MOTION ANALYSIS OF HEAD AND NECK DURING FOOTBALL HELMET FACEMASK REMOVAL

By

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To Emily and Christopher

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TABLE OF CONTENTS

APPENDIX

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2-D	two-dimensional
3-D	tThree-dimensional
A-P	anterior-posterior x-ray view
AP	anvil pruner
AT	athletic training student who served as subject
ATC	Certified Athletic Trainer
Atlas	first cervical vertebra
Axis	second cervical vertebra
C1…C7	cervical vertebra #1 ...#7
C-Spine	cervical spine
CT	computed topography
DICOM	Digital Imaging and Communications in Medicine
EFF	efficiency ratio
EMG	electromyography
EMS	Emergency Medical Service
EMT	Emergency Medical Technician
FME	Facemask Extractor
IATF	Inter-Association Task Force for the Care of the Spine Injured Athlete
MRI	magnetic resonance imaging
NATA	National Athletic Trainers' Association
NATABOC	National Athletic Trainers' Association Board of Certification
NCAA	National Collegiate Athletic Association
NCCSIR	National Center for Catastrophic Sports Injury Research
NFHNIR	National Football Head and Neck Injury Registry

NFHSAA	National Federation of High School Athletic Associations
NOCSAE	National Operating Committee on Standards for Athletic Equipment
RAP	anvil pruner with a ratcheting handle
ROM	range of motion
SCM	sternocleidomastoid muscle
SD	screwdriver
T1…T8	thoracic vertebra #1…#8
TA	Trainers' Angel
TMT	total movement

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Cervical spine injuries in football have the potential for catastrophic results. First responders must be prepared to manage these injuries. Most healthcare professionals have adopted a common protocol that includes removing the facemask from the helmet. Several tools are available to accomplish facemask removal, however, it remains unclear which works most efficiently.

This two-part project aims to examine tool efficiency and cervical spine motion during football helmet facemask removal. Study I established a mathematical relationship between head movement and cervical vertebral movement while wearing football equipment. Two-dimensional fluoroscopic video images of the cervical spine and head motion of 26 subjects were recorded during passive movement. A regression analysis was performed to determine the link between head and neck motion. Results show a linear relationship between head and neck motion although the motion of the skull was much greater than that of the neck.

Study II examined the efficiency of four tools commonly used for facemask removal. Three-dimensional video analysis was performed while using the tools. Twenty-six athletic training students removed the facemask with each tool. The positional data of the helmet and head markers were used to calculate the minimum and maximum angle, total amount of

movement, efficiency ratio and time to remove the facemask. Significant differences were found among various tools when the angular data from the head and helmet were analyzed using a MANOVA with repeated measures. Interestingly, when the regression equation from Study I was applied to the data to estimate cervical motion, no significance was found among the tools. The motion of the head is the result of combined motion at the eight intervertebral joints, therefore the amount of C4/5 motion was much smaller than skull motion. Understanding the relationship between skull and spine motion provides new insight into previous research and avenues for future research. However, until vertebral motion is examined directly during facemask removal, we must rely on motion data from external head markers. Overall, results indicate that trainers preferred using the FM Extractor and performed better with respect to time and efficiency. The FM Extractor is recommended for educational and clinical situations.

CHAPTER 1
INTRODUCTION

Cervical spine injury is perhaps the most devastating traumatic injury an athlete can suffer and one of the most challenging injury situations for sports medicine professionals. Athletic cervical spine injuries have the potential for catastrophic results, including quadriplegia or death. Therefore, medical professionals in prehospital settings must be trained and prepared to properly manage potential cervical spine injuries in athletes.

Cervical spine injuries can occur in virtually any sport setting; however, sports with high contact rates and high movement speeds are more commonly associated with greater risk of cervical spine injury. Football has frequently been cited as having the highest incidence of cervical spine injury among organized sports, second only to recreational diving.[1] Football also poses greater difficulty to healthcare providers because the protective equipment worn by the athlete can hinder the management of a potential cervical spine injury.

