UNIVERSITY OF ALBERTA

# POSITION OF THE CERVICAL VERTEBRAE DURING HELMET REMOVAL AND CERVICAL COLLAR APPLICATION IN FOOTBALL AND HOCKEY

BY



ROSANNE K. E. PRINSEN

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Master of Science.

DEPARTMENT OF PHYSICAL EDUCATION OF SPORT STUDIES

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12 March 1993

J.S. Torg M.D.
Professor of Orthopaedic Surgery
University of Pensylvania
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Philadelphia, Pensylvania

Dear Dr. Torg;

I am a graduate student at the University of Alberta, working towards completion of my MSc in Athletic Therapy. My research project involves documenting the effects of equipment removal (helmet and shoulder pads) on the position of the cervical vertebrae as determined by radiographic imaging. The rationale for my research is as follows:

At the present time, there is lack of agreement among pre-hospital personnel (athletic therapists, paramedics, sport physiotherapists and such) as to the proper treatment and handling of injured athletes presenting signs and symptoms of a cervical spine injury. This problem becomes compounded when dealing with athletes who wear protective equipment including a helmet and shoulder pads; as in the case of football and hockey players. In instances of serious injury involving the head and/or spine, complicated by altered levels of consciousness, this protective equipment may become a hinderance.In this situation management becomes more complicated and varied as decisions must be made as to whether the equipment may remain on the athlete or be removed.

With the helmet in place, basic and advanced airway manouvers may be compromised. As a result, helmet removal techniques have been developed, and many articles, textbooks and emergency medical technician journals illustrate a variety of these techniques. However, these standards advocate the removal of the helmet in participants without injury to the spine. This orthopaedic abnormality can only be identified radiologically, thus this information is not available to the responding emergency medical personnel. In order to gain the greatest benefits from these procedures an understanding of the implications and consequences of unnecessary movement of suspected cervical spine injured participants must be investigated. Research is needed to ascertain the most appropriate methods of evaluating and managing cervical spine injuries in these athletes.

The major objective of my study, is to characterize the position of the cervical vertebrae prior to, during and following removal of protective equipment for the upper body. X-rays are the most accurate method of determining the movement of the vertebrae. Utilizing fluoroscopy, a videotape will be made of the cervical vertebrae during equipment removal. The position of the vertebrae will be digitized and the resulting positions analyzed by computer. In my research of this area, I have found that axial loading is most often implicated as the primary mechanism of injury. In football it is associated with the act of spearing and in hockey it is associated with a check from behind into the boards or sliding head first into the boards.

In reviewing the literature of axial loading, I have found that your diagram from your publication in the American Journal of Sports Medicine 1990 18:50-57 is by far the best at depicting the axial loading mechanism. As the saying goes, this picture says a thousand words. This mechanism of injury is an important component of my thesis, I am seeking your permission to reproduce your diagram (with appropriate referencing and acknowledgements), and include it in my thesis with my discussion of the axial loading mechanism.

I look forward to your anticipated co-operation in aiding me to complete this research project. If you require additional information, or clarification please do not hesitate to contact me. I can be reached at home after 6pm at (403) 433-6344, or my fax number is (403) 492-7307.

Respectfully,

Rosanne PINSEN

Rosanne K.E. Prinsen BPE

cc. Dr. P. Baudin
Dr. P.G. Heslip
Dr. D. Magee
Dr. D.C. Reid
Dr. D. Syrotuik

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **POSITION OF THE CERVICAL VERTEBRAE DURING HELMET REMOVAL AND CERVICAL COLLAR APPLICATION IN FOOTBALL AND HOCKEY** submitted by **ROSANNE K. E. PRINSEN** in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE.**

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Date: 17 August 93

## DEDICATION

This degree is dedicated to my grandmother,

**Alma (Werner) Smith,**

a wonderful lady who has always been my source of inspiration and inner strength. Grandma you have taught me, through actions not words, what it really means to be "our brothers keeper".

"Life is mostly froth and bubble;
Two things stand like stone:-
Kindness in anothers trouble,
Courage in our own."

- Gordon

Neither words of gratitude nor praise can fully express my feelings of love and thanks to my parents **Ted** and **Merle Prinsen**. Mom and dad, this work is a symbol of my determination to live life to its fullest, to make the most of the opportunities opened to me through your never ending love and support.

"We have lived and loved together through many changing years;
We have shared each others gladness and wept each others tears;
I have known Ne'er a sorrow that was long unsoothed by thee;
For thy smiles can make a summer where darkness else would be....
And let us hope the future as the past has been will be:
I will share with thee my sorrows, and thou thy joys with me."

- Charles Jefferys

## ABSTRACT

There is lack of consensus among prehospital personnel (athletic therapists, paramedics, sport physiotherapists) concerning specific aspects of initial care and assessment of injured athletes presenting signs and symptoms of a cervical spine injury (CSI). Specifically there is a disagreement concerning the need or advisability of removing protective equipment such as helmets and shoulder pads as in the case of football and hockey players. Emergency care procedures may advocate or necessitate the removal of such equipment. However, in such cases, an understanding of the implications and consequences of unnecessary movement of the cervical spine must be fully appreciated.

The purpose of this study was to determine the magnitude of cervical spine motion during helmet removal in healthy subjects. Using the technique of fluoroscopy, the cervical spine displacement of twenty-one elite male football and hockey players was determined while wearing protective shoulder pads and appropriate protective head equipment during the following conditions: 1) during helmet removal, 2) during cervical collar application and 3) as the helmetless head was allowed to rest on o long spine board. Subsequent frame by frame video arthokinematic analysis, using computer assisted digitization, revealed significant alterations in the position of adjacent cervical vertebrae during helmet removal, cervical collar application and head rest.

The results of this study clearly support the stabilization and transportation of football and hockey athletes with suspected CSI in their respective protective equipment in order to reduce the risk of further trauma by unnecessary cervical spine motion. This

statement recognizes that accompanying specific closed or open head injuries or airway compromise may necessitate prompt removal of any equipment that hinders assessment or life saving maneuvers.

## ACKNOWLEDGMENTS

Thank you Lord for the gifts you have given me.

My sincere thanks and profound gratitude to my advisor Dr. Dan Syrotuik, undeniably one of the best advisors a graduate student could ask for. A gentleman who never considered any problem too trivial, whose door was always open and whose support was never ending. I also wish to acknowledge the members of my committee who provided invaluable assistance and advice: Dr. Pierre Baudin, Dr. Pat Heslip, Dr. David Magee and Dr. David Reid.

Although not part of my committee, Dr. Patrick Bishop (U of Waterloo), Dr. Marcel Bouffard, Dr. Brian Fisher, Mr. Duane Mandrusiak (Edmonton Eskimos) Dr. Charles Tator (U of Toronto) and Dr. Joseph Torg (U of Pennsylvania), must be acknowledged for the assistance given to me in planning and researching this thesis.

My heartfelt thanks go to Jan Dubeta, Isabel Grondin and Joan Matthews, without whose assistance the collection of my data and consequently this thesis, would not have been possible. I am grateful to the members of the Golden Bears football and hockey teams and members of the Nor'Westers rugby football club, as these men gave freely of their time to participate as subjects in this study.

The Edmonton Eskimos, the Department of Radiology (U of A Hospital) and United Cycle (Edmonton) must be acknowledged for their donation of equipment and personnel.

To my brother Teddy (Ted), my friends Gilda, Michelle, Simone and the rest of you delinquents, thanks for putting up with me the last few years, your support has been appreciated more than you realize.

Table of Contents

List of Tables

List of Figures

List of Plates

# CHAPTER 1

# INTRODUCTION

Greater than any army with banners is an idea whose time has come. - Victor Hugo

## 1.1 PURPOSE

At the present time, there is lack of consensus among prehospital personnel (athletic therapists, paramedics, sport physiotherapists) concerning specific aspects of initial care and assessment of injured athletes presenting signs and symptoms of a cervical spine injury (CSI). In instances of serious injury involving the head and/or spine, complicated by altered levels of consciousness, protective equipment such as helmets and shoulder pads may provide a hinderance to prompt, safe and efficient management. Thus, frequently a decision must be made as to whether the equipment remain on the athlete or be removed.

Emergency care protocols may advocate the removal of such equipment. However, in these cases an understanding of the implications and consequences of unnecessary movement of suspected cervical spine injured participants must be fully appreciated. While there appears to be well established principles, the number of investigations clearly documenting the magnitude of unguarded cervical motion is limited. Thus, there is a need for research to ascertain the most appropriate methods of evaluating and managing CSI in these athletes. The major objective of this study was to characterize the position of adjacent cervical vertebrae prior to, during and following helmet removal and cervical collar application, in healthy male football and hockey subjects.

## 1.2 SIGNIFICANCE OF STUDY

Recreational activities are the fourth most common cause of spinal fracture and the second most common cause of paralysis (Reid et al 1991). These activities account for some 10-15% of all spinal injuries (Karbi et al 1988, Schields et al 1978). Non-contact activities such as hang gliding, trampolining, horseback riding, rodeo, mechanical bull riding and water sports (McCoy et al 1984, Mennen 1981, Mueller et al 1989, Reid et al 1991, Saboe et al 1991), and activities involving collision or sudden impact blows such as rugby, football and hockey (Clark 1966, Oh 1984, Rapp et al 1978, Tator et al 1984a, Thompson et al 1982, Torg et al 1985) have been associated with severe neck injuries.

Participants in hockey and football present a unique situation. These athletes wear a significant amount of protective equipment including a helmet and shoulder pads. In instances of serious injury involving the head and/or spine, complicated by altered levels of consciousness, this equipment may become a hinderance to assessment. With the helmet in place, basic and advanced airway maneuvers may be compromised and available splinting techniques may not be satisfactory (Aprahamian et al 1984b).

In the supine lying position, with the helmet and shoulder pads in place, the cervical spine remains in relatively neutral alignment. Upon removal of the helmet and application of a cervical collar, the head falls into extension as a result of the presence of the shoulder pads which elevate the torso off the ground. The shoulder pads must be removed or the head must be blocked up if it is to remain in alignment with the thorax when the helmet is removed and the athlete is stabilized in supine lying position.

Notwithstanding the dilemma caused by the presence of the shoulder pads, the literature acknowledges the existence of set protocols for on-field removal of the helmet (Aprahamian et al 1984b, Denegar et al 1989, Feld et al 1988, Jackson et al 1986, Long et al 1980, Meyer et al 1985, Torg 1987, Vegso et al 1987, Vegso et al 1991, Watkins 1986). Helmet removal techniques have been developed, and many articles, textbooks and emergency medical technician journals demonstrate a variety of these techniques (American Association of Automotive Medicine 1980, American College of Surgeons 1980, Gallup et al 1981). However, these standards advocate the removal of the helmet in participants **without** injury to the spine. Since bony injury can only be confirmed radiologically (Riggins et al 1977), this information is not available to the responding emergency personnel. According to Aprahamian et al (1984b) and Meyer et al (1985), helmeted injured patients must therefore be stabilized on the field without any attempts by prehospital personnel to remove the helmet.

If anything is more tragic than severe spinal injury in sporting activities, it is the severe injury made catastrophic by improper management at the scene. Reid et al (1987) reported that of all cervical spine injuries, 22.9% exhibited a delayed diagnosis ranging from less than one day to 36 days; providing evidence that not all injuries are immediately apparent and may lead to improper acute management and worsening of injury. Roger (1977) reported 10% of patients had onset or worsening of a neurological deficit following the initial trauma. Podolsky et al (1983) reported that 40% of all cervical spine injuries produced neurological deficit and up to 25% of these injuries were caused by improper assessment and prehospital care. Garrick et al (1990) reported the existence of numerous accounts of patients who, due to poor primary care, became quadriplegic after having been allowed to ambulate on their limbs at the scene of the trauma.

In the late 1960's there was a greater emphasis placed on prehospital stabilization of the trauma patient. Cervical spine immobilization devices designed to stabilize the cervical spine and prevent neurological deficits associated with unstable fractures became widely used in the prehospital emergency department setting (Caroline 1977). Today, numerous devices are used including soft collars, hard collars, extrication collars and sand bags. Recommendations for their use are the teaching objectives of both prehospital care and athletic therapy texts (Arnheim 1989, Cloward 1980).

In their article reviewing the protocol for on field management of the potentially cervical spine injured football player, Denegar et al (1989), who are qualified Athletic Trainers (AT's) and Emergency Medical Technicians (EMT's), document the prevailing protocols and decision making processes followed by EMT's and AT's in the United States. They note that (as also found in the Province of Alberta):

> "These two allied medical professions may follow different cervical spine injury management protocols, which may lead to confusion and poor team work when emergency medical personnel are called upon for assistance." (Denegar et al 1989:108)

Despite these conflicts, it is clear that the need for immobilization begins at the time of injury, continues during transportation and emergency department stabilization, and ends only when a cervical spine injury is ruled out or definitive stabilization occurs. Thus, to gain a further understanding of the implications and consequences of

**unnecessary** movement of suspected cervical spine injured athletes, vertebral motion must be investigated so that the most appropriate management protocols for those injuries be followed by prehospital personnel.

## 1.3 DELIMITATIONS

The following delimitations apply to this study:

1. Athletes from two sports involving protective equipment for the upper body were included in this study (football and hockey).
2. Movements of the vertebral column were assessed only in the cervical spine region, using Fluoroscopy.
3. Possible movements of the cervical vertebrae were assessed in subjects lying supine with the neck and head in neutral alignment.
4. Only volunteers without a history of previous or current cervical spine disease or injury were allowed to participate in this study.
5. The study was restricted to the influence of extrinsic factors (removal of the helmet, application of a cervical collar, presence of shoulder pads) on the position of adjacent cervical vertebrae and did not examine the possible effects of intrinsic factors (ligamentous structures, bony structures, musculature and so on).
6. Subjects in this study were either members of the University of Alberta Golden Bears Football or Hockey teams, or select members of the Nor'Westers rugby football club with hockey or football experience.

7. Use of fluoroscopic equipment to visualize the position of the cervical vertebrae resulted in somewhat less than optimal conditions for helmet removal and cervical collar application, as in some instances the researchers were required to work around the equipment.

## 1.4 LIMITATIONS

The following limitations apply to this study:

1. The subjects were volunteers.
2. The possible influence of various physiological and anatomical factors on the position of the cervical vertebrae of each individual subject was not examined.
3. The primary researcher's evaluation of the position of the cervical vertebrae from the fluoroscopic recordings, were assumed to be correct.
4. Errors in the process of collecting, interpreting, and summarizing the accumulated data may have occurred, but minimized.
5. Kinematic analysis of the movement may have been limited by the ability to locate and digitize anatomical locations (corners of vertebral bodies), and other reference points from the video image.
6. Only flexion-extension movements of the cervical vertebrae were documented. Medial-lateral movements, anterior-posterior (shear) and side flexion of the cervical vertebrae were not documented.
7. The football equipment, containing metal rivets and cantilevers, as well as very thick plastic made obtaining a clear fluoroscopic image very difficult. In many

instances, even with the metal removed, the thick plastic interfered with the ability to visualize some of the vertebrae (C-3/C-4).

8. The picture quality of the fluoroscopic procedure was less than optimal and sacrificed some measure of reliability. This poor quality made it difficult to visualize the cervical vertebrae when digitizing. As a result, it was difficult to be consistent when choosing the anatomical landmarks of the vertebral bodies across all subjects, and sometimes within subjects. Using live subjects made it difficult to retake procedures or to spend additional time adjusting the picture as both of these correctional techniques would require the subjects to receive unacceptable levels of radiation.

## 1.5 DEFINITION OF TERMS

**Advanced Airway Maneuvers**

Techniques, such as endotracheal intubation, which are used by pre-hospital personnel to assist patients (athletes) having difficulty with or absence of respiration in those instances where basic airway maneuvers are inappropriate or ineffective.

**Altered Level Of Consciousness**

An impaired cognitive level of alertness. Associated with a score of less than 15 on the Glasgow Coma Scale - Appendix A (a practical scale used to monitor changes in the level of consciousness).

**Basic Airway Maneuvers**

Basic techniques, such as artificial respiration, which are used by pre-hospital personnel to assist patients (athletes) having difficulty with or absence of respiration.

**Cartesian Coordinates**

Consist of an x-axis which is a number line that extends infinitely horizontally and a y-axis which is a number line that extends infinitely vertically. These two axis cross at right angles to each other and the point of intersection is point 0 on the vertical number line and point 0 on the horizontal number line. The two axis are marked off so that the positive integers go up and to the right and the negative integers go down and to the left. Every pair of co-ordinates (x,y) corresponds to a unique point in the co-ordinate plane and every point in the plane has co-ordinates that can be written in the form (x,y). (Wheeler 1992)

**Cervical Spine Injury**

Damage or displacement of the cervical spinal vertebrae with or without accompanying damage to neurologic tissues.

**Cervical Spinal Cord Injury**

"An acute traumatic lesion of the spinal cord or nerve roots, resulting in varying degrees of motor and/or sensory deficit." (Riggins et al 1977:126)

**Clinical Stability of the Spine**

The ability of the spine under physiologic loads to limit patterns of displacement so as not to damage or irritate the spinal cord or nerve roots. (White et al 1975:86)

**Cranial Injury**

Injury to the skull, or the tissues outside or within the skull such as the scalp, the brain or the meninges.

**Deformity**

Unnatural position of a joint or other such tissues.

**Delayed Diagnosis**

Determination of extent of the injury some time following the initial injury or, not identified at the time of the initial assessment.

**Digitizing Board**

A board incorporating a wire grid which allows the accurate determination of Cartesian coordinates.

**Digitized Coordinates**

A set of Cartesian coordinates taken from a video image as determined from a digitizing board.

**Extension/Hyperextension (of the cervical vertebrae)**

Occurs when a person, as example, looks up to the ceiling. The posterior surface of the head falls backwards, the spinous processes of the vertebrae move relatively closer together, while the anterior aspects of the vertebral bodies move relatively further apart.

**Flexion (of the cervical vertebrae)**

Movement of the cervical spine in the sagittal plane, for example, when a person, touches the chin to the sternum. The spinous processes of the vertebrae move relatively further apart while the anterior aspects of the vertebral bodies move relatively closer together, usually accompanied by slight anterior translation.

**Lateral**

At or belonging to the side, away from the midline of the body. (Roper 1988)

**Potential Cervical Spinal Cord Injury**

Injury to an athlete where signs and/or symptoms are found suggesting damage to the spinal cord.

**Roentgenogram**

Radiographic evaluation of skeletal structures. The use of X-radiation to create images of the body from which medical diagnosis can be made.

**Sella Turcica (of sphenoid bone)**

A bony landmark on the inner surface of the skull, where the pituitary gland sits.

**Sign**

Any objective evidence of injury - observable/visible to pre-hospital personnel.

**Smoothing Value**

In the APAS system, when used with the spline algorithm, is the average error allowance for each point on the curve in the users units (millimetres).

**Spline Function**

A spline function consists of a number of polynomials, all of some low degree m, that are "pieced together at points in t called "knots" (x,:j=1,2....n) and joined in such a way as to provide a continuous function g(t) with m-1 continuous derivatives. (Wood 1982)

**Stable Cervical Spinal Cord Injury**

An injury "in which additional spinal cord or root damage is not anticipated with gentle spine movement or normal routine nursing procedures." (Pavlov 1991:393)

**Supine**

Lying on the back with face upwards.

**Symptom**

Any subjective evidence of injury as reported/felt by the injured athlete.

**Unstable CSI**

An injury "in which there is significant ligamentous damage, and any movement of the spine may further compromise the neurologic status by injuring the nerve roots or the spinal cord or both." (Pavlov 1991:393)

## 1.6 MAJOR QUESTIONS

The major question in this study is whether or not a football or hockey player with a suspected cervical spine injury, should be stabilized in their equipment for transport to the hospital or if their helmets should be routinely removed and their necks stabilized using cervical collars prior to transportation. Specifically, the questions were:

1. During helmet removal and cervical collar application, was the position of adjacent cervical vertebrae altered?

2. If the position of adjacent cervical vertebrae was altered, to what extent was it altered?

3. Based on the findings, and keeping in mind that prevention of any further injury to the cervical vertebrae and spinal cord is the goal, what would be the best method of stabilizing and transporting a potentially cervical spine injured football or hockey player?

## 1.7 HYPOTHESES

Based on the review of literature, the following hypotheses were generated for the study:

**Hypothesis 1**

Helmet removal using the standard two person technique will result in angular displacement between adjacent vertebrae.

**Hypothesis 2**

Application of a cervical collar results in no angular displacement of adjacent cervical vertebrae.

**Hypothesis 3**

Resting of a helmetless head, while the subject is wearing shoulder pads, will result in angular displacement between adjacent vertebrae.

# CHAPTER 2

## REVIEW OF LITERATURE

Literature is the immortality of speech. - August Wilhelm Von Schlegel

### 2.1 INTRODUCTION - Incidence of Spinal and Head Injury in Football and Hockey

In football and hockey, injuries to the cervical spine resulting in damage to the vertebrae and spinal cord are rare but catastrophic events (Bishop et al 1989, Denegar et al 1989, Feld et al 1988, Fine et al 1991, Liggett et al 1990, Maroon 1981, Otis et al 1991, Reid et al 1991, Tator 1991, Tator et al 1991, Tator et al 1984a, Tator et al 1984b, Torg 1991, Torg 1987, Torg et al 1979). Such injuries in football have a well documented history (Feld et al 1988, Fine et al 1991, Liggett et al 1990, Maroon 1981, Otis et al 1991, Torg 1991, Torg 1987, Torg et al 1979), while in hockey, the documented occurrence is a relatively new phenomenon (Bishop et al 1989, Reid et al 1991, Tator 1991, Tator 1987, Tator et al 1991, Tator et al 1984a, Tator et al 1984b).

In response to the prevalence of such catastrophic injuries and the desire to prevent them, injury recording centres have been established. SportSmart Canada, formerly the Committee on Prevention of Spinal and Head Injuries Due to Hockey - a permanent subcommittee of the Canadian Sports Spine and Head Injuries Research Centre established in 1981, collects all information dealing with hockey-related major injuries of the spine with or without injury to the nerve roots or spinal cord excluding minor spinal injuries including sprains, strains, flexion-extension injuries and whiplash. The National Football Head and Neck Injury Registry established in 1971 within the United States, collects data based on four parameters: 1. intracranial haemorrhages, 2.

intracranial injuries resulting in death, 3. cervical spine fractures, subluxations and dislocations, and 4. cervical spine trauma resulting in permanent quadriplegia. From these committees, common etiologic factors may be established, providing valuable information in the campaign to reduce these injuries.

