrutinised for accuracy. All TLDs were seen to be within 3% of the mean.

The TLDs were annealled in the oven and this test was repeated once more and assessed for accuracy. Again all TLDs were seen to be within 3% of the mean which is considered an acceptable deviation.

All TLDs were now ready for use.

2.4 PHANTOM STUDY

A preliminary dose-study was carried out using a Rando® anthropomorphic phantom and TLDs. For the purposes of accuracy when performing Swimmers, an arm was used belonging to the Pixie anthropomorphic phantom, as the Rando® phantom does not have any arms. Both of these phantoms are tissue equivalent and sized to represent “average man”, who is defined by the World Health Organisation as 70kg weight and 1.63m tall. The phantom was imaged using the same x-ray tube, cassettes, films, screens and processing that would be used in the study for a patient of that size. Both projections were performed.

2.4.1. Method

Rando® was placed supine on a trolley and the arm was positioned with the humeral head next to the glenoid area, with the hand above the head, as for Swimmers.

Swimmers

The phantom was first irradiated, in the Swimmers position, without TLDs in place and using film, to determine the correct exposure factors needed to produce an acceptable image. The film was viewed and when deemed acceptable, the TLDs were placed on the phantom exactly as they would be on a patient and another film taken using the identical factors. The film was developed and seen to be acceptable and identical to the previous one. The TLDs were removed and read immediately in the Harshaw TLD reader.

CTLP

The arm was positioned by the side for this projection, as the patient's arm would be in the clinical setting, and the same method as for Swimmers, was used to obtain a diagnostic film and the doses relating to it.

The following table shows the exposure factors used for each projection and the results in mGy of the TLD readings:

PROJECTION	EXPOSURE FACTORS USED	ENTRANCE SURFACE DOSE (mGy)	THYROID DOSE (mGy)
Swimmer's	85kv, 111mAs (AEC), FFD 100cms, Broad focus, moving grid.	27.03	2.22
Coned True Lateral	85kv, 16mAs, FFD 100cms, Fine focus, no grid.	3.58	0.25

Table 2.1. Dose information from the phantom study

The entrance surface doses and thyroid doses for the coned true lateral projection were seen to be below that of the swimmer's projection and it was known from the pilot study that the quality was at least as good as the swimmer's projections. It was decided on these grounds to proceed with the prospective study.

2.5 PROSPECTIVE STUDY

This prospective study started on September 8th, 2003 and finished on May 18th, 2004. 86 patients who presented for radiography of their cervical spine following trauma were included in the study.

2.5.1 Technology In Use

X-Ray Tube and Generator

All films were obtained in the A/E x-ray room where the x-ray system in use was a Siemens 3D system. The x-ray tube had the following characteristics:
Fine focus 0.6mm
Broad focus 1.0mm
Filtration 1.5mm Aluminium
Added filtration 1.0mm Aluminium
Half Value Layer (HVL) 3.00mm Aluminium
The generator was a Siemens Polymat 50, 50kW generator.

Cassettes, Screens and Films

The cassettes in use were Konica, suitable for use in the Konica daylight processing system. The intensifying screens were Konica 400 speed, green emitting and the films were Fuji Super HR-L 30, 400 speed, green sensitive.

Processing

All films were processed in the Konica Daystar DS7 processor.
Development time 45 seconds

Developer temperature 32^{0}C

The chemicals used were Champion Devalex Air developer and Champion Fixaplus Air fixer.

2.5.2 Quality Assurance

Quality control monitoring is carried out daily on the processing system check that processor temperature, base fog, contrast and density of the films are within accepted tolerances. Weekly tests are carried out on the replenishment rate of the fixer and developer. There are weekly tests on the x-ray equipment to ensure that the beam quality and quantity is within an acceptable level of +/- 10% of the set value and the accuracy of the Light Beam Diaphragm. This continued as usual throughout the period of the study and detected no decline in the performance of any of the equipment.

2.5.3 Inclusion and Exclusion Criteria

The following criteria were applied:

1. All patients were over 17 years of age (Hart et al.,2002, p50/51)
2. The patient was supine on a trolley, wearing a cervical collar
3. The patient had suffered cervical spine trauma that required x-ray evaluation (Royal College of Radiologists, 1998)
4. There were at least six cervical vertebrae on the first horizontal lateral, which was still inadequate for diagnosis (ACS,1997; Pilot study, 2002)
5. There was no additional pathology that makes it difficult to obtain visualisation of C7/T1, specifically, osteoporosis and metastatic disease of the cervical spine (Martin et al., 1999)

2.5.4 Randomisation

As this study was testing a new radiographic technique and comparing it with the current protocol, it was necessary to include both projections in the study (Martin et al, 1999). The patients were randomised into two groups, one half imaged with the current protocol of swimmer's projection and one half with the proposed projection. This was achieved by providing a sealed brown envelope containing all the necessary equipment and instruction on which projection to perform.

Upon presentation of a suitable patient the radiographer chose a brown envelope.

2.5.5 Contents of the envelope

- A questionnaire which stated clearly which projection to perform and on which the radiographer recorded the patient information.
- A collimator.
- A tape measure
- A white envelope containing two packets of numbered TLDs, marked ESD (Entrance Surface Dose) and Thyroid, each one containing two TLDs. The outside of the envelope was marked with the words

TLDS for first projection of C7/T1 only. Measure all C7/T1 doses, use new TLDs for each one. Patient's name; MRN/DOB/ ID no. ESD 31/32 Thyroid 14/15 (the TLD numbers for verification with the contents)

As this envelope contained radio-sensitive TLDs, it was kept in the processing room which is a radiation free area and has no natural daylight.

- A consent form
- Instructions, including photographs, indicating where to place the TLDs.

The Questionnaire

<u>Radiography</u>

These forms were designed for ease of use, having as much information as possible already pre-printed so that the radiographer had only to circle the relevant answer, keeping writing to a minimum. They were tested on three cases and no amendments were seen to be necessary.

On the information sheet, the radiographer recorded the following information:

1. A means of patient identification, e.g. Medical Record Number (MRN), or Date of Birth (DOB), or X-ray number.

2. Patient's date of birth
3. Patient's height and weight as stated by the patient (NRPB, 1992)
4. Size of cervical immobilisation collar worn by the patient (McEntee, 2002)
5. Shoulder width, from the greater trochanter of the humerus on one side to the same point on the other side (McEntee, 2002)
6. Time the patient entered and left the x-ray room
7. Number of cervical spine projections done
8. Exposure factors used for the first projection of the cervico-thoracic region
9. Informed verbal or written consent

CT

Where someone in the prospective study went on to have CT scanning of the cervico-thoracic region the CT radiographer was asked to fill out a form. As it was intended to compare the time that patients spent in the x-ray room with the time spent in the CT scanning suite, these forms had boxes for recording information on

- which CT scanner was used,
- exposure factors used
- the time that the patient entered and left the room.

These forms are Appendix 2 and 3.

The Collimator

These were made from the offcuts of the laminator, which are normally discarded. They consisted of two sheets of laminating film, fused together and cut to a size of 7ins by 7ins (17.7cms^2), which gave an exact fit across the exit of the Light Beam Diaphragm so the collimator could be slotted on and left in place while in use. The collimation for the Coned True Lateral projection, 2.5cm^2, was marked exactly in the centre using black permanent marker. It showed clearly against the patient's skin but was not visible on the x-ray image.

Two collimations for the swimmer's projection were also drawn on the collimator, one, 12cm by 4cm would demonstrate the whole cervical spine for the purposes of identification of the vertebrae. The smaller collimation was 6cm by 4cm. This was considered necessary as some radiographers always include the whole cervical spine on Swimmer's projection and some collimate tightly. As the proposed coned true lateral was being compared with the current protocol of Swimmer's projection, it was necessary that swimmer's did not change from its present method. These collimations were tested for accuracy on three patients. The extremely tight collimation of the coned true lateral projection was seen to be variable depending on the patient size, but the chosen size of $2.5cm^2$ was deemed appropriate for the average and small size patient. It was decided to recommend to the radiographers that they use it as a first attempt and use larger collimation only when the first attempt indicates that it is needed.

The collimator was x-rayed, to ensure that it would not show on the final film if left in place during the imaging.

The collimator and the TLD packaging were home-made.

The Tape Measure

The tape measure was made of stiff paper and measured up to 76cms or 30inches.

The TLD packaging

The only commercially available packets, called H-sachets, were unsuitable due to their design so home-made packets were used. These were made from stiff paper, approximately 2.5cm by 1.5cm, with two TLD identification numbers written on it. It was wrapped in cling film to minimise the chance of accidental TLD movement during packaging and the two TLDs were placed on it. This was then wrapped again in cling film followed by a double layer of micropore tape. The TLD identification numbers were written on one side and either ESD or Thyroid written on the other. These holders are in common use in the radiotherapy department where they are known to be suitable for holding TLDs while patient dose measurement is performed. It was unknown however, if they would show on X-ray film, so they were placed on the phantom while a coned true lateral projection was taken. Another coned true lateral using identical factors was also taken, but without TLD holders; both films were developed. There was no visible difference between them, no artefact that could be attributed to the holders, as confirmed by a Consultant Radiologist.

Consent Form

The consent form explained the study simply, assured the patient of confidentiality and asked for consent to use any information given. This forms Appendix 4

Instructions and photographs of TLD placement

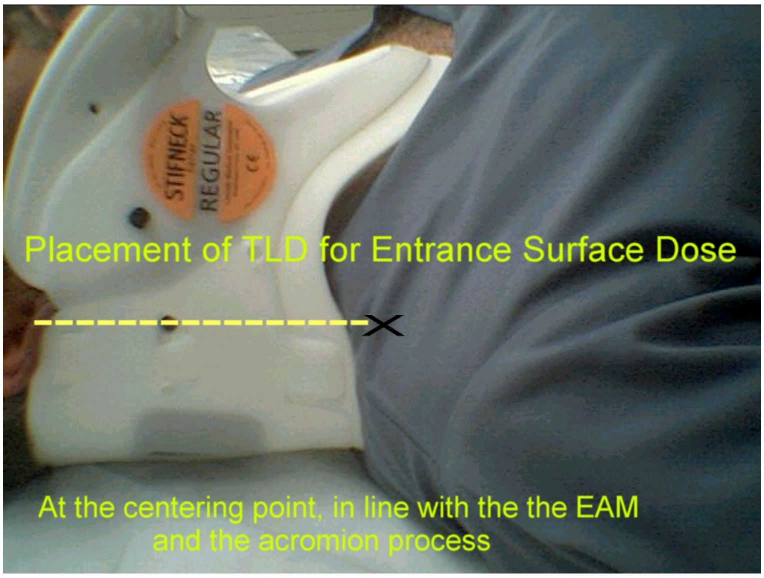


Figure 2.1. Instruction photograph for placement of the TLD for ESD measurement.

Posed by a volunteer.

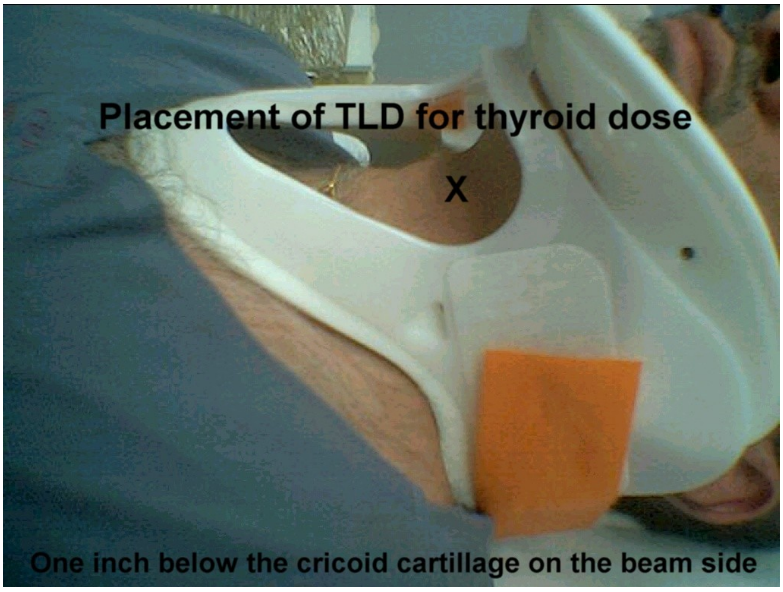


Figure 2.2. Instruction photograph for placement of the TLD for Thyroid dose measurement.

Posed by a volunteer.

2.5.6. Pre-study training

Before the study started, each radiographer in the department where the study was taking place was given a handout that described how the radiographer could participate in the study. It forms Appendix 5. There was also an oral presentation where they could ask any questions they may have had. The doctors in the A&E Department also had an oral presentation and training on how to interpret the CTLP images.
Throughout the study, instructions and photographs of TLD placement were situated at prominent places in the X-ray and processing rooms.

2.5.7. Method

The radiographer verbally consented the patient and where the patient's condition permitted, written consent was obtained. The patient was asked the relevant questions and the answers were recorded on the questionnaire. The patient's torso width was measured, collar size noted and TLDs placed at the correct positions.

Position of the TLDs

The TLDs for measurement of Entrance Surface Dose (ESD) were placed at the entry point of the central ray of the x-ray beam, which was at the level of the acromion process of the scapula and in line with the external auditory meatus. This co-ordinate changed depending on how well or how badly the cervical collar worn by the patient fitted. Where the collar was causing the head to tilt posteriorly, the centring point was anterior to the line of the EAM, and posterior where the collar was too lax and the chin depressed.
The TLDs for measurement of the dose to the thyroid gland were placed 2.5cm below the cricoid cartilage on the side of the incident ray.

The projection, as indicated clearly across the top of the information sheet, was performed using 100cms FFD and collimating to the size indicated by the collimator.

Focus -Film Distance

The FFD in use for this projection was kept at 100cms because Swimmer's is carried out at 100cms FFD and a direct comparison between the two projections was the aim of this study. The accuracy of this distance was important as dose measurement is dependent on distance due to the effect of the inverse square law. To ensure that the distance used was not variable, the tape measure, which is part of the tube design, was checked for accuracy by the engineer from the company who supply and service the X-ray equipment. The desired FFD, 100cms, was marked on it clearly, in red permanent marker.

When the projection was taken, the TLD holders were removed from the patient, and the questionnaire, consent form if used, TLDs and collimator were replaced in the brown envelope. The tape measure was discarded for infection control reasons.

Repeat projections

Repeat projections were not randomised to ensure the acquisition of a diagnostic image with the minimum of dose, so in the event of a projection needing to be repeated the radiographer was free to perform any type deemed suitable for demonstration of the region. A contingency envelope contained sheets for recording which projection was used, the exposure factors used and the attempt number. It also contained several white envelopes containing two sets of TLDs, marked ESD and Thyroid and numbered with the TLD identification numbers. The outside of the envelope had a section for recording which projection these TLDs were used for and the number of the attempt. These were placed as before and the exposure made. After exposure, the radiographer recorded the relevant exposure information on the sheet, put the TLDs back into their white envelope and filled in the information on the front of the envelope. This was done for each projection of the cervico-thoracic region. When the imaging was finished all information sheets, all white envelopes containing exposed TLDs, the collimator, consent form and tape measure were put back into the original brown envelope which was put into a collection box. This was also placed in the processing room, safe from radiation and ultra-violet light.

Extracting the dose information from the TLDs

Within 24 hours the TLDs were removed from their holders and placed in the reader for evaluation. Each holder contained two TLDs and the doses measured for each of the two TLDs were averaged, to give the patient dose for that projection. This was considered necessary as TLDs can occasionally give dose information that is widely at variance with that of the surrounding TLDs (McAllister, 2003). It was recommended that three be used for greater accuracy, but this would probably have resulted in an occasional shortage, so it was decided to use two rather than compromise the number of patients included in the study. Cumulative doses for those patients who had repeat projections were calculated and recorded along with all other patient information.

2.6 EVALUATION OF THE IMAGES

Films were retrieved for evaluation. The cervico-thoracic projection and the lateral projection were segregated and put into a separate envelope. This was marked with the study number and the notation C for CTLP and S for Swimmer's, so the study numbers became 1C, 2S etc. The names on the films were covered with opaque tape ***so the*** patient identity was not revealed to the evaluators. Each reader was given a verbal explanation of what was expected.

Only the cervico-thoracic projection was evaluated, the lateral being present only for purposes of identification of the vertebral levels, as this is the way in which levels are assessed in normal practice.

2.6.1 Evaluation Forms

The forms consisted of questions on

- technical considerations such as contrast and density
- visibility of anatomical features
- the usefulness of this image for diagnosis of injury
- the need for further imaging
- the reason for further imaging if needed.

The questions were divided into two groups with different methods of scoring. The first three questions were concerned with contrast and density, the next eleven were visibility of anatomical detail and the usefulness of the film for diagnosis. The questions on the visibility of anatomical detail were adapted from the CEC Image Quality Criteria for the lateral lumbar spine projection (European Commission, 1996).

The forms were piloted on the readers using ten films, five of each projection. This ensured that the questions asked were clearly stated, unambiguous, relevant to the usual interpretation of the cervico-thoracic projection and understood by all the evaluators. It also served to show the evaluators what was expected of them in the final evaluation. (Bailey, 1997). It is also recommended that this be done prior to the actual evaluation as reader thresholds have been known to change during the early stages of image analyses of this type (Martin et al, 1999). This eliminates a "learning curve" during the actual evaluation. A Coned True Lateral image, which the researcher deemed to have demonstrated all of the eligibility criteria, was included among the ten films. If there was evaluator consensus on full marks for this film, it could be presumed to be a "gold standard" image and could be used as such. Included in this pilot study were two extra evaluators, who were not going to be in the final panel but have expert knowledge of the cervico-thoracic region. They were a neuro-surgeon and an orthopaedic surgeon.

Suggestions were made regarding ambiguity of the wording, the scoring system for the answers and the font type, size and layout of the questions. These were taken into account and the final form was arrived at.

The questions on technical factors and visibility of anatomical features were based on the CEC image quality criteria.(European Commission, 1996)

2.6.2 Evaluators

The evaluators were chosen for their expertise in this area. They were all healthcare professionals for whom some aspect of the imaging of the cervico-thoracic junction is a relevant and ongoing part of their work.

They were:

- A Consultant General Radiologist
- A Consultant Neuro-radiologist
- A Consultant Emergency Medicine Physician

- A Specialist Permanent Registrar in Emergency Medicine
- A Radiographer with many years experience of accident and emergency work.

2.6.3 Viewing Conditions

All of the films were read in the conference room of the X-ray department where there is a bank of eight viewing boxes, two tiers of four each. Before evaluations began an entire set of new bulbs, all of the same colour and intensity, was inserted in the viewing box structure. The luminance of the viewing boxes and the ambient lighting in the room was measured before and after each evaluation using a Hagner Universal Photometer, Model S2 which has a range of 0-100,000 cd/m^2 or lux. The viewing boxes were assessed by dividing each one into six equal areas, using opaque card cut to shape to shield all but the area under investigation.

It was recommended that the evaluators use the same viewing box, 2nd from left on the bottom row, as this was the one that conformed most closely with the luminance for film viewing, recommended by the CEC criteria. This recommended level is 2000 – 4000 cd/m^2. Within the chosen box, there was a variance from 1700cd/m^2 to 2400cd/m$^{2.}$ This variation was consistent throughout all of the readings, consequently the evaluators were told to use the middle and lower segments of the right hand side of the viewing box when assessing the films of the cervico-thoracic region; these; both were 2200 cd/m$^{2.}$

The ambient light in the room was always between 50 - 60 lux.

2000 cd/m^2	2400 cd/m^2
1700 cd/m^2	2200 cd/m^2
2200 cd/m^2	2200 cd/m^2

Table 2.2: Luminance of the selected viewing box.

2.6.4 Intra-Observer Variability

Two images, one of each projection and both of which, the researcher felt, were not easily identifiable, were used for testing intra-observer variability. These films, numbers 10S and 53C were given to the evaluators three times, at the beginning, middle and end of the readings.

2.6.5 Marking The Forms

There were fifteen closed-ended questions and one open-ended. (Doordan, 1998)
The first three questions were closed-ended questions of the multiple-choice type. The answers were graded, Good, Adequate and Poor and were marked 3, 2 and 1 respectively, giving a full score of 9 marks for this section. They were concerned with the contrast and density of the image and included one question on the visibility of the pre-vertebral soft tissues of the neck. Although this was a question on the visibility of anatomical detail, it was included in this section because of a suggestion by two readers during the pilot study. Both stated that the visibility of these tissues is an extremely important part of diagnosis that is compromised by erroneous contrast and ***density and*** therefore, in this evaluation, that should be qualified rather than just stated as visible or invisible. It is also a factor that can be controlled by the radiographer, therefore it was included in this first section.
The next eleven questions were also closed-ended questions. They were dichotomous questions, marked yes or no. The first nine referred to the visibility of anatomical features at the C7 and T1 levels. These questions were concerned with the elements of the image over which the radiographer has little control.