For decades the protocols for managing cervical spine injuries in athletes wearing protective equipment were a source of controversy among various medical professionals. Emergency Medical Technicians (EMTs) have been trained to remove helmets from potential spine injured patients in order to gain access to the airway and to examine the head and neck.[2, 3] On the other hand, certified athletic trainers (ATCs) are instructed not to remove the helmet or shoulder pads and only remove the facemask to gain access to the airway.[2, 3] In recent years, through the work of the Inter-Association Task Force for the Care of the Spine Injured Athlete (IATF), most healthcare professionals have adopted a common management protocol. The current management strategies include immobilizing the athlete with helmet and shoulder pads in place and removing the facemask from the helmet.[4]

Several tools are available to accomplish facemask removal. Two tools were specifically designed for the task, the Trainers' Angel (TA) and the Facemask Extractor (FME). However, several other tools have been used effectively to remove the facemask including EMT shears, utility knives, screwdrivers, anvil pruners (AP) and PVC pipe cutters. It remains unclear which tool(s) work most efficiently. To proficiently remove the facemask the tool must be used to accomplish the task in the least amount of time and with the least amount of cervical spine motion possible. The amount of force and motion to cause secondary injury to a potential spine injured athlete would be difficult to determine. Therefore, the accepted gold standard of care is that little to no motion of the head and neck is ideal when a cervical injury is suspected.[5, 6] Many studies have compared various tools for their efficiency in facemask removal, however until recently most of those studies only tested the time to remove the facemask. In recent years, studies have addressed the motion component of efficiency, comparing the most widely accepted tools. However, to the best knowledge of this author, no study has examined the motion of the skull directly, nor has the motion occurring within the spine during facemask removal been quantified. Previous studies have inferred head and neck motion by measuring helmet motion while the facemask is removed.[5-9]

Purposes

This project consists of two parts and aims to examine tool efficiency and motion occurring in the cervical spine during football helmet facemask removal. Study I establishes a mathematical relationship between head movement and cervical vertebral movement while wearing football equipment. This was accomplished through analyzing two-dimensional fluoroscopic video images of the cervical spine and head motion at the same time. The mathematical model can be used to estimate the amount of motion occurring at the vertebral level during facemask removal.

Study II examines the efficiency of four tools commonly used for facemask removal, taking into consideration both time and motion. This was accomplished through three-dimensional video analysis of both head and helmet motion during facemask removal using the various tools. Unlike previous studies, head motion was measured directly through the use of a marker system placed in the subject's mouth.

Hypotheses

It is expected that the results of these studies would reveal the existence of the following information: (a) a relationship between the movement of the head and neck, (b) a relationship between head and helmet motion, (c) differences among tools in time required to remove a facemask, and (d) differences among tools in the amount of motion occurring during facemask removal.

Limitations

The most direct methods of measuring cervical spine motion would be to take radiographic images during the facemask removal. However, the length of time the subjects would be exposed to radiation would be too great to allow this measurement. Therefore, a limitation of the project is that spine motion will be estimated from the head motion, rather than measured during facemask removal.

Clinical Significance

This project presents a unique method for examining the current techniques for the care of potential cervical spine injuries in the football setting. By directly measuring head motion and estimating vertebral motion, it may be possible to determine if the tools currently used truly limit cervical spine motion. Also, we can determine which tool(s) are most efficient in accomplishing the task of facemask removal. The results are important for physicians, athletic trainers, EMTs, coaches, officials, and other professionals responsible for the prehospital care of the spine-injured athlete. It is of particular importance to the athletic trainer whose education includes training in the emergency management of the spine-injured athlete. The National Athletic Trainers' Association (NATA) Education Council has not specifically addressed this task in the competencies for athletic training students.[8] Therefore, because there is no universally accepted technique to remove a facemask, this skill is not tested on the certification examination for entry-level athletic trainers. Findings of this project could improve education for athletic trainers by identifying the best methods for removal of the facemask.