A common mechanism of injury associated with both sports is axial loading (Bishop et al 1990, Bishop et al 1989, Fine et al 1991, Otis et al 1991, Tator 1991, Tator 1987, Tator et al 1991, Tator et al 1984a, Torg 1991, Torg 1985). Axial loading of the vertebrae occurs when the cervical vertebrae are straightened from their neutral lordotic alignment, as occurs when the neck is flexed 30 degrees. This straightened cervical spine responds to forces as a segmented column. An axial load occurs when force is transmitted along the length of the column, as when the crown of the head strikes an opponent in the act of spearing or when a hockey player strikes the boards head first. As rapid deceleration of the head occurs, the cervical vertebrae are compressed between the decelerating head and the oncoming trunk of the body. Bishop et al (1990) report that the trunk continues to travel 24-40 msec after the head has come to a stop. This results in a series of reactions best described by Torg (1991). The axial load first results in compressive deformation of the intervertebral disc. As the load continues, maximum compressive deformation occurs resulting in angular deformation and buckling. Finally, the vertebral column fails resulting in, fracture, dislocation and/or subluxation (Figure 2.1).

Prior to the identification of this mechanism, two other explanations enjoyed much popularity. Hyperflexion of the cervical vertebrae had been implicated (Fine et al 1991).

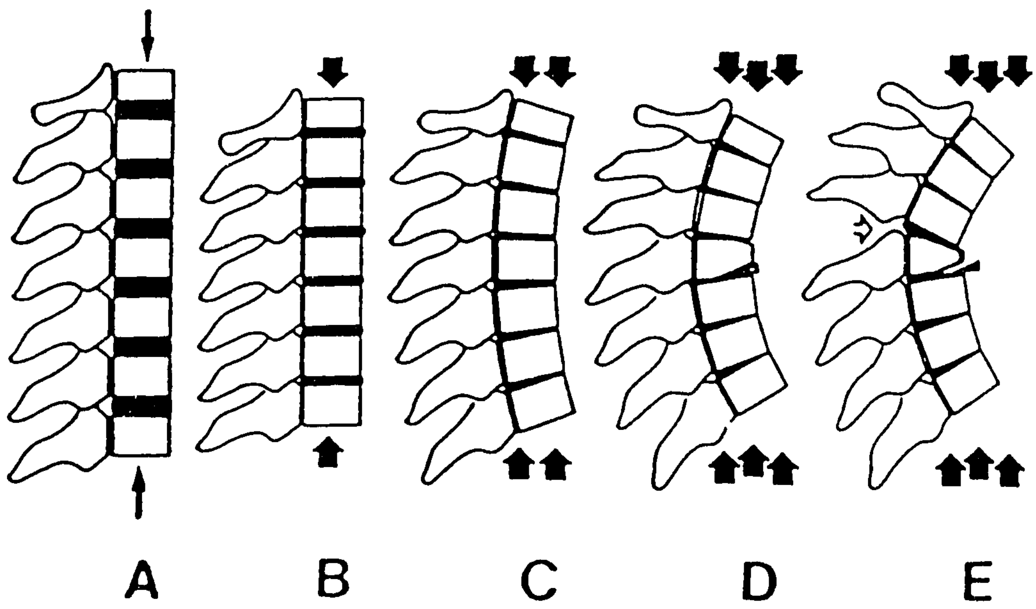



**FIGURE 2.1: AXIAL LOADING MECHANISM**

Biomechanically, the straightened cervical spine responds to axial loading forces like a segmented column. Axial loading of the cervical spine first results in compressive deformation of the intervertebral discs (A and B). As the energy input continues and maximum compressive deformation is reached, angular deformation and buckling occur. The spine fails in a flexion mode (C), with resulting fracture, subluxation or dislocation (D and E). Compressive deformation to failure with a resultant fracture, dislocation, or subluxation, occurs in as little as 8.4 msec.
(Torg JS, et al: Am J Sports Med 1990; 18:50-57. Used by permission)

In the majority of instances after further analysis of the data, axial loading was implicated once the description of the hyperflexive motion was discerned. In the early 1970's, another expounded theory was that of the guillotine effect of the helmet (Torg 1985, Virgin 1980, Schneider 1973, Fenner 1964). It was believed that in extreme extension of the neck, the posterior rim of the helmet acted as a fulcrum driving into the cervical vertebrae, causing the fractures and dislocations observed. This theory was refuted by Virgin (1980) who, using cineradiography, demonstrated that at no time did the edge of the helmet come close to the spinous processes of C1-C6. Analysis of the measurements obtained from this work "indicate that the helmet's posterior rim plays no role in the injury to the cervical spine in hyperextension"(Virgin 1980:314).

In the game of football, axial loading is most often observed during the act of spearing. As defined by the NCAA Football Rules Committee in 1976, the act of spearing involves: "intentionally striking an opponent with the crown of the helmet or otherwise using the helmet to butt or ram an opponent" (Fine et al 1991:62). In football, athletes most commonly injured play the positions of defensive back and linebacker (Maroon 1981, Otis et al 1991, Torg 1991, Torg et al 1979). Defensive backs and linebackers commonly spear opposing players, whether intentional or not, in their attempts to tackle oncoming wide receivers and/or running backs. Maroon (1981) believes that defensive backs are at the greatest risk of CSI due to the fact that they are usually light weight, thin-necked players and frequently called upon to tackle much larger and stronger players.

Otis et al (1991) and Torg et al (1979) reported that high school defensive backs were involved in 52% of all occurrences of permanent cervical quadriplegia and 23% of all incidences of cervical fracture-dislocations without quadriplegia. Similarly, they reported that college defensive backs were involved in 73% of all incidences of cervical quadriplegia and 33% of all cervical fracture-dislocations without quadriplegia. Focusing on linebackers, they reported that in high school 10% of all incidences involving permanent cervical quadriplegia, and 18% of all incidences involving cervical fracture-dislocation without quadriplegia involved these athletes. Linebackers in college did not account for any incidences of permanent cervical quadriplegia, but did account for 17% of all incidences involving cervical fracture-dislocation without quadriplegia.

Turning our attention away from injuries by position, to general head and cervical spine injury patterns; Torg et al (1979) and Torg (1991) provided some revealing statistics. The results of a study by the National Football Head and Neck Injury Registry for the years 1971-1975 revealed 259 cervical spine fractures, dislocations or subluxations (4.4 injuries/100,000 participants) and 99 cases of permanent cervical quadriplegia (1.58 injuries/100,000 participants). This data appears to demonstrate an increase in such injuries when compared with the study conducted by Schneider et al (1956) encompassing 1959-1963, when only 56 cervical spine fractures, dislocations or subluxations (1.36 injuries/100,000 participants) and 30 (0.73 such injuries/100,000 participants) cases of permanent cervical quadriplegia were reported. Between the two studies, the injuries to the cervical spine appear to have increased by 204% while the incidence of quadriplegia appears to have increased by 116%.

These findings may be primarily attributed to improvements in protective coverings for the head and face. During the early part of this century, the head was protected by nothing more than the hair and scalp. More recently, the value of protective coverings for the head was realized and continued improvements in helmet and facial covering designs were developed, affording the athlete superior head and face protection. As Torg et al (1979) reported between 1959-1963, 139 (3.39 injuries/100,000 participants) intercranial haemorrhages and 65 (1.58 injuries/100,000 participants) craniocerebral deaths were documented; as opposed to 72 (1.15 injuries/100,000 participants) intercranial haemorrhages and 58 (0.92 injuries/100,000 participants) craniocerebral deaths between the years of 1971-1975. This report represents a 66% decrease in intercranial haemorrhages and a 42% decrease in deaths. It seems that while head injuries associated with intercranial haemorrhaging and death have decreased, CSI associated with fractures, dislocations or subluxations, and quadriplegia have increased. It appears that the implementation of effective head and face protection has led to the development of harmful playing and coaching techniques in which the head is used as a battering ram - the act of spearing. Torg et al (1979) attributed the apparent decrease in serious head injuries to the protective capabilities of the helmet-face mask unit. They concluded, based on observations and data compiled in their study, that they "firmly believe that the increase in CSI and permanent paralysis is due to the implementation of playing techniques that use the top or crown of the helmet as the primary point of contact in a high-impact situation"(Torg et al 1979:1479).

The aforementioned findings were reported to the NCAA Football Rules Committee in January 1976 and as a result, the act of spearing was defined and rule changes implemented banning spearing from the game. Subsequent to this rule change, Torg (1991) reports the findings of an analysis of the Registry data from the years 1976-1987. Fractures, dislocations or subluxations of the cervical spine decreased from 7.72 injuries/100,000 participants in high school and 30.66 injuries/100,000 participants in college to 2.31 injuries/100,000 participants and 10.66/100,000 respectively. The largest decrease occurring between 1977 and 1978 when high school rates decreased by 47% (from 7.06 injuries/100,000 participants to 3.72 injuries/100,000 participants) and college rates declined by 47% (from 20 injuries/100,000 participants to 10.66 injuries/100,000 participants).

Similarly, CSI resulting in permanent cervical quadriplegia decreased from a total of 34 cases in 1976 to 5 cases in 1984. The largest decrease occurred in 1977, when these injuries decreased in high school by 42% (from 2.24 injuries/100,000 participants to 1.30 injuries/100,000 participants) and in college by 75% (from 10.66 injuries/100,000 participants to 2.66 injuries/100,000 participants). It appears that with the identification and definition of the act of spearing, subsequent rule changes and improved coaching techniques, the incidence of CSI has decreased.

CSI in football was reported as early as 1959 (Torg 1991). While the occurrence of CSI in hockey has been documented (Tator et al 1991), it is a relatively recent phenomenon when compared with football. In 1981, Charles Tator organized the Committee on Prevention of Spinal Cord Injuries due to Hockey and conducted a national survey to ascertain the extent of CSI in hockey. The first report of CSI in hockey was documented in 1966, with the next report not until 1975 (Tator et al 1991). It was not until the beginning of the 1980's that the annual number of CSI in hockey began to notably increase, reaching to approximately 15 cases of CSI per year for the years 1982-86 (Tator et al 1991). During the interval between the first national survey encompassing 1966-1984 and the recent survey encompassing 1984-1987, the committee received 10 to 15 reports/year of CSI in hockey. Although this data only includes information up to mid 1987, it appears that this injury pattern is a trend that will continue.

The factors related to this increase in CSI in hockey are multifaceted. The most common factor appears to be the act of pushing or checking a player from behind (26.5% or 31/117 incidences of cervical spine injuries) so that individual contacted the boards headfirst (Bishop et al 1989, Tator 1987, Tator et al 1991). The athlete at highest risk plays the position of defenceman. As these athletes are most commonly skating to the boards to retrieve and clear the puck, they are most vulnerable to checks or hits from behind and forced (pushed) into the boards (Bishop et al 1898, Tator 1987, Tator et al 1991, Tator et al 1984). In an attempt to curtail this injurious act, the Canadian Amateur Hockey Association, in 1985, instituted a rule prohibiting pushing or checking from behind. The continued incidence of CSI in hockey has led Tator et al (1991) to speculate, "either the rule has not been enforced as vigorously as it should be or the time required for the referees, coaches and players to adjust their behaviour has not been sufficient" (Tator et al 1991:66).

Tator et al (1991), reported the findings of the Canadian Sports Spine and Head Injuries Research Centre which identified several additional casual factors noting that no single factor could be held responsible. The use of helmets became much more popular in the 1970's led to a marked decrease in injuries to the face, scalp and brain while preceding a great increase in CSI, similar to football statistics. Before helmet use became popular, head injuries accounted for up to 40-50% of all injuries. After their implementation, these injuries accounted for only one third of all injuries. Research into the capabilities of these new helmets to absorb impacts has shown that the helmet alone does not provide sufficient properties which would allow it to absorb all of the energy generated by impact with the boards (Bishop et al 1990, Bishop et al 1989). Bishop et al (1990) reported

> "...that the helmet/head/neck system becomes trapped between the two large masses moving toward each other and the forces needed to reduce their relative velocities to zero are determined by the combined properties of the helmet/head/neck system - not by those of the helmet alone....only small reductions in compression can be achieved with helmets or padding....the two factors that make helmets ineffective in **head-first collisions** are the high energy levels and the relative stiffness of the helmet compared to the neck. The high energy associated with this collision causes the helmet liner to bottom out and become almost rigid before the large torso mass has been brought to rest. Since the head and neck are not rigid (unrestrained) and appear to be as stiff or less stiff than the helmet, the cushioning influence of the helmet is minimized, so the forces experienced by the neck are dictated largely by its own properties". (Bishop et al 1990:204)

Other possible etiologic factors cited include: 1) physical factors related to current players who are bigger, stronger and faster, 2) social and psychologic factors among young players whose tendency is to be more aggressive, more willing to sacrifice their bodies because they feel invincible, 3) rules and refereeing which must be enforced as many injuries are due to illegal play, and finally, 4) coaching proper technique, fair play and conditioning.

## 2.2 BIOMECHANICS OF THE CERVICAL SPINE AND ASSOCIATED INJURIES

The biomechanical definition of an injury is an "irreversible change in structure as a result of mechanical overload" (Frymoyer et al 1990a:264). This definition includes injuries to ligaments, motion segment subluxations and dislocations, end-plate fractures and annular fissures (Frymoyer et al 1990a, Frymoyer et al 1990b, Roaf 1960, White et al 1975). Therefore, in order to understand the implications and consequences of injuries to the cervical vertebrae, it is important to understand the mechanical events involved in producing such injuries. There are a number of definitions and concepts that provide important background information in the understanding of spinal mechanics.

The Basic Spinal Unit consists of two intact vertebrae joined by an intervertebral disc, two posterior articulations and a number of ligaments. (Frymoyer et al 1990a, Roaf 1960)

The Functional Spinal Unit, also known as the motion segment, consists of two adjacent vertebrae and the connecting ligamentous tissue. It is the smallest segment of the spine that exhibits biomechanical characteristics similar to those of the entire spine. (White et al 1990).

Material Properties (Creep). Biological material is strain-rate sensitive, meaning that different patterns of strain are observed as a function of the rate of applied loading (Frymoyer et al 1990a). If the load is applied over time, a second time-dependent phenomenon is also observed in biological tissues. A continued slow deformation, defined as "Creep", will be observed. Release of the applied load results in return to the original shape of the structure over a time-dependent course.

Spinal Kinematics (Spinal Coupling) - The normal range of motion of the spine is quite varied. Spinal motion is defined in three planes: flexion/extension, lateral bending and axial rotation. It must be remembered that the application of a load will result, in addition to internal deformations, strain (for example compression of the tissue within the vertebral body) and movements between structures, when the system is unrestrained, (for example gliding of one vertebral body on another or alterations between facet joints). The study of spinal motion has defined an important kinematic property of the spine: spinal coupling. Spinal coupling "is that property whereby input of one direction of load application will produce more than one resulting direction of spinal movement" (Frymoyer 1990a:61). Coupling is a function of anatomical location, and orientation of the facet joints. The facets determine the axis of rotation, which is usually the posterior 1/3 of the disc, and as body position changes, the axis of rotation changes.

Stress-Strain is associated with measurements of load and the resulting deformations under static conditions. Stress is the measure of applied load/unit area of application, whereas, Strain is the measure of deformation produced as a proportion of an original dimension of the structure (Frymoyer et al 1990a).

Torque. When an external force acts on a unrestrained system, it causes that body's centre of gravity to move in a linear path. If the system is restricted to moving around an axis, the body rotates when the force is applied, but only if the force does not act through the axis of rotation. Such an off axis force is called an eccentric force and the turning effect it has on the body in called torque (Kreighbaum et al 1985).

Types of Loading. Force has a direction and a magnitude. Therefore, when forces are applied the resulting deformations also have a direction and a magnitude. Depending on their direction, these loads are commonly referred to as, compression (axial loading), bending (flexion/extension, lateral bending), torsion (axial rotation), and shear stress and strain (Frymoyer et al 1990a, Roaf 1960).

The effects of spinal loading can be observed at many different anatomical sites of the cervical vertebral column, including: the vertebral body, the intervertebral disc, and the neural arch (Frymoyer et al 1990a, Frymoyer et al 1990b, Roaf 1960, White et al 1975). Approximately 25% of an applied axial compressive load is transmitted through the facet joints.

The cervical spine is anatomically most susceptible to injuries as a result of extremes of motion (flexion/extension, rotation). Many different kinds of fractures involving the neural arch can occur (Frymoyer et al 1990b). Compressive forces are most often responsible for crush injuries to the vertebral bodies and/or the end plates, and damage to the intervertebral discs (Frymoyer et al 1990a, Frymoyer et al 1990b, Roaf 1960). The vertebral bodies are part of the compression load-bearing system of the vertebral column. They can be broken down into three distinct structural features; a core of cancellous bone, a cortical shell and vertebral end plates. Dynamically, Frymoyer et al (1990a) proposed these structures provided a shock absorbing mechanism in the spinal column, stating, that as they are fluid filled, it is probable that they are hydraulically strengthened for transient applied loading.

When a compressive load is applied, structural damage to the vertebral bodies does not occur without concomitant damage of the intervertebral disc (Frymoyer et al 1990a, Frymoyer et al 1990b, Roaf 1960, Torg 1991). The disc is made up of two identifiable components; the annulus fibrosis and the nucleus pulposus. In the young healthy disc, a hydrostatic pressure is generated in the nucleus in response to an applied compressive load. The annular fibres, which surround the nucleus, are also attached to the end plates of the vertebral bodies. These fibres are criss-crossed in order to contain the high pressures generated in the nucleus. The tension forces transmitted to these fibres produce a tension force on the end-plates to counteract the building hydrostatic pressure in the nucleus pulposus. When a compressive load is applied, the intradiscal fluid pressure is counteracted by tension in the fibres of the annulus fibrosus, which are in turn associated with stretching of these fibres and radial bulging of the disc (Frymoyer et al 1990a).

A compressive load, applied to the vertebral column, results in a series of reactions best described by Roaf (1960). As compressive load increases, there is a very slight bulge of the annulus fibrosus but no alteration in the shape of the nucleus pulposus, with the major distortion being the bulge of the vertebral end-plate. Bulging of the end-plates causes blood to be squeezed out of the cancellous bone of the vertebral body (this is an important shock-absorbing mechanism in the spine). As the pressure continues to increases the end-plate bulges more and more until it finally cracks. Once the end-plate breaks, nuclear material is displaced into the vertebral body (this is known as a Schmorl's node). The disc loses its turgor and begins to bulge posteriorly (into the spinal canal). With the loss of the protective cushioning of the intervertebral disc, continued pressure leads to fractures and crush fractures of the vertebral body. Frymoyer et al (1990b) note that the addition of flexion or extension movements to the compressive force will produce wedging and displacement of fracture fragments.

Tator (1984b) in a retrospective study of CSI hockey players, found that an axial compressive load combined with flexion resulted in the forces concentrating mainly on the vertebral body and disc. This resulted in burst fractures with marked posterior protrusion of the vertebral body. Of the patients studied presenting this mechanism of injury, all sustained burst fractures and fractures of the laminae at the levels of C4 or C5 or C6, including protrusion of the fractured bodies into the spinal canal up to 8mm.

Specifically looking at the incidence of various types of injuries to the cervical vertebrae and their locations, Miller et al (1978) provided valuable statistics. They found the most vulnerable areas of the cervical spine to be at the levels of C2 and C6, which account for 27% of all injuries. Eighteen percent of all 399 patients suffered an equal number of fractures at C5 and C7. Ten percent or fewer patients had fractures at C1(6%), C3(10%) and C4(10%). At least half of the 399 patients in this study had at least one injury at the following vertebral arch locations: the pedicles, laminae, transverse and spinous processes, and the articular pillars with the superior and inferior articular processes at the ends. Of these structures, the articular pillars appeared most vulnerable, as 21% of the patients had fractures at this site, and of the pillar fractures documented, 43% occurred at C6. Fractures of the lamina, pedicle and the spinous processes each occurred in 13% of the patients. Over half of all lamina fractures occurred at C5 and C6, while two-thirds of the spinous process fractures occurred at C6 and C7. C6 was the site of 30% of all of the vertebral arch fractures in this series. As comparison, the middle region was relatively uninvolved, as only 8% of such fractures occurred at C3.

Fractures of the vertebral bodies occurred in 30% of the patients. With half of these fractures occurring at C6 or C7. As with fractures of the vertebral arch, the middle portion of the cervical vertebrae were relatively resistant to injury, with only 9% of fractures reported at C4.

It must be pointed out that most of the patients involved with the Miller et al (1978) study were neurologically intact following injury. Other studies of cervical spine trauma, such as Selecki et al (1970), only included patients with objective neurologic findings. In this study, instead of having the fracture locations somewhat spread throughout the cervical spine, they documented 66% of their patients having injuries at C4-C6 and only 8% of injuries at C7. Lob (1954), reported similar findings, documenting C5-C7 as being the most frequently injured cervical vertebrae with associated neurological findings.

Karbi et al (1988) reported 82% of upper CSI at the level of C2, and 72% of lower CSI at the levels of C5, C6 and C7. The most often injured structure was the vertebral arch (50% of injuries), followed by the vertebral body (30% of injuries). Tator (1991) reported 48% of CSI in hockey occurred at C4-C5, C5, and C5-C6 and most commonly involved burst fractures and fracture dislocations.

White et al (1975) conducted a quantitative biomechanical analysis of the effects of destroying ligaments and facets on the stability of the cervical spine below C2. Cervical vertebrae from eight fresh cadavers as well as the contributing ligamentous structures which provide stability to the cervical vertebral column were, assessed. A compressive load equivalent to 25% of body weight was applied during four separate conditions. Through the movement of flexion, as ligaments were transected from anterior to posterior, the structures were transected in sequence until the upper vertebrae either rotated at least 90 degrees in the sagittal plane or completely separated from the subadjacent one. This same procedure was done through flexion, transecting ligaments from posterior to anterior, and through extension, transecting in the same manner. It was found that removal of the facets altered the motion segment such that in flexion, there was less angular displacement and more horizontal displacement. The posterior ligaments contributed more to stability in flexion than the anterior structures, and the anterior ligaments contributed more to stability in extension than the posterior structures. It was generally concluded that the majority of ligaments had to be transected before failure occurred. Although they recorded a maximum angular displacement of 15.7 degrees, the greatest horizontal displacement recorded just before complete failure was only 4.89mm. It appeared that there was only modest displacement just before the spine was about to fail; "failure usually occurred suddenly and completely without warning or with little evidence to suggest failure was imminent" (White et al 1975:91). These findings provide several important guidelines for determining clinical stability and instability of the cervical spine.

**1.** Although muscles exert some force, they did not play a significant role in clinical stability.

**2.** A motion segment would remain stable under physiologic loads if it had all its anterior elements plus one additional structure, or all of its posterior elements plus one additional structure.