- Questions 1 & 2 of this group asked about rotation of the vertebrae which is proven to be present due to arm raising but can be limited by good positioning (Theodoridis & Ruston, 2002).
- Questions 3 & 4 asked about sharpness and this can be controlled only somewhat by the radiographer. The round nature of the vertebral bodies gives rise to an inherent lack of sharpness of the image (Meredith & Massey, 1977; p267).

- Questions 5 & 6 concerned visualisation of the spinous processes which may be compromised by overlying anatomical structures or by collimation of the beam that is too tight.
- Questions 7 & 8 concerned visualisation of the facet joints which can be hindered by overlying anatomical structures; in the Swimmers projection the arm overshadows these.
- Question 9 was about identification of vertebral levels. This can be dependent on collimation for both projections, but is also a product of the visibility of anatomical features.
- Question 10 is the question that clinicians ask themselves in the clinical setting when making a decision on the presence or absence of injury in the patient and it was included for two reasons:
  1. To elicit a definitive answer on the usefulness of these films for diagnosis
  2. To test the CTLP in a setting as close to the clinical setting as possible.
- Question 11 was about the need for further imaging and the answer was dependant on the answer to the previous question. A film that cannot be meaningfully interpreted for injury demands that further imaging take place and vice versa. The only instance where this relationship does not exist is when there are definite signs of injury on the film and CT scanning is required. In that instance the answer to both questions is “yes”.

All of these yes and no answers were allocated marks of 1 for yes and 0 for no.

The eleventh question was marked in reverse to the other questions in this group, with a “yes” answer receiving a 0 score and a “no” answer receiving a score of 1.

The answers to this group of questions were assessed together giving a score out of 11, therefore a film which was considered perfect by an evaluator had a total score of 20, 9 out of a possible 9 marks plus 11 out of a possible 11 marks.

The final questions were not allocated a mark; they were clarifications of the previous answer.

- The first of these was a forced-choice question which listed the types of further imaging that the evaluator required, based on the previous answers.
- The final question was open-ended and asked why the evaluator requested this particular type of imaging.

2.7 REJECT ANALYSIS

Throughout the data collection a special box for rejected films of the cervical spine was kept in the processing room. The rejects were analysed to get an idea of the reasons for repeat films.

2.8 RADIOGRAPHERS' QUESTIONNAIRE

When the data collection was finished a questionnaire was distributed to the radiographers to gather their experiences of the CTLP, with regard to the ease of use and ease of identification of the vertebral levels. This also included questions on the reasons why patients were not included in the study, which projections were chosen for repeat attempts and why. There were a total of ten questions, not all of which needed to be answered, depending on the radiographer's participation in the data collection. Two of the ten questions needed a written reply, seven were dichotomous, requiring a "yes" or "no" answer and one suggested answers based on anecdotal information, with an option to answer freely.

2.9 STATISTICAL TESTS USED

The data gathered was ordinal, nominal and ratio data and therefore suitable for non-parametric tests and for parametric, provided that parametric assumptions are satisfied. However, dose data, although ratio in nature is positively skewed and not of a normal distribution, so this will not allow for the use of parametric testing. The numbers in the sample are small, 86 in total, and will be subdivided by projection. Attrition due to missing dose data and non-retrievable films, further reduces the size of the data sample for analysis and this too puts it outside parametric assumptions. Any data that is ordinal or nominal in nature will be analysed using non-parametric tests. In addition, the BMI values were calculated by using the height and weight as stated by the patient. Although these factors are ratio in nature, this data was gathered in a way that is based on human estimation and it is therefore not recommended that it be analysed using parametric tests (Rushton, 1999).

The tests suitable for the data in this study are

- Pearson's Chi-Squared (χ^2) for data that is nominal, characterised by frequency and unrelated (gathered by two or more subjects)
- Mann Whitney U for data that is ranked and is ordinal and unrelated.
- Spearman's rho for correlations
- T-tests for equality of means
- Fishers Exact test where the numbers are very small (Chi-square tests are unreliable where there are less than five expected values in a cell).

CHAPTER THREE

RESULTS

3.1 PATIENT DEMOGRAPHICS

3.1.1. Age and Gender

A total of 86 people (mean age = 35, median = 32, range 14-94 years), were entered into the study.
38.37% (n=33) of these were female (mean age =35, median =32, range 17-80 years).
61.63% (n=53) were male (mean age =35 and median = 31, range 14-94 years).

3.1.2 Torso Width

The torso widths measured ranged from 32.5cm to 62.5cm, mean =42.4 cm and a median = 42.5 cm.

3.1.2.1 Female

The female patients' widths ranged from 32.5- 55 cm, mean = 41.7 cm, median = 40cm.

3.1.2.2.Male

Male patients had torso widths ranging in size from 32.5- 62.5 cm, mean = 42.85 cm, median = 42.5.

3.1.2.3 CTLP

The 29 patients whose final, successful film was a CTLP, had torso widths from 32.5cm - 55 cm, mean = 42.07, median = 40.

3.1.2.4 Swimmer's

The 57 patients who had a successful swimmer's projection had a range of torso widths from 32.5cm - 62.5cm, mean = 42.57 cm and median = 42.5.

3.1.3. Collar Sizes

The collar sizes in use, in order of length from the shortest to the longest, are named Paediatric, No Neck, Short, Regular and Long. For statistical analysis these were coded from 1-5 with increasing length.

All of the smallest size, Paediatric, and none of the longest size, Long, were worn by female patients. The opposite is true for males; none of the shortest size and all of the longest size were worn by men.

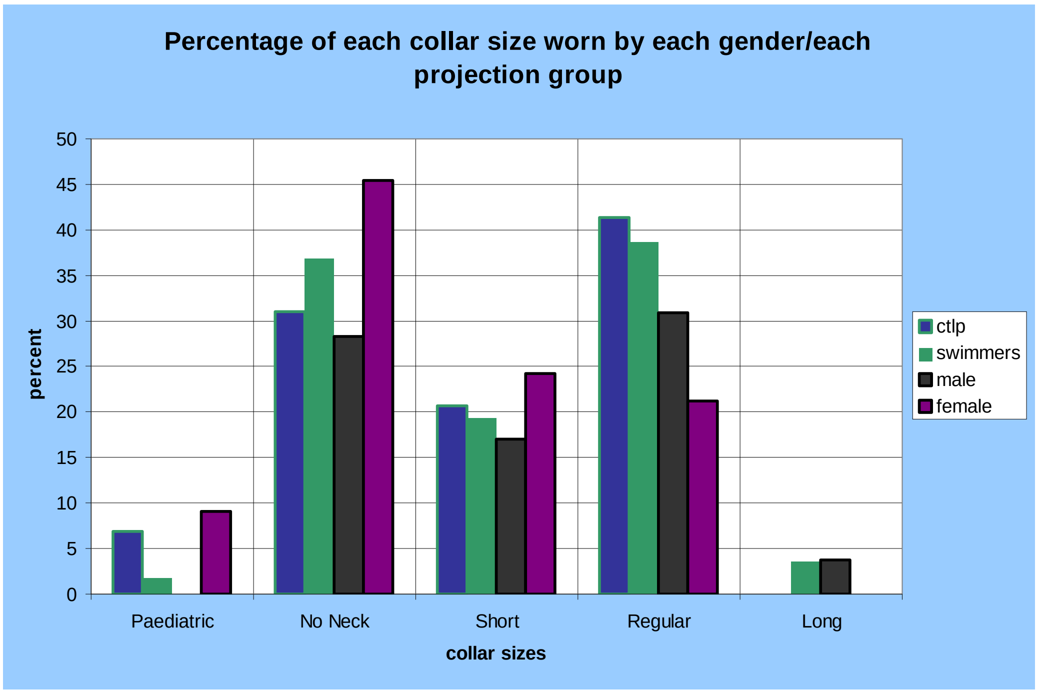


Figure3.1 Percentage of each collar size worn by the patients in each group

3.1.4. Weight

Weights recorded for all 86 patients were in the range of 41kg to 121kg. The mean weight was 77.58kg, Median weight was 76 kg and mode = 70kg.

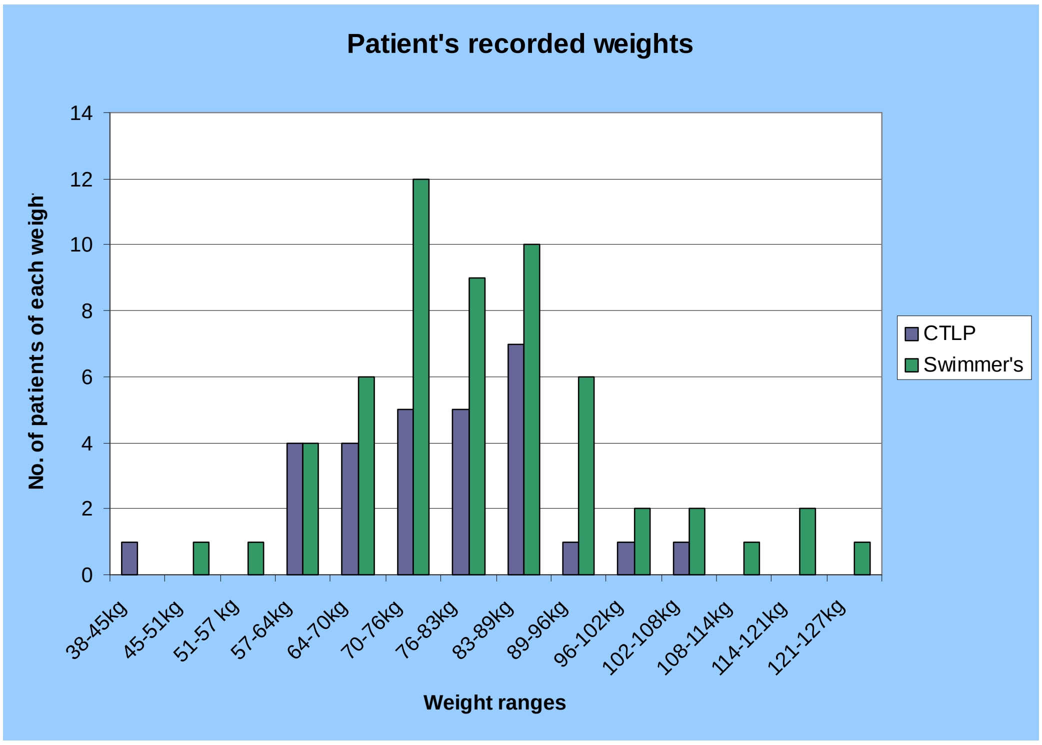


Figure 3.2 Patient weights

3.1.4.1. CTLP

Among the 29 patients whose final projection was a CTLP, the weights recorded ranged form 41 kg - 102kg. The mean weight = 74.52kg, median weight = 76 kg and mode = 83kg. This group had a mean weight that was 70kg +3.164%.

3.1.4.2.. Swimmer's

The 57 patients with a successful swimmer's projection gave weights in the range 48kg to 121kg. Mean weight = 77.73 kg, median = 76 kg and mode70kg. This group had a mean weight that was 70kg +11.04%

3.1.5. Height

Heights measured were in the range 1.5metres - 1.9m. Mean height was 1.7m and median = 1.72m.

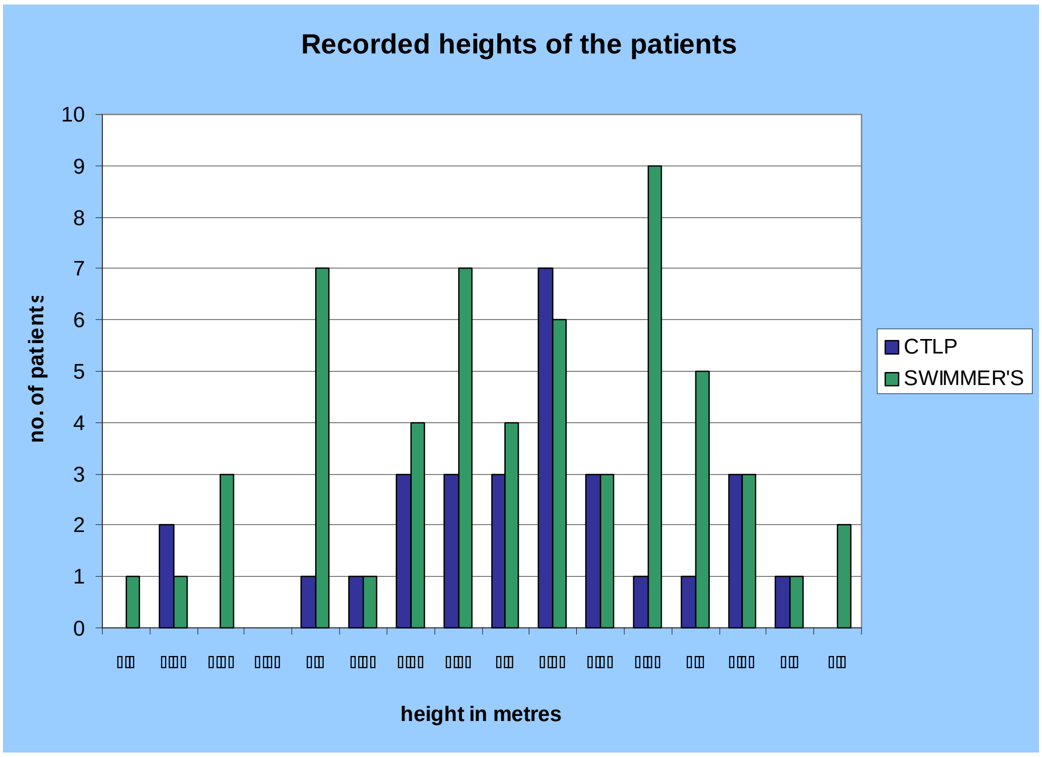


Figure 3.3 Patient heights

3.1.5.1. CTLP

For those whose final, successful film was a CTLP, the range of heights recorded was 1.52m -1.88m, mean = 1.7m and median = 1.72m.

3.1.5.2. Swimmer's

The 57 patients who had successful swimmer's projections had heights in the range 1.5m -1.9m. Mean height was 1.7m, median = 1.72m.

3.1.6. Body Mass Index

The World Health Organisation groups BMI ratings as follows:

Weight	**Status**
Below 18.5	Underweight
20-25	Normal
25.0-29.9	Overweight
30.0 and above	Obese
Above 40	Very obese

Table 3.1 World Health Organisation table of Body Mass Index

The 86 patients had BMI values in the range of 17.2 - 39.5, the mean value = 25.57 and the median = 24.9, mode = 23.4.

2.32%, n=2 were underweight with BMI values less than 18.5.

51.16%, n= 44 had a BMI value that fell within the 18.5 - 24.9 range, which is defined as normal.

34.88%, n= 30 were in the overweight category with BMI of 25-29.99

11.63%, n=10 had BMI values greater than 30 which are in the obese range.

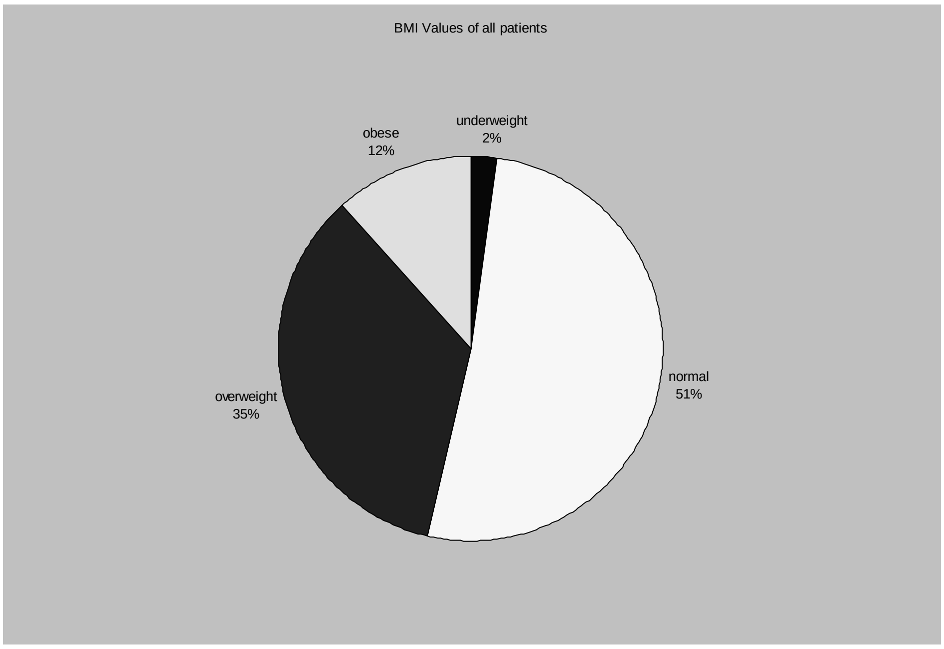


Figure3.4. Body Mass Index of the patients

A total of 46.51%, n=40, had BMI in the ranges above normal**.**

3.1.6.1. Females

BMI values for the 33 female patients were in the range 17.2 - 39.5, mean = 26.24, median = 24.9. Two (6.06%) were underweight, 14 (42.42%) were in the normal range, 12 (36.36%) were overweight and five (15%) were obese.

3.1.6.2. Males

BMI values for the 53 male patients were in the range 19.6 - 33.2, mean = 25.16, median = 24.8. No-one was underweight, 29 (54.71%) were in the normal range, 19 (35.85%) were overweight and five (9.43%) were obese.

3.1.6.3. CTLP

BMI values for those 29 whose final image was a CTLP were in the range 17.2 -30.4. The mean was 24.43, median = 24.8 and mode =24.8

3.1.6.4. Swimmer's

BMI values for the 57 swimmer's patients were in the range 18-39.5. The mean = 26.16, median = 25.1 and mode 23.4

3.2. PROJECTIONS

There were 86 patients in total. 45 had CTLP as a first attempt and 41 had Swimmer's. 29 CTLPs and 57 Swimmer's went forward as final projections, for diagnosis and evaluation.

3.2.1 Successful projections (in which the starting projection was the same as the final projection)

	CTLP	SWIMMERS
Starting projection	45 times 52.3%	41 times 47.7%
Starting & final projection	27 times 60%	39 times 95.1%

Table 3.2 Successful projections

3.2.2 Unsuccessful projections (those which strayed from their assigned group)

	Final projection CTLP	Final projection Swimmers
First projection CTLP n=45	27 times 60%	18 times 40%
First projection Swimmers n=41	2 times 4.87%	39 times 95.12%

Table 3.3. Unsuccessful projections

3.3. EXPOSURE FACTORS USED FOR THE PROJECTIONS

3.3.1. Tube Potential (kV)

	Mean	Median	Range
All swimmers	92.18	90	77-102
Successful swimmer's	93.22	90	77-102
All CTLPs	84.02	85	70-109
Successful CTLPs	83.75	85	73-90

Table 3.4 kV values used

3.3.2. Tube current x time (mAs)

	Mean	Median	Range
All swimmers	212.53	146.5	6-999
Successful swimmers	199.8	156	6-729
All CTLPs	19.5	16	8-60
Successful CTLPs	19.5	16	8-60

Table 3.5 mAs values used

-

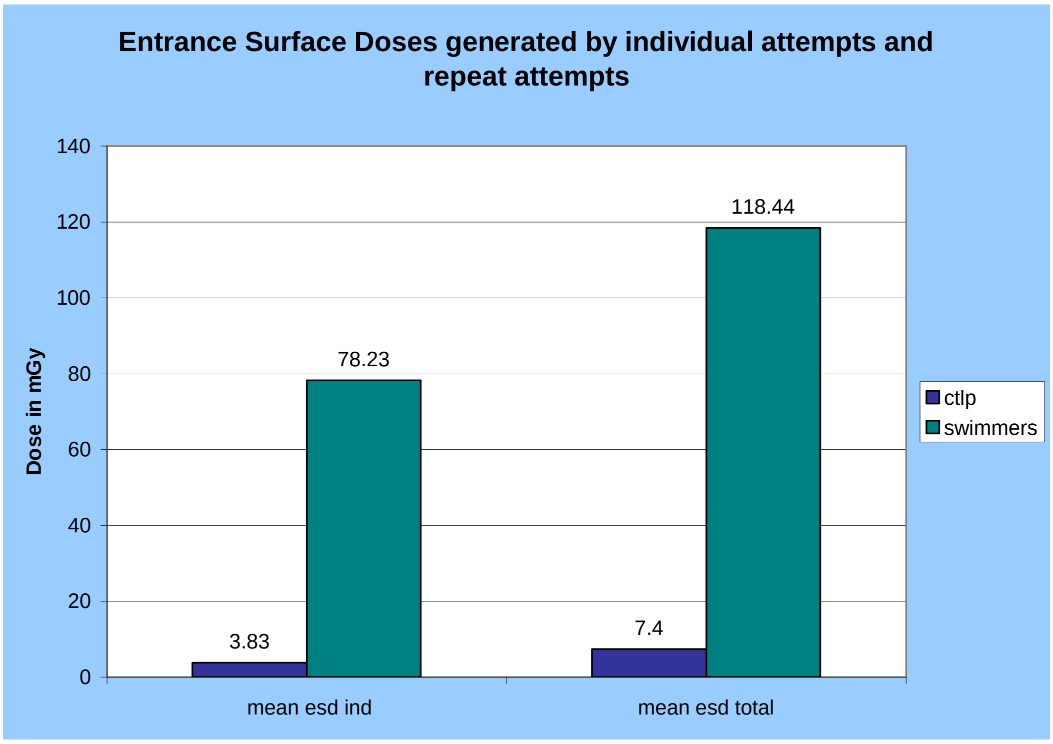
3.4. RADIATION DOSES GENERATED BY THE EXPOSURES

Doses were measured using TLDs and the readings were calculated in milliGray (mGy). The doses measured were the Entrance Surface Dose (ESD) and thyroid dose.