CHAPTER 2
REVIEW OF LITERATURE

Despite the precautions in place to protect athletes, injuries in football occur. Sometimes these injuries can have catastrophic effects, requiring sports medicine personnel be prepared to manage such injuries in the athletic environment. The purpose of this chapter is to discuss the relevant literature related to the emergency management of cervical spine injuries. Specifically, this chapter will review the epidemiology, relevant anatomy, mechanism of injury, and injury management of catastrophic spine injuries in American football. Finally, pertinent research on the tools used for facemask removal in the emergency management of these injuries will be reviewed.

Epidemiology

Approximately 10,000 catastrophic cervical spine injuries occur in the United States each year[10, 11] Medical care over a lifetime for partial or complete quadriplegia can cost in excess of $900,000.[11] Of patients who sustain an upper cervical injury, 25-40% die prior to receiving medical care.[11] A spinal cord injury is possibly the most devastating traumatic injury an athlete can survive. According to the National Spinal Cord Injury Data Research Center, sports related injuries accounted for 15% of all spinal cord injuries and 25% of quadriplegia cases reported between 1973-1981 and 95% of spinal injuries in sports involved permanent neurological deficit.[1] Cervical spine injuries account for approximately 2-3% of all sports related injuries and can occur in any recreational activities or organized sports.[12] However, sports such as diving, football, wrestling, gymnastics, snow/water skiing, trampoline, track and field, and skydiving have historically had higher incidence of neurological injuries than other sports activities.[11-14] Diving accidents account for the majority of spinal injuries in recreational activities, producing

10% of all spinal injuries.[15] Organized sports that have high levels of bodily contact or impact, such as football, hockey, wrestling and gymnastics, account for 2-4% of all spinal injuries. [15]

Historically, football has received a tremendous amount of attention in the area of head and neck injuries. Football is second only to recreational diving and has the highest incidence of spinal cord injuries in organized sports.[1] Cervical spine injuries account for 17% of football related fatalities.[16]

In 1904, 19 catastrophic injuries, resulting in death or quadriplegia, prompted President Theodore Roosevelt and Ivy League officials to meet and find a way to end the brutality, while preserving the competition.[17], resulting in the formation of the National Collegiate Athletic Association (NCAA).[18] In a further attempt to establish increased safety standards, the National Operating Committee on Standards for Athletic Equipment (NOCSAE) was established in 1968.[17] In 1975, Joseph S. Torg, MD established the National Football Head and Neck Injury Registry (NFHNIR).[13, 14] By surveying neurosurgeons for the frequency of injuries, Torg was able to research trends in head and neck injuries as well as establish an on going registry to track injury rates throughout the years.[1] In 1998, the registry was absorbed by the National Center for Catastrophic Sports Injury Research (NCCSIR).[1]

The preliminary analysis conducted by the NFHNIR included injury data from the 1971-1975 seasons and documented 259 cervical fracture/dislocations, with 99 resulting in quadriplegia.[13] When these findings are compared with a similar study conducted by Schneider, who examined the 1959-1963 seasons, it demonstrates a 204% increase in the incidents of fracture/dislocation and 116% increase in quadriplegia.[13, 14] This increase occurred despite the improvements in football equipment over the years.

Retrospective study by Clarke, et al. showed an increasing trend of quadriplegia in football between 1973-1975.[1] The increase in injury rates prompted response from governing bodies and researchers. Between 1978-1980, college and high school governing bodies adopted the NOCSAE standards for football helmets.[19] Ongoing research, conducted by the NCCSIR, revealed 229 cervical spine injuries in football resulting in incomplete neurological recovery between 1976 and 2002 (Table 2-1).[20]

Advances in modern football helmet design have been cited as a reason for the increase in cervical injury rates in the early 1970s.[1, 13, 14, 19, 21, 22] Although improvements in the modern helmet resulted in a decrease in head injuries, the improved protection of the head led to the use of the helmet as a weapon.[13, 14] Research by Torg et al.[13, 14] resulted in rule changes forbidding spearing, reducing the incidence of catastrophic spine injuries in football to single digits in recent years.[20] In 1976, the NCAA and National Federation of High School Athletic Associations (NFHSAA) enacted rule changes banning spearing, defined as the use of the head as an initial point of contact (Figure 2-1).[1, 13, 17]