**3.** No normal adult spine should permit horizontal motion (shear) greater than 2.7mm between vertebrae.

**4.** When handling an injured patient with all the anterior elements destroyed, support to prevent extension is most important.

**5.** The spine is unstable or on the brink of instability if:

a) either all anterior or posterior elements are destroyed or unable to function.

b) more than 3.5mm horizontal displacement of one vertebra in relation to an adjacent vertebra anteriorly or posteriorly, is found on standard lateral or flexion-extension roentgenograms of the neck of an acutely injured adult.

c) more than 11 degrees of rotational difference to that of either adjacent vertebrae are measured on resting lateral or flexion-extension roentgenograms of the neck of an acutely injured adult.

It is important to note that identification of minor subluxations of facet joints by radiography is difficult. Sweezey et al (1971) investigated the extent to which facet displacement might go undetected radiologically. Using a human skeleton, measured displacements were created at select vertebral locations in the cervical and lumbar vertebrae. Metal dots (the heads of pins) were glued on to the side of each facet as close to the articular surface as possible. Standard radiographs were then taken, including anterior-posterior, lateral, and right and left 45 degree oblique views. The data revealed that unilateral overriding displacements of a C5-C6 facet joint of 3mm, and an L5-S1 facet joint of 3.5mm, and a cephalad-caudad C5-C6 facet widening of 3mm, and an L5-S1 facet widening of 4.5mm was almost undetectable radiographically. Gross displacements of the facet joints including 4.5mm vertical displacement of C5-C6 and 4.5mm vertical displacement of L5-S1, were easily identified on the oblique view of the affected side.

## 2.3 SUPPORT FOR EQUIPMENT REMOVAL

The question of equipment removal has become a fundamental principal in the assessment and safe packaging of athletes with suspected CSI. Those who believe the helmet should be removed are representative of Emergency Medical Technicians. EMT's who often work with injured motorcyclists wearing full coverage helmets, remove this equipment to allow airway management. Due to the high speeds and large impact forces associated with a motorcycle accident, the injured individuals often sustain serious head injuries and multiple organ system damage (Aprahamian et al 1984b). With the helmet in place, injuries such as skull fractures, significant soft tissue facial injuries and warning signs of these injuries, such as cerebrospinal fluid (CSF) from the ears or pooling of blood at the base of the skull, are hidden.

Injured athletes, such as those found in football and hockey, also wear protective helmets. Using the protocol for dealing with injured motorcyclists as a guide, EMT's have developed a set protocol for dealing with CSI football and hockey players. This protocol involves removing the helmet of these injured athletes. The following reasons for helmet removal are provided:

1. Unable to obtain proper immobilization.
2. Unable to visualize injuries.
3. Unable to control airway.
4. Hyperflexion of the head with the helmet in place.

(Feld et al 1988)

There are additional situations which advocate the removal of the helmet from an athlete with suspected CSI and which all pre-hospital personnel (EMT's., athletic therapists, sport physiotherapists and team physicians) are in agreement. As described by Denegar et al (1989), they are:

1. When the facemask or visor cannot be safely removed and interferes with adequate ventilation or the responding personnel's ability to restore the airway.
2. When the helmet is so loose that adequate spinal immobilization cannot be obtained with the helmet in place.

3. Signs or symptoms of open or closed head injury which requires evaluation by direct inspection.

4. Significant haemorrhage from the cranium requiring direct pressure.

If the helmet is removed, in addition to the application of a cervical collar and standard securing to a hard spine board, it was suggested at the 1992 Canadian Athletic Therapists Association (CATA) conference, that the head be blocked up after collar application and prior to securing to the spine board, in order to limit the head from extending backwards. If the helmet is not removed on site, the athletic therapist, after ensuring qualified field coverage for his/her team, must travel with the athlete to the hospital. The therapist will then remove the helmet after clearance from the attending emergency room physician. Finally, the CATA proceedings suggest the training of more emergency room personnel in the proper removal of athletic helmets, in order that these personnel can properly deal with injured athletes in the absence of athletic therapists, or others (EMT's) trained in helmet removal techniques.

## 2.4 ADVOCATES OF STABILIZATION WITHOUT EQUIPMENT REMOVAL

Optimal care for athletes with activity induced (acute) CSI includes early recognition of the injury, immediate stabilization of the spine, and early transfer of the athlete to a trauma centre with special capabilities for spinal cord injury treatment and rehabilitation (Burney et al 1989). The underlying principle of all emergency medicine is to minimize the risks of additional injury to the patient, while stabilizing the injuries incurred. Thus, the main concern surrounding the initial management of athletes with suspected, acute CSI is that the neurological function of those athletes with unstable or other vertebral injuries will be further impaired as a result of motion before definitive care can be provided (Burney et al 1989).

Following this train of thought, there are many who advocate the stabilization of the cervical spine injured athlete without removing the helmet and shoulder pads. Such advocates include sport physiotherapists, athletic therapists, team physicians and some EMT's (Burney et al 1989, Denegar et al 1989, Feld et al 1988). The reasons for stabilization without equipment removal are multifaceted. Some are in direct opposition to those reasons provided by EMT's advocating removal of the helmet and are as follows:

1. With the helmet in place, proper immobilization can be maintained. Both football and hockey helmets must fit snugly to be effective. Neither athlete will play with helmets that are extremely loose.

2. For the injured motorcyclist, hidden cranial injuries such as depressed skull fractures, are a concern due to the high speeds and large impact forces involved. For the injured athlete, hidden cranial injuries and significant facial soft tissue injuries are not as likely due to the relatively slower velocities and smaller impact forces. Thus, checking under the helmet for hidden cranial injuries in the majority of cases is not required. Additionally, as Feld et al 1988 explained, the athletes ears can easily be inspected through the ear holes and the facemask does not hinder pupil examination. With the helmet in place, palpation of the cervical vertebrae is also possible.

3. With the helmet in place, airway management is reasonable. Feld et al (1988) noted that, any sharp knife can cut the clips holding the facemask of the football helmet. With removal of the facemask and the chin strap, which is easily cut away, access to the nose and mouth is obtained. Denegar et al (1989) concurred, declaring that with the facemask out of the way, there is no reason that optimal victim preparation and airway management cannot proceed with the helmet in place. They suggest the chinstrap not be cut unless necessary, as it assists in stabilizing the athletes' head within the helmet.

4. While hyperflexion of the head due to the presence of the helmet may be associated with injured motorcyclists, this finding is not the case when dealing with injured football and hockey players. Feld et al (1988) reported that the protective shoulder pads worn by these athletes elevated the shoulders and chest such that the cervical spine remained in a relatively neutral position in relation to the helmeted head and body.

5. Upon removal of the helmet, even if the neck is collared, the head falls into an additional 3 to 4 degrees of hyperextension (Reid 1990).

6. Even with the helmet removed, modern shoulder pads with neck restraints may make the application of rigid cervical collars difficult (Denegar et al 1989).

7. The field setting may not offer the ideal environment for helmet removal. In the hospital, the helmet removal process can be reviewed and removal performed in a warm, dry, well lit setting (Denegar et al 1989).

By removing the helmet, and applying a cervical collar, it is believed that the collar will assist in stabilizing the neck, limiting any additional movement. However, there is a great deal of literature that questions this belief. Indeed, Aprahamiam et al (1984b), concluded after examining the effectiveness of a number of cervical collars to stabilize a surgically created C5-C6 instability that "the soft collar and semirigid collar do little to prevent movement, and their presence may serve only as a warning to physicians that a neck injury may be present" (Aprahamiam et al 1984b:584).

Evaluation of cervical collars have used cadavers (Aprahamian et al 1984b), and normal healthy volunteers (Cline et al 1985, Karbi et al 1988, McCabe et al 1986, Podolsky et al 1983, Secor 1983). In all studies, the protocol followed a similar framework. The normal full range of motion of the neck was determined, including flexion, extension, lateral bending and axial rotation. After application of the devices to be studied and/or application of the devices and fixation to a rigid board, the motion of the neck was once again determined. It must be noted that the use of healthy volunteers presented a drawback, as the possible stabilizing effect of muscle spasm in combination with the collars could not be determined.

Immobilization which incorporated fixture to a hard rigid board, was commonly found to be most effective (Cline et al 1985, Karbi et al 1988, Podolsky et al 1983). As noted by Karbi et al (1988), it is typically believed that adequate immobilization of the cervical spine involved securing of the head and shoulders to a single rigid plane. Of the extrication devices available, it is postulated that the Halo vest is the most effective in immobilizing the cervical vertebrae. Unfortunately its difficulty of application renders it inappropriate for prehospital care (Podolsky et al 1983).

Of the remaining available collars, the Philadelphia collar is considered the best, especially with respect to limiting extension (Aprahamian et al 1984b, Cline et al 1985, Karbi et al 1988, McCabe et al 1986, Podolsky et al 1983). Unfortunately, this device is two pieced and not often chosen due to its relative difficulty of application. The most common collars used are semi-rigid (extrication) collars, the best known being the Stifneck™ Extrication Collar. These collars are easily transported, assembled and not too difficult to properly apply. These collars do not perform well in the studies that have been conducted. Their ability to limit flexion is quite good (Secor 1983), but their ability to limit extension, lateral bending and axial rotation is inferior to all other methods with the exception of the soft collar and no immobilization at all (Karbi et al 1988, Podolsky et al 1983, Secor 1983).

Cline et al 1985, Karbi et al 1988, and Podolsky et al 1983, have shown that stabilization using a hard board, tape and sandbags is superior to all other methods, with the exception of use of the Philadelphia collar in addition to the above.

## 2.5 RADIOGRAPHIC IMAGING/FLUOROSCOPY

Radiographic evaluation of skeletal structures involves the use of X-radiation (short wave-length, penetrating rays of the electromagnetic spectrum produced by electrical equipment) to create images of the body from which medical diagnosis can be made. Fluoroscopy entails the X-ray examination of body parts (skeletal and soft tissue structures), and their movement patterns, observed by means of a fluorescent screen and television system.

Krohmer (1989) provides us with information and insight into the history of radiography and fluoroscopy. As early as the 1920's, many significant advances had been made in radiographic and fluoroscopic techniques. These advances were dictated by medical needs and the discovery that these X-rays were also very dangerous when improperly used. The 1920's was mainly a time of consolidation and learning. In the 1940's, World War II (WWII) proved to be both helpful and a hinderance. While advances in radiology were obstructed in some respects by the war, in others, WWII provided a stimulus for advancement. The decade of the 1960's was similar to the 1920's in that it became a period of consolidation and refinement of equipment and techniques. The 1970's resulted in the introduction of computed tomography (CT) and magnetic resonance imaging (MRI) as methods of medical imaging. The decade of the 1980's and the beginning of the 1990's has had manufacturers focusing on maintaining and making modest improvements in conventional radiographic and fluoroscopic equipment. Their main efforts have been directed at the more commercially viable and technologically sophisticated equipment of the future.

In the late 1980's and early 1990's Magnetic Resonance Imaging and Computed Tomography began to be utilized as methods of imaging the osseous and soft tissues of the cervical spine (Flanders et al 1990, Mirvis et al 1988). Data from these studies assisted in defining the scope of use of these imaging techniques. It was found that Magnetic Resonance Imaging was most accurate at determining the condition of the cervical spinal cord (including swelling and haemorrhage), the intervertebral disc (including herniation and bulging) and the remaining paraspinal soft tissues (Flanders et al 1990, Mirvis et al 1988). Computed Tomography was most accurate at detecting and defining cervical vertebral fractures, especially those of the posterior elements (Flanders et al 1990, Mirvis et al 1988). Indeed, Mirvis et al 1988, report that Magnetic Resonance Imaging could probably replace Computed Tomography and Myelography in assessing the condition of the thoracolumbar vertebrae following trauma but would have to play a more limited role in the assessment of the condition of the cervical spine due to the smaller bones and limited epidural fat. An additional limitation in the use of Magnetic Resonance Imaging, is its contraindicated use when dealing with clinically unstable cervical spine injuries. As Mirvis et al 1988 report, many patients cervical spine injures are too clinically unstable in the acute setting to be studied safely in a strong magnetic field, or they require ventilatory support and other such sophisticated equipment that may not function properly in the magnetic field.

Presently, radiography and fluoroscopy are widely used research tools for creating images of the body. Specifically looking at research involving the spinal column, radiography and fluoroscopy have been used in researching cervical spine injuries and related structures (Fielding 1957, Fielding 1964, Pavlov 1991, Virgin 1980), in assessing the effectiveness of procedures for stabilizing injuries to the cervical spine (Karbi et al 1988, Meyer et al 1985, Thomas 1986), and the evaluating the effectiveness of protocols for assessing the injured cervical spine. (Lally et al 1989, Mirvis et al 1989, Vandemark et al 1990).

It is interesting to note that in addition to this research project, the author was able to find only one other study which used the technique of fluoroscopy in an attempt to ascertain and document the real time movement of adjacent cervical vertebrae. Meyer et al (1985) attempted to record the movement of the cervical vertebrae during helmet removal using both the two-person and single person technique (Appendix C). Unfortunately, in this instance the authors reported that the "videotaped fluoroscopy resulted in an image too soft to permit accurate measurements" (Meyer et al 1985:329).

## 2.6 SUMMARY

The literature has shown that in the sports of football and hockey, cervical spine injuries most commonly occur as a result of an axial compressive load to the athletes head. The use of biomechanical principles has greatly aided in the analysis and identification of this injury and the resulting guidelines that determine the stability or instability of the injured cervical spine. In both sports, the occurrence of theses injuries has been well documented and at the moment appear to be on the decline as a result of the identification of the events leading to CSI and the implementation of rules designed to prohibit these events.

However, the controversy surrounding these injuries does not concern the injury itself, but the protocols for dealing with the injury once it has occurred. Two schools of thought have been identified. The first, advocate the removal of the athlete's upper body protective equipment as initial prehospital preparation of the athlete prior to transportation to the hospital. The second, advocate the stabilization of the injured athlete without removal of the protective equipment for the upper body, as initial prehospital preparation of the athlete prior to transportation to the hospital.

The concern surrounding the maintenance or removal of the protective equipment for the upper body is centred around the notion that during stabilization and/or equipment removal, possible movement of the cervical spine may result, compounding the nature of the injury. Specific concerns include: 1) the prehospital personnel's inability to accurately identify the presence or absence of an unstable fracture of a cervical vertebrae or any other injury which would render the cervical spine unstable, and 2) the absence of an effective immobilization device for the athletes helmetless head. The lack of a practical, effective cervical (extrication) collar appears to lend support to those who believe stabilization should occur without equipment removal. Once the athletes' helmet has been removed, even with a collar applied, without adequate padding of the head, the neck may fall into additional degrees of extension, as a result of the shoulder pads elevating the thorax. It would seem sensible to remove the shoulder pads to correct for this problem, however, removal of the shoulder pads would involve some additional movement of the individual - an impractical idea if limiting the amount of unnecessary movement is the goal.

Radiographic imaging techniques have been employed as a method of data collection to identify the position of adjacent cervical vertebrae when injured, and when testing the effectiveness of cervical collars to limit vertebral motion. The use of fluoroscopy as a data collection tool has been identified as the best method for visualization of movement of the cervical vertebrae (Penning, 1978), subject to refinement of technique (Meyer et al, 1985).

# CHAPTER 3

## METHODS AND PROCEDURES

Knowledge is essential to conquest; only according to our ignorance are we helpless.

Thought creates character. Character can dominate conditions. Will

creates circumstances and environment. - Annie Besant

### 3.1 NATURE OF THE SAMPLE

Twenty-one healthy male volunteers between the ages of 18 and 27 were recruited from the University of Alberta Golden Bears hockey and football teams and select members of the Nor'Westers rugby football club with football or hockey experience. Prior to participation in the study, all of the subjects completed informed consent forms (Appendix C). None of the subjects had a history of cervical spine injury or cervical spine disease, nor were any noted during the initial radiographic examination. Volunteers were excluded if they presented a history of:

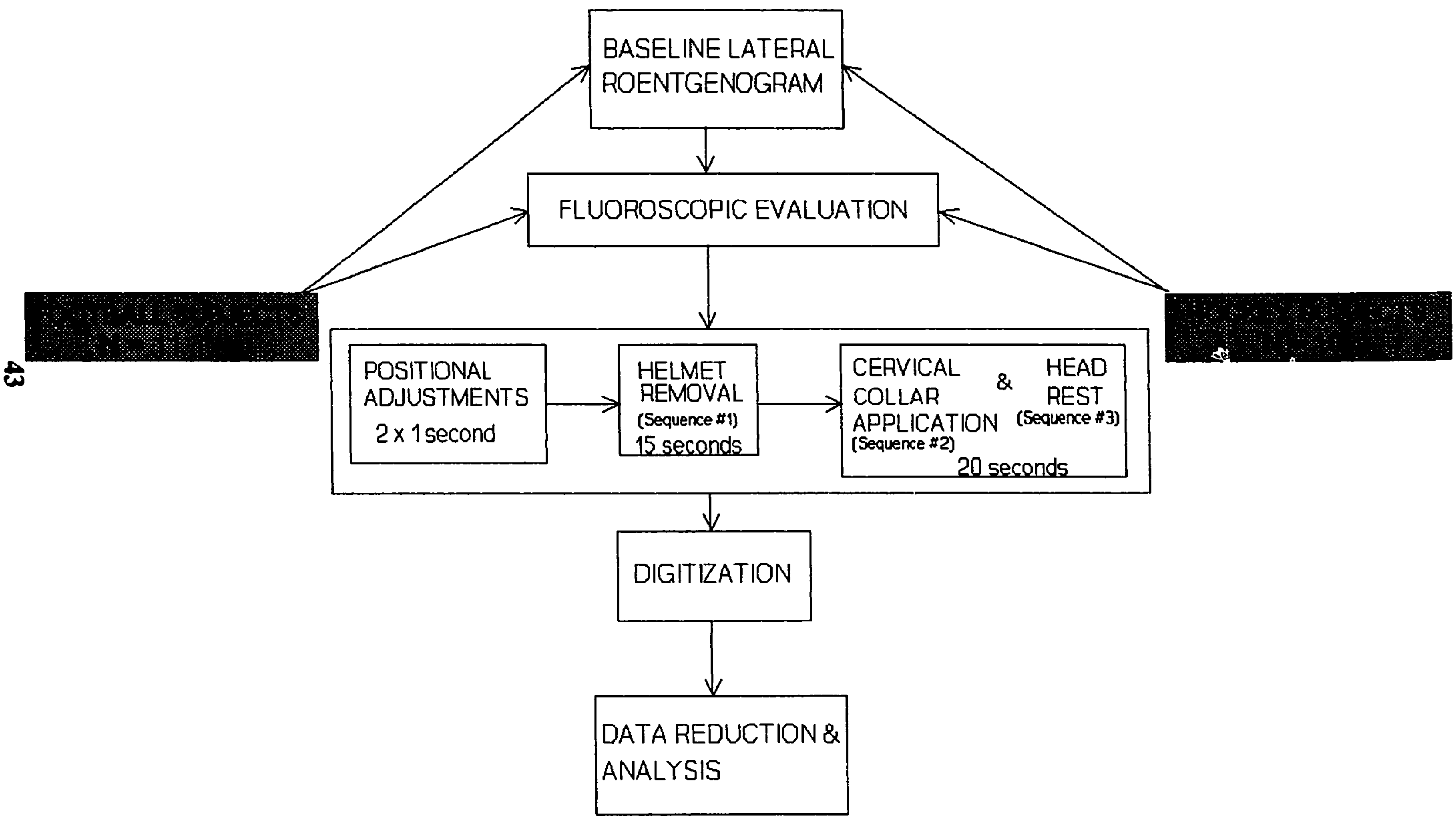
1. Previous radiation therapy
2. Thyroid gland problems
3. Pre-existing or current cervical spine disease or trauma

All subjects from the football team and select individuals from the Nor'Westers with football experience were assigned to the football group. All members of the hockey team and select individuals from the Nor'Westers with hockey experience were assigned to the hockey group.

### 3.2 EXPERIMENTAL DESIGN

Figure 3.1 highlights the major experimental components of the study. Following

**FIGURE 3.1 : EXPERIMENTAL DESIGN**



baseline lateral roentgenograms, the football and hockey subjects were assigned to their respective subject pools for fluoroscopic evaluation.

The fluoroscopic examination and assessment for each subject consisted of two, one second initial positional exposures to ensure proper alignment, followed by Sequence #1, a 15 second helmet removal routine and Sequence #2 and #3, consisting of a 20 second exposure while the cervical collar was being applied and the helmetless head was allowed to rest on the spine board. Post examination location of cervical spine anatomical landmarks and computer aided digitization were assessed for C2 through C6.

## 3.3 EQUIPMENT

### 3.3.1 Athletic Equipment

The football subjects were properly fitted into Rawlings football shoulder pads. Two sets of pads were available, a size CL66-XXL (8 subjects) and a size CP46-XL (3 subjects). These are common sizes worn by linebackers and defensive backs respectively. To ensure a proper fit, the subjects wore their own football helmets. Only two brands of helmets were used, Riddel Model VSR3 (6 subjects) and Bike "Air Power" (5 subjects).

The hockey subjects were properly fitted into Cooper Defender Super Pro hockey shoulder pads, as these are commonly worn by defencemen (all 10 subjects wore size large). To ensure a proper fit, the subjects wore their own hockey helmets. Only two brands of helmets were used, CCM model M-HT2(4 subjects) and Cooper model SK 2000 (6 subjects).

Stifneck™ Extrication Collars were used to stabilize the necks of all football and hockey subjects. Only two sizes of the collar were used, the No Neck (11 football/4 hockey subjects) and the Short (6 hockey subjects).

3.3.2 X-ray Equipment

The baseline x-ray examination was completed at the Glen Sather Sports Medicine Clinic under the supervision of Jan Dubeta a Radiology Technician. All guidelines and procedures, as specified by the Clinic, were followed (Appendix D).

The examinations were performed with a general stationary radiographic unit (RMX 625R, RMS Division Fischer Medical Imaging Corp. Addison Illinois) using 72" focal film distance, non-bucky exposure, 400 speed Kodak lanex regular screens, Kodak TMatG film (24cm x 30cm), and 60 second processing. The angle used was an erect lateral view of the area; defined as an area from the sella turcica of the sphenoid bone in the skull, to the level of the first thoracic vertebrae of the spinal column.

3.3.3 Fluoroscopic Equipment

The fluoroscopic examinations were completed in the Department of Radiology, University of Alberta Hospital, under the supervision of Dr. P. G. Heslip and Jan Dubeta. All guidelines and procedures as specified by the department, were followed (Appendix E).