Mean Entrance Surface Dose (mGy)			
CTLP Individual attempts (successful and unsuccessful)	Swimmers Individual attempts (successful and unsuccessful)	CTLP Cumulative doses from repeat attempts	Swimmer's Cumulative doses from repeat attempts
3.83	78.23	7.4	118.44

Figure 3.6 Mean ESDs

Figure 3.5 Mean ESDs for individual and repeat attempts



Mean Thyroid dose (mGy)			
CTLP Individual attempts (successful and	Swimmers Individual attempts (successful and	CTLP Cumulative doses from repeat attempts	Swimmer's Cumulative doses from repeat attempts

unsuccessful)	unsuccessful)		
0.24	4.89	0.51	7.16

Table 3.7 Mean Thyroid doses

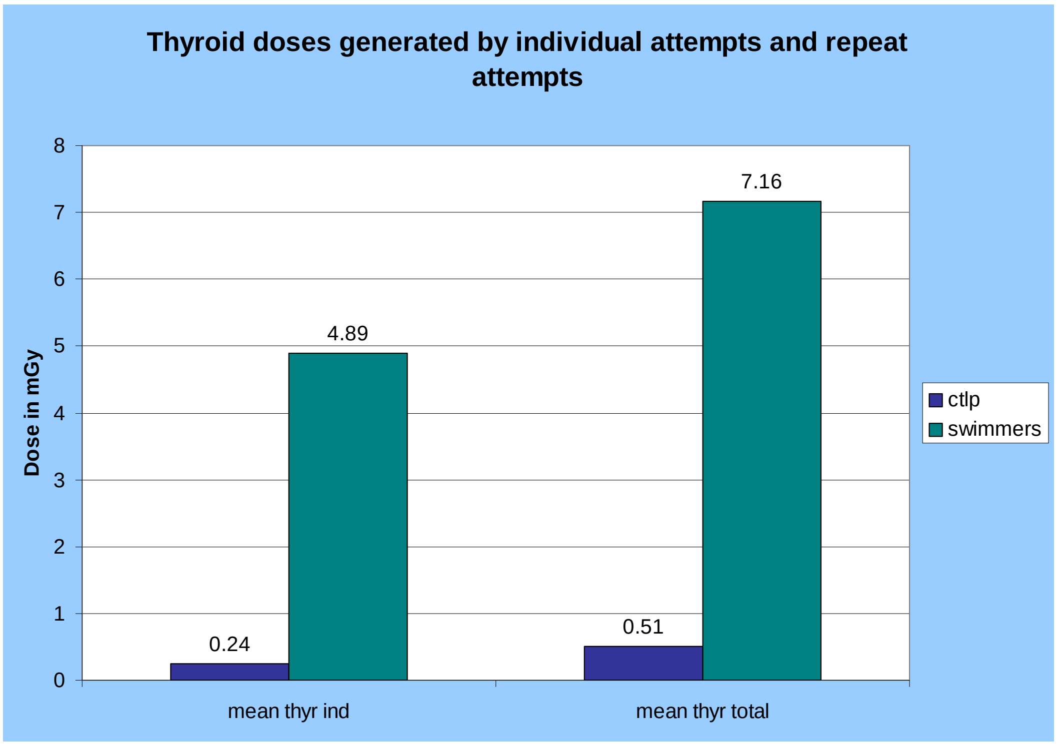


Figure 3.6 Mean Thyroid doses for individual and repeat attempts

The doses generated by the CTLPs were much smaller than those of Swimmer's projections. In both cases, repeat projections added significantly to the dose.

3.5. SCORES AWARDED BY THE EVALUATORS

The five evaluators' marks for each film were averaged to give an overall score. The minimum possible mark was 3, the maximum 20.

The mean score for all films = 13.02 out of 20, (65.11%) and the median = 13.4 out of 20, (67%). The range was 5 - 18.8 (25% - 94%).

3.6. THE OVERALL RESEARCH QUESTION - STATISTICAL ANALYSIS

To answer the overall research question: “Can visualisation of the cervical spine in trauma patients be improved without increasing patient dose” the following tests were performed.

3.6.1. Analysis of the number of evaluators (from none to all five) agreeing that the film is diagnostically useful

	CTLP	Swimmer’s	Chi-Square value	p Value
3 or more evaluators agree	14 56.0%	20 45.5%	χ^2 = 0.350	NS
2 or fewer evaluators agree	11 44.0%	24 54.5%		

Table 3.8. Statistical analysis of evaluator agreement

56% of the CTLPs were considered diagnostic by a majority of the evaluators, while 45.5% of the Swimmer’s projections were.

3.6.2. Relationship between the starting projection and the final, successful projection.

		Starting projection	
		Swimmer’s	CTLP
Successful (final) projection	Swimmer’s	(39) 95.1%	(18) 40%
	CTLP	(2) 4.9%	(27) 60%

Table 3.9 Starting projection v. final projection

These figures show that if the starting projection was Swimmer’s then the final projection was also Swimmer’s 95% of the time and a CTLP just 5% of the time. Where the CTLP started the series, it was the final projection in 60% of cases and a Swimmer’s became the final successful projection in the other 40% of cases.

A Chi Square test found this to be statistically significant.

χ^2 = 26.751 (Yates continuity correction), df = 1, p = <0.001.

As this shows a significant difference between the successful projections in relation to the starting projection, it was investigated further.

3.6.3. Relationship between the starting projection and the presence of a different projection in the series:

Presence of at least one Swimmer's:

Starting projection	Total no. of attempts	No. of cases where there was no Swimmer's in the series	No. of cases where there was at least one Swimmer's in the series
Swimmer's	41	0	41 (100%)
CTLP	45	27 (60%)	18 (40%)

Table 3.10. Presence of Swimmers projections in the series

In every case where the Swimmer's projection was the starting projection, there was at least one swimmer's in the series (100%). 60% of all first attempt CTLPs culminated in a successful CTLP, some after several attempts, but without the use of a Swimmer's projection anywhere in the series. However, 40% of the cases which began with a CTLP, did use a Swimmer's projection in the follow up series.

Using a Chi Square test gave the following values:

$\chi^2 = 29.803$; df = 1; p=< 0.001 which is significant.

Presence of at least one CTLP:

Starting projection	Total no.of attempts	No of cases where there was no CTLP in the series	No.of cases where there was at least one CTLP in the series
Swimmer's	41	36 (87.8%)	5 (12.2%)
CTLP	45	0	45 (100%)

Table 3.11. Presence of CTLPs in the series

Where the CTLP began the series, there was a CTLP included in the series 100% of the time. Where Swimmer's began the series, the CTLP was tried in just 12.2% cases (n=5). This was considered statistically significant with $\chi^2 = 64.401$; df =1; p = <0.001. Where the Swimmer's was unsuccessful there appeared to be a strong tendency to try another Swimmer's in preference to a CTLP.

3.6.4. Relationship between the starting projection and frequency of each type of projection in the repeat series:

Analysis of the Number of Swimmer's projections among the repeats

Starting projection	Number	Median	Interquartile range			Range	Mann Whitney U	p Value
CTLP	45	0	0.00	0.00	1.00	0-3	285.00	<0.001
Swimmers	41	1	1.00	1.00	2.00	1- 4		

Table 3.12. Statistical analysis of the number of the presence of Swimmers

This was found to be a statistically significant difference between the projections, tested using a Mann Whitney U test. When Swimmers started the series there was a significantly greater number of Swimmers projections among the repeats.

Number of CTLPs among the repeats

Starting projection	Number	Median	Interquartile range			Range	Mann Whitney U	p Value
CTLP	45	1	1.00	1.00	2.00	1-3	89.00	<0.001
Swimmers	41	0	0.00	0.00	0.00	0-2		

Table 3.13. Statistical analysis of the number of the presence of the CTLP

Using a Mann Whitney U test again showed a significant difference between the starting projections with regard to the amount of times a different type of projection featured among the repeats. There was a significantly greater tendency to follow an unsuccessful Swimmer's projection with a Swimmer's, rather than a CTLP. This table also shows that the Swimmers projection needed a maximum of four attempts while the CTLP needed a maximum of three.

3.6.5. Statistical analysis of the number of repeat attempts used, with regard to starting projection.

Starting	Mean	Median	IQR	Range	Mann	p Value

projection					Whitney U	
CTLP	2.02.	2	1-3	1-4	681.00	p<0.05
Swimmers	1.66	1.00	1-2	1- 4		

Table 3.14. Statistial analysis of the number and type of repeat projections

Where the CTLP was the first attempt, there were more attempts before reaching a final, successful film.

The overall score awarded by the evaluators is a good indication of the quality of visualisation of the cervical spine on these films. Consequently, the following tests were performed to assess the similarities and differences between the two projections with regard to improving the quality of the film.

3.6.6. Correlations with the scores awarded by the evaluators

Correlation between overall score and Torso width, BMI, Age, Collar size, Exposure factors (kV & mAs), Entrance surface doses and thyroid doses of the evaluated projections and gender.

A Spearman's rho test was used to calculate the correlation coefficients and gave the following results:

Correlations for the CTLP group (excepting gender)

SCORE v	*Spearman's rho value*	p Value
Width	-0.323	NS
BMI	-0.218	NS
Age	0.096	NS
Collar size	0.144	NS
KV	-0.473	<0.05
MAs	-0.456	<0.05
ESDs (evaluated)	-0.216	NS
Thyroid doses (evaluated)	0.054	NS

Table 3.15 Correlation of score with recorded variables for the CTLP group

Correlations for the Swimmers group (excepting gender)

SCORE v	Spearman's rho value	p Value
Width	-0.375	<0.05
BMI	-0.300	<0.05
Age	0.273	NS
Collar size	-0.124	NS
KV	-0.170	NS
MAs	-0.084	NS
ESDs (evaluated)	-0.053	NS
Thyroid doses (evaluated)	0.082	NS

Table 3.16. Correlation of score with recorded variables for the Swimmers group

The Spearman's rho correlations show that for CTLP films lower tube potential and tube currents correlated with higher scores.

Higher scoring Swimmer's films were achieved on patients with lesser torso widths and a lower Body Mass Index.

To assess the impact of gender on the film score, a Mann Whitney U test was applied to the data as follows:

SCORES		CTLP		SWIMMERS	
		Female	Male	Female	Male
Range		7.4- 18.8	8.6- 17.2	5.0- 17.0	5.6- 18.4
Median		15	13.2	13.8	13.00
Inter-quartile range	25^{th}	11.4	12.4	12.2	8.3
	50^{th}	15.0	13.2	13.8	13.00
	75^{th}	16.20	14.95	16.4	15.20
Mann Whitney U value		64.00		179.5	
p Value		NS		NS	

Table 3.17. Statistical analysis of the effect of gender on score

This shows that gender has no effect on the scores awarded to the films by the evaluators.

The overall score can be broken down into two parts

1. radiographer - controlled contrast & density (C/D)
2. visibility of anatomical features (Detail).

The following tests were performed to assess the affect that each of these has on the overall score of both projections and the consequent implications for improving the quality of the film.

3.6.7. Correlation of the scores for C/D and Detail (both projections), with the incidence of a high level of agreement on the usefulness of the image for diagnosis (three or more evaluators).

Evaluated projection = CTLP

CTLP v 3+ evaluators	C/D	Detail
Spearman's rho correlation coefficient	0.735	0.938
p Value	p<0.001	p<0.001

Table 3.18. Statistical analysis of the effect of the component parts of the score on evaluator agreement for CTLP

There is a highly significant correlation between both aspects of the CTLP film quality and the number of evaluators agreeing that the film can be interpreted for the presence or absence of injury. This is close to a true linear correlation for visibility of anatomical detail.

Evaluated projection = Swimmers

Swimmers v. 3+ evaluators	C/D	Detail
Spearman's rho correlation coefficient	0.745	0.909
p Value	p<0.001	p<0.001

Table 3.19. Statistical analysis of the effect of the component parts of the score on evaluator agreement for Swimmers

Again, for the Swimmer's projection both aspects of the film quality influence the evaluators ability to use the film for diagnosis, with the contrast and density having a close to linear correlation with the number of evaluators giving a positive response.

The total number of attempts needed is a trait that indicates ease of use, time taken for imaging and the cumulative dose, therefore it was analysed.

3.6.8. The total number of attempts taken to reach a successful projection of that type, sorted by starting projection

START	FINISH	CTLP	REJECT	SWIMMERS	REJECT
CTLP	CTLP (27)	43	16	0	0
CTLP	SWIMMERS (18)	27	27	21	3
SWIMMERS	CTLP (2)	4	2	2	2
SWIMMERS	SWIMMERS (39)	3	3	59	20
TOTAL		77	48	82	25
REJECT RATE		62%		30.5%	

Table 3.20. Number of attempts of each projection

	CTLP	SWIMMERS
KNOWN CUMULATIVE DOSE	145.66mGy	4884.47mGy

Table 3.21. Radiation dose for both projections; all recorded attempts

Where the projections were successful, the reject rate was equal

- Swimmers reject rate = 36%
- CTLP reject rate = 34%

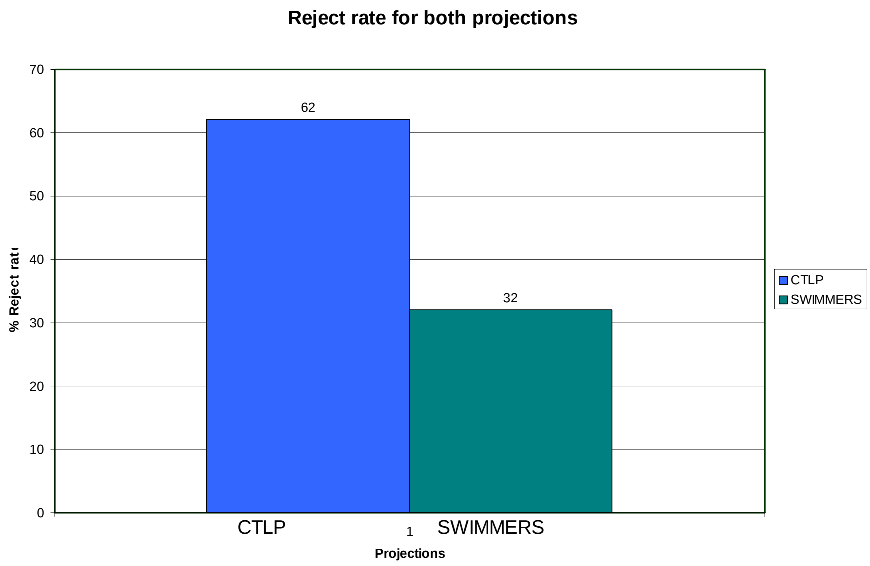


Figure 3.7 Reject rate for both projections

The overall reject rate was greater for the CLTP by a factor of approximately 2:1 Despite the greater reject rate for CTL projections, the population dose was smaller by a factor of approximately 1:33.

The CTLP cumulative dose for the entire study was 2.98% of the recorded Swimmers' doses. On five occasions the doses for repeat Swimmers projections were not recorded so the actual Swimmers population dose is higher but unknown. All CTLP doses were recorded.

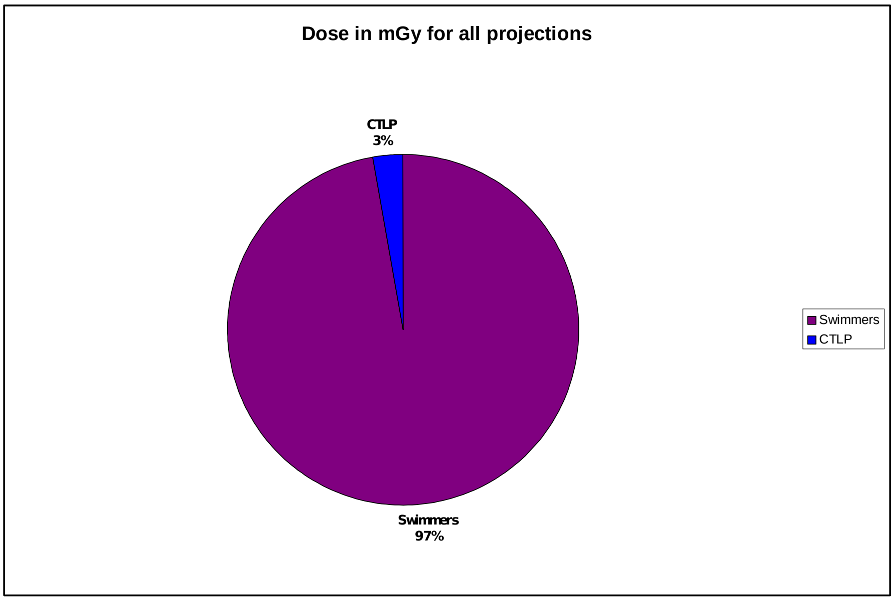


Figure 3.8. The doses generated by both projections for the entire study

3.6.9. Statistical tests on dose measurements

The dose was always stated as Entrance Surface Dose (ESD) and Thyroid dose and these were examined in three ways;

1. the dose of the final (successful) projection (FP).
2. the cumulative dose attributable to the projections of the same type as the final, successful projection (CFP).
3. the cumulative dose that the patient received from all attempts, both projections (CAP).

All doses are expressed as milligray (mGy).

The non - parametric test used to analyse this data was a Spearman's rho.

The following tests were performed to assess the dose implications for each projection.

Correlations

Width v. dose

Final successful projection = CTLP;

WIDTH v.	ESD FP	Thyroid FP	ESD CFP	Thyroid CFP	ESD CAP	Thyroid CAP
Spearman's rho correlation coefficient	0.401	0.478	0.457	0.713	0.489	0.729
p Value	p<0.05	p<0.05	p<0.05	p<0.001	p<0.05	p<0.001

Table 3.22. Statistical analysis of width on patient dose for CTLP

Wider torso measurements meant increased ESD and significantly increased Thyroid doses for all CTLP patients.

Final successful projection = Swimmer's

WIDTH v.	ESD FP	Thyroid FP	ESD CFP	Thyroid CFP	ESD CAP	Thyroid CAP
Spearman's rho correlation	0.260	0.200	0.288	0.334	0.324	0.367

coefficient						
p Value	NS	NS	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$

Table 3.23. Statistical analysis of width on patient dose for Swimmers

Width was seen to be positively correlated with all cumulative doses for both projections and with the doses generated during the successful CTLP projections. However, width had no relationship to the dose generated during the final, successful swimmer's projection.

As cumulative dose is a combination of doses from successful and unsuccessful attempts, it was important to find out if the patient's width was correlated in any way with the doses generated by the unsuccessful attempts. Again, a Spearman's rho test was used to assess this, with the following result;

Final, successful projection = CTLP

WIDTH v.	ESD unsuccessful	Thyroid unsuccessful
Spearman's rho correlation coefficient	0.476	0.468
p Value	$p<0.05$	$p<0.05$

Table 3.24. Statistical analysis of width on patient dose for unsuccessful CTLPs

Final, successful projection = Swimmer's

WIDTH v.	ESD unsuccessful	Thyroid unsuccessful
Spearman's rho correlation coefficient	0.564	0.451
p Value	$p<0.001$	$p<0.05$

Table 3.25. Statistical analysis of width on patient dose for unsuccessful Swimmers

It was therefore seen that there is only one instance where the width of the patient's torso has no bearing on the patient's dose and that is when the Swimmer's projection is successful.