Between the years of 1976-1987 there was a dramatic decline in the number of catastrophic cervical injuries, from 34 to as few as 5 per year (Figure 2-2).[13, 14, 17, 19, 22] In the early 1990's a rise in the frequency of quadriplegia back to double digits caused in increased focus on the "heads up" tackling technique to discourage spearing. The educational campaign successfully reduced the injury rates back to single digits, however without long term focus on the problem, injury rates can continue to increase.[1] In 2000, there were eight cervical spinal cord injuries reported involving incomplete neurological recovery.[20, 23, 24] While the incidence of spinal cord injuries in football is low when compared to exposure rate, 0.44 per 100,000 participants, the topic still demands significant attention from the sports medicine community due to the permanent nature and profound impact of these traumatic injuries.[20, 24]

Relevant Anatomy

Cervical spine is an extremely complex structure. It is composed of seven vertebrae, ligaments, intervertebral discs, and paraspinal musculature. The large number of articulations and soft tissue attachments in the cervical spine makes it difficult to determine and classify an injury on the field without the aid of radiographic imaging.

Primary motions of the cervical spine are flexion, extension, rotation, and lateral bending. Minor accessory motions of distraction and anterior-posterior translation also occur. The approximate range of motion in the sagittal plane is 100º, with 10º of flexion and 25º of extension occurring at the articulation between C1 and the skull, also called the atlanto-occipital joint. There are variable amounts of motion, up to 15º, available in the articulation between C1 and C2, also called the atlantoaxial joint. The remainder of the motion in the sagittal plane takes place incrementally between the lower cervical vertebrae (C3-7).[25]

Rotational range of motion is approximately 160º total, with 80º to each side. Approximately 50% of this motion occurs at the atlantoaxial joint, with decreasing increments in the lower vertebrae. There is no rotation motion allowed at the atlano-occipital joint.[25]

Lateral bending occurs incrementally throughout the cervical column, with only about 5º allowed at the atlanto-occipital joint. Lateral bending in the cervical spine is always accompanied by some rotation due to the arrangements of the articular surfaces of the vertebrae.[25]

Atlanto-Occipital Joint

The first cervical vertebra is referred to as the atlas and is unique in its shape and function (Figure2-3). The atlas (C1) articulates with the skull as its superior articular facets cradle the occipital condyles. This atlanto-occipital articulation is very strong and allows primarily flexion and extension movement to occur due to the shape of the deep sockets in which the condyles sit. The condyles are convex and the sockets are concave providing a great deal of stability to the joint. Flexion occurs when the condyles roll forward and slide backward causing a rotation of the condyle within the socket.[26] The atlanto-occipital joint is responsible for 40% of cervical flexion and 5-10° of lateral bending.[27]The transverse processes protrude from either side of the atlas and each contains a foramen tranversarium for passage of neurovascular structures.[25]

Atlanto-Axial Joint

The atlas has an anterior and posterior arch, however it lacks a vertebral body. Posterior aspect of the anterior arch contains a facet for articulation with the odontoid process of C2 (Axis)(Figure 2-4). The odontoid process is held in place by the transverse atlantal ligament, allowing the anterior arch of the atlas to pivot around the odontoid process. In addition, the articular facets of the atlanto-axial joint are oriented nearly horizontally and are biconvex. Therefore, 60% of axial rotation occurs at the articulation between C1 and C2.[26, 27]

The Root

The axis has a vertebral body that appears like a deep root, from which the odontoid protrudes superiority. It has two transverse processes with foramina transversarium and a spinous process extending posteriorly. Inferior articular facets are oriented forward and downward to fit the superior articular facet of C3.[25] Superior articular surfaces of C3 are oriented not only superiorly and posteriorly, but also medially at approximately 40º. They are also located lower with respect to the vertebral body then those of the remaining vertebrae. This results in the axis bending towards the contralateral side during lateral rotation.[26]