The examinations were performed with a mobile C-arm unit (Series 9000 Mobile C-Arm, OEC-Diasonics Inc., Salt Lake City, UT) consisting of a microprocessor controlled X-ray mainframe and dual screen monitor with integrated real time digital image processing. The system had a 0.3mm focal spot with 40-120 kilovoltage (kVp) and 0.5 to 5.0 miliamperage (mA) with boost capability of 20mA maximum, high resolution television camera with 360 degree manual rotation, choice of 15 or 23 cm input screen with central resolution of approximately 40 line pairs(LP)/mm and peripheral resolution of approximately 35 LP/mm and an image storage system with videocassette recorder. The unit was powered by a 220V, 10A electrical outlet. The examinations were recorded on an RCA videocassette recorder (RCA VHS HQ, model VMT285A).

The fluoroscopic unit operates in the automatic brightness mode so that it automatically adjusted the kvp and amperage(A) to optimize the image brightness. These values were approximately the same as those encountered with conventional fluoroscopy. For 11 of the subjects (football), the kVp value was increased an average of 10kVp to increase penetration of the shoulder pads. The total fluoroscopy time per subject, ranged from 32 seconds to 54 seconds with an average time of 44 seconds (Plate 3.1 & 3.2).

### 3.3.4 Biomechanical Analysis Equipment

Biomechanical analysis of the position of the cervical vertebrae was carried out by the primary researcher using the Ariel Performance Analysis System (APAS)(Ariel Life Systems, INC. La Jolla, CA) consisting of an AST Premium II 386 SX/20 computer containing the central processing unit, a math co-processor, the computer memory, a graphics processor, and a video image processor. This system used two monitors; the primary screen was a monochrome monitor, on which instructions, menus and data was inputed; the colour graphic monitor displayed results of data analysis as well as the video image for digitization purposes. Integral to this system was the video playback unit

Plate 3.1: Fluoroscopic Equipment Setup - Full Room View

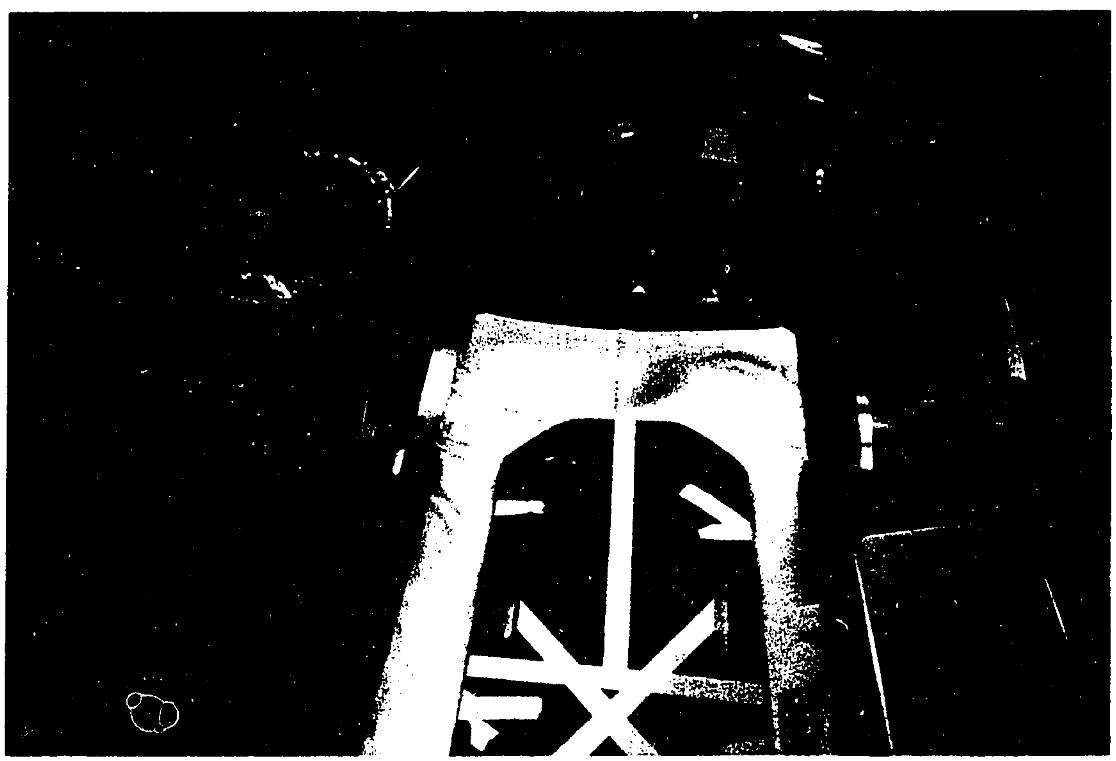


Plate 3.2: Fluoroscopic Equipment Setup - Overhead View

(Panasonic Time Lapse Video Cassette Recorder AG-6750A), which allowed high precision, freeze-frame video imaging with accurate single frame advance and reverse.

## 3.4 PROCEDURES

### 3.4.1 Baseline Data

The subjects were assigned to two groups, with eleven in football and ten in hockey. In all instances, lateral roentgenograms were taken of the subjects while sitting erect. The main known side effect of x-rays is the development of cancer. Taking into account the protocol of this project, the statistical risk of this occurring was 1 in 15 000 individuals. The statistical risk of developing cancer while living ones' life is 1 in 5 individuals.

Following an initial baseline x-ray, the researcher and x-ray technologist assessed the lateral roentgenogram for any degenerative changes to the cervical vertebrae which might indicate previous or current cervical spine disease or injury. If the x-ray showed evidence of any of the conditions explained above, the subject was informed and asked to withdraw from the study. Conversely, if the x-ray was free of abnormalities, the subject was allowed to participate in the study and assigned to their respective group.

After the initial baseline x-ray and assessment, subsequent fluoroscopy data was collected on C2 through C6 while the subject was in a supine position.

### 3.4.2 Fluoroscopic Technique

Collection of the data involved the co-ordinated efforts of a four member research team: a) a radiology technician from the Glen Sather Sport Medicine Clinic, b) two research assistants, both trained in helmet removal techniques, and c) the primary researcher, who ensured all procedures were carried out as designed. The research team and their responsibilities remained the same for all subjects.

Prior to data collection using the designated subjects, the primary researcher assumed the role of a subject, to allow the research team to practice their specific responsibilities. This prac[illegible] allowed the two research assistants to find the best position for themselves [illegible] to the equipment and the subject, and to practice and co-ordinate themselves during the helmet removal and cervical application procedures. At the sametime, it allowed the radiology technician to find the fluoroscopy unit settings that provided the best picture quality and image of the cervical vertebrae.

During all fluoroscopic procedures, the thyroid gland of the assistants was shielded. The subjects, research assistants,principal investigator and radiology technician wore body shields. As the assistants hands were out of the primary beam, they were not required to wear protective gloves.

To familiarize the subjects with the data collection procedure an initial series of events took place. The subjects were welcomed, introduced to the research team and instructed to put on their specific sporting equipment while the primary researcher ensured a proper fit. The chin strap of the helmet was initially fastened to ensure correct helmet fit. It was then removed, to simulate on field conditions where the chin strap would be cut off. Cutting the chinstrap using scissors available to prehospital personnel does not cause movement of the helmet or head, therefore, possible movement due to unsnapping of the chin strap, was not of concern.

The x-ray technologist correctly placed the athlete on the spine board. The machine was coned down on the area of interest; the cervical vertebrae (C-1 to C-6) including the body, posterior elements, and the spinous processes. The fluoroscopic beam was then turned on for one second, to ensure the athlete was positioned correctly in relation to the fluoroscopic equipment. Positional adjustments were made accordingly.

For the benefit of the subject and the two assistants, one practice run of the procedure was performed. Subsequent determination of facemask removal and choice of Stifneck™ collar size was made by the assistants. (Plate 3.3 & 3.4)

To ensure accuracy, the beam was turned on for another second, prior to beginning of the procedure to ensure the subject did not move during the practice run. After the assistants positioned themselves ready to remove the helmet, the beam was turned on and the helmet was removed. The helmet removal procedures followed the guidelines in Appendix F. (Plate 3.5)

With the beam still energised, the head of the subject was manually stabilized by the first assistant, while the second assistant removed the helmet and positioned herself to take control of the head from the first assistant (Plate 3.6). After the transfer of control, the beam was turned off. This procedure took approximately 15 seconds. The first assistant positioned the cervical collar for application. The beam was again energised and the collar applied to the neck region of the subject (Appendix G). The head was then slowly lowered until it rested on the spine board. At this point, the beam was turned off. This phase of the procedure took approximately 20 seconds. All

Plate 3.5: Helmet Removal Hand Position (Hockey)

Plate 3.6: Transfer of Control Hand Position (Hockey)

procedures were recorded on a VHS videocassette recorder for post fluoroscopy digitization.

Following initial fluoroscopic evaluation of one subject from each of the football and hockey subject pools, in order to minimize error and maximize image clarity, the following adjustments were made prior to collecting data from the remaining subjects:

1. Athletic tape was placed on the spine board, to limit downward sliding of the subjects.

2. Boger straps (Watkins 1986) were used to allow better visualization of the lower cervical vertebrae. In this instance rubber tubing was used. The tubing was positioned so that it stretched from one hand, down to hook around the subjects feet and then up to the other hand. As the subject grasped the ends of the tubing in his hands, he was instructed to relax his shoulders and allow the tubing to pull his arms and shoulders toward his feet.

3. With the football subjects, the epilauts (shoulder cups) were pinned down, as the thick plastic edges interfered with visualization of the lower cervical vertebrae. In performing preliminary x-rays using the football pads, it was determined that the metal rivets anchoring the epilauts and the cantilevers interfered with adequate visualization of C-4 to C-6. After consultation with a recognized equipment expert, it was agreed that the best way to solve the problem without losing integrity of the equipment (no effect on the height or stiffness of the shoulder pads) was to have the metal rivets and metal cantilevers removed and the shoulder pads sewn back together.

### 3.5 DATA COLLECTION AND REDUCTION

All data analysis was carried out by the primary researcher. Each subject was numbered and analyzed individually using three separate sequences. Sequence #1 identified the position of the cervical vertebrae during helmet removal and transfer of control of the subjects head. It began at the start of the helmet removal procedure and ended when movement was no longer discernable. Sequence #2 identified the position of the cervical vertebrae during cervical collar application. It commenced at the start of the collar application procedure and ended when the assistant's finger was no longer visible at the top of the picture (the assistant's finger passed through the image from the bottom to the top, as the assistant fastened the collar). Sequence #3 identified the position of the cervical vertebrae as the head was allowed to rest on the spine board. It began from the point that the assistant's finger was no longer visible and ended when movement was no longer discernable. Therefore, three sets of data points existed for each subject: Subject# Sequence1 (Sub#Seq1), Subject# Sequence2 (Sub#Seq2), Subject# Sequence3 (Sub#Seq3). For each sequence the required information was "grabbed", digitized, transformed and smoothed.

Using the video tape of the fluoroscopic images, the position of the cervical vertebrae was digitized and the resulting positions analyzed by computer. Prior to digitization, the frames to be analyzed were chosen from all frames collected for each subject, as not all of the frames for each subject contained movement. Recording the image involved the use of a television monitor and a video cassette recorder (VCR). The image on the monitor displayed the real time image from the fluoroscope during the actual procedure, and a static image when the beam was turned off. The VCR recorded the real time and the static image in between steps. Therefore, in order to determine cervical spine movement, it was necessary to view all frames collected from each subject, and identify only those in which the procedure was being performed.

All data reduction was performed with the aid of the Ariel Performance Analysis system (APAS). Once the frames were chosen, the next step was to "grab" the designated frames, converting the video image into the digital format used by the APAS system. Following this step, the digitization process began with the reference frame being identified first. All frames were viewed in a specific sequence. The reference frame, from which all subsequent frames were compared, was chosen as the frame with the clearest image so that all the important anatomical reference points in the frame could be accurately identified to the computer.

To start the analysis, a reference object of known length was digitized. The reference object for each trial was a lead number of known dimensions which was clearly in view in the reference frame. This known length was used by the APAS system in calculating the cartesian coordinates.

Next those points in the frame needed to accurately measure the movement of the cervical vertebrae being examined were identified. Two points on each individual vertebral body were digitized and labelled. The posterosuperior and posteroinferior corners were chosen, as these corners were the easiest to identify and were consistently visible across all subjects (Figure 3.2). A line connecting these two points, identified the posterior border of each vertebral body. Once all points on the reference frame had

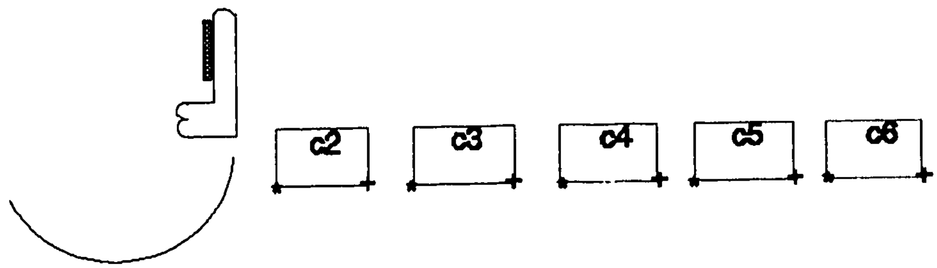



**FIGURE 3.2: VERTEBRAL BODY DIGITIZATION POINTS**

Two points on each individual vertebral body were identified and digitized in the reference frame and all digitized frames.
* the posterosuperior corner / + the posteroinferior corner

been defined and identified, digitization of the reference frame was completed and digitization of the remaining frames of interest was initiated.

In each subsequent frame, both anatomical points of each vertebrae were identified and digitized. Accuracy and consistency was aided by the fact that each new frame was superimposed on the digitized markings from the previous frame. As the program moved from point to point, the cursor was initially displayed at the last position digitized. In this manner, if there was no cervical displacement between frames, the previous position was recorded as unaltered. On the contrary, if there was movement between frames it could be detected, correctly identified and recorded.

After the data was digitized, it was transformed and smoothed. Both processes involved accessing the computer generated points from the computers memory and then designating the smoothing or transforming process to be used. Transformation was the process of converting the digital video coordinates of points of interest, to true cartesian coordinates. The smoothing process was used to remove random digitizing errors or noise from the sequence data. Each measurement consisted of two parts: the actual or true value (the exact extent to which the position of the vertebral bodies changed), plus an error value due to the inability to exactly determine points for analysis. With repeated measurements being made, statistical theory allows the estimation and removal of the error, provided the error is of a random nature. The smoothing technique used was a cubic spline with a smoothing value of 0.5, as this smoothing value provided the best fit to the data. Spline functions have been used in biomechanical research for both data smoothing and differentiation; and have provided very acceptable results (Wood 1982).

The smoothed data was then converted into a format that could be exported to the spread sheet, data base program (Microsoft Excel 3.0) for analysis.

Analysis of the data involved determining the mean average value of the data for each group (hockey or football) and each subject and sequence within the group (helmet removal, cervical collar application, and head rest). Values calculated demonstrated the mean and range of displacement, for each designated grouping.

## 3.6 DATA ANALYSIS

Initial data analysis involved calculating the angular displacement of the intervertebral disc space between pairs of adjacent vertebrae in each frame. For example, the hypothetical positions of C4 and C5 vertebra were determined through digitization as previously described. The relationship between C4 and C5 vertebra (disc space C4-C5) would then be determined by subtracting the value for the position of C5 from the value for the position of C4 (C4-C5=#). As an illustration, the position of C4 (Figure 3.3) was 200 degrees, while the position of C5 (Figure 4) was 180 degrees. Therefore, for this hypothetical frame, C4 (200) - C5 (180) = +20 degrees. If the vertebrae were moving in the same direction at the same rate, there would be little to no difference between the two values. However, if one vertebrae was moving more or less quickly than the other vertebrae or in the opposite direction, a difference in the values would be noted. The hypothetical example above indicates that C4 and C5 were not moving synchronously, and in fact, differed in position by +20 degrees.

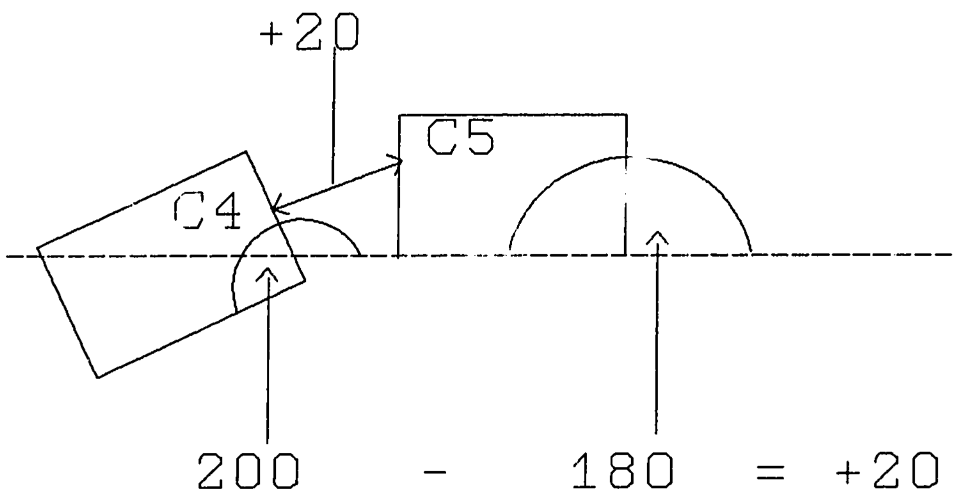



**FIGURE 3.3: CALCULATION OF THE ANGULAR DISPLACEMENT OF THE INTERVERTEBRAL DISC SPACE BETWEEN TWO HYPOTHETICAL VERTEBRAE**

In each frame of each sequence for all subjects, the angular displacement of the intervertebral disc space between C2-C3, C3-C4, C4-C5, and C5-C6 was determined. Using 180 degrees (the dotted line) as a reference point the computer program determined the angle of each vertebral body. The angular displacement between the vertebral body pairs was then calculated by subtracting the position of one vertebrae from the other.

A positive number indicated that the anterior part of the intervertebral disc space was increasing, and a negative number indicated that the vertebral disc space was decreasing. This process was followed for each subject and sequence, for each point in time (frame) for C2-C3, C3-C4, C4-C5 and C5-C6 vertebral pairs. Over the entire time period (set of digitized frames), any cumulative difference between vertebrae could be detected. Using as example the hypothetical intervertebral disc space C4-C5 the first time period (frame 1) yielded a difference of 4.00 degrees and the last time period (frame 19) yielded a difference of 10.00 degrees. Thus, the overall difference between the position of the vertebrae was 6.00 degrees (10.00 degrees - 4.00 degrees).

When calculating the range of displacement, in the majority of cases only one value was recorded, as in the example above. However, in some instances, more than one value was recorded, as the disc space between the vertebrae increased and decreased as a result of torque on the vertebrae. As example (Figure 3.4), at hypothetical joint C2-C3 at the first recorded time period (frame 1), the value indicating the degrees of difference between C2 and C3 was 9.00 degrees. At the twelfth recorded time period (frame 12), the value indicating the degrees of difference between C2 and C3 equalled 1.00 degree, an absolute difference of -8.00 degrees (9.00 degrees - 1.00 degree) from frame 1 to frame 12. Then at the last recorded time period (frame 19), the value indicating the degrees of difference between C2 and C3 equalled 4.00 degrees, an absolute difference of 3.00 degrees (1.00 degree - 4.00 degrees) from frame 12 to frame 19. In this instance, both values were used but recorded and identified separately. The value indicating the intervertebral disc space was decreasing (-8.00 degrees), was

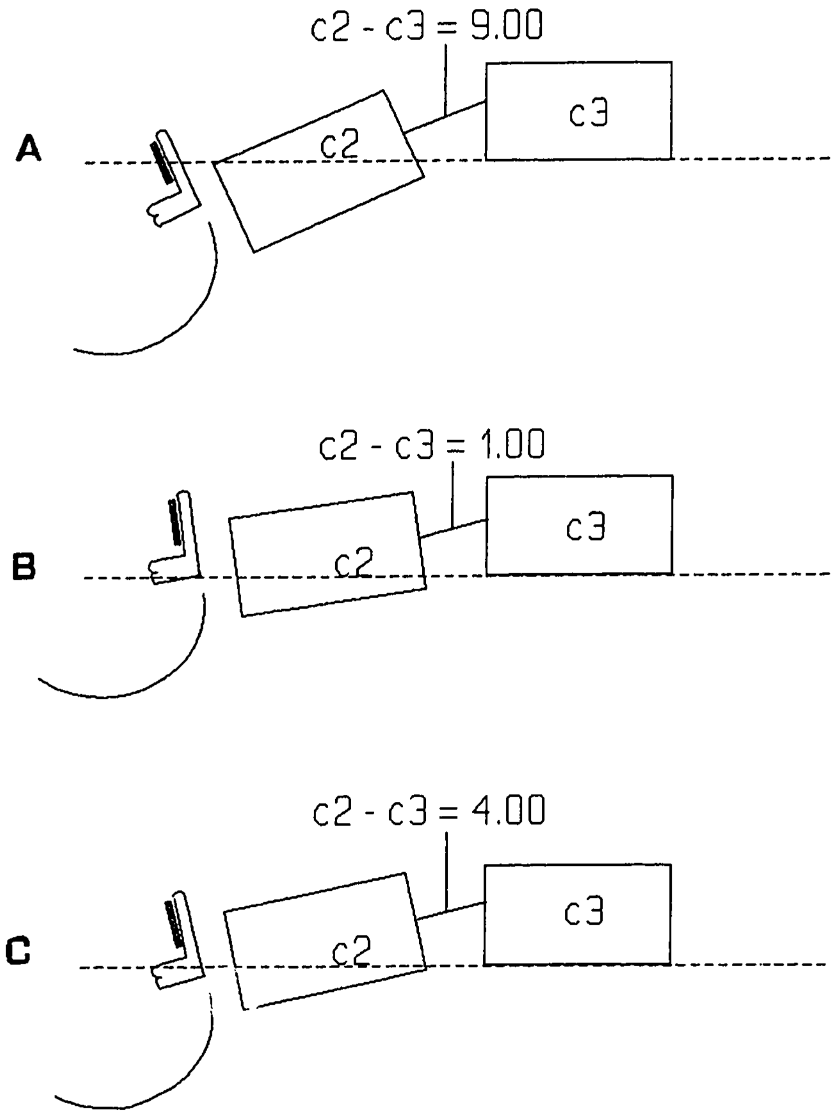



**FIGURE 3.4: ALTERATIONS IN THE INTERVERTEBRAL DISC SPACE AS A RESULT OF A TORQUING FORCE ON TWO HYPOTHETICAL VERTEBRAE**

In may instances the intervertebral disc space increased and decreased (torqued). The above example illustrates this event. Using hypothetical intervertebral disc space C2-C3 at point A (frame 1) a 9.00 degree difference in the disc space can be noted. At point B (frame 12) as the head and neck slightly flex, the desc space decreases resulting in a 1.00 degree difference at the intervertebral disc space. Finally at point C (frame 19) as the head and neck extend, the intervertebral disc space increases, resulting in a 4.00 degree difference.

recorded with all other values indicating similar positional change (Tables 4.4, 4.6, 4.8, 4.10, 4.12, 4.14). The value indicating the intervertebral disc space was increasing (3.00 degrees), was recorded with all other values indicating similar positional change (Tables 4.3, 4.5, 4.7, 4.9, 4.11, 4.13). To use the single value 11.00 degrees (8.00 degrees + 3.00 degrees) would be misleading as even though joint C2-C3 moved through 11.00 degrees, the maximum degrees of difference in either direction, between C2 and C3 did not exceed 8.00 degrees.