<u>BMI v dose</u>

Final projection = CTLP

BMI v.	ESD FP	Thyroid FP	ESD CFP	Thyroid CFP	ESD CAP	Thyroid CAP
Spearman's	0.286	0.242	0.258	0.253	0.229	0.221

rho correlation coefficient						
p Value	NS	NS	NS	NS	NS	NS

Table 3.26. Statistical analysis of BMI on CTLP dose

BMI has no relationship to any of the doses generated by the CTLP.
The BMI of patients in the successful CTLP group was not related in any way to either their entrance surface dose or their thyroid dose, individual or cumulative.

Final projection = Swimmer's

BMI v.	ESD FP	Thyroid FP	ESD CFP	Thyroid CFP	ESD CAP	Thyroid CAP
Spearman's rho coefficient	0.337	0.103	0.332	0.073	0.313	0.072
p Value	$p<0.05$	NS	$p<0.05$	NS	$p<0.05$	NS

Table 3.27. Statistical analysis of BMI on Swimmers dose

Patients in the successful Swimmer's group with larger BMI, got larger entrance surface doses, but not larger thyroid doses. This applied to the single successful Swimmer's projection as well as the cumulative entrance surface doses from all attempts.
Age v dose

Final projection CTLP

Age v.	ESD FP	Thyroid FP	ESD CFP	Thyroid CFP	ESD CAP	Thyroid CAP
Spearman's rho coefficient	0.082	-0.040	0.031	0.034	0.021	0.058
p Value	NS	NS	NS	NS	NS	NS

Table 3.28. Statistical analysis of age on CTLP dose

Final projection Swimmers

Age v.	ESD FP	Thyroid dose FP	ESD CFP	Thyroid CFP	ESD CAP	Thyroid CAP
Spearman's rho coefficient	0.009	-0.010	0.073	0.055	0.021	0.058
p Value	NS	NS	NS	NS	NS	NS

Table 3.29. Statistical analysis of age on Swimmers dose

Age had no relationship with any of the doses measured for any of the projections.

Collar size v. dose

Final projection CTLP

COLLAR SIZE v.	ESD FP	Thyroid dose FP	ESD CFP	Thyroid CFP	ESD CAP	Thyroid CAP
Spearman's rho coefficient	0.278	0.173	0.311	0.144	0.359	0.195
p Value	NS	NS	NS	NS	NS (0.056)	NS

Table 3.30. Statistical analysis of Collar size on CTLP dose

Final projection Swimmers

COLLAR SIZE v.	ESD FP	Thyroid dose FP	ESD CFP	Thyroid CFP	ESD CAP	Thyroid CAP
Spearman's rho coefficient	-0.162	-0.337	-0.143	-0.237	-0.139	-0.234
p Value	NS	p<0.05	NS	NS	NS	NS

Table 3.31. Statistical analysis of Collar size on Swimmers dose

Patients with longer necks received smaller thyroid doses during the successful Swimmer's projection only. This was not true for the cumulative doses for repeat attempts, even where the repeat projections were all Swimmer's, nor was there any relationship between collar size and ESD.

Gender v. dose

Dose information for Female / CTLP group

Gender v.		ESD successful	Thyroid successful	ESD CFP	Thyroid CFP	ESD CAP	Thyroid CAP
	Range	1.17-5.45	0.05-1.50	1.17-9.02	0.08-1.50	1.17-36.65	0.08-2.33
	Median	2.29	0.17	2.71	0.24	2.29	0.25
Interquartile range	25th	1.53	0.09	1.48	0.16	1.48	0.16
	50th	2.29	0.17	2.29	0.25	2.29	0.25
	75th	3.24	0.39	6.12	0.42	6.12	0.42

Table 3.32. Descriptive analysis of doses received by the female CTLP group

Dose information for Male / CTLP group

Gender v.		ESD successful	Thyroid successful	ESD CFP	Thyroid CFP	ESD CAP	Thyroid CAP
	Range	1.79-10.54	0.06-2.38	2.15-20.76	0.08-2.42	2.15-24.93	0.08-14.03
	Median	3.50	0.12	4.37	0.23	4.37	0.235
Interquartile range	25th	2.44	0.09	2.68	0.12	2.68	0.12
	50th	3.50	0.12	4.37	0.23	4.37	0.235
	75th	4.68	0.30	10.32	0.45	11.74	0.54

Table 3.33. Descriptive analysis of doses received by the male CTLP group

Males received larger ESDs for the CTLP

Dose information for Female / Swimmers group

Gender v.		ESD successful	Thyroid successful	ESD CFP	Thyroid CFP	ESD CAP	Thyroid CAP
	Range	7.06-204.46	0.56-78.57	7.06-630.36	0.56-78.57	7.81-630.36	0.56-79.75
	Median	51.82	3.48	53.86	3.95	53.86	3.95
Interquartile range	25th	16.97	1.14	18.69	1.78	20.49	1.85
	50th	51.82	3.48	53.86	3.95	53.86	3.95
	75th	70.73	14.86	105.34	19.19	107.09	19.37

Table 3.34. Descriptive analysis of doses received by the female Swimmers group

Dose information for Male / Swimmers group

Gender v.		ESD	Thyroid	ESD	Thyroid	ESD	Thyroid

		success-ful	success-ful	CFP	CFP	CAP	CAP
	Range	1.24-342.85	0.04-21.50	1.31-800.27	0.04-35.33	1.35-800.27	0.04-35.33
	Median	45.58	1.02	47.87	1.3	54.05	1.4
Interquartile range	25th	22.54	0.63	26.13	0.79	27.08	0.85
	50th	45.58	1.02	47.87	1.3	54.05	1.40
	75th	111.29	1.81	130.63	2.64	137.22	2.78

Table 3.35. Descriptive analysis of doses received by the male Swimmers group

Females received larger thyroid doses during Swimmers projection.

A Mann Whitney U analysis of the doses received by each gender gave the following result:

		Mann Whitney U value	p Value
ESD FP	CTLP	53.0	<0.05
	Swimmers	271.0	NS
Thyroid FP	CTLP	89.5	NS
	Swimmers	138.5	<0.05
ESD CFP	CTLP	57.0	NS
	Swimmers	277.0	NS
Thyroid CFP	CTLP	98.5	NS
	Swimmers	149.0	<0.05
ESD CAP	CTLP	58.0	<0.05
	Swimmers	269.0	NS
Thyroid CAP	CTLP	102.5	NS
	Swimmers	152.0	<0.05

Table 3.36. Statistical analysis of the effect of gender on patient dose

This shows that females received significantly less entrance surface dose than the male group for the successful CTLP and less overall dose where there were multiple attempts which started with a CTLP.

All of the thyroid doses measured during swimmers were significantly lower for the male patients.

Tube potential (kV) v. dose

For the CTLP group

Kv	ESD FP	Thyroid FP	ESD CFP	Thyroid CFP	ESD CAP	Thyroid CAP
Spearman's rho coefficient	0.397	0.181	0.441	0.363	0.500	0.406
p Value	p<0.05	NS	p<0.05	NS (0.058)	p<0.05	p<0.05

Table 3.37. Statistical analysis of the effect of kV on CTLP dose

For the CTLP, lower kV was significantly associated with lower entrance surface doses, individual and cumulative. Lower kV was also associated with a lower cumulative thyroid dose where there were multiple attempts of both projections and where there were only CTL projections there was a borderline significance which is, nonetheless, non-significant.

For the Swimmers group

KV	ESD FP	Thyroid FP	ESD CFP	Thyroid CFP	ESD CAP	Thyroid CAP
Spearman's rho coefficient	0.385	0.180	0.374	0.250	0.371	0.221
p Value	p<0.05	NS	p<0.05	NS	p<0.05	NS

Table 3.38. Statistical analysis of the effect of kV on Swimmers dose

For the Swimmers' group lower kV was associated with lowered entrance surface doses, individual and cumulative, but had no correlation with the thyroid dose.

Tube current x time (mAs) v. dose

The mAs was correlated positively with most of the doses that were measured.

Final projection = CTLP

MAs	ESD FP	Thyroid	ESD CFP	Thyroid	ESD	Thyroid

		dose FP		CFP	CAP	CAP
Spearman's rho coefficient	0.902	-0.063	0.844	0.214	0.799	0.210
p Value	p<0.001	NS	p<0.001	NS	p<0.001	NS

Table 3.39. Statistical analysis of the effect of mAs on CTLP dose

Where the CTLP was the final successful projection the mAs correlated very significantly with the entrance surface doses of the successful projection and all the cumulative entrance surface doses. This was a very strong positive correlation, which was close to linear for the ESD for the successful CTLP. However, the mAs had no influence on the thyroid doses for the CTLP patients. Therefore increasing the mAs increased the entrance surface dose for the CTLP patients but had no effect on their thyroid dose.

Final projection = Swimmer's

mAs	ESD FP	Thyroid dose FP	ESD CFP	Thyroid CFP	ESD CAP	Thyroid CAP
Spearman's rho coefficient	0.827	0.323	.815	0.359	0.833	0.361
p Value	p<0.001	p<0.05	p<0.001	p<0.05	p<0.001	p<0.05

Table 3.40. Statistical analysis of the effect of mAs on Swimmers dose

The mAs had a linear correlation with all the measured doses for the Swimmer's projection. This was highly significant with regard to the entrance surface doses. Where the mAs value was increased the patient dose increased.

3.6.10. Comparison of the dose of the evaluated projections

Having examined the various aspects of the scores of the evaluated projections, the entrance surface doses and the thyroid doses for the evaluated projections were assessed using a Mann Whitney U test. The following results were obtained:

		Median	Interquartile range	Mann Whitney U value	p Value
ESD	CTLP	2.65	1.90-3.50	38.00	<0.001

Evaluated	Swimmers	45.58	22.54-96.48		
Thyroid Evaluated	CTLP	0.18	0.09-0.32	87.00	<0.001
	Swimmers	1.3	0.81-3.48		

Table 3.41. Statistical analysis of the doses of the evaluated projections

This shows a dose reduction attributable to the CTLP, which is highly significant. (Figure 3.8)

These tests show that the CTLP is of equal quality to the Swimmers projection while contributing a significantly lower dose to the trauma population and this answers the overall research question, which is "Can visualisation of the cervical spine in trauma patients be improved without increasing patient dose?"

.7. THE FIRST HYPOTHESIS

To test the first hypothesis **"This projection is of lower dose than swimmer's projection"** the following data sets were analysed:

3.7.1. Comparison of all the dose information for both projections

Dose information for the CTLP

		ESD FP	Thyroid FP	ESD CFP	Thyroid CFP	ESD CAP	Thyroid CAP
Range		1.17-10.54	0.05-2.38	1.17-20.76	0.08-2.42	1.17-36.65	0.10-14.0
Median		2.93	0.14	3.89	0.25	3.89	0.25
Inter-quartile range	25th	2.04	0.09	2.185	0.145	2.185	0.145
	50th	2.93	0.14	3.89	0.25	3.89	0.25
	75th	4.04	0.325	7.22	0.445	7.54	0.49

Table 3.42. Descriptive analysis of the doses of all CTLP projections

Dose information for the Swimmers

	ESD FP	Thyroid FP	ESD CFP	Thyroid CFP	ESD CAP	Thyroid CAP

Range		1.24-342.85	0.045-78.57	1.31-800.27	0.045-78.57	1.35-800.27	0.045-79.80
Median		47.87	1.37	49.85	1.79	54.05	1.79
Inter-quartile range	25th	20.72	0.85	23.71	0.85	23.77	0.94
	50th	47.87	1.37	49.85	1.79	54.05	1.79
	75th	102.69	3.95	119.9	6.97	123.58	7.47

Table 3.43. Descriptive analysis of the doses of all Swimmers projections

Mann Whitney U test values of the doses

	ESD FP	Thyroid FP	ESD CFP	Thyroid CFP	ESD CAP	Thyroid CAP
Mann Whitney U value	73.00	108.00	98.00	100.00	93.00	161.5
p Value	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001

Table 3.44. Statistical analysis of the doses of all projections

There was a considerable difference in the median and interquartile ranges of both groups, with the CTLP group receiving the lower doses. A Mann Whitney U analysis found this to be a highly significant difference thus the CTL projection is of lower dose than Swimmers. This was also the case when the doses of the evaluated projections only were compared. See Table 3.40. Section 3.9.10.

3.7.2. The total number of attempts following a CTLP starting projection and a Swimmers starting projection.

This showed that the CTLP generated more attempts overall and had a higher reject rate yet still generated just 3% of the dose of the Swimmers projection. See Table 3.19 and Table 3.20. Section 3.10.8.

3.7.3. Correlation of the measured variables with doses

Width

Wider torso measurements meant increased ESD and significantly increased Thyroid doses for all CTLP patients.

Width is positively correlated with all cumulative doses for both projections but has no relationship to the dose generated during the final, successful swimmer's projection.

It is a significant factor in generating doses during unsuccessful projections of both kinds. See Tables 3.21, 3.22, 3.23, 3.24. Section 3.10.9.

BMI

BMI has no relationship to any of the doses generated by the CTLP.

Patients in the successful Swimmer's group with larger BMI, received larger entrance surface doses, but not larger thyroid doses. See Tables 3.25, 3.26. Section 3.10.9.

Age

Age had no relationship with any of the doses measured for any of the projections. See Tables 3.27, 3.28. Section 3.10.9.

Collar size

Smaller collar sizes, which are indicative of shorter neck length, correlated with larger thyroid doses for the Swimmers projection only but had no relationship with ESD. The doses of the CTLP were not influenced by the collar size. See Tables 3.29, 3.30. Section 3.10.9.

kV

Lower kV, was significantly associated with lower entrance surface doses for the CTLP, individual and cumulative. Lower kV was also associated with a lower cumulative thyroid dose where there were multiple attempts of both projections.

In the Swimmers' group lower kV was associated with lowered entrance surface doses, individual and cumulative, but had no correlation with the thyroid dose. See Tables 3.36, 3.37. Section 3.10.9.

mAs

In the CTLP group, increasing the mAs increased the entrance surface dose but had no effect on the thyroid dose.

In the Swimmer's group the mAs had a linear correlation with all the measured doses. See Tables 3.38, 3.39. Section 3.10.9.

Gender

Males received larger ESDs for the CTLP and females received larger thyroid doses during Swimmers projection.

See Tables 3.31., 3.32., 3.33., 3.34., 3.35. Section 3.10.9.

These tests show that the CTLP is of significantly lesser dose than the Swimmers projection.

3.8. THE SECOND HYPOTHESIS

To test the second hypothesis **"The proposed CTL projection (CTLP) is of better quality than the swimmer's projection in demonstrating the cervico-thoracic junction in trauma patients"** the data sets analysed were those pertaining to score or evaluator agreement.

3.8.1. Comparison of the score of the CTLP films and the Swimmers films

Scores for the CTLPs v. the scores for the Swimmer's projections

Score of the evaluated view	Mean	Median	Range	Std. Error Mean
CTLP	13.68	13.6	7.4 - 18.8	0.5863
Swimmer's	12.65	13.2	5 - 18.4	0.5410

Table 3.45. Descriptive analysis of the scores for both projections

Using a t-test for Equality of Means gave the following result:

t = 1.221, df = 67, p = 0.226 which is non-significant.

Mann Whitney U test gave a value of 472.5, p = 0.333 which is also non -significant.

3.8.2. Correlation of the measured variables with Scores

Correlation between overall score and Torso width, BMI, Age, Collar size, Exposure factors (kV & mAs), Entrance surface doses and thyroid doses of the evaluated projections and gender gave the following results:

Spearman's rho tests for correlation found that the kV and mAs values set by the radiographer were the factors that significantly influenced the scores awarded by the evaluators to the CTLP films. Lower values correlated with higher scores. No other factor was significant.

The scores of the Swimmers films were influenced significantly by the patient's body habitus, with torso width and body mass index correlating negatively with the score. Larger patients and those with broader chests had lower scoring films.

See Tables 3.14., 3.15., 3.16. Section 3.9.6.

3.8.3. Analysis of the number of evaluators (from none to all five) agreeing that the film is diagnostically useful

56% of the CTLPs were considered diagnostic by a majority of the evaluators, while 45.5% of the Swimmer's projections were.

This was considered non-significant using a Mann Whitney U test.

See Table 3.8. Section 3.9.1.

3.8.4. Correlation of the scores for C/D and Detail (both projections), with the incidence of a high level of agreement on the usefulness of the image for diagnosis (three or more evaluators).

Both aspects of the overall score have a highly significant correlation with evaluator agreement for both projections. See table 3.17., 3.18. Section 3.10.7.

3.8.5.Correlation of the measured variables with evaluator agreement

Incidence of agreement between three or more evaluators correlated with BMI, Age, Width, Gender, Collar size, Exposure factors (kV & mAs), doses of the evaluated projections yielded the following result:

Evaluated projection = CTLP

Three or more evaluators v.	Spearman's rho correlation coefficient	p Value
BMI	-0.241	NS
WIDTH	-0.330	NS
AGE	0.252	NS
COLLAR SIZE	0.107	NS
ENTRANCE SURFACE DOSE	-0.196	NS
THYROID DOSE	-0.028	NS
TUBE POTENTIAL (kV)	-0.420	p<0.05
TUBE CURRENT (mAs)	-0.468	p<0.05

Table3.46. Statistical analysis of the number of evaluators v. measured and recorded variables for the CTLP group

The tube potential and tube current had a significant negative correlation with the evaluator agreement that this CTLP film can be interpreted for injury. Lower kV and mAs values meant greater agreement among the evaluators. None of the other factors analysed showed any correlations with evaluator agreement.

Evaluated projection = Swimmers

Three or more evaluators v.	Spearman's rho correlation coefficient	p Value
BMI	-0.267	NS
WIDTH	-0.248	NS
AGE	0.338	p<0.05
COLLAR SIZE	-0.132	NS
ENTRANCE SURFACE DOSE	0.062	NS
THYROID DOSE	-0.005	NS
TUBE POTENTIAL (kV)	-0.245	NS

TUBE CURRENT (mAs)	0.034	NS

Table3.47. Statistical analysis of the number of evaluators v. measured and recorded variables for the CTLP group

For the Swimmers projection only one of the factors analysed had a significant influence on the amount of evaluator agreement and that was age. This was a positive correlation so as the age of the patient increased the number of evaluators stating that they can interpret this film for injury also increased and that number decreased with younger patient's films.

Gender and the evaluator agreement:

The following table gives the breakdown of the number of evaluators agreeing on film utility by gender:

	25 CTLPs evaluated		44 Swimmers evaluated	
	3 or more agree	2 or less agree	3 or more agree	2 or less agree
Female	7	4	7	8
Male	7	7	13	16

Table 3.48. Descriptive analysis of the effect of gender and evaluator agreement

Due to the small numbers in these groups a Fishers Exact Test was used to analyse the data for significance. The value calculated was 0.689 for the CTLP which is non-significant and 1.00 for Swimmers; this is also non-significant.

Therefore it was seen that gender has no bearing on the ability of an evaluator to use these images of C7/T1 for diagnosis.

The scores and the evaluators decision to accept the film as diagnostically useful or not, are both indicators of image quality. The results of these tests were not significantly better for the proposed projection in comparison to Swimmers but descriptively they were at least equal thus the CTLP is of equal quality to the Swimmers projection.

3.9. INTRA-RATER RELIABILITY

To assess the intra-rater reliability the following data sets were analysed:

The scores awarded by each evaluator for films 10s and 53c.

Throughout the evaluations, two films, one of each type of projection were given to the evaluators three times, at the beginning, the middle and the end of the evaluations. The scores awarded to the film at each stage were assessed. The standard deviation was calculated as a measure of consistency.

Results were as follows:

	CTLP		Swimmers	
	Standard Deviation	Range	Standard Deviation	Range
General Radiologist	1.52753	12.00-15.00	0.55735	16.00-17.00
Neuro-Radiologist	0.00	16.00-16.00	1.1547	12.00-14.00
Consultant In A&E Medicine	NA	NA	NA	NA
SPR In A&E Medicine	1.52753	15.00-18.00	1.00	11.00-13.00
Radiographer	0.57735	19.0-20.00	5.1316	10.00-20.00

Table 3.49. The standard deviation of the scores awarded to10S and 53C

The standard deviation was quite small in all but one case, the Swimmers film, but the same reader had a very small standard deviation of the score awarded to the CTLP. Overall the scores were consistent throughout the evaluations. One evaluator was not assessed for intra-rater reliability.

3.10. INTER-RATER RELIABILITY

This was analysed using a Spearman's rho test of the scores awarded by the evaluators to both projections.