The Column

The third through seventh cervical vertebrae are considered typical vertebrae and share many distinguishing characteristics (Figure 2-5). Each consists of a body, stacked one on top of the other, separated by intervertebral discs. Each vertebra has a spinous process and two lateral processes for muscular attachment. The anterior aspect of the inferior surface slopes downward forming a lip. The superior surface of each body slopes downward anteriorly, therefore the disc is oriented at a slight angle. This is conducive to the primary motion in the sagittal plane. Articular surfaces are oriented at a 45° angle allowing for rotation coupled with lateral flexion, but limits pure side to side motion of each vertebra (Figure 2-6).[26]

Ligaments

Ligamentous structures add to the stability of the cervical spine. Perhaps the most important of the cervical ligaments is the transverse ligament (Figure 2-7). This horizontal band of fibers is attached to the medial side of each lateral mass of the atlas. It passes posterior to the odontoid process, holding the process against the posterior surface of the anterior arch of the atlas. Thus the odontoid process is prevented from sliding anteriorly into the space for the spinal cord. The apical dental ligament works with the transverse ligament. It is a slender, weak ligament that extends from the tip of the odontoid to the anterior aspect of the foramen magnum, running perpendicular to the transverse ligament.[25]

Right and left alar ligaments extend upward and obliquely from the odontoid to the occipital condyles, anchoring the skull to C2 (Figure 2-7). They help to limit lateral and rotational motions. They also serve as additional protection to prevent the odontoid from translating posteriorly. Right and left accessory bands function similarly to the alar ligaments and blend into the joint capsules of the antlanto-occipital and atlantoaxial joints.[25]

Anterior longitudinal ligament covers the anterior surface of the vertebral bodies and discs and acts to limit extension (Figure 2-8). Posterior longitudinal ligament is a broad band that covers the posterior surface of the vertebrae and intervertebral discs, which lack the crisscrossing of the annulus fibrosis in this area.[25] Posterior longitudinal ligament helps to limit flexion. [26]

Ligamnetum flava also assists in limiting flexion and bridges the gap between the laminae of the neural arches (Figure 2-8).[25, 26] Ligamentum nuchae takes the place of the supraspinous ligaments in the cervical region and attaches to the tips of the spinous processes (Figure 2-8). Interspinous ligaments run between the spinous processes and are poorly developed in the cervical region (Figure 2-8).[25] With ligamentum nuchae, the interspinous ligaments help to limit flexion.[26]

Spinal Cord

Spinal cord junction with the brain stem is at the level of the foramen magnum, just superior to the atlas. The spinal cord ends near the level of the first lumbar vertebra.[25] The cord is housed in the space of the vertebral foramina, and is surrounded by cerebrospinal fluid. At the C1-2 level, this space can be described by Steele's rule of thirds (Figure 2-9). One third of the vertebral space is occupied by the odontoid structure, leaving one third for the cord and the remaining one third for the fluid.[25] Therefore, any fracture or dislocation allowing anterior translation of the odontoid, significantly reduces the available space for the spinal cord and likely results in compression on the cord.

There are eight pairs of cervical spinal nerves that arise from the spinal cord and exit the column through the intervetebral foramina, with the exception of the first. The first cervical spinal nerve exits through the atlanto-occipital membrane, superior to the posterior arch of the atlas.[25] This makes the numbering for cervical nerve roots unique from the rest of the spinal column, in that the nerve is named for the cervical vertebra directly below its exit point.

Musculature

Muscles in the cervical region can be divided into anterior, posterior and lateral groups. Anterior muscles of the cervical region are responsible for flexion of the head and neck. Rectus capitis runs from the occipital bone to the lateral mass and transverse process of C1. In addition to flexion of the head it acts to stabilize the head. Similarly the longus capitis originates at the basilar portion of the occipit and inserts at the transverse processes of C3-6. Longus colli runs from the anterior tubercle of C1 to the bodies of T3 and C1-3 and the transverse process of C3-6.[28]