Certain limitations in the collection of the data points was encountered. In some instances, most often in football (31 occurrences) and infrequently in hockey (5 occurrences), during the digitization process, it was found that certain vertebrae were very difficult, if not impossible, to accurately digitize. This difficulty was due to poor video picture quality, coupled with the protective shoulder pads interfering with visualization of the cervical vertebrae and associated anatomical landmarks, most commonly C3 and C4. Subsequent joint calculations were not used in the analysis of the data for any such vertebral pairs. In the following results such data points are represented by the word "unacceptable". This limitation resulted in more data points being available for hockey subjects, and less data for football subjects. Additionally, due to such imaging problems, the fluoroscopic data collected for two subjects, (#1 & #9) could not be digitized, and therefore, was not used.

The reliability of the data was determined by calculating the root mean square (RMS) value of the original data compared to the redigitized data of the same sequence Tables 4.1 & 4.2). Two different subjects and sequences were chosen, one from hockey where the fluoroscopic video image was very clear, and one from football where the fluoroscopic video image was not very clear. The RMS value indicates the average difference in values between the two data. The lower the number, the less the data differed between the two sequences.

# CHAPTER 4

## RESULTS AND DISCUSSION

For good or ill, your conversation is your advertisement. Every time you open your mouth, you let men look into your mind. - Bruce Barton

Collectively, the data clearly documents alterations in the position of the cervical vertebrae during helmet removal, cervical collar application and head rest. The results provided in Tables 3 through 14 document the changes in the angular displacement between specific vertebral pairs (C2-C3, C3-C4, C4-C5, C5-C6) at the intervertebral disc space. These figures indicate the resultant angular displacement and were deemed the most important when dealing with unstable cervical spine injuries as the changes in the angular displacement of these vertebral pairs indicates whether the vertebrae were moving asynchronously. Such movement could prove disastrous in the presence of an unstable CSI (Burney et al 1989, Vegso et al 1987). As well, if the vertebra were moving at different rates, any unstable fractures fragments could be displaced relative to each other (Frymoyer et al 1990b, White et al 1975). Of greatest concern would be displacement of vertebral body, pedicles or lamina fracture fragments, as these structures surround the vertebral foramen. Any movement of fracture fragments into the vertebral foramen may result in compression or laceration of the spinal cord (Frymoyer et al 1990a, Frymoyer et al 1990b, White et al 1975). Additionally, any soft tissue injuries which might render the cervical spine unstable might result in further injury to the spinal cord, if the movement resulted in one cervical vertebrae shifting (either horizontally (shear) or flexion-extension or both) in relation to an adjacent cervical vertebrae (Frymoyer et al 1990a, Frymoyer et al 1990b, White et al 1975).

An unstable CSI has been defined by White et al (1975) when any of the following conditions exist: 1. either all anterior or posterior elements are destroyed or unable to function, 2. if more than 3.5mm horizontal displacement of one vertebra is found in relation to an adjacent vertebrae anteriorly or posteriorly, on standard lateral or flexion-extension roentgenograms of the neck of an acutely injured adult, 3. if more than 11 degrees of rotational difference relative to either adjacent vertebrae are measured on resting lateral or flexion-extension roentgenograms of the neck of an acutely injured adult.

Reid et al (1988) provided an additional means of describing spinal column injury due to axial compression by drawing on Denis' (1983) three-column theory of spinal stability. This theory divided the spinal column into the following three specific areas:
1. the posterior column including the spinous processes, laminae, pedicles, facet joints and interspinous ligaments.
2. the middle column including the pedicle, posterior longitudinal ligament, and the posterior half of the vertebral body and disc.
3. the anterior column including the anterior half of the vertebral body and disc, and the anterior longitudinal ligament.
Thus, another means of determining stability or instability of a CSI would be to consider which structures have been damaged, using the three-column theory as a guide.

Other tables in Appendix H illustrate the change in the position of each individual vertebra relative to all other cervical vertebrae. The displacement of each individual vertebra, during the majority of sequences, was much greater than the changes in the position of the intervertebral disc spaces. However, this data was not deemed as important as it did not represent as great a hazard to neurological deficit in the presence of an unstable CSI, as these large positional changes were most often associated with synchronous movements of adjacent vertebra. The following example illustrates this point. In Figure 4.1 Point A, C2 moved 22 degrees and C3 moved 21 degrees, suggesting there was a great deal of movement by each vertebra. But when considered relative to one another, they were moving almost synchronously and only differed in position by 1 degree. In Figure 4.1 Point B, C2 moved 11 degrees and C3 moved only 5 degrees. In this instance, even though the total change in the position was less (11 vs. 22 degrees and 5 vs. 21 degrees), the angular displacement of this second vertebral pair relative to each other was much greater. The second vertebral pair was not moving synchronously, and in fact, the angular displacement at that intervertebral disc space equalled 6 degrees. In the presence of an unstable CSI, the angular displacement between vertebral pair C2-C3 Point B has the potential to cause more damage than the overall displacement of vertebrae C2 and C3 Point A.

Overall, the greatest mean angular displacement of the intervertebral disc spaces between vertebral pairs from greatest to least was: C4-C5 (5.41 degrees), C2-C3 (5.02 degrees), C3-C4 (4.67 degrees), and C5-C6 (4.00 degrees). The range of absolute angular displacement spanned from a minimum of 0.00 degrees to a maximum of 19.24 degrees. The greatest amount of mean displacement of individual vertebra relative to all other vertebrae from greatest to least was: C3 (8.15 degrees), C2 (8.09 degrees), C4 (7.71 degrees), C5 (5.54 degrees), and C6 (4.23 degrees).

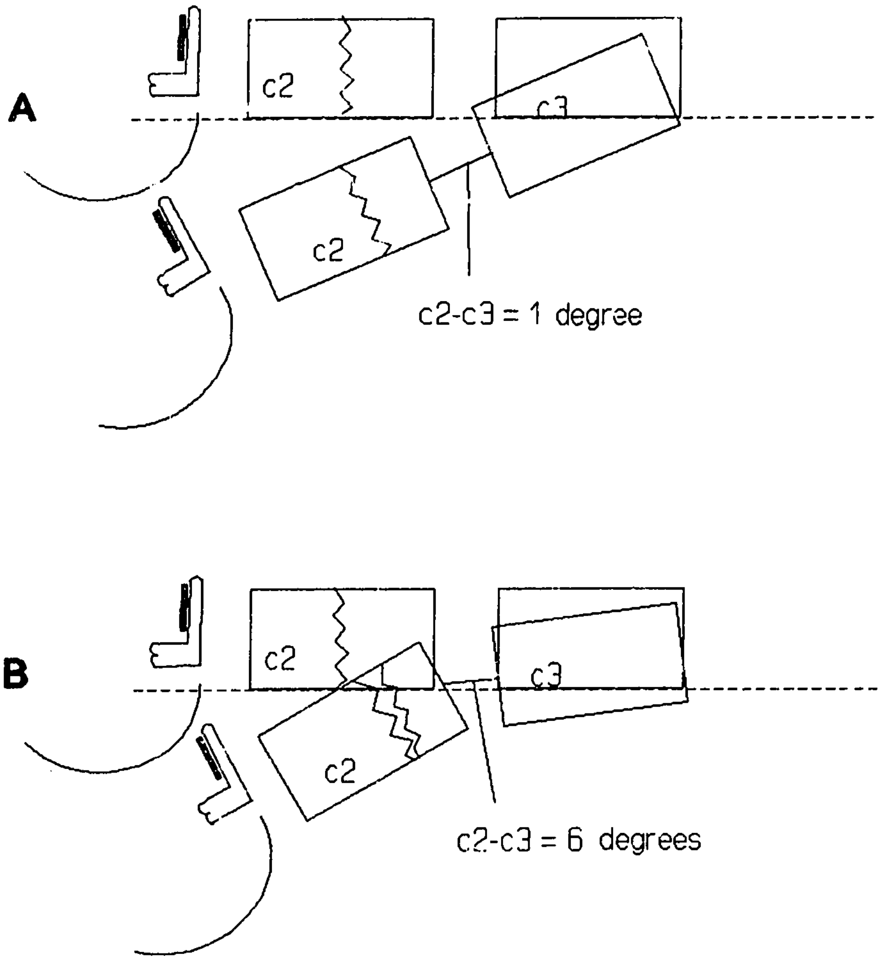



**FIGURE 4.1: VERTEBRAL MOTION**

When dealing with unstable fractures of the cervical vertebrae, asynchronous movements of the vertebrae were deemed more hazardous than synchronous movements. At point A, the vertebrae are moving together, when the movement stops, there is only a very small change in the angular displacement of this hypothetical vertebral pair placing very little stress on the fracture site. At point B, the hypothetical vertebrae are not moving together, when the movement stops, there is a relatively large change in the angular displacement of this vertebral pair, placing stress on the fracture site, causing the fracture fragments to be displaced relative to each other.

In all instances, across both football and hockey subjects, the greatest change in the angular displacement of the cervical vertebrae occurred during Sequence 1 as the helmet was being removed from the head of the subject. The greatest to least mean angular displacement between vertebral pairs was: C2-C3 (5.89 degrees), C3-C4 (4.87 degrees), C4-C5 (4.49 degrees) and C5-C6 (4.48 degrees). The absolute angular displacement ranged from a minimum of 0.00 degrees to a maximum of 17.25 degrees. Conversely, across all football and hockey subjects the greatest change in the position of individual cervical vertebra occurred during Sequence 3, as the head was allowed to rest on the spine board. From greatest to least the mean displacement of individual vertebra was: C3 (14.71 degrees), C2 (14.14 degrees), C4 (13.14 degrees), C5 (10.04 degrees), and C6 (5.11 degrees). The absolute individual displacement ranged from a minimum of 0.22 degrees to a maximum of 23.57 degrees.

## 4.1 RELIABILITY

**Table 4.1: Reliability Check (Football Data)**
Subject 3 Sequence 1 (Redigitized) vs. Subject 3 Sequence 1

| DATA | *C2-C3 | *C3-C4 | *C4-C5 | *C5-C6 |
|---|---|---|---|---|
| RMS value | 2.83 | **4.49 | 3.54 | 2.83 |
| MAXIMUM | 4.64 | 6.25 | 6.72 | 6.61 |
| MINIMUM | 0.00 | 2.89 | 0.41 | 0.23 |

All values expressed in degrees. The RMS value indicates the average degrees of difference between the redigitized sequence and the original sequence.
* Denotes the intervertebral disc space between the two cervical vertebrae indicated.
** Note the relatively high RMS value, due to difficulty in visualizing cervical vertebrae C3 and C4.

**Table 4.2: Reliability Check (Hockey Data)**
Subject 17 Sequence 3 (Redigitized) vs. Subject 17 Sequence 3

| DATA | *C2-C3 | *C3-C4 | *C4-C5 |
|---|---|---|---|
| RMS value | 2.26 | 1.42 | [illegible].57 |
| MAXIMUM | 3.[illegible]8 | 2.97 | 1.75 |
| MINIMUM | 0.[illegible] | 0.00 | 1.52 |

All values expressed in degrees. The RMS value indicates the average degrees of difference between the redigitized sequence and the original sequence.
* Denotes the intervertebral disc space between the two cervical vertebrae indicated.

As noted previously, the fluoroscopic video image of cervical vertebrae C3-C4 in the majority of the football subjects, was obstructed due to the bulk of the protective shoulder pads (Plate 4.1). As a result, it was difficult to accurately digitize the posterosuperior and posteroinferior corners (reference points) on these vertebral bodies.

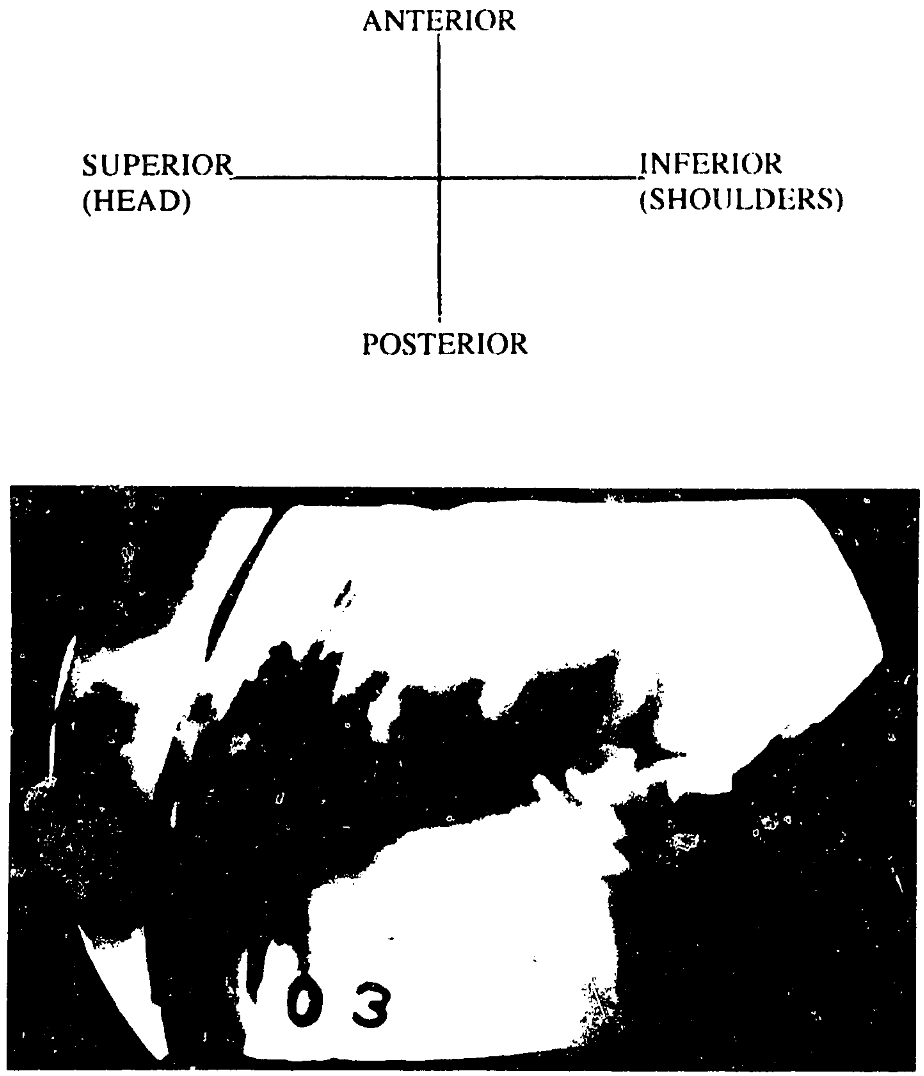



Plate 4.1: Fluoroscopic Image - Subject 3 Sequence 1

This difficulty is clearly illustrated in Table 4.1. The RMS value of intervertebral disc space C3-C4 was the highest of all RMS values calculated, confirming the difficulty for the researcher to accurately digitize the reference anatomical landmarks on these vertebrae. In other instances, poor video picture quality lead to difficulties identifying the reference points on the cervical vertebrae of both the football and hockey subjects.

In general, the fluoroscopic video image of the football subjects was less clear than that of the hockey subjects. Comparison of Tables 4.1 and 4.2 illustrate this difference. The RMS values of intervertebral disc spaces C2-C3, C3-C4, and C4-C5 in Table 4.1 (football subject) are higher than those found for the same vertebra pairs in Table 4.2 (hockey subject). Not including the RMS value of intervertebral disc space C3-C4 Table 4.1, the average RMS value across all other vertebral pairs was 2.43 degrees. On average, the researcher was able to identify the reference points on each vertebral body within +/- 2.43 degrees.

The data found in Tables 4.3 - 4.14 and Tables H1 - H6 is representative of the data collected in this study, but does not take into account the RMS value. As the average RMS value for this data equalled +/- 2.43 degrees, the values indicated in the tables may be either 2.43 degrees greater or less than indicated. In some instances, 2.43 degrees less would result in values close to zero degrees of displacement, and in these instances, this minimal movement would not be considered hazardous. On the other hand, in some instances, 2.43 degrees more would result in values indicating larger degrees of displacement, which might elevate slightly significant degrees of movement to large degrees of displacement, which could be potentially hazardous.

4.2 POSITION OF THE CERVICAL VERTEBRAE - Helmet Removal (Sequence #1)

At the end of the helmet removal procedure, the control of the subjects head was transferred between research assistants. It was interesting to note that as transfer was being completed, (for example when the second research assistant was assuming control of the head as the first research assistant was releasing control), the head and entire cervical vertebral column moved upward in each case. A possible explanation may be due to preloading of the muscle spindles which resulted in contraction of the biceps muscle fibres. Alternatively, this upward movement may have been the result of simple leverage, as the assistants elbows were resting on the table during transfer of control and stabilization (Plate 3.6). The placement of the elbows may have served as a pivot, resulting in the observed upward movement. However caused, this upward movement occurred in all football and hockey subjects in every performing of sequence #1. This information was not indicated in the tables provided, but was observed by the researcher during the digitization process.

The two person helmet removal procedure resulted in the position of the cervical vertebrae or the intervertebral disc spaces being altered to a large extent (Tables 4.3 - 4.6). During review of the fluoroscopic video, the primary researcher detected what appeared to be a widening of the intervertebral disc space as the helmet was being removed. It appeared that this helmet removal procedure resulted in slight axial traction being applied to the head of the subject. However, video analysis of this suspected movement was not possible due to limitations in the manner in which the anatomical reference points were digitized. The effect of axial traction on the cervical spine could be potentially dangerous. If, for instance, the soft tissue structures supporting any motion segment had been damaged, axial traction could have placed a great deal of stress on these injured tissues. Neither the image from x-rays nor from fluoroscopy would have been able to predict such potentially disastrous consequences as these imaging techniques only indicate the status and relationship of the bony components of the cervical vertebral column (Flanders et al 1990, Mirvis et al 1988, Penning 1978). Additional techniques such as Magnetic Resonance Imaging are needed to identify the status of the soft tissue structures of the cervical vertebral column (Flanders et al 1990, [illegible] et al 1988). If detailed investigation of the bony structures is indicated, the [illegible]ed image provided by Computed Tomography is the best method for scanning these structures (Flanders et al 1990, Mirvis et al 1990).

The fluoroscopic video image from the initial sequence (Sequence 1) also provided the position of the cervical vertebrae while the athlete was wearing protective shoulder pads and headgear. It was noted that while both pieces of equipment were in place, the head and thorax of the athlete remained in neutral alignment. This information would lend additional support to those who believe that the injured football or hockey athlete can be stabilized in their equipment (Burney et al 1989, Denegar et al 1989, Feld et al 1988).

4.2.1 Hockey

**Table 4.3: Position of the Cervical Vertebrae During Helmet Removal (Hockey Subjects)**
Intervertebral disc space increasing (+)

| **SUBJECT #** | ***C2-C3** | ***C3-C4** | ***C4-C5** | ***C5-C6** |
|---|---|---|---|---|
| SUBJECT 2 | N/A | | 8.73 | N/A |
| SUBJECT 12 | 6.69 | | 4.41 | 8.72 |
| SUBJECT 13 | 8.39 | 6.80 | 5.89 | N/A |
| SUBJECT 14 | 17.25 | 8.29 | | N/A |
| SUBJECT 15 | 3.55 | 4.72 | | 0.68 |
| SUBJECT 16 | | 4.43 | | 0.00 |
| SUBJECT 17 | | 7.55 | | N/A |
| SUBJECT 18 | unacceptable | 2.00 | | N/A |
| SUBJECT 19 | 0.45 | unacceptable | 0.52 | 2.29 |
| SUBJECT 20 | 6.50 | | 8.65 | |
| AVERAGE | 42.83/6=**7.14** | 26.99/5=**5.40** | 28.2/5=**5.64** | 11.69/4=**2.92** |
| MAXIMUM | 17.25 | 8.29 | 8.73 | 8.72 |
| MINIMUM | 0.45 | 2.00 | 0.52 | 0.00 |

All values expressed in degrees. The values shown indicate the increase in angular displacement at the each intervertebral disc space during the helmet removal sequence #1 involving hockey subjects.
* Denotes the intervertebral disc space between two adjacent cervical vertebrae.

**Table 4.4: Position of the Cervical Vertebrae During Helmet Removal (Hockey Subjects)**
Intervertebral disc space decreasing (-)

| SUBJECT # | *C2-C3 | *C3-C4 | *C4-C5 | *C5-C6 |
|---|---|---|---|---|
| SUBJECT 2 | N/A | - 3.22 | | N/A |
| SUBJECT 12 | - 4.64 | - 5.40 | - 1.70 | - 12.97 |
| SUBJECT 13 | - 7.67 | - 5.00 | | N/A |
| SUBJECT 14 | - 16.40 | - 4.17 | - 6.13 | N/A |
| SUBJECT 15 | - 0.45 | - 8.98 | - 1.48 | - 0.28 |
| SUBJECT 16 | - 3.35 | | - 4.16 | |
| SUBJECT 17 | - 0.54 | - 7.5[illegible] | - 6.18 | N/A |
| SUBJECT 18 | unacceptable | | - 3.87 | N/A |
| SUBJECT 19 | - 3.70 | unacceptable | | |
| SUBJECT 20 | - 6.13 | - 7.62 | | - 2.68 |
| AVERAGE | 42.88/8=**5.36** | 41.94/7=**6.00** | 23.52/6=**3.92** | 15.93/3=**5.31** |
| MAXIMUM | - 16.40 | - 8.98 | - 6.18 | - 12.97 |
| MINIMUM | - 0.45 | - 3.22 | - 1.48 | - 0.28 |

All values expressed in degrees. The values shown indicate the decrease in angular displacement at the each intervertebral disc space during the helmet removal sequence #1 involving hockey subjects.
* Denotes the intervertebral disc space between two adjacent cervical vertebrae.