For the CTLP;

The Consultant general radiologist's scores were not correlated with those of any other evaluator although there was a borderline Spearman's rho correlation coefficient, =0.394, $p = 0.051$ when compared with the scores of the Consultant neuro-radiologist. This is still considered non-significant.

The Consultant neuro-radiologist correlated with the

- Consultant In A&E Medicine (Spearman's rho correlation coefficient = 0.409, $p<0.05$)
- SPR In A&E Medicine (Spearman's rho correlation coefficient = 0.585, $p<0.05$)

There was borderline correlation with the Consultant general radiologist, as stated.

The consultant in A&E medicine correlated with:

- ConsultantNeuro-Radiologist as stated and with
- SPR In A&E Medicine (Spearman's rho correlation coefficient =0.563, <0.05)

The SPR in A&E medicine correlated with:

- Consultant Neuro-Radiologist and
- Consultant In A&E Medicine as stated, and also with
- Radiographer (Spearman's rho correlation coefficient = 0.558, $p<0.05$)

The radiographer correlated with:

- SPR In A&E Medicine as stated.

The evaluators varied in the way they scored the CTLP.

For the Swimmers:
The general radiologist correlated with all other evaluators. All p values were $p<0.05$.

The neuro-radiologist also correlated with all other evaluators. There was a p value of $p<0.05$ for the correlation with the consultant general radiologist as stated. All other p values were $p<0.001$.

The consultant in A&E medicine correlated significantly with all evaluators. As stated there was a highly significant correlation with the consultant neuro-radiologist and all other p values were $p<0.05$.

The SPR in A&E medicine correlated highly significantly with the consultant neuro-radiologist, the consultant in A&E medicine and the radiographer, $p<0.001$. As stated there was a p value of $p<0.05$ for the correlation with the consultant general radiologist.

The radiographer, as stated, correlated significantly with the general radiologist and with the consultant in A&E medicine, and highly significantly with the neuro-radiologist and the SPR in A&E medicine.
The tables of correlation coefficients and p values are Appendix 6 .

For the Swimmers projection there was excellent correlation between the scores awarded by each evaluator, with all pairings either significantly correlated or highly significantly correlated. There was zero incidence of non-correlation.

3.11. KAPPA ANALYSIS OF INTER-RATER RELIABILITY

Kappa analysis was performed on the answers to Question 10 on the evaluation sheet, "Can you meaningfully interpret this film for injury at the C7/T1 level?"
The Kappa coefficient denotes the level of agreement as outlined in the following table:

$K = 1$	Perfect agreement
$K > 0.75$	Excellent agreement
$0.4 < K < 0.75$	Fair to good agreement
$K<0.4$	Poor agreement
$K = 0$	Agreement by

	chance

Table3.50. Kappa values

The data analysed was the number of times out of the 69 films evaluated, that each reader answered “yes” to question 9 and the number of times “no”. These were then cross-tabulated to give the following result:

Readers	% agreement	Kappa coefficient	p-Value	Good (g), Fair (f) or Poor (p) agreement
Consultant General Radiologist v. Neuro-Radiologist	53.6	0.049	NS	p
Spr In A&E Medicine v. Consultant General Radiologist	57.4	0.169	NS	p
Consultant In A&E Medicine v. Consultant General Radiologist	52.9	0.021	NS	p
Radiographer v. Consultant General Radiologist	52.9	0.072	NS	p
Radiographer v. Consultant Neuro-Radiologist	79.4	0.597	<0.001	g
Radiographer v. SPR In A&E Medicine	79.1	0.571	<0.001	f
Radiographer	74.6	0.507	<0.001	f

v. Consultant In A&E Medicine				
Consultant In A&E Medicine v. Consultant Neuro-Radiologist	73.5	0.440	<0.001	f
Consultant In A&E Medicine v. SPR In A&E Medicine	58.2	0.198	NS	p
SPR In A&E Medicine v. Consultant Neuro-Radiologist	76.5	0.544	<0.001	f

Table 3.51 Result of the kappa analysis using both projections

As can be seen from this table, the agreement between the evaluators on this question was of a level that is considered good just once and the rest of the time it was fair or poor. This was based on the both projections. Overall Kappa was 0.3139 which is considered poor.

When the projections were looked at separately the result was this:
For Swimmers

Readers	Kappa coefficient	p-Value	Good (g), Fair (f) or Poor (p) agreement
Consultant General Radiologist v. Consultant Neuro-Radiologist	0.079	NS	p
SPR In A&E Medicine v. Consultant General Radiologist	0.237	NS	p
Consultant In A&E Medicine v. Consultant General Radiologist	0.036	NS	p
Radiographer v. Consultant	0.04	NS	p

General Radiologist			
Radiographer v. Consultant Neuro-Radiologist	0.633	<0.001	g
Radiographer v. SPR In A&E Medicine	0.626	<0.001	g
Radiographer v. Consultant In A&E Medicine	0.622	<0.001	g
Consultant In A&E Medicine v. Consultant Neuro-Radiologist	0.473	<0.05	f
Consultant In A&E Medicine v. SPR In A&E Medicine	0.211	NS	p
SPR In A&E Medicine v. Consultant Neuro-Radiologist	0.550	<0.001	f

Table 3.52. Result of the kappa analysis using Swimmers only

This shows slightly better agreement than when both projections were considered together but there is still poor agreement overall, with overall Kappa = 0.3502

For CTLP

Readers	Kappa coefficient	p-Value	Good (g), Fair (f) or Poor (p) agreement
Consultant Neuro-Radiologist v. Consultant General Radiologist	-0.025	NS	p
Spr In A&E Medicine v. Consultant General Radiologist	-0.036	NS	p
Consultant In A&E Medicine v. Consultant General Radiologist	0.096	NS	p
Radiographer v. Consultant General Radiologist	0.098	NS	p
Radiographer v. Consultant Neuro-Radiologist	0.531	<0.05	f
Radiographer v. SPR In A&E Medicine	0.442	<0.05	f
Radiographer v. Consultant In A&E Medicine	0.348	<0.05	p
Consultant Neuro-Radiologist v. Consultant In A&E Medicine	0.403	<0.05	f
Spr In A&E Medicine v. Consultant In A&E Medicine	0.241	NS	p
Spr In A&E Medicine v. Consultant Neuro-	0.517	<0.05	f

Radiologist			

Table 3.53. Result of the kappa analysis using CTLPs only

This shows very poor agreement above chance. For the CTLP overall Kappa was 0.2421 There was excellent correlation on the scores awarded by the evaluators to the Swimmers projection and good correlation between the evaluators on the scores they gave to the CTLP but there was marked differences between the evaluators answers to Question 10.

Question 10 asked the evaluators to make a decision on the usefulness of this film in the clinical setting but to do so by interpreting the film for the presence or absence of injury. There were four patients in this study who's films were evaluated and who had a subsequent CT scan of the cervico-thoracic region because of suspicion of injury.

When Kappa analysis was applied to these films only, the overall Kappa value was 0.2857, which still indicates poor agreement above chance.

3.12. FURTHER DATA ARISING FROM THE STUDY

3.15.1.Correlation between number of attempts and BMI, Width, Age, Collar size and Gender

Width

Using a Spearman's rho test showed that the torso width was significantly positively correlated with the total number of attempts needed to acquire a diagnostic image. This was true for both projections and was highly significant for the Swimmer's projection.

Total no. of attempts v width	Starting projection	
	CTLP	Swimmer's
Spearman's rho Correlation coefficient	0.459	0.466
p Value	$p<0.05$	$p<0.001$

Table 3.54 Torso width and total no. of attempts

The number of attempts needed to produce a diagnostic image of either projection is greater for patients with wider torso widths.

BMI, Age, Collar size and Gender were not found to have any correlation with the number of attempts needed to produce a diagnostic film.
Gender had no influence on the type of final successful projection.

3.15.2. Gender and final projection
The effect of gender on whether the final successful projection was a CTLP or a Swimmers was assessed using a □□□□□□□□□□df=1 and p=0.520 which is non-significant.□

3.13. REJECT ANALYSIS

The rejected films were collected and analysed. There were 45 CTLP reject films and 30 rejected Swimmer's projections.
CTLP rejects were found to have three errors

- exposure factors
- centring point errors
- collimation errors

80% (n= 36) had exposure factor errors, all but one were too pale at the level of T1. One was too dark.
56% (n= 25) had centring point errors
20% (n = 9) had collimation errors
51% (n= 23) films had more than one of the above faults.
Swimmer's rejects were found to have four errors

- exposure factors
- centring point errors
- unsharpness
- obstruction of detail by the overlying humerus

87% (n= 26) had exposure factor errors, all but one were too pale. One was too dark.
10% (n= 3) had centring point errors
37% (n= 11) had poor visibility of detail due to unsharpness
10% (n= 3) had poor visibility of detail due to the overlying humerus
40% (n= 12) had more than one of the above faults.

3.14. EVALUATIONS

There were 29 CTLPs and 57 Swimmers projections put forward as final attempts by the radiographers. It was not possible to retrieve all of these films for evaluation and the final number for evaluation was 25 CTLPs and 44 Swimmer's, this was 80% of the films originally submitted.

The scores awarded by each evaluator to each section of the questionnaire were added, to give a total score out of 20 for each film. All five evaluators' scores were then averaged to give a final score out of 20 for each film and this was converted to a percentage score.

Overall scores (out of 20) ranged from 5 -18.8 (25%-94%). Mean score was 13.02 and median 13.4.

Scores for contrast and density questions were in the range of 44.44% - 100%.

Scores for the questions on visibility of anatomical detail and diagnostic utility, were in the range of 0% - 98.18%.

CTLP

The mean score for CTLPs = 13.6 and the median also = 13.6. Range was 5 - 18.8.

Swimmer's

Mean score = 12.18, median = 13.4. Range was 5 - 18.4.

If an evaluator stated that further imaging was required they were asked to state why and no options were given so they were free to state their reason in any way they wanted to. The answers to this varied as follows:

Comments are in order of the frequency of appearance

	No. of times each reason was stated by these readers					
Evaluators coded by initials	CGR	CNR	CAE	SPRAE	Rad	Total
A. For clarity of T1	6	15	6	5	18	50
H. C7/T1 not seen	1	9	4	2	2	18
C. ? Levels	1	9	3	2	2	17

K.? Injury (fracture or misalignment)	3	0	6	5	2	16
I. Very poor/awful/appalling/inadequate/hopeless film	0	9	1	1	1	12
E. Humerus/Clavicles/Ribs obscuring anatomical detail	1	0	0	9	0	10
J. Needs increase in density or penetration	0	0	0	3	5	8
R. Overall quality needs to be improved	0	0	5	0	2	7
X. Film not assessed by this evaluator	1	1	2	1	1	6
B. Swimmer’s unlikely to improve significantly	0	0	4	1	0	5
L. To see spinous processes	5	0	0	0	0	5
D. Shoulders/body habitus obscuring T1	0	0	0	2	1	3
Q. To see alignment	0	0	3	0	0	3
F. Rotation	0	1	1	0	0	2
G. Blurring/unsharpness	0	0	0	2	0	2
P. If clinically indicated	2	0	0	0	0	2
N. Need to see patient to evaluate which projection is most suitable	0	0	0	0	1	1
O. Soft tissues look suspicious of underlying injury	0	0	1	0	0	1
S. Least intrusive. “Best value”	0	0	1	0	0	1

Table 3.55. Evaluators comments ordered by the number of times stated

3.15. TIME TAKEN

The times taken for the imaging of the 86 patients were recorded in 62 cases. This was for all of the imaging, not just the cervical spine imaging. It was not possible to measure the time taken for the cervical spine imaging accurately; the first lateral is done in the resuscitation room and the rest of the series is taken in the x-ray room, with transportation time and possible time spent in the CT scanning room in between. The intention was to compare the time taken for all the plain film radiography with that taken for all of the CT scanning, in those cases where the patient had both. However, only five patients had both forms of imaging and there was only one form returned from CT. So this comparison had to be abandoned.

Of the 62 recorded cases the time taken for radiography had a range of 70 minutes. The minimum was10 minutes, maximum was 80 minutes. The mean was 33.02 minutes and the median was 30 minutes.

3.16. RADIOGRAPHERS' QUESTIONNAIRE

A questionnaire was distributed to 40 radiographers. 19 were returned (42.5%).
Of these 19, nine (52.94%) said that they did not put any patients into the cervical spine study. Six of the nine gave the reason as "no suitable patient presented".

- In one case the radiographer elaborated and cited the accompanying request for thoracic spine x-ray for several of her patients as the reason for the non-participation. This would require a swimmer's projection to show the upper thoracic vertebrae and therefore could not be a random selection.
- One radiographer said that he/she forgot about it.
- One said that he/she didn't want to.

Ten radiographers said that they did participate in the study. Six of the ten did the Coned True Lateral as first projection and four did Swimmers.
Of the six in the CTLP group, the projection worked first time for two.

- In one of these cases the radiographer also did a Swimmers and gave the reason as the inexperience of the Accident & Emergency doctors at reading these films and her own doubt as to the usefulness of this film.

Of the four radiographers who said that the CTLP did not work first time, three followed with repeat CTLPs and one with a Swimmers projection.

- The radiographer who did a Swimmers as the first repeat stated the reason as the certainty that the Swimmer's would be successful first time.
- One radiographer did two more CTLPs, which did not work and then followed with Swimmers.
- The other two radiographers said that the repeat CTLP was successful.

Of the four radiographers who did Swimmers, one used the CTLP as a repeat projection.
The main reason for distributing the questionnaire was to ascertain the radiographers' experience of the ease or difficulty of some aspects of the CTLP. The seven radiographers who did the CTLP (six first attempts and one done as a repeat when Swimmers did not work) commented on these as follows:

	Easy	Difficult	Total no. of radiographers
Positioning	7	0	7
Centring	7	0	7
Collimating	7	0	7
Choosing exposure factors	2	5	7
Evaluation of the image	2	5	7
Identification of the vertebral levels	2	5	7

Table 3.56. Radiographers opinion of some aspects of the CTLP

3.17. SCORES GREATER THAN 15

There were not enough numbers in the study to allow the use of statistical tests once films were divided by type and then grouped according to the overall score awarded by the evaluators. Despite this it is worth looking at the highest scoring group descriptively. There were three distinct groups among the evaluated projections, the scores greater than 15, those of 10-15 and those 5 -10. No film scored less than 5.

3.17.1. Number of attempts.

Nine CTLP and 14 Swimmers scored more than 15/20 (>75%). Six of nine CTLPs and eight of 14 Swimmers were achieved first time. This is a total of 14 of 23 films or 60.87%.

The other three CTLPs were achieved on the 2nd attempt while, of the Swimmers films, three were achieved on the 2nd attempt and three on the 3rd attempt.

3.17.2. Position in the study

The position of these CTLP films in the study was notable. The nine high-scoring CTLPs were spread from position no.32 to the final film of the study, no.86, with seven of the nine done in the latter half of the study and four of these in the last ten. Only two from the earlier half of the study scored highly. In the first 30 films there were no high-scoring CTL projections.

	Position in study of those films which scored >15													
Ctlp						32	34	53	62	74	76	78	79	86
Swimmers	3	5	7	15	16	17	20	37	49	52	58	67	69	85

Table 3.57. Chronological order of the high scoring projections in the study

The good quality Swimmers views were spread across the entire time span of the study.

3.17.3. kV and mAs

The kV values used for the CTLP were in the range of 73-85, for Swimmers 85-102.
The mAs values for the CTLP were in the range 8-20, for Swimmers 20 - 413.
These factors contributed to the entrance surface doses and thyroid doses, which varied greatly between the projections.

Entrance Surface Doses

ESD	Range	Mean	Median
High scoring CTLP	1.36 - 4.33	2.29	1.94
All Successful CTLPs	1.17 - 10.54	3.30	2.93
ESD	Range	Mean	Median
High scoring Swimmers	2.76 - 287.87	68.85	40.06
All Successful Swimmers	1.24 - 342.85	77.40	47.87

Table 3.58. Descriptive analysis of entrance surface doses

The total ESD attributable to the high scoring CTL projections = 20.59mGy, Swimmers = 895.09mGy

Thyroid Doses

THYROID DOSE	Range	Mean	Median
Successful CTLP	0.05 - 1.5	0.32	0.13
All Successful	0.05 - 2.38	0.32	0.14

CTLPs			
Successful Swimmers	0.45 - 12.96	2.58	1.12
All Successful Swimmers	0.045 - 78.57	5.57	1.37

Table 3.59. Descriptive analysis of thyroid doses

_The total Thyroid Dose attributable to the high scoring CTL projections = 2.28mGy, Swimmers = 33.6mGy

3.17.4. Age

The mean age of the CTLP group was 36.77 years, range 18 -80 and the Swimmers group was 41.78 years, range 19 -94.

3.17.5. Body Mass Index

The range of BMI s in the CTLP group was 17.2 -30.3, mean 22.88. For the Swimmers group the range was 21.5 - 27.5 and the mean = 24.11. Both groups were largely within the normal range.

3.17.6. Torso Width

Torso widths for the CTLP patients were in the range of 15 -19, for Swimmers 14 -21. Six of the nine CTLP patients had a 15” torso, one 16”, one 16.5” and one 19”. For Swimmers patients, five of the 14 had 14” torso, three had a 15” torso, two measured 16”, three, 17” and one 21”.

14 of the 21 patients were relatively narrow with torso widths of 15” or less.

3.17.7.Collar size

The CTLP group wore collars that tended to be longer.

	CTLP	Swimmers
Size 1 Paediatric	1	1
Size 2 No Neck	1	6
Size 3 Short	3	3
Size 4 Regular	4	4
Size 5 Long	0	0

Table 3.60. Collar sizes of the high-scoring group

There was a greater spread of collar sizes among the Swimmers group with seven of 14 (50%) wearing the two shortest sizes and the other seven (50%) wearing sizes 3 and 4. Among the CTLP group there were seven of nine patients (77.77%) wearing the longer collars, sizes 3 and 4. In this high scoring group no patient was wearing the longest collar, size 5.

3.17.8. Gender

Six of nine CTLP patients were female and three male.

Five of 14 Swimmers patients were female and nine male.

3.17.9. Number of evaluators stating that the film is diagnostically useful.

For the CTLP the range was 3-5 and for Swimmers 2-5.

No. of evaluators agreeing that the film is diagnostically useful	No. of CTLPs out of 9	No. of Swimmers out of 14
0	0	0
1	0	0
2	0	2
3	2	2
4	4	6
5	3	4

Table 3.61. Agreement among evaluators on diagnostic utility

CHAPTER 4

DISCUSSION

One of the more difficult, yet vitally important, aspects of trauma radiography is visualisation of the cervico-thoracic region. Plain film radiography remains the primary means of demonstration of this area despite technological advances and the imperfections of the Swimmers projection.

The aim of this study was to test a tightly collimated true lateral projection of the cervico-thoracic region against the present protocol of Swimmers projection, to ascertain if this lateral could be of use in the trauma setting. If it met or exceeded the present standards of the quality of demonstration of this region, time constraints, patient safety and patient radiation dose that is currently accepted from the Swimmers projection, it could be assumed to be of use.

4.1 DATA COLLECTION

The data collection was carried out from 8th September 2003 - 18th May 2004 during which time 86 patients were enrolled in this prospective study. This was much longer than anticipated based on departmental statistics and the initial pilot study that was carried out in the same department. It was envisaged that at least 100 patients would be enrolled and more if time permitted, but this did not materialise. Nine of 19 radiographers, who replied to the post-study questionnaire, stated that they did not put any patient into the study and six of these 9, (66.66%), stated that “no suitable patient presented”. The time plan for this study was based on the most recently available departmental statistics, which at that time were those for 2002. On 31st October 2002 a new road traffic control system known as “Penalty Points” came into effect in Ireland, aimed at decreasing the number of fatalities due to motor vehicle accidents. An investigation into the effect of penalty points on acute hospital trauma services was running concurrently with this study, in the same institution. The researchers have reported a 40% decrease in the first 12 months, in road traffic related acute hospital admissions, as a result of this new law (Linehan et al., 2004). Motor vehicle accidents are a well documented cause of cervical spine injury, so it is not surprising that this 40% drop in acute admissions should cause a decrease in requests for cervical spine radiography (Takhtani & Melhem, 2002; Mann et al., 2003; Ross et al., 1987). This is a wonderful achievement but unfortunately it decreased the number of patients in this study.

4.2 PATIENT DEMOGRAPHICS

There were 33 females (38.37%), mean age 35years and 53 males (61.63%) mean age also 35 years, in this study. This concurs with other studies of multi-trauma patients where there is a predominance of young males in the group (Shatney et al., 1995; Jelly et al., 2000). Cervical spine injury occurs mostly as a result of high-energy trauma and young males are the group of people most likely to participate in those high energy activities that so often cause injury, such as sports-related accidents and mostly work-related, falls from heights (Shatney et al., 1995). Road traffic related trauma, which is a major cause of cervical spine injury is not confined to males and is the most likely reason for the inclusion of the 33 females among the 86 trauma patients.