Posterior muscles are the cervical portions of the erector spinae group that runs the entire length of the spine. In addition to their role as extensors, the cervical portions of the erector spinae have accessory actions. Iliocostalis cervicis attaches to ribs 3-6 and extends upward to the transverse processes of C2-6. Its accessory action is lateral flexion of the neck. Longissimus cervicis originates at the transverse process of T4-5 and inserts at the transverse process of C2-6. Longissimus capitis begins the upper portion of T4-5 and lower portions of C3-4 and runs to the mastoid process of the temporal bone. In addition to extending the head, these two muscles rotate and laterally flex the head and neck. Spinalis cervicis runs from the ligamentum nuchae and spinous process of C7 to the spinous process of the axis. Spinalis capitis begins at the transverse process of C7-T7 and extends up to the occipital bone. In addition to extending the head and vertebral column, these two muscles also rotate the head to the opposite side. Semispinalis cervicis runs from the transverse process of T1-5 to the spinous process of C2-5, while the semispinalis capitis runs from the transverse process of C7-T7 to the occipital bone. The two also rotate the head and neck to the opposite side.[28]

Deep lateral muscles are the scalenes, including anterior, medial and posterior portions and the spenius capitis and cervicis. Scalenes originate on the transverse processes from C3-7 and insert into either the first or second rib. They act to raise the first and second ribs, flex the neck forward and laterally and rotate the neck to the opposite side.[28] Splenius capitis and cervicis arise medially and pass laterally as they ascend. Splenius capitis runs from the lower half of the ligamentum nuchae and spinous process of C7-T4 to the mastoid process and occipit. Splenius cervicis runs from the spinous process of T3-6 to the upper C2-4 transverse processes. When contracted bilaterally these muscles aid in extension of the head and neck. If only one side contracts, it results in rotation of the head towards that side.[29]

Also lateral, but more superficial are the sternocleidomastoid muscles (SCM). Originating both from the anterior surface of the manubrium of the sternum and the medial third of the clavicle and inserting on the lateral aspect of the mastoid process, the SCM has multiple functions. When the two sides contract together they flex the head. However, if only one side contracts, it acts to laterally flex the head and neck and rotate the face towards the opposite side.[28]

Finally, the most posterior of the lateral muscles is the superior portion of the trapezius muscle. It runs from the external occipital protuberance and ligamentum nuchae to the lateral third of the clavicle and acromion. Similar to the SCM, bilateral contraction acts to retract the head, while unilateral contraction causes lateral flexion of the head to the same side and rotation of the face to the opposite side.[28] The remainder of the musculature in the cervical region is primarily anterior and does not act directly on the spinal column or head.

Injury Management

In the event of a cervical spine injury, the sports medicine team must prevent secondary injury with immediate and proper evaluation, transport and treatment of cervical spine injuries.[12] In recent years, continued research has resulted in improvements in teaching and coaching techniques, rule changes, better equipment standards and revised emergency medical protocols.[20]

For decades, controversy existed as to how a spine-injured athlete should be treated and transported prior to reaching a medical facility. Much of the controversy surrounded the unique situation presented by the athletic equipment. Although protective athletic equipment is designed to prevent and minimize injuries to the athlete, serious injuries do occur. When the athlete is injured the protective equipment can be a hindrance to the medical team evaluating and treating the injury. This difficulty is most prevalent in collision sports such as football, hockey and lacrosse, where a helmet and facemask limits the access to the head and face.

Discrepancies existed between EMT protocols and sports medicine protocols for the prehospital care of the spine injured athlete.[4] Prior to the 1990s, most Emergency Medical System (EMS) protocols called for the removal of the helmet. The EMS procedures were based on the removal of motorcycle helmets, which are a hindrance to maintaining an open airway, interfere with immobilization, cause hyperflexion to the neck and do not allow visualization of injuries to the head. However, the design of football helmets differs from motorcycle helmets in that football helmets have a removable facemask, fit more securely to the head, and are worn with shoulder pads. [4, 30] Previous research has shown if the head and a properly fit helmet are immobilized as a unit, very little motion occurs at the head.[2] In addition, hyperflexion is prevented because the torso is raised approximately 2.5 cm by the shoulder pads. If the facemask is removed in this position, the airway can be maintained and CPR can be performed. Finally, the forces in sports are not sufficient to cause the type of head trauma see in other EMS situation, such as motorcycle accidents.[2, 3] Therefore, adequate visualization is possible by virtue of the football helmet design.[31]