4.2.2 Football

**Table 4.5: Position of the Cervical Vertebrae During Helmet Removal (Football Subjects)**

Intervertebral disc space increasing (+)

| **SUBJECT #** | ***C2-C3** | ***C3-C4** | ***C4-C5** | ***C5-C6** |
|---|---|---|---|---|
| SUBJECT 3 | unacceptable | unacceptable | unacceptable | 0.95 |
| SUBJECT 4 | 4.34 | | 2.29 | N/A |
| SUBJECT 5 | unacceptable | unacceptable | unacceptable | 3.05 |
| SUBJECT 6 | N/A | unacceptable | unacceptable | 8.02 |
| SUBJECT 7 | unacceptable | 4.84 | 0.07 | N/A |
| SUBJECT 8 | unacceptable | unacceptable | | N/A |
| SUBJECT 10 | 8.50 | 5.69 | | 1.96 |
| SUBJECT 11 | | 9.73 | 1. [illegible] | N/A |
| SUBJECT 21 | 3.69 | 2.86 | | N/A |
| AVERAGE | 16.53/3=**5.51** | 24.82/5=**4.96** | 10.62/4=**2.66** | 13.98/4=**3.50** |
| MAXIMUM | 8.50 | 9.73 | 6.55 | 8.02 |
| MINIMUM | 3.69 | 1.70 | 0.70 | 0.95 |

All values expressed in degrees. The values shown indicate the increase in angular displacement at the each intervertebral disc space during the helmet removal sequence #1 involving football subjects.

* Denotes the intervertebral disc space between two adjacent cervical vertebrae.

**Table 4.6: Position of the Cervical Vertebrae During Helmet Removal (Football Subjects)**

Intervertebral disc space decreasing (-)

| SUBJECT # | *C2-C3 | *C3-C4 | *C4-C5 | *C5-C6 |
|---|---|---|---|---|
| SUBJECT 3 | unacceptable | unacceptable | unacceptable | |
| SUBJECT 4 | | - 5.34 | - 5.97 | N/A |
| SUBJECT 5 | unacceptable | unacceptable | unacceptable | - 6.99 |
| SUBJECT 6 | N/A | unacceptable | unacceptable | |
| SUBJECT 7 | unacceptable | - 2.42 | - 1.54 | N/A |
| SUBJECT 8 | unacceptable | unacceptable | - 4.59 | N/A |
| SUBJECT 10 | - 4.49 | - 3.33 | - 13.51 | - 3.10 |
| SUBJECT 11 | - 13.14 | unacceptable | unacceptable | N/A |
| SUBJECT 21 | - 1.11 | - 1.39 | - 3.15 | N/A |
| AVERAGE | 22.18/4=**5.55** | 12.48/4=**3.12** | 28.76/5=**5.75** | 18.71/3=**6.2** |
| MAXIMUM | - 13.14 | - 5.34 | - 13.51 | - 8.62 |
| MINIMUM | - 1.11 | - 1.39 | - 1.54 | - 3.10 |

All values expressed in degrees. The values shown indicate the decrease in angular displacement at the each intervertebral disc space during the helmet removal sequence #1 involving football subjects.
* Denotes the intervertebral disc space between two adjacent cervical vertebrae.

4.3 POSITION OF THE CERVICAL VERTEBRAE - Collar Application (Sequence #2)

In the majority of instances (16 of 19) in this study, the application of the collar went smoothly without any observed problems and did not cause great alterations in the position of the cervical vertebrae or the intervertebral disc spaces; a best case scenario (Tables 4.7 - 4.10). However, in some instances (Subjects #3, #4, and #11), difficulty was experienced with collar application which is a situation more apt to occur on the field (Denegar et al 1989). The data collected from these subjects showed large alterations in the position of the cervical vertebrae and angular displacement of the intervertebral disc spaces. For example, problems occurred applying the collar with Subject 3 Sequence 2. When examining Tables 4.9 and 4.10, it is interesting to note that data for Subject 3 Sequence 2 are the maximum values for displacement of the intervertebral disc spaces C2-C3 (13.99 degrees), C3-C4 (19.24 degrees) and C4-C5 (17.32 degrees). In the sports of football and hockey, prehospital personnel are likely to encounter difficulties applying a cervical collar to the neck of an injured athlete (Denegar et al 1989) due to many factors including: 1. the field setting (long grass or slippery ice), 2. weather conditions (for example wind or rain), and 3. the presence of the shoulder pads making proper sizing and application of the cervical collar difficult (Denegar et al 1989).

The cervical collar application procedure in this study was performed in a dry, well lit setting, and the data was collected **after** a practice run of the procedure. The presence of the fluoroscopic equipment did present some positional problems, as the research assistants were required to position themselves around the equipment. The most notable alteration was by that of the assistant removing the helmet, as she was required to position herself slightly off centre from the head of the subject (ideally the assistant would be in direct line with the subject's head (Plate 3.4). However, the fluoroscopic equipment also resulted in the subject lying on a table which was elevated, this placed him in a better position for helmet removal and collar application than occurs when he is lying on the field or ice surface. Even with the benefit of a practice run and a very good setting for application, alterations in the position of the cervical vertebrae occurred. Prehospital personnel attending to an injured athlete with a suspected CSI, may have the opportunity to practice dealing with and preparing athletes with suspected CSI, but do not have the benefit of a practice run on the acutely injured athlete, nor do they always work under optimal conditions. If the research team, working under very good conditions was unable to perform the cervical collar application procedure without significantly altering the position of the cervical vertebrae, it follows that prehospital personnel, usually working in less than optimal conditions, would produce similar or greater alterations in the displacement of the cervical vertebrae. This information would lend additional support to those who believe, that given an adequate airway, the injured football or hockey athlete should be stabilized in their equipment, on a long spine board and transported to the hospital for definitive assessment and treatment (Burney et al 1989, Denegar et al 1989, Feld et al 1988, Karbi et al 1988). It also may point out that practising a technique is of value and prehospital personnel should be encouraged to practice their emergency procedures.

4.3.1 Hockey

**Table 4.7: Position of the Cervical Vertebrae During Cervical Collar Application (Hockey Subjects)**
Intervertebral disc space increasing (+)

| SUBJECT # | *C2-C3 | *C3-C4 | *C4-C5 | *C5-C6 |
|---|---|---|---|---|
| SUBJECT 2 | N/A | 2.60 | 0.64 | N/A |
| SUBJECT 12 | | 1.72 | | |
| SUBJECT 13 | 4.16 | 1.33 | 3.56 | N/A |
| SUBJECT 14 | 7.48 | | 5.63 | N/A |
| SUBJECT 15 | 1.91 | 2.50 | | 1.29 |
| SUBJECT 16 | | | | |
| SUBJECT 17 | 4.71 | 0.56 | | N/A |
| SUBJECT 18 | unacceptable | 0.01 | | N/A |
| SUBJECT 19 | unacceptable | unacceptable | 0.72 | |
| SUBJECT 20 | | 11.49 | | |
| AVERAGE | 18.26/4=**4.57** | 20.21/7=**2.89** | 10.55/4=**2.64** | 1.29/1=**1.29** |
| MAXIMUM | 7.48 | 11.49 | 5.63 | 1.29 |
| MINIMUM | 4.16 | 0.01 | 0.64 | 1.29 |

All values expressed in degrees. The values shown indicate the increase in angular displacement at the each intervertebral disc space during the cervical collar application sequence #2 involving hockey subjects.
* Denotes the intervertebral disc space between two adjacent cervical vertebrae.

**Table 4.8: Position of the Cervical Vertebrae During Cervical Collar Application (Hockey Subjects)**
Intervertebral disc space decreasing (-)

| SUBJECT # | *C2-C3 | *C3-C4 | *C4-C5 | *C5-C6 |
|---|---|---|---|---|
| SUBJECT 2 | N/A | | | N/A |
| SUBJECT 12 | - 2.11 | - 1.06 | - 10.03 | - 0.72 |
| SUBJECT 13 | - 3.62 | - 2.85 | - 2.10 | N/A |
| SUBJECT 14 | - 2.66 | - 4.95 | | N/A |
| SUBJECT 15 | - 1.46 | | - 9.13 | |
| SUBJECT 16 | - 1.50 | - 0.49 | - 5.24 | - 2.25 |
| SUBJECT 17 | - 1.06 | | - 5.72 | N/A |
| SUBJECT 18 | unacceptable | - 0.04 | - 0.65 | N/A |
| SUBJECT 19 | unacceptable | unacceptable | | - 1.30 |
| SUBJECT 20 | - 1.89 | | - 11.64 | - 1.56 |
| AVERAGE | 14.3/7=**2.04** | 9.93/5=**1.88** | 44.51/7=**6.36** | 5.83/4=**1.46** |
| MAXIMUM | - 3.62 | - 4.95 | - 11.64 | - 2.25 |
| MINIMUM | - 1.06 | - 0.04 | - 0.65 | - 0.72 |

All values expressed in degrees. The values shown indicate the decrease in angular displacement at the each intervertebral disc space during the cervical collar application sequence #2 involving hockey subjects.
* Denotes the intervertebral disc space between two adjacent cervical vertebrae.

4.3.2 Football

**Table 4.9: Position of the Cervical Vertebrae During Cervical Collar Application (Football Subjects)**
Intervertebral disc space increasing (+)

| SUBJECT # | *C2-C3 | *C3-C4 | *C4-C5 | *C5-C6 |
|---|---|---|---|---|
| SUBJECT 3 | | 19.24 | | 3.06 |
| SUBJECT 4 | 7.86 | 2.95 | 8.50 | N/A |
| SUBJECT 5 | unacceptable | unacceptable | unacceptable | |
| SUBJECT 6 | unacceptable | unacceptable | unacceptable | |
| SUBJECT 7 | unacceptable | 3.78 | 2.00 | N/A |
| SUBJECT 8 | unacceptable | unacceptable | | N/A |
| SUBJECT 10 | | 5.04 | | 10.64 |
| SUBJECT 11 | 5.44 | 5.22 | 16.32 | N/A |
| SUBJECT 21 | 3.06 | 4.75 | 1.75 | N/A |
| AVERAGE | 16.36/3=**5.46** | 40.98/6=**6.83** | 28.57/4=**7.14** | 13.70/2=**6.85** |
| MAXIMUM | 7.86 | 19.24 | 16.32 | 10.64 |
| MINIMUM | 3.06 | 2.95 | 1.75 | 3.06 |

All values expressed in degrees. The values shown indicate the increase in angular displacement at the each intervertebral disc space during the cervical collar application sequence #2 involving football subjects.
* Denotes the intervertebral disc space between two adjacent cervical vertebrae.

**Table 4.10: Position of the Cervical Vertebrae During Cervical Collar Application (Football Subjects)**
Intervertebral disc space decreasing (-)

| **SUBJECT #** | ***C2-C3** | ***C3-C4** | ***C4-C5** | ***C5-C6** |
|---|---|---|---|---|
| SUBJECT 3 | - 13.99 | | - 17.32 | |
| SUBJECT 4 | - 4.95 | - 6.60 | - 2.07 | N/A |
| SUBJECT 5 | unacceptable | unacceptable | unacceptable | - 3.71 |
| SUBJECT 6 | unacceptable | unacceptable | unacceptable | - 3.16 |
| SUBJECT 7 | unacceptable | | | N/A |
| SUBJECT 8 | unacceptable | unacceptable | - 10.18 | N/A |
| SUBJECT 10 | - 7.93 | | - 10.40 | |
| SUBJECT 11 | - 1.34 | - 6.34 | - 11.65 | N/A |
| SUBJECT 21 | - 0.73 | - 3.57 | - 2.28 | N/A |
| AVERAGE | 28.94/5=**5.79** | 16.6/3=**5.53** | 53.9/6=**8.98** | 6.87/2=**3.44** |
| MAXIMUM | - 13.99 | - 6.60 | - 17.32 | - 3.71 |
| MINIMUM | - 0.73 | - 3.57 | - 2.07 | - 3.16 |

All values expressed in degrees. The values shown indicate the decrease in angular displacement at the each intervertebral disc space during the cervical collar application sequence #2 involving football subjects.
* Denotes the intervertebral disc space between two adjacent cervical vertebrae.

4.4 POSITION OF THE CERVICAL VERTEBRAE - Head Rest (Sequence #3)

As expected, resting the athlete's helmetless head and collared neck on the spine board resulted in large alterations in the position of the cervical vertebrae and angular displacement of the intervertebral disc spaces (Tables 4.11 through 4.14). Upon examination of the fluoroscopic video, the researcher could easily visualize the movement of the cervical vertebrae (Plate 4.2 & 4.3). Additionally, the angular displacement at the intervertebral disc spaces were apparent to the unaided eye. Of particular note was the

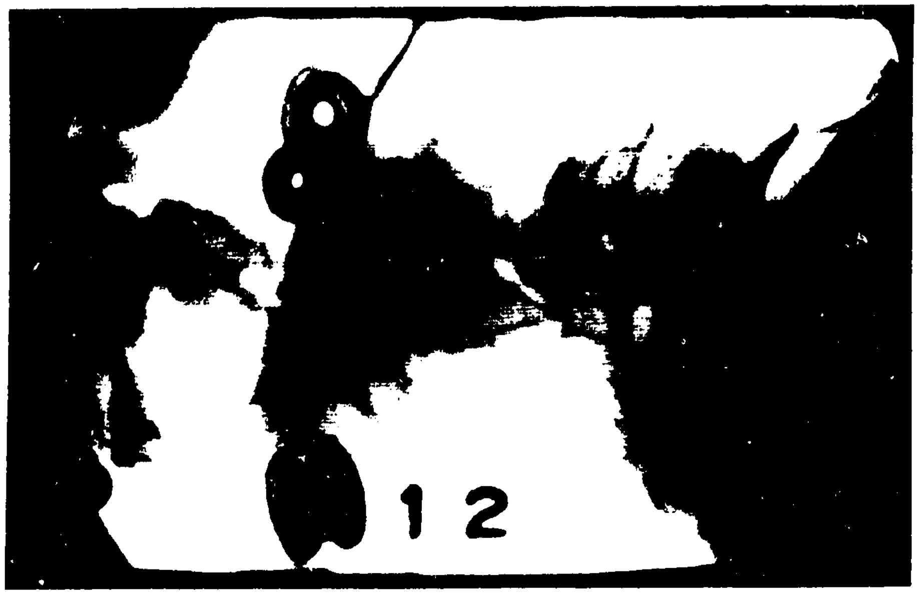



Plate 4.2: Fluoroscopic Image - Subject 12 Sequence 1


Plate 4.3: Fluoroscopic Image - Subject 12 Sequence 3

displacement observed in Subject #4, #10, #12, #14, #16, and #20.

This large amount of movement was probably due to two main factors. The first involved the presence of the protective shoulder pads which elevated the head and thorax region of the body as they rested on the spine board (Feld et al 1988). The elevation of the thorax resulted in a larger distance than normal existing between the posterior aspect of the athlete's head and the spine board (approximately 4.5 centimetres). Thus, there was more space between the head and the board resulting in a greater distance for the head and neck to hyper-extend before coming to rest on the spine board. The second factor associated with the large amount of movement of the cervical vertebrae was related to the inability of the cervical collar to limit hyper-extension of the head and neck. In all instances, for all of the football and hockey subjects, the cervical collar did not limit hyperextension of the head and neck (Tables 4.11 - 4.14). As reported earlier, the literature documents that the cervical collars used in this study (Stifneck™ Extrication Collars), while being the most common collar used by prehospital personnel, are inferior to all other methods of prehospital stabilization, with the exception of using a soft collar or no immobilization at all to limit extension, lateral bending and rotation (Karbi et al 1988, Podolsky et al 1983, Secor 1983). Compounding the ineffectiveness of these collars was the inability of the researcher to properly size and fit the collar to the subject's neck. This problem was caused by the presence of the protective shoulder pads which made application of the properly sized collar difficult (Denegar et al 1989).

Hyperextension of the head and neck appeared to be more pronounced in the football subjects than in the hockey subjects. This observation was the result of the larger and bulkier protective shoulder pads of the football subjects relative to the protective shoulder pads worn by the hockey subjects. As a result, the head and thorax of the football subjects were further away from the spine board and in turn, resulted in more space between the posterior aspect of the football subject's head and the spine board.

An unexpected finding from the data was the evidence that the cervical vertebrae were influenced by an anteroposterior rotational torquing force as the head was allowed to rest on the spine board. In many instances, the cervical vertebrae moved into a position of flexion, before beginning to extend and then hyperextended to finally rest on the spine board. Therefore, the data derived from the Sequence 3 in both hockey and football commonly involved more than one value. In some instances, the torquing involved as little as 1 degree, while in other instances, as much as 17 degrees. This torquing could be potentially disastrous to the injured football or hockey athlete with an unstable CSI. In the presence of an unstable CSI, stresses could be placed on the fracture sites, or soft tissue injury sites as the vertebrae were pulled in one direction (flexion) and then the other (extension/ hyperextension), thus exposing instabilities of the injury from multiple directions of stress.

4.4.1 Hockey

**Table 4.11: Position of the Cervical Vertebrae During Head Rest (Hockey Subjects)**
Intervertebral disc space increasing (+)

| SUBJECT # | *C2-C3 | *C3-C4 | *C4-C5 | *C5-C6 |
|---|---|---|---|---|
| SUBJECT 2 | N/A | | 9.02 | N/A |
| SUBJECT 12 | 0.46 | 7.56 | 5.69 | 6.23 |
| SUBJECT 13 | 3.94 | | 4.90 | N/A |
| SUBJECT 14 | 7.65 | 6.70 | 17.48 | |
| SUBJECT 15 | 0.70 | 9.21 | 1.91 | 0.79 |
| SUBJECT 16 | | 7.75 | | 10.61 |
| SUBJECT 17 | 8.64 | | 0.34 | N/A |
| SUBJECT 18 | 1.54 | 2.21 | 1.67 | N/A |
| SUBJECT 19 | 2.05 | | 2.33 | 3.63 |
| SUBJECT 20 | 4.78 | 7.04 | 11.39 | 10.55 |
| AVERAGE | 31.05/9=**3.45** | 44.96/7=**6.38** | 55.09/10=**5.51** | 31.81/5=**6.36** |
| MAXIMUM | 8.64 | 9.21 | 17.48 | 10.61 |
| MINIMUM | 0.46 | 2.21 | 0.34 | 0.79 |

All values expressed in degrees. The values shown indicate the increase in angular displacement at the each intervertebral disc space during the head rest sequence #3 involving hockey subjects.
* Denotes the intervertebral disc space between two adjacent cervical vertebrae.

**Table 4.12: Position of the Cervical Vertebrae During Head Rest (Hockey Subjects)**

Intervertebral disc space decreasing (-)

| SUBJECT # | *C2-C3 | *C3-C4 | *C4-C5 | *C5-C6 |
|---|---|---|---|---|
| SUBJECT 2 | N/A | - 8.21 | | N/A |
| SUBJECT 12 | - 5.14 | - 2.43 | - 3.60 | - 1.46 |
| SUBJECT 13 | - 0.75 | - 3.08 | - 1.22 | N/A |
| SUBJECT 14 | - 7.65 | - 5.69 | | - 0.89 |
| SUBJECT 15 | - 1.16 | - 2.76 | - 1.20 | |
| SUBJECT 16 | - 7.79 | | - 8.83 | |
| SUBJECT 17 | | - 1.19 | - 0.12 | N/A |
| SUBJECT 18 | | - 4.02 | - 3.89 | N/A |
| SUBJECT 19 | - 3.38 | - 1.18 | | |
| SUBJECT 20 | - 5.17 | - 5.63 | - 7.70 | |
| AVERAGE | 31.04/7=**4.43** | 34.19/9=**3.80** | 26.56/7=**3.79** | 2.35/=**1.18** |
| MAXIMUM | - 7.79 | - 8.21 | - 8.83 | - 1.46 |
| MINIMUM | - 0.75 | - 1.18 | - 0.12 | - 0.89 |

All values expressed in degrees. The values shown indicate the decrease in angular displacement at the each intervertebral disc space during the head rest sequence #3 involving hockey subjects.

* Denotes the intervertebral disc space between two adjacent cervical vertebrae.

4.4.2 Football

**Table 4.13: Position of the Cervical Vertebrae During Head Rest (Football Subjects)**
Intervertebral disc space increasing (+)

| **SUBJECT #** | ***C2-C3** | ***C3-C4** | ***C4-C5** | ***C5-C6** |
|---|---|---|---|---|
| SUBJECT 3 | 1.52 | | 10.25 | |
| SUBJECT 4 | 10.91 | 4.57 | 6.26 | N/A |
| SUBJECT 5 | unacceptable | unacceptable | unacceptable | 9.72 |
| SUBJECT 6 | unacceptable | unacceptable | unacceptable | 3.12 |
| SUBJECT 7 | 4.18 | 12.11 | 3.46 | N/A |
| SUBJECT 8 | unacceptable | unacceptable | 7.73 | N/A |
| SUBJECT 10 | 5.30 | 4.93 | 10.04 | 6.64 |
| SUBJECT 11 | 2.36 | 2.44 | 8.54 | N/A |
| SUBJECT 21 | 1.87 | 6.01 | 4.08 | N/A |
| AVERAGE | 26.14/6=**4.36** | 29.52/5=**5.90** | 50.36/7=**7.19** | 19.48/3=**6.49** |
| MAXIMUM | 10.91 | 12.11 | 10.25 | 9.72 |
| MINIMUM | 1.52 | 2.44 | 3.46 | 3.12 |

All values expressed in degrees. The values shown indicate the increase in angular displacement at the each intervertebral disc space during the head rest sequence #3 involving football subjects.
* Denotes the intervertebral disc space between two adjacent cervical vertebrae.

**Table 4.14: Position of the Cervical Vertebrae During Head Rest (Football Subjects)**
Intervertebral disc space decreasing (-)

| SUBJECT # | *C2-C3 | *C3-C4 | *C4-C5 | *C5-C6 |
|---|---|---|---|---|
| SUBJECT 3 | - 1.52 | | - 10.25 | |
| SUBJECT 4 | | | | N/A |
| SUBJECT 5 | unacceptable | unacceptable | unacceptable | |
| SUBJECT 6 | unacceptable | unacceptable | unacceptable | - 1.29 |
| SUBJECT 7 | - 12.86 | - 3.91 | - 2.99 | N/A |
| SUBJECT 8 | unacceptable | unacceptable | - 5.21 | N/A |
| SUBJECT 10 | - 8.57 | - 5.37 | - 3.84 | - 4.83 |
| SUBJECT 11 | - 7.73 | - 2.29 | - 4.56 | N/A |
| SUBJECT 21 | - 2.30 | - 1.85 | - 5.22 | N/A |
| AVERAGE | 32.98/5=**6.60** | 13.42/4=**3.36** | 32.07/6=**5.35** | 6.12/2=**3.06** |
| MAXIMUM | - 12.86 | - 5.37 | - 10.25 | - 4.83 |
| MINIMUM | - 1.52 | - 1.85 | - 2.99 | - 1.29 |

All values expressed in degrees. The values shown indicate the decrease in angular displacement at the each intervertebral disc space during the head rest sequence #3 involving football subjects.
* Denotes the intervertebral disc space between two adjacent cervical vertebrae.