The mean weight of this group was 74.52kg which is +6.46% on the average person of 70kg weight but the range of patients' weights recorded during this study, at 41-121kg, were considerably below and above the defined normal (WHO, 2004). These figures represent a range of 70.73% under 70kg to 72.85% above.

The patient heights were more closely aligned with normal at 1.5m - 1.9m, which is -8.66% to +16.56% of normal, which is defined as 1.63m (ibid, 2004). Height and weight were combined to give a value for Body Mass Index.

BMI is a subjective measurement as the patients' heights and weights could not actually be measured in the clinical setting and so the patients were asked to state their height and weight. As not everyone knows exactly what their height or weight is, there was, inevitably, some estimation and this may have led to inaccuracies in the data.

When the BMI was calculated for each patient using the data they supplied, 51% of the group were within the normal limits of 19-25, as defined by the World Health Organisation (ibid, 2004). Just 2% were underweight and the remaining 47% were overweight or obese (Figure 3.4). The mean BMI of the group was 25.57, which puts the group into the overweight category but the figures in this study, when broken down by gender, concur with a joint report of the World Health Organisation and the European Commission, (1998), on health in Ireland. This gives figures for male and female obesity levels that are exactly the same as was found in this study.

This study is therefore a truly representative sample of Irish victims of high-energy trauma.

4.3 IMAGE AND RADIOGRAPHIC QUALITY

The overall research question asked if visualisation of the cervical spine in trauma patients could be improved without increasing patient dose. Visualisation of any part of the anatomy in radiography is inextricably linked with image quality.

Quality is defined as “the degree of excellence of a thing” (Oxford English Dictionary, 1993) which is still a non-specific explanation, because quality is often subjective and the definition of a degree of excellence changes with the “thing” in question. Consequently it is necessary to define what is considered good quality and poor quality for the purposes of this study.

This study was concerned with testing a projection for use in the clinical setting and so anything that would be an inherent part of its use in the clinical setting will be considered.

4.3.1. Factors that define image quality

Berlin, (1996) describes two cases where malpractice lawsuits against radiologists were successful. In one of these the contrast and density was not optimal and in the other there was a lack of visibility of all of the anatomical detail. These are linked as the “substandard quality of the radiologic examinations”. The logical assumption from this is, that a radiograph that clearly demonstrates that which it is meant to demonstrate, cannot be of poor quality. This same assertion is made by Martin et al.,(1996), who define the requirements of image quality as whether the clinical information required is contained in the image and whether it can be interpreted by the observer. Situations arise where a film that demonstrates the area, but not clearly, may well be of poor quality yet still be considered functional (Berlin, 1996). The role of the radiographer is of vital importance in this respect, as the radiographer is the only member of the trauma team who can influence the quality of the image by the choice of exposure factor settings and technique.

While making a decision on the presence or absence of injury, the referring clinician has the benefit of clinical examination along with the radiographs, but a radiologist does not, as stated by Berlin, (1996);

> "A radiologist's accuracy can be no greater than the quality of radiographs presented for interpretation".

This quotation highlights the importance of the role of the radiographer.

Radiographic quality refers mostly to the accuracy with which the area under investigation is portrayed on the radiograph. High quality radiographs accurately portray all of the structures and tissues, as is necessary for accurate interpretation of the film by the radiologist or emergency physician. Poor quality radiographs may be a contributory factor in missed diagnosis or otherwise unnecessary repeat examinations (ibid, 1996).

Contributory factors in poor quality radiographs are

1. The character of the anatomical structure of the patient
2. The exposure factors (i.e. kV, mAs, focus-film distance, type of film/screens)
3. The conditions under which the radiograph is viewed.

(Meredith & Massey, 1977, p264)

The anatomical position of the cervico-thoracic junction falls into the first of the above categories and is an inherent problem with regard to the production of a clear and diagnostic film. There is nothing that the radiographer can do about this, nor can the radiographer control the conditions under which the emergency physician views the films. It is therefore essential that the radiographer use the optimum choice of technique and the correct technical factors necessary for the production of high quality radiographs. Body habitus is a known factor in the difficulties of demonstration of C7/T1 and this cannot be changed by the trauma team. What should be changed is any technique that is affected by it.

There are some things other than the clarity of the final image that define its quality.

In the trauma setting, the time allocated for radiography can be limited because of the patient's condition. Clearing the cervical spine does not take priority over other, life saving, interventions, as immobilisation can be maintained until there is a better opportunity to clear the spine. There is usually though, some opportunity at this point for the radiographer to demonstrate the cervical spine and if it can be clearly seen, the subsequent treatment of the patient may change according to the interpretation of that radiograph. A good quality radiograph therefore, is one that can be achieved quickly and reasonably unobtrusively.

A good radiograph is one that can be used for its purpose They should allow clinicians to diagnose with reasonable certainty by clear demonstration of the area (Martin et al., 1999). Therefore any film that is not of use in the clinical setting is of no value and must be considered poor quality. The visibility of anatomical detail and the contrast and density of the radiograph will control its usefulness in the clinical setting; a film that is too over- or underexposed will hinder any clinician's ability to use it for diagnosis. Likewise, if the anatomical detail of the region is not seen clearly on the radiograph it is unlikely that an evaluator would be confident to use it for diagnosis.

4.3.2. Factors that define radiographic quality

Patient safety is an inherent part of the quality of radiography. In any setting, patient safety is paramount and techniques and treatments that carry a degree of risk, must always be replaced, where possible, by safer ones. Where they cannot be replaced they should at least be controlled and used only in those instances where they can be controlled. In radiography, ongoing research and protocols achieve this.

It almost goes without saying that a reduced radiation dose is infinitely preferable to a higher one, providing that all of the other factors are met.

4.3.3. Measurement of quality in this study

In this study the quality of the films was adjudicated by a panel of experts in the fields of trauma, radiography and radiology. All of these people are faced with the challenges of the visualisation of the cervico-thoracic junction regularly and are therefore skilled in the intricacies of demonstration and interpretation of this part of the body. The average of their scores for each film was seen as one way of defining quality in this study, as was their decision on whether or not to use the film for diagnosis. There were five evaluators all of whom made a decision on their ability to use each of the films for diagnosis. Question 10 on part 2 of the evaluation forms asked if they could meaningfully interpret each film for injury at the C7/T1 level and an affirmative answer meant that film was considered useful in the clinical setting. A negative answer was indicative of a film that is not fit for its purpose, a poor quality film. As the evaluators did not have a consensus opinion on the usefulness of every radiograph a decision had to be made on the exact number of "yes" answers out of five that would indicate good agreement and hence indicate a good quality film. This number was set at three or more evaluators, as this was a majority (60%).

4.3.4. The effect of the measured variables on image quality

4.3.4.1. Width and BMI

The Swimmers projection can be very useful for diagnosis and of very good quality, as was seen by the scores that the evaluators awarded to some Swimmers films. In the high scoring group of radiographs, there were 14 of the 44 Swimmers films that were evaluated, which is 32% (Table 3.54.). The other 30 scored less than 75%, some as low as 25%. These scores correlated negatively with the patients' torso widths and BMIs, the larger patients and those with wider torsos had Swimmers films that the evaluators did not rate highly (Table3.16.).

The only recorded variable that had any bearing on the number of attempts needed was yet again, the patient's torso width. This was found to be a significant factor for the CTLP and a highly significant factor for the Swimmers patients. So for Swimmers, width affected both the number of attempts and the score, for the CTLP it influenced the number of attempts needed but not the quality of the final image. Therefore a patient with a wider chest needed more attempts at CTLP but the quality of the final image was not diminished because of this whereas a Swimmers image was. (Table 3.54).

Apart from using the technique correctly, there is no more that the radiographer can do to influence the quality of the Swimmers projection. There are inherent factors in the patients that control the quality of the film. Therefore it should be replaced where necessary by a technique in which the radiographer controls the quality of the final film.

Producing radiographs delivers radiation dose to the patient and is not without risk. So if it is known that certain factors will lead to

- reject films,
- greater cumulative dose,
- increased time in the DDI
- a poorer quality radiograph that may not be clear enough for diagnosis
- a possible CT scan and a greatly increased cumulative dose

those factors should be precisely defined so that they may be eliminated or controlled. The patients' torso widths are not a factor that can be eliminated and therefore further investigation of these is necessary to determine the exact levels of torso width and body mass index that generate high and low scoring Swimmers films and those that need to be repeated. This may facilitate the writing of a protocol, which dictates at what measurements a Swimmers film is not indicated. However, to introduce this, a better alternative would have to be available, one that is controllable by the radiographer and has fewer disadvantages.

The new projection under consideration, the coned true lateral projection, proved itself worthwhile in this regard. The only aspect of it that is not totally under the control of the radiographer is the number of attempts needed and the additional time for which the patient is delayed in the DDI. There is no indication that the quality of the final image and its diagnostic utility will be diminished.

4.3.4.2. kVp and mAs

What influenced the evaluators' opinion of the CTL were the quality and the quantity of the beam and these are controllable. Lower values of kV and mAs were significantly associated with higher scores (Table 3.14.). It may be that these patients to whom the higher scoring films belonged, were smaller people who needed less exposure. The mean weights and BMIs of the CTL group were slightly below those of the Swimmers group indicating that this projection was more likely to be of good quality on smaller patients, but the mean torso width for this group was of negligible difference. However, statistical tests did not discover any correlation between this group's BMI and their score, so that is probably not the reason that those who received lower exposure factors had higher scoring films. It is more likely that the consequent reduction in the amount of scatter produced by using lower exposure factor settings, is what influences the quality of the film.

This is true for all radiography and should be applicable also to the Swimmers projection, however, it was not found to be statistically significant for Swimmers. The most likely reason for this, is that the dense body structures that the primary beam must penetrate in Swimmers, cause significant attenuation and scattering of the beam, whereas in the CTL, the area irradiated is much smaller and also less dense. The tight collimation and reduced density of the area due to the positioning, have already reduced to a minimum the factors that affect the production of scattered radiation so the primary influence is from the kV and mAs values used.

In the Swimmers projection, tighter collimation and reduced exposure factor settings will reduce scatter and therefore must enhance the quality of the radiograph, but will not significantly control it. The benefit of reducing the kV and mAs is better seen in the CTLP.

kV and mAs were significant variables for the CTLP with regard to the readers' ability to use the film for diagnosis (Table 3.46). Lower kV values and lower mAs values meant more evaluators stating that this film was diagnostically useful. This is probably due to the increased contrast and the reduced amount of scatter produced, along with the effect of the tight collimation of the primary beam. There was no relationship between exposure factors and the evaluators' opinion of the usefulness of the Swimmers projection. Therefore, again it can be seen that the factors that increase the quality of the CTLP are under the control of the radiographer.

The mean kV value used for the CTL (73kV) was 10kV lower than that for Swimmers and the mean mAs value used (19.5mAs) was 10% that of the mean Swimmers value (199.8) (Tables 3.4 and 3.5.). The maximum mAs used for a CTLP was 60mAs while the maximum used for a successful Swimmers was 729mAs and for an unsuccessful one, 999mAs. Apart from the dose implications, one must also consider the effect of these extreme mAs values on heating effect and the consequent shortened X-ray tube life.

4.3.4.3. Age

The age of the patients had no effect on their score for either projection but did influence the evaluators' decision on whether or not they would use the Swimmers film for diagnosis.

A greater number of evaluators would use the film for diagnosis if the patient was older and less evaluators were able to use the film for diagnosis where the patient was younger. The logical conclusion is therefore that the films of younger people are harder to interpret. This may be because younger patients tend to be broader and more muscular, their bones are denser and these factors have an influence on the attenuation and scattering of the X-ray beam which degrades the image.

The possibility that evaluators are less willing to make a decision on the films of younger patients cannot be ruled out. During the evaluations the patient details were not available to the readers, there was no clinical data supplied, but age can be implied from anatomical details, such as osteoporosis and arthritic lipping of bony structures and may have been assumed, albeit subconsciously, by the readers. With the significant morbidity and mortality of cervico-thoracic junction injury, there could be a tendency to treat younger patients' films with more caution as is stated by Tan et al., (1999).

4.3.4.4. Collar size

The collar sizes worn by the patients were not found to have any influence on either the score awarded by the readers or their decision on whether or not to use the film for diagnosis.

4.3.4.5. Gender

Gender had no effect on the score or the diagnostic usefulness of the film, nor did it dictate which projection would be successful. (Table 3.17; 3.48)

It is somewhat surprising that gender had no influence on quality. The majority of the patients in this study were young males who have a genetic predisposition to having a broader torso width and much more developed torso muscles than females. Width was a significant factor in the quality of the Swimmers film so it could be expected that the Swimmers films of young males would be rated lower, yet they were not. Probably because the females in this study had a mean torso width that was just 1cm less than the males. That width may have been due to the percentage of body fat present, because the same percentage of female patients as males, were overweight, but a higher percentage were obese (10% males, 15% females). It would be interesting to know if this assumption is true as different types of tissue have different attenuation coefficients and some difference in the quality of the films could be expected, depending on the type of tissue irradiated. Yet in this study width was a significant factor in the quality of all Swimmers films. Measurements of difference in body fat percentage and muscle mass, in patients for radiography of the cervico-thoracic region, were beyond the scope of this study but may be worth pursuing.

4.3.4.6. Number of attempts needed to produce a successful image

The time spent in the Department of Diagnostic Imaging (DDI) is a critical factor in the care of the multi-trauma patient. They have multiple injuries and need treatment, sooner rather than later and many have distracting painful injuries (DPI) (Ullrich et al., 2001). There is a proven association between head injury and cervical spine injury; figures quoted are between 5% - 50% and linked with a Glasgow Coma Scale of less than 3 (Iida et al., 1999; Drainer et al., 2002). Patients with a traumatic brain injury must be imaged expeditiously and handed over to the expert care of the neuro-sciences team. The number of repeat attempts needed by the Swimmers projection and the subsequent delaying of the trauma patient in the DDI is one of the reasons that it is so maligned by front-line staff in the clinical setting. A projection that can be achieved in as few attempts as possible would be a strong contender for a replacement for the Swimmers projection providing that other criteria are met.

There were 77 CTL projections performed in this study and these produced 29 successful CLTPs and 48 rejects (Table 3.20). This is a 62% reject rate. The recorded Swimmers projections were 82 in number and produced 57 final films and 25 rejects, which is a 30% reject rate. The CTLP projections were rejected and repeated at twice the rate of the Swimmers but when either projection was successful, there was little difference in their reject rate, with Swimmers rejected at 34% and CTLP rejected at 37%. There are two possible explanations for this high reject rate.

- The first is the bias in favour of the Swimmers projection, which meant that there was 18 times when the CTLP did not successfully show the cervico-thoracic region and was replaced by Swimmers. This produced 27 rejected radiographs which was the highest number of rejects for any one group of radiographs in the study, but when Swimmers did not work first time it was replaced by the CTL in only two cases, which produced just two rejected Swimmers films. This imbalance in the rejects meant that 7% of the rejected radiographs from the “crossover projections” were Swimmers and 93% were CTLPs but this was due to a bias rather than an inherent fault in the CTLP.

- The second possible reason is that the CLTP was rejected instantly when it did not work, possibly because of something inherent in it, which makes it quite clear to the radiographer immediately, whether or not this projection is worth repeating. When the CTLP was the first projection, it was tried without the intervention of Swimmers, in 27 cases. In 14 of these it succeeded first time and in the other 13 it was tried repeatedly and did succeed. This is an overall success rate of 60% for the CTLP and a 31% success rate for perfect achievement, i.e.just one successful attempt. This figure does not include the two projections that followed an unsuccessful Swimmers. When they are included, the success rate of the CTLP is 61.7% (29 of 47). In 18 cases, it was rejected in favour of Swimmers.
  When Swimmers was the first projection it was repeatedly attempted with little resort to the CTLP. There were 41 randomised Swimmers projections and only twice did the radiographer resort immediately to a CTLP when the first Swimmers did not work. In both cases the CTL did succeed in showing the cervico-thoracic junction. Of the total of 41 randomised Swimmers, 39 were successful, an overall 95% success rate and 25 were achieved first time. This is a 61% success rate for perfect achievement but when the obvious bias is taken into account this does not look like a true success rate in comparison to the CLTP. Swimmers was obviously deemed successful by the radiographers 95% of the time, which is what would be expected with the years of familiarity and experience of it that radiographers have acquired. It must be considered that this 95% may contain some cases that were randomised as CTLs and would have been successful with some more experience on the radiographer’s part. Had this happened it would have reduced the Swimmers’ success rate somewhat. Perhaps too, an unsuccessful Swimmers projection is not so clearly indicative of the futility of further attempts. There were after all, some Swimmers projections where there were four attempts recorded but the maximum number of CTL projections performed on any one patient was three.

With this in mind it is worth comparing the percentage of films that the radiographer passed as diagnostic and the percentage considered diagnostic by the evaluators.. The radiographers passed 60% of the randomised CTL projections and the evaluators decided that 56% of the evaluated ones were diagnostic. The radiographers passed 95% of the randomised Swimmers projections and the evaluators passed 45.5% of the evaluated ones. Due to the fact that not all radiographs could be retrieved for evaluation, it is difficult to describe mathematically exactly what the discrepancy between radiographers and evaluators was. It appears that they were closer to agreeing on diagnostic utility on the CTLP than on the Swimmers but again because of the bias in favour of Swimmers this is not a true test. It would be interesting to investigate this further.

4.3.4.7. Doses of the evaluated projections

There was no correlation between diagnostic utility or score for either projection and the doses of the evaluated projections, showing that high scoring films are not necessarily those that are high, or low, dose.

4.3.5. Evaluator agreement on the diagnostic utility of both projections

When the answers were grouped according to whether the radiograph was a CTLP or Swimmers, it was found that 55% of the CTL projections were considered useful by a majority of readers, while 45.5% of Swimmers were. This is a good result for the novice CTLP even though the statistical test used did not find it to be significant. It can be considered at least equal to the Swimmers in its usefulness for diagnosis.

4.3.6. The constituent parts of the score

It has been seen that where the proposed CTL is concerned, kV and mAs are the factors that control the image quality. The overall score awarded by the readers to the radiographs had two constituent parts, the contrast and density and the visibility of anatomical detail.

The radiographer can control contrast and density to varying degrees, by the judicious use of exposure factors. The visibility of anatomical detail is less controllable and affected mainly by body habitus, although patient positioning and the removal of clothing and other artefacts can enhance it somewhat. In light of these findings on exposure factors, these constituent parts of the score were analysed to ascertain which, if any, had the most influence on the evaluators' confidence in using the film for diagnosis. Was it the contrast and density which is totally under the radiographer's control, or the visibility of anatomical detail, which is only partly controlled by the radiographer?

The visibility of anatomical detail had the highest correlation factor with evaluator agreement for both projections, but both parts of the score were considered highly significant. There was no difference in this finding for either projection, indicating that what makes a radiograph of the cervico-thoracic region diagnostically useful is the same for both projections (Table 3.18; 3.19). As can be seen already, the radiographer's ability to influence this is only significant for the CTLP.

4.3.7. Bias and a learning curve

When Swimmers was the randomised projection there was almost a bias against the use of the CTL as a repeat projection when the Swimmers did not work (Tables 3.9-3.14). The randomisation of the type of first projection was an attempt at removing any bias, but repeat projections had to be the choice of the radiographer, to ensure the acquisition of a diagnostic image in as few attempts as possible. Where Swimmers failed there was a much greater tendency to follow it with another Swimmers in preference to a CTLP. The multiple attempts at the CTL when it failed first time demonstrate no bias against it therefore this bias, which was detected by statistical testing and deemed significant, was in favour of the Swimmers projection. This demonstrates a comfort and familiarity with Swimmers and a learning curve in relation to the CTL. The questionnaires distributed to the radiographers after the data collection attempted to elicit an explanation for this

tendency to follow Swimmers with Swimmers, but just one person gave an explanation which stated that the CTL needs multiple repeats.
The learning curve was very apparent when the high-scoring projections of both types were investigated (Table 3.57). The successful Swimmers, those scoring over 75% in the evaluations, were spread evenly throughout the time frame of the study. The high-scoring CTL projections were not in existence until approximately one third of the way through the study and were concentrated in the final fifteen. This happened in spite of a training period of approximately two years and is difficult to explain but is most likely due to an intake of new staff at or around the beginning of the study. These new staff participated freely in the study without the benefit of the practice period and would consequently have been able to produce and evaluate the CTL much better as time went by. If this is the case, it shows that all it takes is practice for radiographers to consistently produce CTL images of the cervico-thoracic junction that are of excellent quality.