In an effort to educate all healthcare professionals and standardize the prehospital care of the athlete, in 1998 the NATA sponsored the creation of the IATF. The purpose of this task force was to develop standard guidelines to be used by all providers for the prehospital care of the athlete with a suspected spine injury.[4] Guidelines were developed as a consensus endorsement by representatives of various healthcare professionals and include general guidelines, facemask removal and football helmet removal guidelines. Task force guidelines for the prehospital care of the spine-injured athlete are outlined in Table 2-2.[4]

The IATF guidelines illustrate the consensus opinion to remove the facemask rather that the entire helmet when there is a suspected spine injury. Also, the guidelines clarify the need for all medical professionals involved in the prehospital care of football players, including athletic trainers, to be competent and practiced in these procedures. Yet, the NATA has not included this skill in the list of skills that must be tested on the certification exam. Consensus of the best method and equipment to accomplish facemask removal has not been established. Therefore, there is no standard method of facemask removal taught to athletic training students and the NATA Board of Certification (NATABOC) is not able to test entry-level athletic trainers on this skill on the certification exam.

Equipment Studies

Football helmets and shoulder pads have been the focus of many studies because of their potential to cause secondary injury to the spine when removed. Much of the literature has evaluated the tools and techniques for facemask and helmet removal in an effort to determine the best, most efficient method to gain access to the athlete's airway. However, few of these studies have measured motion occurring while the facemask is removed.

Donaldson et al. used video fluoroscopy to evaluate motion in an unstable spine during helmet and shoulder pad removal from 6 fresh cadavers. Results indicate significant motion in the head and neck occurs when the helmet is removed from the head.[32] Removing only the helmet forces the neck into extension, because the shoulder pads raise the torso relative to the head.[3, 33] However, CT scans of the spine confirm that when either all of the equipment is removed together or none of it is removed, the neutral cervical alignment is maintained.[33] This has led the IATF to recommend protocol changes, including removing only the facemask and, if necessary, removing the helmet and shoulder pads together (Table 2-2).[4]

Facemask is attached to the helmet by four plastic loops with a screw and T shaped nut (Figure 2-15). Unscrewing or cutting all four loop straps can remove the facemask. If only the two lateral loop straps are removed, the facemask may be retracted (Figure 2-16).

Facemask Removal Tools

There are several tools and methods that may be employed to accomplish facemask removal, many of which have been studied. The Trainer's Angel (TA) and FM Extractor (FME) are tools specifically designed and marketed for removing the facemask. Often tools such as bolt cutters, screwdrivers, anvil garden pruners (AP), utility knives, EMT shears and PVC cutters have all been shown to successfully free the facemask from the helmet. However, with the exception of the AP, many of these have been reported to be inefficient or dangerous to the athlete and the ATC and thus are not recommended for facemask removal.

Bolt cutters have been rendered obsolete with the plastic loop strap. Before loop straps were made of plastic that can be cut, it was necessary to cut through the metal bars of the facemask to gain access to the athlete's airway. Cutting of the facemask with bolt cutters created a great deal of mechanical rebound and motion to the head and neck. Therefore, bolt cutters are no longer a recommended tool for facemask removal.[34, 35]

Utility knives are capable of cutting through the soft plastic loop straps. However, they are dangerous to both the people removing the facemask and the athlete. Knox, et al. removed utility knives from their study due to incidence of subjects cutting themselves.[36]

In one study, 12% of ATCs surveyed chose EMT shears as the tool they would use for facemask removal (Figure 2-17). However, when the EMT shears were evaluated on various loop straps, Knox et al. found times from 1 minute 10 seconds up to and exceeding 35 minutes to retract the facemask. This led to the conclusion that EMT shears are not the most efficient tool for facemask removal.[37]