## 4.5 SUMMARY

The techniques and procedures used in this study to remove a helmet, apply a Stifneck™ collar and rest the head of a football or hockey athlete on a long spine board resulted in alterations in the position of the athlete's cervical vertebrae. These positional changes could lead to further injury post trauma when dealing with an athlete having a suspected unstable CSI (Burney et al 1989, Vegso et al 1987). The literature documents that the majority of fractures, subluxations and unilateral or bilateral facet dislocations of the cervical vertebrae occur at the levels of C4, C5 and C6 (Karbi et al 1988, Miller et al 1978, Selecki et al 1970, Tator et al 1984b). The data collected in this study documents the angular displacement of the intervertebral disc spaces from greatest to least as: C4-C5 (5.41 degrees) C2-C3 (5.02 degrees), and C3-C4 (4.67 degrees), and C5-C6 (4.00 degrees). The combination of the highest incidence of fractures, and the large amount of angular displacement at these vertebral sites could lead to very serious complications if injury occurred in this region. If the vertebral fractures or soft tissue injuries do not compromise the stability of the cervical spine, then this movement might not be as potentially hazardous. However, if the vertebral fractures or soft tissue injuries render the cervical spine unstable, even the slightest alterations in the angular displacement at the intervertebral disc space of the cervical vertebral pairs could render the injured athlete paraplegic or quadriplegic. Jackson (1986) reported that an unstable CSI could potentially lead to cervical cord involvement, paralysis and death and therefore, due to the potentially serious consequences of unstable CSI, all suspicious CSI should be held in a stable position until screening assessments could be completed.

Unfortunately, at this time, the responding prehospital personnel do not have a definitive method of determining if any of the cervical vertebrae are fractured, if the soft tissue associated with the cervical vertebrae are injured, or if these injuries render the cervical spine unstable (Denegar et al 1989). In light of the data presented, when dealing with a football or hockey player with an adequate airway and a suspected CSI, whether stable or unstable, the responding prehospital personnel should leave the protective equipment in place, stabilize the injured athlete using a long spine board, tape, and foam pads and transport the individual to a medical facility for preliminary radiographic evaluation including the following views: lateral, anterior-posterior, open mouth, and right and left 45 degree oblique (Jackson 1986, Sweezey 1971, Watkins 1986), prior to equipment removal.

If the airway of the injured athlete must be accessed, the first attempt should involve removing the facemask or protective visor. In the majority of instances, the clips holding the mask or visor in place can be easily cut or unscrewed (Feld et al 1988). If the face shield cannot be removed in this manner, as a last resort, the helmet may be removed to gain access to the airway. From the observations of this study, a great deal of care must be taken when removing the helmet. It is very important that once the headgear is removed, the helmetless head be supported and not be allowed to drop into extension. Application of a cervical collar may assist the prehospital personnel in controlling the position of the head, but once the collar is in place, the head must not be released until it can be secured in a manner that prevents extension. The data from this study concurs with that of previous research, indicating that the cervical collar alone does not support the head and neck in its original position (Karbi et al 1988, Podolsky et al 1983, Secor 1983). Therefore, the athlete cannot be considered stabilized until he has been secured and stabilized on a long spine board (Cline et al 1985, Karbi et al 1988, Podolsky et al 1983).

In either case, whether the protective equipment was removed or left in place, securing the athlete to the long spine board is a very important step, as the long spine board will support the head, the neck, the thorax and the rest of the body (a short spine board is inappropriate as it will not adequately support the thorax or the rest of the body). Indeed, Karbi (1988) reported that in order to immobilize the cervical spine, the head and shoulders must be fastened to a common rigid plane. If a fracture is present in the cervical spine region, then stabilizing the head and thorax will help stabilize above and below the injury site. If an athlete fractured his tibia, proper on field procedure dictates that the fracture be stabilized below the ankle to at least above the knee. Affixing a stiff plastic cuff around the fracture site would not be considered proper stabilization. Yet in many instances, this procedure is, in effect, what prehospital personnel do when applying a cervical collar. In this case, a hard plastic cuff is placed around the suspected injury site and the prehospital personnel unfortunately believe that the injury has been stabilized. As a matter of procedure, the athlete should still be secured to a long spine board as a final means of stabilization prior to transportation. However, the extrication collar was never intended as a form of definitive stabilization. It was designed to assist prehospital personnel with accessory stabilization of the head while the spine board was being positioned and then while the athlete's head and torso were secured to the spine board (McSwain 1983).

# CHAPTER 5

## SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

In nature there are no punishments and no rewards - just consequences. - Pierce Harris

### 5.1 SUMMARY

This study was conducted to assess the most appropriate management protocols for prehospital personnel in dealing with suspected cervical spine injured football and hockey athletes. At the present time there is lack of consensus among prehospital personnel concerning specific aspects of initial care and assessment of injured athletes wearing protective equipment for the upper body (shoulder pads and helmets) who present with signs and symptoms of a cervical spine injury.

The literature documents that in the sports of football and hockey, cervical spine injuries most commonly occur as a result of an axial compressive load to the athletes head. The use of biomechanical principles has greatly aided in the analysis and identification of this injury and the resulting guidelines that determine the stability or instability of the injured cervical spine. In both sports, the occurrence of these injuries has been well documented and at the moment, appear to be on the decline as a result of the identification of the events leading to CSI and the implementation of rules designed to prohibit these events.

However, the controversy surrounding these injuries does not concern the injury itself, but the on field protocols for dealing with the injury once it has occurred. Two schools of thought have been identified. The first, advocate the removal of the athletes upper body protective equipment for initial prehospital preparation of the athlete prior to transportation to the hospital. The second, advocate the stabilization of the injured athlete without removal of the protective equipment from the upper body, as initial pre-hospital packaging of the athlete prior to transportation to the hospital.

The concern surrounding the maintenance or removal of the protective equipment for the upper body is directly related to the prehospital personnel's inability to conclusively identify the presence or absence of an unstable fracture of a cervical vertebrae or any other injury which would render the cervical spine unstable. In this instance, during stabilization and/or equipment removal, possible movement of the cervical spine may result, compounding the nature of the injury.

The methods and procedures of this study were designed to ascertain the position of the cervical vertebrae during 3 specific events: 1. helmet removal, 2. cervical collar application and 3. the resting of the helmetless head on a spine board. Twenty-one healthy male volunteers were recruited to participate in this study. Eleven subjects, with football experience, were assigned to a group representing football athletes and ten subjects, with hockey experience, were assigned to a group representing hockey athletes. Using the technique of fluoroscopy, the displacement of the cervical vertebrae was determined while performing the three events enumerated above. The data was analyzed frame by frame using video biomechanical analysis with computer assisted digitization.

The results showed significant alterations in the position of the cervical vertebrae during helmet removal, cervical collar application and head rest, most significantly at the levels of C4, C5, and C6, the levels most commonly associated with stable and unstable cervical spine fractures, subluxations and unilateral or bilateral dislocations resulting from axial compressive loading. Therefore this study clearly supports the stabilization and transportation of football and hockey subjects with suspected CSI, without airway management complications, in their respective protective equipment in order to reduce further trauma.

It must be noted that this study was performed with normal volunteers. Although studying normal volunteers may be a useful model for initial assessment of the position of the cervical vertebrae during helmet removal, cervical collar application and head rest, it is difficult to decide how to extrapolate these results to the spine-injured athlete. The conclusions and recommendations resulting from this study are based on the presumption that a procedure that would alter the position of the cervical vertebrae in normal volunteer would do the same in the injured athlete. However, application to this setting should be made cautiously.

## 5.2 CONCLUSIONS

Based on the results of this study, the following conclusions may be drawn:

A. Taking into account equipment and techniques used in this study, in order to prevent unnecessary movement of the cervical spine of an injured football or hockey player presenting signs and symptoms of a cervical spine injury, without (airway) complications, the athlete's equipment should not be removed. The athlete should be stabilized as found, secured to a long spine board and transported to hospital for preliminary radiographic prior to equipment removal.

B. Two person helmet removal, cervical collar application, and head rest, resulted in movement of the cervical vertebrae which may be unnecessary and could lead to complications.

C. Stifneck™ collars do not adequately limit/prevent extension of the cervical vertebrae of a helmetless football or hockey player wearing protective shoulder pads.

Therefore, the hypothesis' presented were accepted or rejected as follows:

**Hypothesis 1**

Helmet removal using the standard two person technique resulted in angular displacement between adjacent vertebrae, thus the hypothesis was accepted.

**Hypothesis 2**

Application of a cervical collar resulted in angular displacement of adjacent cervical vertebrae, thus the hypothesis was rejected.

**Hypothesis 3**

Resting of a helmetless head, while the subject is wearing shoulder pads, resulted in angular displacement between adjacent vertebrae, thus the hypothesis was accepted.

## 5.3 CLINICAL IMPLICATIONS

Following are three possible procedures that may be followed by prehospital personnel (based on their knowledge and skill), when dealing with a suspected CSI football or hockey athlete with an unobstructed airway. Based on the results of this study, they are listed from the most conservative approach to the most aggressive approach.

1. Regardless of skill or knowledge level, the most conservative on field procedure, resulting in minimal amount of movement of the cervical spine, would involve securing and stabilizing the athlete as found to a long spine board and transporting the individual to the hospital.

2. The second procedure which might be considered moderately hazardous and could result in unnecessary movement of the cervical spine, would involve removing the facemask or visor from the injured athlete, securing and stabilizing the individual to a long spine board and transporting to the hospital. One would consider using this technique if a) the athlete was having difficulty breathing, b) had swallowed his tongue or c) was choking on something.

3. The most aggressive on field procedure, which would result in angular displacement between adjacent vertebrae, slight axial traction of the cervical vertebrae, and angular displacement of individual vertebrae, would involve removing the helmet, applying a cervical collar to the neck of the athlete, blocking up the helmetless head in order to limit extension, securing and stabilizing the individual to a long spine board and transporting to the hospital. As the data from this study showed, resting the helmetless

head on the spine board, resulted in the greatest angular displacement of individual cervical vertebrae. Blocking the head up (using something to prevent extension of the cervical spine) may reduce some of this potentially dangerous movement. The author does not recommend this third procedure unless absolutely necessary. One would consider using this technique if a) the facemask or visor could not be safely removed and interfered with adequate ventilation or the responding personnel's ability to restore the airway, b) the helmet was so loose that adequate spinal immobilization could not be obtained with the helmet in place, c) signs or symptoms were present that indicated the presence of an open or closed head injury which required direct inspection or d) significant haemorrhaging from the cranium was present and required direct pressure.

There are two additional points to consider. First, CSI in football and hockey does not occur often, but when it does, the injuries can be catastrophic. On field management of these injuries leaves little room for error. Unfortunately due to the low incidence of these injuries, AT's, EMT's, Physical Therapists and Team Physicians do not deal with these injuries often and unless the procedures are regularly practised (as in maintaining CPR certification), the specific skills needed are lost.

Second, in the majority of instances, hospital personnel are not trained in helmet removal procedures. Therefore, if the helmet is left in place a person qualified in helmet removal techniques must travel with the athlete to the hospital, so that the helmet can be removed correctly when the need arises. In many instances, orderlies, x-ray technicians and even physicians could compound the nature of CSI's, by inappropriate management of the patient.

5.4 RECOMMENDATIONS

A. This study examined the position of the cervical vertebrae using a two person method of helmet removal. As a one person method of helmet removal is also used, the position of the cervical vertebrae should be examined using this technique.

B. Athletic therapists performed the helmet removal and cervical collar application procedures. As EMT's are also trained in these techniques, a repeat investigation having EMT's perform the procedures would be beneficial. As it is EMT's who package the injured participant and transport him/her to the hospital, using these personnel to collect the data would enhance the external validity (generalizability) of the results.

C. The cervical spines examined, were healthy and free of abnormalities thus, the data gathered represented the position of the cervical vertebrae of a clinically stable spine. It would be advantageous to perform these procedures on spinal columns that are unstable as this procedure would be more applicable to the injured athlete with an unstable cervical spine injury. However, creating instabilities in prepared cadavers was not deemed acceptable as the surrounding soft tissues would not respond in the same manner as live tissue. A possible solution unavailable to this researcher, would be to use fresh cadavers, immediately following death. Using fresh cadavers would permit the surrounding soft tissues to respond more like live tissue.

D. To help ensure a high degree of external validity it is recommended that more than one individual locate the anatomical landmarks on the vertebrae and digitize them. In this manner in addition to confirming the intraobserver reliability of the data points, comparison of data points from two individuals will assist in gauging the interobserver reliability of the digitized anatomical landmarks.

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APPENDIX A

## THE GLASGOW COMA SCALE

The Glasgow Coma scale is based upon eye opening, verbal and motor responses, and is a practical method of monitoring the level of consciousness of an injured athlete. Each response on the scale is given a number; the responsiveness of the athlete can be expressed by the summation of the numbers.

| | | | |
|---|---|---|---|
| **Eyes** | Open | Spontaneously | 4 |
| | | To verbal command | 3 |
| | | To pain | 2 |
| | | No Response | 1 |
| **Best Motor Response** | To verbal command | Obeys | 6 |
| | To painful stimulus | Localizes pain | 5 |
| | | Flexion-withdrawal | 4 |
| | | Flexion-abnormal (Decorticate rigidity) | 3 |
| | | Extension (Decerebrate rigidity) | 2 |
| | | No response | 1 |
| **Best Verbal Response** | | Oriented and converses | 5 |
| | | Disoriented and converses | 4 |
| | | Inappropriate words | 3 |
| | | Incomprehensible words | 2 |
| | | No response | 1 |
| **Total Score** | | | |

# APPENDIX B

# ANATOMY OF THE CERVICAL SPINE

As described by: Gray 1974, Hoppenfeld 1976, Sherk 1989

The vertebral column is the core structural unit of the trunk and plays a key role in the movement and maintenance of the upright biped stance. Typically, the human vertebral column consists of 33 vertebrae: 7 cervical, 12 thoracic, 5 lumbar, 5 sacral (fused to form the sacrum) and 4 coccygeal (the first is often separate and the remaining three are fused). The human vertebral column is therefore, made up of a total of twenty-six (or twenty-seven) moveable parts. Even though the general structure of the vertebrae is similar from one region to another, each of the five vertebral regions is characterized by specific differences in structure and function. The cervical vertebrae are the smallest and superior most vertebrae found in the spinal column and permit an extremely wide range of movement for both the head and neck. The cervical spine has three functions:

1. to provide support and stability for the head.

2. its articulating vertebral facet allows for the heads range of motion.

3. to provide housing for and protect the passage of the spinal cord and the vertebral artery, in addition to permitting the passage of spinal nerves.

Two landmarks on the body help to locate and orient the position of the cervical vertebrae. The first is the Hyoid bone, a horseshoe shaped bone situated above the thyroid cartilage. On a horizontal plane, the third cervical vertebrae (C-3) is opposite this bone. To palpate the hyoid, cup your hand around your neck just below your chin and above the thyroid cartilage. Swallow, as you do so the movement of the hyoid bone becomes palpable. The second easily found landmark is located on the posterior surface of the neck; it is the spinous process of the seventh and last cervical vertebrae (C-7). This long process is known as the vertebral prominens and can be found by placing your fingers at the base of your neck and bending your head forward, dropping your chin to your chest. As you do this a, lumpy bump will become obviously palpable.

Of the seven cervical vertebrae, the third through seventh can be considered typical, while the first two are atypical. Concentrating on the typical vertebrae first, they have many common bony characteristics:

1. - each vertebrae consists of two essential parts; a solid anterior portion (body) and a posterior segment (arch).

2. Body - the largest part of the vertebrae, it is small and kidney shaped, and is thicker from side to side than front to back. The body is concave on its superior surface, lipped by a raised edge of bone on its margins and convex on its inferior surface. The core of the body is comprised of cancellous bone and surrounded by an outer covering of bone (cortical shell).

3. Vertebral Arch - consist of two parts; the pedicles which are attached to the body midway between the upper and lower borders and directed outward and backwards. The laminae are narrow and long, meeting and overlapping each other to enclose the posterior border of the vertebral foramen.

4. Vertebral Foramen - a foramen is a hole or an opening. Thus the vertebral foramen is a hole in a vertebrae, this opening allows the safe passage of the spinal cord. It is bounded by the body anteriorly, and the pedicle and lamina laterally and posteriorly.

5. Transverse Process - these processes project laterally from the vertebral bodies and roots of the pedicles. They are short, directed downward, outward and forward, bifid at their extremity and marked by a groove along their anterior surface which runs downward and outward from the body and serves for the transmission of one of the cervical nerves. At their base they are pierced by a foramen. A distinctive feature found only in the cervical vertebrae.

6. Transverse Foramen - openings which permit the passage of a plexus of nerves and the vertebral artery, and vein on its way to and from the inner skull.

7. Spinous Process - projecting from the posterior-most aspect of the vertebrae (C-2 to C-7) is a process which is bifid. The spinous processes of C-2 to C-5 are short in relation to those of C-6 and C-7 which are longer and tapered at the ends.

8. Articular Process - processes that arise from the junction of the pedicles with the laminae. The two superior processes project upward, with the articular surfaces (facets) facing posterior; the two inferior processes project downward, with the articular surfaces (facets) facing anterior. The superior processes articulate (contact) with the inferior processes of the vertebrae above it, while the inferior processes articulate with the superior processes of the vertebrae below it. These articulations form connections known as facet joints.

The first and second cervical vertebrae are considered atypical largely due to their shape. They display the above mentioned bony characteristics of cervical vertebrae, with the following exceptions. The first cervical vertebrae or the atlas, is the superior most vertebrae and its superior articular facets articulates directly with the occipital condyles of the occipital bone of the skull (this joint allows the nodding motion of the head). It has no typical body, consisting instead of a bony ring with two lateral masses. Compared to other cervical vertebrae, the atlas has very long, wide transverse processes.

The second cervical vertebrae or axis, works in very close association with the atlas. It is easily identified by a relatively large tooth-like projection known as the odontoid process or the dens. This process projects upward and occupies the anterior compartment of the vertebral foramen of the atlas. The dens serves as the pivot (axis) of rotation of the atlas (this joint allows the side to side motion of the head, as when indicating "no").

Turning our attention to the soft tissue structures of the cervical vertebral column, a number of ligaments and other structures of importance must be identified:

1. Accessory Atlantoaxial Ligaments - span from the lateral masses of the atlas merging at the base of the odontoid process and the body of the axis.

2. Anterior Longitudinal Ligament - is closely attached to the intervertebral discs and margins of the vertebral bodies. It attaches from the outer surface of the (basilar portion) of the occipital bone of the skull to the anterior surface of the vertebral bodies and extends to the anterior surface of the sacrum.

3. Interspinous Ligament - weak ligaments joining the lower surface of one spine to the upper surface of another.

4. Inter-transverse Ligament - weak ligaments joining the lower surface of one transverse process to the upper surface of the next.

5. Intervertebral Disc - has four components: the nucleus pulposus at the interior of the disc, two cartilaginous end-plates on the facing vertebral surfaces and the annulus fibrosus. The discs are contained more closely in the cervical spine than at any other levels due to the concave surface of the body of the lower vertebrae and the convex surface of the body of the upper vertebrae. The disc serves three important functions:

a) acts as a shock absorber

b) the elastic annulus allows for transient compression of the fluid nucleus

c) it allows fluid displacement within the elastic container permitting movement between adjacent vertebrae including: rocker motions, rotary movements, and gliding on the horizontal plane.

6. Ligamentum Flavum - very important to the cervical spine as a stabilizer in flexion. It attaches to the anterior surface of the vertebral arch above, and to the superior margin of the lamina of the vertebrae below. There are two of these ligaments at each level - a right and a left. They merge with the interspinous ligaments posteriorly and with the fibrous capsule of the synovial facet joints anteriorly.

7. Ligamentum Nuchae - an essential structure that maintains the head in an extended position and a major stabilizer of the head and cervical spine. It extends from the vertebrae prominens (C-7) to the external occipital protuberance of the occipital bone of the skull.

8. Posterior Longitudinal Ligament - is widest in the cervical spine and narrows as it descends, it is attached to the intervertebral discs and margins, free from the vertebral body where veins and arteries enter and leave. It is situated within the spinal cord, extending from the body of the axis down to the sacrum, and extends upward into the skull and the membrane tectoria onto the inner surface of the (basilar portion) of the occipital bone of the skull.

9. Supraspinous Ligament - strong ligaments connecting the tips of the spinous processes; it is continuous with the ligamentum nuchae.

10. Transverse Ligament - extends across the ring of the atlas to enclose the odontoid process.

# APPENDIX C

Informed Consent Form For The Proposed Study:

**Movement of the Cervical Vertebrae During Helmet Removal**

**and Cervical Collar Application in Football and Hockey**

Subject Consent

I, ______________________________________________ do hereby agree to

(please print name)

participate in the study entitled "The Effects of Equipment Removal (helmets, shoulder pads) on Neck Motion as Determined by Radiographic Imaging", to be conducted by Dr. D. Syrotuik or athletic therapist Rosanne Prinsen and their colleagues including an x-ray technician and a radiologist.

I acknowledge that the nature of this study, its purpose, its possible effects and the research procedures have been explained to me, and that any questions that I have asked have been answered to my satisfaction. I understand the lack of direct benefit and the implications of being a subject in this study. I know that I may ask now, or in the future any questions about the study or research procedures. I have been assured that the personal records relating to these experimental protocols will be kept confidential and that no information will be released or printed that would disclose personal identity without my permission.

I understand that the performance of the study is not intended as a form of remedial treatment. I have also been advised that I may withdraw from participation in the study at anytime without prejudice.

______________________________

Subjects Signature

______________________________

Date

______________________________

Address

______________________________

Phone Number

I was a witness during the explanation referred to above and to the signature.

______________________________

Signature of Witness

______________________________

Date

______________________________

Signature of Researcher

______________________________

Date

## APPENDIX D

## GLEN SATHER SPORTS MEDICINE CLINIC -

## X-RAY GUIDELINES AND PROCEDURES

### GENERAL CONSIDERATIONS

### I. RADIATION SAFETY

1. All equipment must conform to the requirements of the Radiation Emitting Devices Act and the Radiation Protection Act (Chapter R2.1 1985). These acts apply to both new and used equipment.

2. All operators of X-ray equipment shall abide by the Radiation Protection Act and Radiation Protection Regulation (Alberta Regulation, 162/90) effective January 1, 1991.