4.3.8. Safety concerns

As stated already, patient safety is paramount. Any technique that puts the patients at risk must be balanced by considerations of benefit. Imaging professionals and those clinicians who request imaging are acutely aware of the dangers of radiation and all imaging using radiation is subject to strict considerations of the benefit that is conferred by the hazard. In practical terms this translates as the ALARA principle and protocols such as the Ten Day Rule.

There are other aspects to patient safety though, that must also be considered, such as movement. It is well accepted that movement of a patient with even a suspected spinal injury is contraindicated although it is unavoidable at times e.g. when moving a patient onto a CT scanning table. The American College of Surgeons Committee on Trauma (1997) state clearly that the movement of a patient with an unrecognised and unstable spinal cord injury can lead to an exacerbation of that injury and patients are immobilised with collars and backboards, tape and sandbags, to limit as much as possible any movement of the spine. Until spinal injury has definitely been discounted, patients are kept at all times with the spine in neutral alignment and moved only if absolutely necessary. Even then there are protocols governing the use of specialised movement techniques such as log-rolling that maintain spinal alignment (ibid, 1997: p240).

In spite of this, when a patient's lateral cervical spine radiograph does not demonstrate C7 and T1 and their spinal status has not yet been established, the first method of choice for demonstration of the area is a Swimmers projection, which involves arm movement. It is known that in at least one case, that movement caused a definite exacerbation of an unstable fracture of the posterior elements of C6 (Davis, 1989). A recently published paper on the biomechanics of spinal movement, has reported that elevation of the arm causes ipsi-lateral bending and rotation of the upper thoracic vertebrae, coupled with extension (Theodoridis and Ruston, 2002). This is exactly the positioning used for a good Swimmers radiograph. This is a significant amount of spinal movement in an area adjacent to the cervico-thoracic junction. Through muscular attachments, this movement of the thoracic vertebrae must translate to cervical spine movement but there have been no other reported cases of exacerbation of injuries by the positioning for Swimmers and it is used extensively and successfully worldwide. It is therefore possible, that the effect of the thoracic vertebral movement on the cervical spine is minimalistic and only of concern when there is an unstable injury but this needs to be clarified.

It is frequently stated in the literature that between 3-25% of patients with a cervical spine injury, who arrive in the emergency department neurologically intact, suffer exacerbation of their injury due to movement while in the care of the hospital (ACS, 1997, Drainer et al., 2000). None of these papers state what movement was involved but there is significant muscular activity involved in arm raising and some of these muscles have a direct attachment to the cervical spine.

1. Trapezius elevates the shoulder, is involved in extension and rotation of the neck and is attached directly to C7 and indirectly, via the ligamentum nuchae, to the spinous processes of the first six cervical vertebrae
2. Levator Scapulae, raises and rotates the scapula and is attached to both the scapula and the transverse processes of the upper four cervical vertebrae
3. Rhomboid minor, has its origins C6 and C7. It rotates the scapula.(Dean & West, 1987; p221-222; Cash M, 1999; p48; O'Leary S, 2004).

It is therefore possible that in the presence of an unstable fracture, this muscular activity has the potential to exert forces on the cervical vertebrae that could cause the fracture site to distend. Clinically, by palpation there is also thought to be motion in the cervical spine when the arm is raised (O'Leary S, 2004).

So, arm raising does exert forces on the cervical spine and therefore Swimmers projection is not as safe as was previously thought, although the lack of reports of further injury would indicate that the level of risk is small.

One further point to consider is that approximately 10% of patients with a cervical spine fracture have a second associated non-contiguous vertebral column fracture and this may well be in the thoracic region (ACS, 1997: 226). The Swimmers projection is often performed before the thoracic spine lateral projection and consequently, the positioning that causes the thoracic vertebral movement is performed before it is known whether or not these vertebrae are injured.

Despite a past abundance of Swimmers projections and just one specific report of damage, there are anatomical and biomechanical features of this area that warrant a more in-depth investigation to be assured that the Swimmers projection is safe for use in trauma patients. It is known to be less than 100% safe and so, for reasons of absolute patient safety there should be strict criteria for performing it.

By contrast, the CTLP does not involve any movement of the patient at all. Distal distraction of the shoulders, arm traction, has been proven in the laboratory and in the clinical setting, to enhance the visibility of the lower cervical region on radiographs (McGill & Yingling, 1999; Ohiorenoya et al., 1996). It would probably have increased the number of patients for whom the CTLP was successful but some patients would not be suitable for this technique due to shoulder or upper limb injuries and the use of traction in this study would have varied, so it was ruled out. More importantly, it is not known to be totally safe in the presence of cervical spine injury as the laboratory tests also showed that traction increased the size of the radiolucent gap of a known fracture and consequently it was not used in this study (McGill & Yingling, 1999). The CTLP was therefore performed without arm traction or arm raising and was seen to be a totally safe and diagnostic projection for use in trauma.

4.4 DOSE CONSIDERATIONS

Radiation dose is inextricably linked to plain film radiography and any investigation involving radiographs must consider patient dose. Sometimes an increased radiation dose can be balanced against the benefit of greatly increased diagnostic utility and is therefore acceptable. This is demonstrated by the fact that 100% detection of fractures was achieved by the use of CT scanning as reported by Jelly et al., (2000), while Rybicki et al., (2002) report a greater than 14 fold increase in the dose to the thyroid gland during CT.

In this study the dose was measured for all projections but there were five times when the Swimmers repeat doses were not measured. This was an error, which means that the information for the cumulative Swimmers projections is slightly less than the true cumulative dose. For accuracy of the statistical analysis these patients' cumulative doses were not included and this further reduced the numbers of patients whose information could be analysed. In spite of this, there were some very definite test results that are not diminished in significance by the smaller numbers, if anything this missing information on the doses of the Swimmers projections further emphasises the vast difference in dose between the two projections. Doses were evaluated as individual doses, the cumulative dose of the same type as the final successful projection and the cumulative dose due to all projections. It was necessary to split the cumulative dose like this, as the dose difference between the projections meant that the CTL projection contributed very little towards cumulative doses where Swimmers projections were also used. This differentiation made it possible to look at the influences on the doses of the successful and the unsuccessful projections separately. The data was analysed to try to ascertain what factors affect the entrance surface dose and thyroid doses during radiography of C7/T1.

4.4.1. The effect of the measured variables on patient radiation dose

4.4.1.1. Width and BMI

The patient's torso width influenced the dose received by the patients who had the CTLP, wider patients received larger entrance surface doses and significantly larger thyroid doses and this is to be expected. The focus-film distance (FFD) for the study was set at 100cms for all projections, therefore the centring point of the primary beam and the TLD holder were closer to the focus where the patients were wider. This will have resulted in an increased ESD for those whose shoulders were closer to the X-ray tube because of the inverse square law, but this is true for both projections as the groups were closely matched in size. The mean torso width of the CTLP group of patients was 42.07cm and for the Swimmers group it was 42.57cm therefore the differential between the doses received by both groups is still a valid comparison. It does serve to highlight the importance of focus-film distance on patient dose. Radiographers work at 100cms FFD for all Swimmers projections even though this translates to larger ESDs for wider patients. It may be wise to consider the use of focus-object distance (FOD) as the set value at which projections are taken. This will decrease the patient dose while reducing magnification of the region of interest and enhancing film quality. Greater width means a greater amount (distance) of tissue irradiated, more scatter produced and of necessity, higher exposure factors. Therefore the TLDs, which are sensitive to back-scatter from within the patient, will have recorded greater doses.

When Swimmers projection was unsuccessful, the patient's torso width was found to have a significant effect on the patient's ESD and thyroid dose but not when it was successful. This is an interesting finding because of the distinction between the successful and unsuccessful. The amount and strength of radiation used is determined by the thickness (width) of the body part and it determines the patient dose, yet that dose was not correlated with the width when the film was successful. The important thing about this finding is the fact that the width was measured when the arms were down by the patient's side but the dose was measured when the arm was raised. Therefore, logically, these two widths must be the same when the projection is unsuccessful and different when it succeeds. The width was measured from the greater tuberosity of the humerus on one side to the same point on the other side. When the arm is raised past the vertical in a supine patient or horizontal in an erect patient, there is movement of the shoulder in a cranial direction (O'Leary S, 2004). The patient width in this position is therefore the measured width minus the width of the arm, as it is now raised sufficiently to exclude it from the measurement. It is not the same as the measured width. Therefore it is the elevation of the arm past 90^0 that determines the success or failure of the Swimmers projection. The recommended technique for performing Swimmers stresses the importance of separating the shoulders by cranial and caudal movement. This finding reinforces that. The unsuccessful Swimmers projections were those where the movement of the raised arm was such that the patient's torso width was equal to the width in an arm-down position. There could not therefore have been elevation of the shoulder, so there must have been no movement of the arm past the vertical position. This, then, may be the factor that creates unsuccessful

Swimmers projections. There will always, of course, be patients who for various reasons such as upper limb injury, cannot extend their arm cranially and for whom there may be an increased likelihood of producing unsuccessful Swimmers projections. This needs further research to determine if there is a group of patients whose width definitely excludes the use of the Swimmers projection for diagnosis.

Body mass index had no effect on the ESDs or thyroid doses of the patients in the CTLP group but it did increase the ESDs of the Swimmers group. Larger patients were subjected to larger ESDs.

4.4.1.2. kV and mAs

kV and mAs values are controlled by the radiographer. There is an optimum value that is dependant on body habitus factors such as the depth and density of the area under examination and image capture methods along with processing times and temperatures also figure in this choice. Within these confines the radiographer can make choices about exposure factors, some of which will affect quality and some will affect dose. Once a level has been reached where the visibility of anatomical detail is optimised, there is a fine balance between dose reduction and acceptable contrast and density levels. These also influence the evaluators' decision on the diagnostic utility of the film so they are important, but so is dose reduction.

The chosen kV values influenced doses for both projections. The CTLP patients received lower entrance surface doses, both individual and cumulative, when the chosen kV was lower. There was also a correlation between the cumulative thyroid dose when both projections were included. It too decreased as the kV was decreased, which would seem to indicate that the inclusion of the Swimmers projections in this addition was the reason for the correlation yet in the Swimmers group, kV was not correlated with the thyroid dose in any circumstance. This unusual finding only applies to two cases because there were only two patients who had Swimmers attempts before having a final successful CLTP. Perhaps this is the reason for the unexpected correlation although it is noteworthy that there was a borderline correlation between the kV and the cumulative dose of CTL projections only. The Swimmers ESD was correlated with the chosen kV, increasing as kV increased and that applied to all ESDs, individual and cumulative.

The mAs values used had an effect on the CTLP entrance surface doses but there was no effect on the CTLP thyroid dose. This was close to a linear correlation with the ESD of the successful CTL projection, which is to be expected. Swimmers patients received significantly higher thyroid doses from increased mAs values and ESDs that were highly significantly correlated with the mAs.

This lack of a relationship between the CTL thyroid dose and the mAs used can be explained by the extremely tight collimation of the beam as it exits the light beam diaphragm, thereby reducing to a minimum the volume of tissue irradiated and the consequent limited production of scattered radiation. When the production of scatter is tightly controlled, the range of mAs values that were used in this study would not be significantly large enough to have had an effect on the dose to the thyroid gland, which is exposed by scatter only, due to its position outside the primary beam. In Swimmers projections, the thyroid is still outside the primary beam but much closer to it because of the larger collimations used. The volume of tissue irradiated is also much greater and so therefore is the production of scatter. The range of the mAs values used was also sufficiently large enough to demonstrate significantly increased thyroid doses.

These results demonstrate the influence of the exposure factors with regard to dose and the most important of these findings is the fact that the radiographer can control them, thereby optimising the balance between image quality and dose. The benefit of tight collimation is also demonstrated and this too is something that gives the radiographer opportunity for dose reduction.

4.4.1.3. Age

Age was not a significant factor in dose.

4.4.1.4. Collar size

The collar size is an indication of neck length. The cervical immobilisation collars are named and increase in length from Paediatric to Long.

The only dose that the collar size influenced was the thyroid dose during Swimmers projection. Patients who wore the shorter collar sizes received the bigger thyroid doses. It seems logical that this correlation was found because the inverse square law dictates that structures closer to the source will receive greater doses and in patients with shorter necks the thyroid is closer to the central ray. This made no difference though to the thyroid dose of the CTLP patients. Again it can be seen that the tight collimation of the CTLP serves to reduce the amount of scatter reaching the thyroid gland, even when the thyroid is closer to the primary beam because of the shorter neck length.

4.4.1.5. Gender

Being male or female made a difference to the doses received. Females received significantly greater thyroid doses during Swimmers projections. This is a logical progression from the previously discussed finding that patients with shorter necks receive increased thyroid doses, as the women in the study wore the majority of the shorter size collars and none of the longest size. Women have shorter necks and consequently receive bigger thyroid doses during Swimmers projections.

The men in the study received the greater entrance surface doses while having a CTLP. This may be because the men are more muscular, muscle is more dense and therefore needs a bigger quantity of radiation of greater beam energy to penetrate it successfully. These larger exposure factors increase the dose as discussed already.

4.4.1.6. The number of attempts needed to produce a successful image

Naturally, the total number of attempts increased the cumulative doses of both projections and this is where the difference in dose between them became very apparent. The CTL may have had double the reject rate of the Swimmers radiographs but it contributed just 3% of the dose to the population and 97% was attributable to the Swimmers. (Figure 3.8; Table 3.21.). In fact, the population dose from Swimmers would be greater than 97% if all of the repeat doses were known. This does not give the radiographer leeway to repeat the CTLP frequently. Even small doses of radiation must be used judiciously and as infrequently as possible so the CTLP should be of a standard that the radiographer can achieve first time.

The doses recorded in the study were significantly affected by repeat projections. The highest individual entrance surface dose was 10.54mGy and the highest due to repeat projections was 20.76mGy. The Swimmers doses were significantly larger with the highest recorded individual entrance surface dose 342.85mGy and the highest recorded cumulative ESD from repeat Swimmers was 800.27mGy. Therefore repeat projections added significantly to the dose.

If we look again at the learning curve, as discussed previously, it has been noted that with practice the radiographers were producing high scoring CTLPs. Six of these nine CTLPs were achieved first time and the other three on the second attempt. So it seems that not only the image quality but also the quality of the technique improved with practice and it is possible for experienced radiographers to produce high-quality projections first time on a regular basis. This needs to be assured by testing the projection again without a learning curve.

4.4.2. Comparison of the doses recorded for both projections

As discussed the ESDs of the projections were considerably different, with regard to repeat projections. The thyroid doses were also significantly different for the two projections. The highest individual thyroid dose was 2.38mGy for the CLTP with a mean of 0.24mGy. The highest cumulative thyroid doses for the CTLP was calculated at 2.42.mGy. Swimmers highest individual thyroid dose was measured at 78.57mGy with a mean of 4.89mGy. Repeat projections were also 78.57mGy.

The highly significant dose difference between the projections demands that more attention be paid to the success rate of the Swimmers. Considering the 100% success rate of CT, a comparison with the dose from CT scan of the region would be justified for those cases where the larger doses are likely and a CTLP has not worked. The problem at the moment is knowing in advance exactly who is likely to get these kind of doses from Swimmers projections. The results of this study may be an indication of this and they definitely show that the proposed projection is a desirable replacement for the Swimmers projection with regard to dose.

4.5 IMAGE EVALUATION

This study set out to compare the two projections from the points of view of quality and of dose. Where a new technique, or technology, is being evaluated for use in the clinical setting, it is important to ensure that any dose reduction is not at the expense of the diagnostic utility of the image (Martin et al., 1999). The quality of the images was based on the scores awarded by the evaluators and on their opinion of whether or not the radiographs were capable of enabling their decision on diagnosis. The evaluation of the images was therefore, a crucially important part of the assessment and comparison of the two projections, therefore the evaluators had to be professionals who between them are expert in the production and evaluation of images of the cervico-thoracic region (ibid, 1996).

4.5.1. The Evaluators

The panel of five evaluators comprised of two consultant radiologists, one consultant emergency medicine physician, one specialist permanent registrar in emergency medicine and one radiographer. One of the radiologists is an expert in the field of neuro-radiology which encompasses the cervico-thoracic region. The other is a general radiologist who reports trauma films regularly. In the clinical setting, the two emergency physicians make decisions on the status of the cervical spine, based on a combination of the results of their clinical examination and their interpretation of the cervico-thoracic radiograph. There were no radiographers in the region with a specialised qualification in trauma radiography, so a radiographer with over twenty years clinical experience of trauma in several different countries, was chosen as the final evaluator.

4.5.2. The evaluated projections

There were 86 patients in the study but only 69 radiographs went forward for assessment. There were five CTLP projections and 12 Swimmers projections that were not available at the time of the assessments so this further reduced the number of films available for analysis and the final numbers were 24 CTLPs and 45 Swimmers. The proportion of each projection available, relative to each other, was still approximately the same as the proportion of final projections. This number is still more than sufficient to prevent the results of one or two patients' images influencing the final result (ibid, 1999).

4.5.3. The Method

The lateral and cervico-thoracic projections of each patient were separated from the rest of the trauma series, the patient identification window was covered with opaque tape and they were put into a separate envelope marked with the study number only. This was the only information presented to the evaluators; no clinical data or patient identification of any kind was available. As this was a prospective study but the evaluations were retrospective, it would have been relatively easy to introduce bias inadvertently because of an evaluator's possible prior knowledge of the patient and the patient's condition. That bias was removed by the removal of all of the patient details and identifying information. Clinical data can change the index of suspicion and that will impact on an evaluator's interpretation of a radiograph, therefore no clinical data was supplied (ibid, 1996).

4.5.3.1. Pilot study

The evaluation forms were based on the CEC criteria for image evaluation of the lumbar spine (European Commission, 1996). They were divided into two sections. Section one posed questions about the factors that the radiographer can control, i.e. contrast and density and section two had questions on the visibility of anatomical detail and the evaluator's decision on diagnosis and the need for further imaging. The forms were piloted on the final evaluators and on a neurosurgeon and an orthopaedic surgeon, using ten projections of both types, to ensure that the questions were phrased in a way they understood and to show them what was expected of them in the final evaluation. (Bailey, 1997; p185; Martin et al., 1996) The pilot study served as a practice session in the correct way to evaluate the CTL radiographs. These were reasonably new to the evaluators compared to the Swimmers projection and because of the tight collimation, practice is a necessary part of becoming confident and accurate in identification of the vertebral levels and other anatomical structures. This was an attempt to remove a learning curve among the evaluators during the final evaluations (ibid, 1996). The work was time consuming and one evaluator withdrew after the pilot study, due to pressure of work and lack of time, proving the benefit of piloting the work to be done, on the chosen evaluators. Another evaluator of equal status and expertise replaced him. They were aware of the fact that they should suggest and explain any changes that they felt would improve the accuracy or ease of use of the questionnaire. Several changes were suggested; for example, it was suggested that "superimposition of the posterior vertebral edges" would not be recognised as meaning rotation of the vertebrae, so the words "denoting that the vertebrae are not rotated" was added for clarity. Changes of font and layout were also suggested and followed.

It was important that there was one question that elicited a decision from the evaluators about the usefulness of the films for diagnosis in the clinical setting. This question had to be as close as possible to that which they pose, every time they make a decision based on radiography of the cervico-thoracic junction. That question was originally phrased using references to fracture or subluxation but an evaluator suggested that it was a leading question and it was rephrased "Can you meaningfully interpret this film for injury at the C7/T1 level?" That choice of words reflected the clinical situation more closely because the radiographs are interpreted for the presence or absence of all types of injury. An affirmative answer to this question meant that the evaluator could make a decision on the status of the spine from this image and that is exactly what is required of a radiograph in the trauma setting. This was a pertinent question and the first one that needed a decision based on expertise, training, education and experience. In practice it carries a level of risk, as the removal of a collar from a patient with an undiagnosed cervical spine fracture can cause an exacerbation of that injury and may result in quadriplegia (Berlin, 1996). The moral and ethical considerations of this decision are borne by everyone but the medico-legal implications of a wrong diagnosis are greatest for the consultants and the registrar and least for the radiographer. Despite this discrepancy in legal liability, the radiographer has the crucial role of choosing technical factors that will not hinder an evaluator's ability to recognise the presence of spinal injury. It has been stated that questions on the contrast and density of an image should not be considered in evaluation of an image for use in a clinical setting, although that referred to digital capture methods (Martin et al., 1999). However, good contrast and density in a radiograph are extremely important in diagnosis of injury and disease and poor contrast and density have been known to mask pathology (Berlin, 1996). Plus, the results of this study proved that both contrast and density and the visibility of anatomical detail, equally influence the evaluators' ability to interpret the film for injury (Table 3.18). Thus the use of these questions when calculating the final score, was justified.

4.5.3.2. The Evaluations

The room chosen for the evaluations is a conference room that can be booked in advance, thereby ensuring that there would be no interruptions during the evaluations. There is a bank of viewing boxes in this room. Before the evaluations began, all of the bulbs were replaced with brand new tubes, all in the colour known as "daylight". The ambient lighting and viewing box luminance was assessed using a Hagner photometer, before and after each sitting and this ensured the objectivity of the evaluations as much as possible (Martin et al., 1999). Despite the brand new bulbs, there was some variation within and between the viewing boxes so one particular viewing box was chosen and the evaluators were told to use only the middle and lower segments of the right hand side of this viewing box. The ambient light in the room was always between 50 - 60 lux. The radiographs were given to the evaluators in a random order. This proved to be beneficial because it showed that the position of the high-scoring CTLPs in the latter half of the study, was due to a radiographers' learning curve and not an evaluators'. (Table 3.57).

4.5.3.3. Intra-observer variability

Intra-observer variability was assessed for four of the five evaluators. It was not possible to be with the fifth evaluator during the evaluations and therefore not possible to assess it for this person. Radiographs no. 10S and 53C, which had no particular identifying features were given to each assessor three times, close to the start of the assessments, again in the middle and at the very end. The scores for these three assessments were then analysed to ascertain their standardisation. This was achieved by comparing the standard deviation of the scores that each assessor awarded each time. Overall the scores were consistent throughout the evaluations. One evaluator marked the Swimmers projection, 10S, quite differently the first and third times and had a standard deviation of 5.13 but this same evaluator had a minimal standard deviation of 0.57 between the CTLP scores so the reason for this difference is difficult to ascertain. The other evaluators had small standard deviations for both projections, indicating consistency throughout the evaluations.

4.5.3.4. Inter-observer variability

Inter-observer variability is important if the evaluators' decisions on scores and diagnostic utility are to be used as a measure of success of the CLTP. It was assessed using Kappa analysis of the answers to question 10 on Section 2 of the evaluation sheet. This question was the only one on the sheet that elicited an answer on the usefulness of the film in the clinical setting. The preceding questions were on the visibility of various aspects of the anatomy and did not stand alone. They did not need an opinion as they were concerned with visibility of anatomical detail, not the extent of it. It was not expected therefore, that there would be any variation in the answers to these, a spinous process, for example, is either visible or it is not visible. The question following question 10 was about the need for further imaging. This requires an evaluator's personal opinion but the answer is dependent on the answer to the previous question and for this reason it was scored in reverse. If the evaluator stated that they could not interpret the film for injury then they would require further imaging so a negative answer to question 10 was followed by a positive answer to question 11. There was, however, an exception to this. When the evaluator could interpret the film for injury and thought that it did indeed demonstrate injury, then CT scanning was requested, therefore a positive answer was followed by a positive answer. So question 11 did not stand alone as a decision making question. Question 10 was also the one most closely representative of the clinical situation and was therefore the truest test of the CTLP as a clinical decision making tool. The question 10 answers were therefore those used for the Kappa analysis of inter-observer variability and the results were disappointing. The overall Kappa for the CTLP was 0.2421 and for the Swimmers it was only slightly better at 0.3502. For both projections together it was 0.3139 but within this there was some good agreement.

For the Swimmers projection there were several instances of good agreement within the range of 0.4 -1.00 that is considered fair to excellent and therefore statistically significant (Fleiss, 1981; p218). When paired, four of the five evaluators had good agreement with their partner, either twice or three times out of a possible four. There was one evaluator whose opinion never correlated with the others and it was this that reduced the score for overall Kappa.

For the CTLP, the results were identical with regard to the agreement between pairs. The same evaluator that did not agree with any of the others on Swimmers, did not agree with anyone on the CTLP either. The Kappa coefficients were lower for this projection, which is to be expected, given the relative lack of exposure to it in comparison to the Swimmers projection. The evaluators are used to making decisions based on the Swimmers projection but have relatively little, if any, experience of decision making, using the CLTP. The agreement between pairs was very interesting and raises questions about risk-taking and responsibility.

The radiographer and the neuro-radiologist had the best and most frequent agreement above chance with each other and with the A&E doctors. For both projections, the Kappa coefficient for both of them was greatest with each other, then with the SPR in A&E medicine and then with the consultant in A&E medicine. The agreement above chance between the A&E doctors was poor and non-significant for both projections. These results are detailed in Appendix 5.

It is possible that the problem lay in the nature of the question on which the Kappa analysis was used. This is a question that demands a decision with enormous implications for the patient and the clinician, if the clinician is wrong. This was a research study and there were no real implications attached to any answer. However, this question was chosen because of its closeness to the clinical situation and it is possible that evaluators translated the caution that is, of necessity, present in the clinical situation, to the study. This was suspected, as discussed previously, when a greater number of evaluators would use an image for diagnosis if the patient was older.

There is one interesting point that must be considered, the agreement between the radiographer and the neuro-radiologist. The radiographer has no legal responsibility when interpreting radiographs, which could translate as no inherent fear of litigation and a consequent willingness to make a decision on interpretation. The neuro-radiologist has very specialised training in interpretation of images, of this area in particular and this may translate as a confidence that overcomes fear of litigation and a willingness to make a decision about injury from the radiograph. It is also interesting to note, in this regard, that the evaluator whose opinion was next most closely aligned with both of these, was the SPR in A&E medicine, a doctor who has more legal responsibility than the radiographer, but not as much as the Consultant doctors. It is also noteworthy that the neuro-radiologist has spent his entire career, until now, in a different country and it may be that the culture of litigation is not as strong there as it is in this country.

While a likely reason for the poor overall Kappa value is the difference in the evaluators' attitude to taking risks, there is one other explanation that is worthy of some consideration. There were just five patients in this study who went on to have CT scanning of the cervico-thoracic region. This is the protocol where there is definite or suspected injury of the region. It is known that Kappa is affected by prevalence and the evaluators in this study were examining the radiographs for the presence or absence of injury. The existence of signs of injury in radiographs in this study was a possible maximum of 5 out of 69 evaluated. Of these, one was not evaluated, one was a clinically suspect cervical spine injury and just three were radiographically suspicious. This is a very low prevalence of signs of injury, which is what the evaluators were looking for on the radiographs. Three cases is not enough on which to perform Kappa analysis and obtain a reliable statistic and that is unfortunate, because in a study with some similarities to this one, radiologists evaluating films for signs of nectrotising enterocolitis (NEC) had Kappa coefficients that were very similar to those in this study (Di Napoli et al., 2004). When the analysis was restricted to only those radiographs with signs of NEC, the Kappa coefficient increased significantly. So, there are three possible reasons for the overall low Kappa coefficients in this study:

1. The closeness of the question to one that in the clinical situation demands extreme caution or absolute certainty
2. The fact that one evaluator was consistently not in agreement with the other evaluators
3. The low prevalence of signs of injury in radiographs where the evaluators were looking for signs of injury.

The scores awarded by the evaluators were assessed using a Spearman’s rho correlation coefficient. They varied in the way they scored the CTLP. When paired there were some significant correlations but the pattern had changed, except for the same evaluator whose scores did not demonstrate agreement with anyone else, using Kappa analysis. This evaluator had borderline agreement only, with one other evaluator. The two A&E doctors had significant agreement between the way in which they scored the CTL projection. The radiographer who had the best agreement with Kappa analysis showed only one relationship and that was with the scores of the SPR in A&E medicine. However, when it came to the Swimmers projection there was excellent correlation. All of the evaluators correlated either significantly or highly significantly with each other. This is a significant difference between the evaluators agreement on the quality of the CTLP and that of Swimmers. This is not necessarily indicative of the fact that Swimmers is easier to interpret, it could also be that the visibility of anatomical detail is definitively poor in the Swimmers projection and that all of the evaluators were in agreement that certain parts of the spinal anatomy were not visible. In Swimmers, the raised arm is always either covering the vertebral body or the spinous process so there was going to be a high probability of agreement on the lack of visibility of anatomical detail. Likewise, because of the density difference between the areas above and below the trapezius muscle on the CTLP, the interpretation of the image is more subjective and thus leads to less agreement. The possibility of an evaluator learning curve cannot be ruled out. All of the evaluators have years of experience of Swimmers and relatively little experience of evaluating the CTLP and making a risky diagnostic decision based on it. If the agreement on the scores for the Swimmers projection is so highly significant there is probably not something inherent in the evaluators that caused the poor agreement. It seems that the interpretation of the Swimmers projection is more objective and that of the CTLP more subjective. This too applies to the answer to question 10, it is a subjective matter.

4.6. OVERALL RESEARCH QUESTION

The overall research question “Can visualisation of the cervical spine in trauma patients be improved without increasing patient dose?” raised issues of quality and dose. Martin et al., (1999), state that when a technique is to be introduced clinically, it should be compared in a clinical trial with the present technique. This is to ensure that the new technique represents a real improvement and that dose saving features do not impact negatively on film quality. This study has replicated the findings of other studies. The population were representative of trauma victims and the findings on their weights and BMIs are exactly the same as other studies on the weight of the Irish people. Some of the results that were uncovered by statistical tests are logical and follow on from one another, some were surprising initially but with some thought can be explained. This study is therefore accurate and reliable.

In this case, the quality of the image has been proven to be equal to that of Swimmers. 55% of the CTLP images were considered diagnostic by the evaluators, in spite of a possible learning curve. That learning curve was very apparent on the part of the radiographers but it also demonstrated how practice not only increases the ability to get the technique right first time, but also the chances of the radiographer controlling the quality to such an extent that practice produced high scoring images. There was a 31.11% success rate for single successful attempts and a 60% overall success rate. The repeat rate was high in the study but this was an inflated figure and will reduce considerably with practice. Image quality was proven to be equal despite a learning curve and despite the higher number of repeats the dose was a fraction of the dose delivered by the Swimmers projection. The overall research question has therefore been answered in the affirmative.

4.7. First hypothesis

The first hypothesis is “This projection is of lower dose than Swimmers projection”. It is without doubt, true. All of the statistical analysis and calculations have proven that the dose of the CTL projection is significantly lower than that of the Swimmers projection. It is, of course, achieved without a grid, and Swimmers is performed with a grid. Therefore, the addition of a grid, were it to be used, would increase the dose but it would still be significantly lower than that of Swimmers. The first hypothesis is therefore proven and accepted.

4.8 The Second Hypothesis

"This projection is of better quality than the Swimmers projection".

There is no significant difference between the scores for the Swimmers films and those of the CTLP proving that the evaluators scored the CTLP, which was reasonably new to them, the same as a projection with which they have years of familiarity. The interesting thing about this is the fact that this study has proven that the radiographers can control the final quality of the CTLP and the learning curve demonstrated by the radiographers also showed that with experience the radiographers were producing high scoring CTLPs consistently (Table 3.57). So if the CLTP scored equally in this study, it should score significantly higher in a study where there is no learning curve. The diagnostic utility of the film was also found to be under the control of the radiographer. Again, with radiographer experience, that too will improve considerably and in this study, at 56% of all CTLPs being considered useful for diagnosis, compared to 45.5% for Swimmers, it was descriptively better, if not statistically significant.

There was no particular aspect of the attributes of either projection that influenced the evaluators decision on diagnosis. Both contrast and density and the visibility of anatomical detail influence the number of evaluators who will use the radiographs for diagnosis. In this regard, the projections were again equal. The CLTP needed more repeats but that was not a true reflection of the repeat rate due to the bias in favour of Swimmers.

The CTL projection is physically safer; it involves no patient movement of any kind and can be performed on any patient, even those with upper limb injuries who cannot raise their arm for Swimmers, or those who are neurologically compromised and cannot co-operate.

It is therefore apparent from this study that the CTLP is at least equal in quality to the Swimmers projection and with radiographer experience can be better.

The second hypothesis is therefore accepted.

4.9 Radiographers' questionnaire

A questionnaire was distributed to the radiographers after the data collection was completed. 47.5% were returned (19 of 40). Nine of the 19 stated that they did not put any patients into the cervical spine study and gave the reason as "no suitable patient presented". This is supported by the findings of Linehan et al., (2004) who found a 40% decrease road-traffic related trauma during the time frame of their research, which overlapped with this study. One radiographer commented that most patients for cervical spine radiography were also for thoracic spine radiography, which needs a Swimmers projection to demonstrate the upper thoracic region, therefore choice of projection could not be randomised. This was a point that should have been given consideration when planning the study. It did cause some attrition of numbers.

The answers given by the radiographers concur with the percentage success rates found overall. Six radiographers did the CTL as a first projection and it worked first time for two. This is 33.33%, the success rate recorded in the study was 31.11%. Those who pursued the CTL to a final successful film were four out of six; this is a reported 66.66% success rate. The rate recorded for the study was 60%. The number of questionnaires returned may have been less than desirable but they are representative of the true experience of the CTLP in the study. The main point to be elicited from this questionnaire was the radiographers' experience of using the CTLP in a clinical trauma setting. The radiographers who had used it found that positioning the patient, centring and collimating were easy. This is an expected finding, the patient positioning is supine, with the arms by the side, which is how the patient presents. The centring point was well explained by photographs, which were very visible in the x-ray room. A collimator, the use of which was compulsory, controlled the collimation.

Five of seven radiographers found choosing exposure factors, evaluation of the image and identification of the vertebral levels was difficult. These are things that become easier with training and experience.

4.10 REJECT ANALYSIS

The rejected radiographs were collected and analysed. This was a worthwhile exercise. There were more rejects in the box than were recorded indicating that there were patients who presented but were not included in the study. It is possible that they were not deemed suitable for randomisation as described previously. CTLP was rejected 36 of 45 times (80%) because of exposure factor errors and all but one were too pale. With Swimmers rejects, 87% had exposure factor errors and all but one were too pale. This is interesting and indicates that radiographers either find it difficult to judge the quality and quantity of radiation needed to penetrate this area, or that they are unwilling to overexpose the patient and err on the side of caution and lower dose. This unfortunately led to repeat attempts and higher dose for the patient. A chart of guideline exposures based on widths and BMIs may be desirable in light of this finding and the results of this study. It would be worth piloting and auditing this idea. This also highlights the fact that demonstration of an area first time, by using whatever level of technical factors are necessary, is the most important aspect of the production of trauma radiographs. Anything else leads to repeat attempts and consequently higher patient dose and time delays.

Along with exposure factors the CTLP rejects had two other errors, centring and collimating. An exact centring point is difficult to describe and the most exact one that can be given is "at the acromion process and in line with the EAM" but this changes with the fit of the cervical collar. If the collar is too long and the patient's head is tilted back, the EAM is posterior to the actual centring point. The opposite is true for those whose collar is too small.

Collimation is extremely important. Radiographers collimation errors were mostly under collimating, which allows greater production of scatter and the consequent decreased image quality. Collimation that was too tight, obscured necessary detail on the image and made evaluation of the levels difficult.

Swimmers rejects included those faults that the CTLP had and also unsharpness and obstruction of detail by the overlying humerus. A high percentage of the rejects had more than one fault.

4.11. FURTHER RESEARCH STIMULATED

There has always been a great difficulty with visualisation of the cervico-thoracic region so the results of this research have proven very worthwhile. The aim of this work was to test the CTLP as a decision making tool in the diagnosis of cervical spine injury, with particular regard to its use as a possible replacement for the Swimmers projection. This research did just that but in the process it shed light on some of the reasons why the Swimmers projection does not always work and that is very worthwhile and definitely worth investigating further.

The further work that needs to be done is as follows:

- The CTLP needs to be investigated again without a learning curve
- The CTLP needs to be investigated again with the use of different technical factors, such as a grid and an increased FFD, or a set FOD (focus-object distance). There are further opportunities for dose reduction and improvement in quality.
- The dangers of arm movement in a patient with spinal fracture need to be clarified and protocols introduced regarding the use of Swimmers in certain circumstances.
- The correlation with the unsuccessful Swimmers doses and the arm-down width needs to be investigated and clarified. It is almost definitely because of improper positioning of the patient but it needs to be researched further. It may enable imaging professionals and clinicians to know for certain before a patient is radiographed, whether that is a worthwhile or futile exercise.
- Swimmers doses need to be compared against those of CT scanning of patients of similar size and width. Some of the doses in this study were large enough to warrant that comparison.
- Further work needs to be done, charting exactly what torso widths and BMIs are contraindications for radiography of C7 / T1. It is possible that there is a level, above which there is no point in attempting radiography.
- A guideline exposure chart for radiography of this area would be desirable, it should be based on torso widths and BMIs. It may diminish the number of repeat radiographs
- It would be interesting to track the quality of the image and technique with regard to gender. The patients muscle mass and body fat percentage should be estimated if possible.
- It would be interesting to compare the radiographers' decisions to pass radiographs with the clinicians' evaluation of their usefulness for diagnosis. There may be a discrepancy and co-ordination at this point is absolutely necessary to ensure the production of diagnostically useful radiographs, especially as the radiographers' primary function is to demonstrate the patient's condition. However, with no legal responsibility attributed to their interpretation and because radiographers' legal brief

is to limit the patient dose, there is a strong likelihood that there is a discrepancy in what these two groups of professionals deem acceptable.

CHAPTER FIVE:
CONCLUSION

5.0 CONCLUSION

Demonstration of the cervico-thoracic region in trauma patients is a well-documented problem of significant proportion. Radiographers often struggle to demonstrate this region diagnostically while delaying the patient in the X-ray room and increasing the patient dose by repeat attempts. The present protocol of Swimmers is not always successful and demands patient movement, which is contra-indicated in trauma. An alternative projection that will increase visualisation of the region without increasing the patient dose is needed.

This study showed that the radiographer can exercise control over the quality of the final image by manipulation of the exposure factors. Image degrading factors such as the presence of very dense structures like the bony humerus are minimised by the positioning and the tight collimation reduces the volume of tissue irradiated. Both of these limit the production of scatter to such an extent that the radiographer-controlled exposure factors, kVp and mAs, now dominate. This gives the radiographer control over the quality of the final image. By contrast, the present protocol of Swimmers has been proven to be uncontrollable. There are factors inherent in the patient that control the quality of the final image and the diagnostic usefulness of the film. The patient's age, torso width and body mass index, exert significant control in this regard. The factors that the radiographer controls, the kVp and mAs have no significant effect on Swimmers quality. So there are some patients for whom the radiographer will not be able to produce a high quality diagnostic image of the cervico-thoracic region. Considering that it is achieved with the use of radiation, that is an unsafe practice.

Patient safety concerns must address both physical safety and radiation safety. There are doubts about the safety of the Swimmers positioning. Patient movement is contraindicated in cervical spine trauma. The necessary arm raising causes definite movement of the upper thoracic vertebrae and has been known to cause exacerbation of an unstable cervical spine injury. Muscular attachments to the cervical vertebrae include three muscles that are involved in arm raising. As a high number of patients with suspected neck injury have upper limb and shoulder injuries also, the Swimmers projection is not suitable for all trauma patients. The CTLP addresses this concern by involving absolutely no movement of the patient. It is achieved with the arms by the patient's side and is therefore totally safe for all trauma patients, no matter what their injury.

Dose concerns are of major concern, particularly when imaging multi-trauma patients. These patients will have treatments that involve more radiation and months or sometimes years of follow-up radiographs. The initial trauma series must be achieved with as little dose as is feasible while demonstrating the patient's condition accurately. The CTLP achieves this exceedingly well, delivering just 3% of the population dose throughout the study, with no loss of image quality compared with the present protocol of Swimmers. The Swimmers doses by comparison were 97% of the population dose and some were high enough to raise questions as to the wisdom of using CT instead of Swimmers in certain cases but only if the CTLP has failed.

Again the control of the dose was very much in the hands of the radiographer where the CTLP was concerned. kVp and mAs controlled the patient dose. Patient width and being male increased CTLP dose but this can be reduced by using larger FFDs, so the radiographer still has ultimate control. Swimmers patients' dose was controlled by the radiographer's choice of kVp and mAs but also by width, body mass index, gender and the length of the patient's neck. These again are factors that the radiographer can do nothing to control and considering the size of the doses that were used for some patients in this study this demonstrates an uncontrollable use of radiation.

It is therefore highly recommended that these issues of patient width, body mass index and gender be investigated immediately and strict protocols for the use of the Swimmers projection be introduced. As a control measure, the CTLP has proven itself to be useful for diagnosis, of equal quality, much more controllable and infinitely lower dose. It should therefore be introduced immediately as a replacement for the Swimmers projection while further attempts to improve the quality of this projection are ongoing.

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