3. All technical staff should wear thermoluminescent dosimeters. Monitors should be returned promptly to Ottawa every three months. Excessive radiation received and noted on the exposure report should be immediately reported to your supervisor.

4. Every precaution must be taken to minimize radiation hazards both to the patient and technologist. Protective devices must be utilized by patients, technologists and radiologists. All personnel must at all times keep as far away from the useful beam as is practical.

    i) Operators should remain inside the control booth or behind protective screens when making x-ray exposures. If this is not practical, protective clothing must be worn.

ii) A pregnant technologist shall inform her employer as soon as her pregnancy is known. The owner shall ensure that radiation exposure to the pregnant worker is kept as low a reasonably achievable (ALARA principle).

iii) Holding devices should be used to support children or weak patients. Protective devices must be provided if parents, escorts or other personnel are called to assist.

iv) Gonadal shields must used on all examinations.

II TECHNICAL CONSIDERATIONS

1. Exposurc of patients must be kept to the lowest practical value without compromising the diagnostic quality of the study.
2. X-ray beam must be well-collimated to the area of clinical interest.
3. Gonadal and other shielding devices must be used where appropriate particularly for blood-forming organs, gonads and thyroid glands of children.
4. Films should be identifies by patient's name, age, department and location and date of examination. Accurate placcment of (L) & (R) side markers is mandatory and should be included in the exposed area in the periphery of the radiograph.
5. Technologists should review films after processing to verify the technique used and to assess the quality of the study.
6. Proper technical factors, positioning of the patient and instruction to patients will prevent retakes.

APPENDIX E

## DEPARTMENT OF RADIOLOGY -

## FLUOROSCOPY GUIDELINES AND PROCEDURES

University of Alberta Hospitals Mobile Radiological Examinations 4.16.2.1

1. In the interest of radiation safety and image quality, mobile radiological examinations shall be limited to situations where examinations within the Department of Radiology and Diagnostic Imaging are no feasible due to patient condition.
2. To aid in maintaining the equipment in working order, the set-up of fluoroscopic and radiographic equipment shall be done by or under the supervision of Department of Radiology personnel.
3. The operator of the mobile unit will be responsible for providing appropriate protection to personnel who must remain in close proximity to the patient during the examination.
4. Where possible, gonadal shielding shall be provided for the patient.
5. During radiographic procedures:

5.1 Radiographic technologists must not "hold" patients during radiological examinations. Care unit personnel will be requested to hold patients as required.

5.2 If no one is available or willing to support the patient for the x-ray examination the radiologic technologist may perform the examination with the patient in supine position.

5.3 The radiologic technologist must warn care unit personnel prior to making an exposure. Adequate time must be permitted for uninvolved personnel to shield themselves or move from the patient vicinity.

6. Only medical staff and residents will be allowed to operate the fluoroscopic equipment. The physician using the fluoroscopic equipment will be responsible for operating the equipment in a safe manner.

7. During fluoroscopic procedures:

7.1 Appropriate protection must be worn by all personnel who cannot leave the area.

7.2 The operation of the fluoroscopic equipment must be supervised by a radiologic technologist or radiologist.

7.3 Fluoroscopic exposure times must be kept to a minimum following the principle ALARA (As Low As Reasonably Achievable). The radiologic technologist shall keep the physician informed of the exposure time.

7.4 Should fluoroscopy time exceed 15 minutes, the technologist must inform the Radiation Safety Officer as soon as possible.

## APPENDIX F

## PROCEDURES FOR REMOVING THE HELMET AND SHOULDER PADS

As described by: Denegar et al 1989, Vegso et al 1991, Vegso et al 1987

Although certain diagnostic x-rays can be taken with some of the equipment in place, eventually the helmet and shoulder pads must be removed.

STEP ONE

As the athletes head is released from the backboard, manual stabilization should be reapplied.

STEP TWO

Before removing the helmet, the chin strap must be cut and discarded. In addition, the cheek pads should be removed from the helmet to allow better control of the helmet during removal.

STEP THREE

A second assistant places one hand on the athletes mandible with a thumb on one side and the middle finger on the opposite side. The other hand is placed behind the athletes neck, and gentle pressure is applied to the occipital region. Stabilization is thus transferred from the first to second assistant and control of the head is maintained.

STEP FOUR

The leader spreads and pulls the helmet off in a straight line with the spine. Spreading of the helmet is enhanced by placing the index fingers in the ear holes.

STEP FIVE

After the helmet is removed the first assistant may once again stabilize the head and neck, by placing a hand on each side of the head and firmly grasping the athletes mandible and base of the skull.

STEP SIX

At this time the shoulder pads may be removed. The jersey is cut away, the straps under the players arms and the lacing on the front of the shoulder pads are also cut.

STEP SEVEN

As manual stabilization is maintained the pads can be carefully separated and slid over the athletes head.

APPENDIX G

# PROCEDURES FOR APPLYING THE CERVICAL COLLAR

As described by California Medical Products -
the makers of the Stifneck™ Extrication Collar

1. SIZING

Step One:with the athlete manually maintained in neutral position, measure the height between the Trapezius muscle (at the base of the neck)and the bottom of the chin. These are the support points of the collar.

Step Two:Use your fingers to measure this distance (ie. three finger widths)

Step Three:Select the correct size collar by measuring from the sizing post (which is in alignment with the chin piece) to the lower edge of the rigid plastic

2. ASSEMBLY

Step One: push the black fastener firmly into the hole

Step Two: Preform the collar by sharply flexing it inward in the area of the hooked velcro (this simplifies application by conforming the collar to the athletes neck).

3. APPLICATION - SUPINE ATHLETE

While the first assistant stabilizes the athlete's head and neck, the second assistant carries out the following steps:

Step One:Slide the back panel behind the patients neck until the velcro can be grasped - but no further

Step Two:As soon as the looped velcro is visible, turn your attention to correct chin piece placement

Step Three:Use both hands to slide the collar up the chest wall so that it supports the chin. (When properly applied the athletes chin will come to the edge of the chin piece.)

Step Four:With the collar in correct position, fasten the velcro strap to the collar, ensuring a snug fit.

NOTE: Sizing and application is the same in adults and children.

"The goal of pre-hospital care is the prompt delivery of the patient to an appropriate medical facility **without** causing secondary damage or aggravating the initial injury."

Transfer to a rigid spine board is a key step in this process.

APPENDIX H

## POSITION OF INDIVIDUAL CERVICAL VERTEBRAE DURING HELMET REMOVAL, CERVICAL COLLAR APPLICATION AND HEAD REST

Table H1: Position of the Cervical Vertebrae during

Helmet Removal (Hockey Subjects)

| **SUBJECT #** | ***C2** | ***C3** | ***C4** | ***C5** | ***C6** |
|---|---|---|---|---|---|
| SUBJECT 2 | | 2.02 | 5.13 | 4.40 | |
| SUBJECT 12 | 5.78 | 6.12 | 3.23 | 4.38 | 10.89 |
| SUBJECT 13 | 6.78 | 4.46 | 3.17 | 5.03 | |
| SUBJECT 14 | 6.52 | 14.73 | 11.34 | 5.21 | |
| SUBJECT 15 | 5.16 | 5.52 | 3.66 | 6.19 | 5.65 |
| SUBJECT 16 | 3.87 | 0.48 | 4.94 | 0.79 | 0.78 |
| SUBJECT 17 | 2.81 | 3.36 | 4.19 | 1.99 | |
| SUBJECT 18 | 1.23 | N/A | 1.40 | 2.46 | |
| SUBJECT 19 | 3.50 | 0.36 | 3.55 | 3.87 | 6.35 |
| SUBJECT 20 | 10.48 | 4.35 | 5.16 | 3.49 | 0.08 |
| AVERAGE | **5.13** | **4.60** | **4.58** | **3.78** | **4.75** |
| MAXIMUM | 10.48 | 14.73 | 11.34 | 6.19 | 10.89 |
| MINIMUM | 1.23 | 0.48 | 1.40 | 0.79 | 0.78 |

All values expressed in degrees. The values shown indicate the maximum positional change of the vertebrae indicated during the helmet removal sequence involving hockey subjects.
* Denotes the cer..cal vertebrae indicated.

Table H2: Position of the Cervical Vertebrae during

Helmet Removal (Football Subjects)

| SUBJECT # | *C2 | *C3 | *C4 | *C5 | *C6 |
|---|---|---|---|---|---|
| SUBJECT 3 | 4.14 | N/A | N/A | 1.37 | 2.32 |
| SUBJECT 4 | 4.11 | 8.27 | 4.15 | 1.93 | |
| SUBJECT 5 | 3.07 | N/A | N/A | 5.05 | 3.22 |
| SUBJECT 6 | N/A | 0.14 | 2.35 | 0.18 | 8.12 |
| SUBJECT 7 | N/A | 2.52 | 2.45 | 2.68 | |
| SUBJECT 8 | 4.61 | 4.94 | 5.53 | 0.94 | |
| SUBJECT 10 | 11.54 | 12.32 | 13.83 | 4.32 | 2.25 |
| SUBJECT 11 | 4.45 | 8.70 | 1.10 | 0.00 | |
| SUBJECT 21 | 1.32 | 2.66 | 2.74 | 0.88 | |
| AVERAGE | **4.75** | **5.65** | **4.59** | **1.93** | **3.98** |
| MAXIMUM | 11.54 | 12.32 | 13.83 | 5.05 | 8.12 |
| MINIMUM | 1.32 | 0.14 | 1.10 | 0.00 | 2.25 |

All values expressed in degrees. The values shown indicate the maximum positional change of the vertebrae indicated during the helmet removal sequence involving football subjects.
* Denotes the cervical vertebrae indicated.

Table H3: Position of the Cervical Vertebrae during

Cervical Collar Application (Hockey Subjects)

| **SUBJECT #** | ***C2** | ***C3** | ***C4** | ***C5** | ***C6** |
|---|---|---|---|---|---|
| SUBJECT 2 | N/A | 8.90 | 6.26 | 5.62 | |
| SUBJECT 12 | 5.95 | 3.85 | 4.68 | 5.79 | 6.52 |
| SUBJECT 13 | 2.69 | 1.09 | 2.59 | 1.61 | |
| SUBJECT 14 | 5.81 | 2.65 | 2.30 | 3.33 | |
| SUBJECT 15 | 2.97 | 2.63 | 5.13 | 4.00 | 2.92 |
| SUBJECT 16 | 5.27 | 3.77 | 4.26 | 0.97 | 3.22 |
| SUBJECT 17 | 3.61 | 1.90 | 2.46 | 3.25 | |
| SUBJECT 18 | 2.53 | 0.39 | 0.42 | 1.07 | |
| SUBJECT 19 | 0.59 | 5.97 | 2.01 | 1.29 | 2.59 |
| SUBJECT 20 | 3.13 | 1.24 | 13.18 | 1.54 | 0.02 |
| AVERAGE | **3.62** | **3.24** | **4.33** | **2.85** | **3.05** |
| MAXIMUM | 5.95 | 8.90 | 13.18 | 5.79 | 6.52 |
| MINIMUM | 0.59 | 0.39 | 0.42 | 0.97 | 0.02 |

All values expressed in degrees. The values shown indicate the maximum positional change of the vertebrae indicated during the cervical collar application sequence involving hockey subjects.
* Denotes the cervical vertebrae indicated.

Table H4: Position of the Cervical Vertebrae during

Cervical Collar Application (Football Subjects)

| **SUBJECT #** | ***C2** | ***C3** | ***C4** | ***C5** | ***C6** |
|---|---|---|---|---|---|
| SUBJECT 3 | 6.25 | 7.74 | 10.50 | 6.82 | 3.75 |
| SUBJECT 4 | 9.57 | 5.02 | 8.80 | 0.39 | |
| SUBJECT 5 | 3.02 | N/A | N/A | 0.71 | 3.01 |
| SUBJECT 6 | 5.72 | 2.57 | 5.11 | 0.81 | 2.36 |
| SUBJECT 7 | N/A | 8.26 | 4.49 | 2.48 | |
| SUBJECT 8 | N/A | N/A | 6.36 | 3.73 | |
| SUBJECT 10 | 7.30 | 2.28 | 4.29 | 6.12 | 4.53 |
| SUBJECT 11 | 7.97 | 5.44 | 8.13 | 16.34 | |
| SUBJECT 21 | 7.66 | 6.75 | 4.15 | 3.73 | |
| AVERAGE | **6.78** | **5.44** | **6.48** | **4.57** | **3.41** |
| MAXIMUM | 9.57 | 8.26 | 10.50 | 16.34 | 4.53 |
| MINIMUM | 3.02 | 2.28 | 4.15 | 0.39 | 2.36 |

All values expressed in degrees. The values shown indicate the maximum positional change of the vertebrae indicated during the cervical collar application sequence involving football subjects.
* Denotes the cervical vertebrae indicated.

Table H5: Position of the Cervical Vertebrae during

Head Rest (Hockey Subjects)

| **SUBJECT #** | ***C2** | ***C3** | ***C4** | ***C5** | ***C6** |
|---|---|---|---|---|---|
| SUBJECT 2 | | 17.08 | 20.78 | 11.61 | |
| SUBJECT 12 | 8.89 | 12.61 | 11.31 | 6.02 | 7.33 |
| SUBJECT 13 | 14.37 | 11.18 | 8.10 | 4.42 | |
| SUBJECT 14 | 9.19 | 16.76 | 13.44 | 9.86 | |
| SUBJECT 15 | 17.37 | 17.67 | 10.00 | 9.30 | 8.66 |
| SUBJECT 16 | 10.14 | 11.09 | 3.72 | 12.18 | 1.58 |
| SUBJECT 17 | 13.84 | 5.20 | 6.40 | 6.17 | |
| SUBJECT 18 | 8.76 | 11.90 | 10.41 | 8.20 | |
| SUBJECT 19 | 4.68 | 4.56 | 5.75 | 3.42 | 0.22 |
| SUBJECT 20 | 13.96 | 13.61 | 16.85 | 8.52 | 2.03 |
| AVERAGE | **11.24** | **12.17** | **10.68** | **7.97** | **3.96** |
| MAXIMUM | 17.37 | 17.67 | 20.78 | 12.18 | 8.66 |
| MINIMUM | 4.68 | 4.56 | 3.72 | 3.42 | 0.22 |

All values expressed in degrees. The values shown indicate the maximum positional change of the vertebrae indicated during the head rest sequence involving hockey subjects.
* Denotes the cervical vertebrae indicated.

Table H6: Position of the Cervical Vertebrae during

Head Rest (Football Subjects)

| **SUBJECT #** | ***C2** | ***C3** | ***C4** | ***C5** | ***C6** |
|---|---|---|---|---|---|
| SUBJECT 3 | 18.39 | 17.51 | 16.00 | 22.57 | 4.05 |
| SUBJECT 4 | 22.92 | 15.22 | 10.88 | 2.53 | |
| SUBJECT 5 | 18.02 | 16.63 | 9.13 | 11.29 | 4.13 |
| SUBJECT 6 | 18.73 | 11.96 | 20.24 | 5.28 | 2.90 |
| SUBJECT 7 | 14.16 | 23.49 | 21.59 | 23.57 | |
| SUBJECT 8 | N/A | N/A | 13.16 | 6.08 | |
| SUBJECT 10 | 19.83 | 23.52 | 23.47 | 17.47 | 13.93 |
| SUBJECT 11 | 10.97 | 16.34 | 16.20 | 9.48 | |
| SUBJECT 21 | 13.20 | 13.62 | 9.69 | 10.76 | |
| AVERAGE | **17.03** | **17.25** | **15.60** | **12.11** | **6.25** |
| MAXIMUM | 22.92 | 23.52 | 23.47 | 23.57 | 13.93 |
| MINIMUM | 10.97 | 11.96 | 9.13 | 2.53 | 2.90 |

All values expressed in degrees. The values shown indicate the maximum positional change of the vertebrae indicated during the head rest sequence involving football subjects.
* Denotes the cervical vertebrae indicated.

APPENDIX I

# PROCEDURES FOR ASSESSING AND STABILIZING THE POTENTIALLY SPINE INJURED ATHLETE PRIOR TO TRANSPORTATION TO MEDICAL FACILITIES

As described by: Vegso et al 1991, Vegso et al 1987

Prevention of further injury is the single most important objective. The first step should be to immobilize the head and neck by holding them in a neutral position. Then in the following order, check for breathing, pulse, and level of consciousness. Do not unfasten the chin strap or remove the helmet. With the chin strap fastened, the helmet stabilizes the head and keeps it properly aligned with the body, thereby reducing the risk of spinal cord injury associated with unstable fractures and dislocations.

If the victim is breathing, simply remove the mouth guard, if present, and maintain the airway. It is necessary to remove the face mask only if the respiratory situation is threatened or unstable, or if the athlete remains unconscious for a prolonged period.

Once it is established that the athlete is breathing and has a pulse, evaluate the neurologic status. The level of consciousness, response to pain, pupillary response, and unusual posturing, flaccidity, rigidity, or weakness should be noted.

At this point, simply maintain the situation until transportation is available, or until the athlete regains consciousness. If the athlete is face down when the ambulance arrives, change his position to face up by log rolling him onto a spineboard. Make no attempt to move the athlete except to transport him or to perform CPR if it becomes necessary.

Log rolling the athlete:

STEP ONE

The person in control of the head is designated the charge person. He or she in turn positions the medical support team members around the athlete. One at the shoulders, one at the hips, one at the knees and one at the ankles. One additional team member positions the spine board beside the athlete, opposite from the other team members.

STEP TWO

The charge person explains that the athlete will be rolled toward the assistants and that they must maintain athletes body in line with the head and spine during the roll. The charge person maintains immobilization of the head by applying slight traction and (in the instance where the athlete is face down) by using the crossed-arms technique. This technique allows the arms to unwind during the roll.

STEP THREE

The charge person explains that on the count of three, the athlete will be slowly rolled up toward the members of the support team. At this time the spine board will be positioned under the athlete at a 45 degree angle. After which, on the count of three the athlete whose back is in contact with the spineboard will be slowly lowered to the ground along with the spine board.

STEP FOUR

Execution of the roll.

STEP FIVE

The athlete is properly positioned on the board. This can be accomplished with very little additional movement of the athlete if a blanket has been placed on the board prior to rolling the athlete onto it. With the blanket in place, the athlete may be positioned by slowly pulling the blanket until the athlete is correctly positioned.

STEP SIX

Once positioned, the athlete is then secured to the board. The head is first to be secured using foam pads and tape (the use of sandbags is not recommended because as Denegar et al 1989 note, they generate lateral forces if the victim and board need to be turned to maintain an open airway). The rest of the body is then secured. Working from the shoulders to the toes; the arms are crossed over the body and secured along with the thorax, the pelvis, thigh, calf and ankles are secured.

STEP SEVEN

The athlete is carefully moved to the ambulance in preparation for transportation the hospital. Lifting and carrying the athlete requires five individuals: four to lift, and the leader to maintain control of the head. As before, the charge person initiates all actions with clear, loud verbal commands.

## APPENDIX J

Explanation of the proposed study:

**Movement of the Cervical Vertebrae During Helmet Removal**

**and Cervical Collar Application in Football and Hockey**

Outline of Procedures

Participants in many sporting activities such as hockey and football wear protective equipment including a helmet and shoulder pads. In instances of serious injury involving the head and/or spine, complicated by altered levels of consciousness, this protective equipment may become a hinderance. With the helmet in place, basic and advanced airway maneuvers may be compromised.

Helmet removal techniques have been developed, and many articles, textbooks and emergency medical technician journals can be found demonstrating a variety of these techniques. However, these standards advocate the removal of the helmet in participants **without** injury to the spine. This orthopaedic abnormality can only be identified radiologically, thus this information is not available to the responding emergency medical personnel. In order to gain the greatest benefits from these emergency care procedures, a further understanding of the implications and consequences of **unnecessary** movement of suspected cervical-spine injured participants must be investigated, to determine the most appropriate protocol to be carried out by pre-hospital personnel.

The major objective of this study, and the reason that you have been asked to participate, is to characterize the movement of the cervical vertebrae prior to, during and following removal of protective equipment for the upper body. Radiographic evaluation is the most accurate method of determining the movement of the vertebrae.

This study will involve taking one (1) x-ray of your neck from the side (a lateral view). This first x-ray will be taken with no equipment on. This initial x-ray will be developed and "read". The researcher and x-ray technologist will be looking for any degenerative changes to the cervical vertebrae which may indicate previous or current cervical spine disease or injury. If the x-ray is free of any abnormalities the remaining data will be collected. If the x-ray shows evidence of any conditions previously explained, you will be informed of this and asked to withdraw from the study.

The remaining data will be collected using fluoroscopy, allowing the researcher to make a video tape of the movement of the cervical vertebrae during helmet removal and cervical collar application (it's like having x-ray vision). Here you will be asked to put on your sporting equipment. You will then lie on the table and relax, as you will not be asked to do anything further. The researcher and research assistants will carry out the following procedure:

1. While one assistant stabilizes your head the second will remove your helmet.
2. While the first assistant continues to stabilize your head the second will apply a cervical collar to your neck.
3. The assistants will then allow your head to rest on the table.
4. As one assistant stabilizes your head the second will remove the cervical collar. Your head will once again be allowed to rest on the table.

As the helmet is being removed and the cervical collar is being applied the beam of the fluoroscope will be turned on. It is expected that the beam will be on a total of no more than twenty (20) seconds. It is anticipated that one hour of your time will be required to fit you into your equipment and collect the data.

The x-rays will be taken at the Glen Sather Sports Medicine Clinic. All guidelines and procedures, as specified by the Clinic, will be followed. Dr. Reid the head orthopaedic surgeon of the clinic, is involved in and fully supportive of the this research protocol. The fluoroscopic imaging will take place in the Department of Radiology, the University of Alberta Hospital. All guidelines and procedures, as specified by the department and the hospital, will be followed. Dr. Heslip, the head Radiologist of the Glen Sather Sports Medicine Clinic is involved and fully supportive of this research protocol.

Exposure to minimal amounts of radiation necessary for procurement of the x-rays is the only risk that you will encounter as a result of your participation in this study. The radiation dose received from this study has been categorized by the University of Alberta Hospitals' Radiation Safety Committee as "Low Level". Although it is impossible to determine with any degree of certainty what will happen to an individual exposed to low levels of radiation, it is the opinion of radiation experts that "Low Levels" of radiation can be considered harmless.

All records will be the property of the principal investigator. No records or property which would permit your identification will be made public without your written consent. Access to all pertinent records will be restricted to those individuals directly associated with this study.

If concerns or questions arise regarding the study, prior to or during the study, please feel free to contact or question the principal investigators, Dr. D. Syrotuik or Rosanne Prinsen at 492-2327.

Please retain with explanation of the reasons for and procedures of the study for your own records.