PVC pipe cutters are also effective in cutting through loop straps and are preferred by some ATCs because they have a ratcheting handle (Figure 2-17). However, they have not been shown to be any more efficient than other cutting tools.[7, 8, 38-41] The cutting blades are large and hard to maneuver into the small spaces near the loops straps. Swartz et al. found that the PVC cutter caused significantly more motion than the FME or TA, and was significantly slower than the AP and TA.[8] Pearson et al. found that the PVC cutter took significantly more time than the AP.[40] In a study comparing the PVC with the AP, TA and FME, O'Sullivan et al. found the PVC required the longest amount of time to retract the facemask.[39] The PVC cutter has been shown to take the most number of cuts to remove the facemask when compared to the TA, FME and AP.[38]

Screwdrivers, both electric and manual, have been shown to be faster and cause less motion in removing loop straps than cutting devices.[5, 6, 9, 36, 42-44] This could be due to the fact that cutting devices often leave the anterior portion of the loop strap in tact. The facemask must then be maneuvered around this portion, causing a mechanical rebound resulting in up to 10 mm of motion.[5] However, screwdrivers can be unreliable outside of the laboratory.[45, 46] Rusty or stripped screws and spinning T-bolts can render the screwdriver useless in the field.[46] Therefore, it is generally accepted that a screwdriver should not be the primary tool for facemask removal.[4, 45, 46]

Three cutting tools believed to be the most effective are the TA, FME and AP. Many recent studies have concentrated on comparing these tools.[30] However the majority of these recent studies have only evaluated the time to remove or retract the facemask. It is important to consider both time and movement elements when considering which technique/tool is most effective.[6]

Trainers' Angel

In one study, the TA was the tool of choice for 54% of the ATCs surveyed. However, the authors discovered that only 12% of those ATCs used the technique recommended by he manufacturer, 60% needed to use two hands, 58% were unable to complete the task on the 1st attempt and 68% reported never practicing the use of the TA.[47] The TA was the first tool designed specifically for facemask removal (Figure 2-18). Its history and marketing could explain why so many ATC choose the TA for their field kit.

Studies performed comparing the TA to other tools illustrate that the TA causes significantly more motion and sometimes require more time than other tools. When changes in center of pressure were measured, the TA produced more motion to the helmet in the sagittal plane, when compared to anvil pruners and screwdriver.[6, 36] Using 2D video based motion analysis, Surace et al.[42] also found significantly more motion in the sagittal plane with the TA. In 1995, using optoelectric motion analysis, Ray found that with the TA there was significantly more rotation in the transverse plane, anterior/posterior translation, lateral rotation and peak displacement, when compared to manual and power screwdrivers and pocket mask insertion under the facemask.[9]

Several reports indicate the TA is significantly faster than the PVC pipe cutter in facemask removal.[8, 39, 48] However, the TA falls short when compared to the times for the AP. [6-8, 39, 42, 48-51] In fact, a sharp TA is has been shown to be less effective than a dull AP.[52]

The TA has been criticized as requiring large strong hands for effective use. In previous studies, subjects have had difficulty or been unable to cut through the loop straps using the TA.[47] In 1997, Kleiner, et al. examined the effect grip strength and hand size had on the time to cut loop straps using the TA and AP. Although there was a significant difference between males and females using the TA, they were not able to attribute the difference to hand size or grip strength.[53] In a similar study, Redden et al. found that hand length, width and grip strength had a greater effect on the time to remove the facemask with the TA than the AP. In addition, they also found a significant difference between males and female when using the TA.[49] Swartz, et al. found no significant correlations between grip strength, hand length and hand width and their dependent variables when comparing SD, TA and FME. [44]

Facemask Extractor

The FME is a more recent tool designed specifically for facemask removal (Figure 2-19). The FME has been shown to be an effective tool in removing the facemask. Research performed by Swartz et al., utilizing video based 3-D motion analysis has revealed that the FME potentially causes less motion to the helmet than the AP. Also, the FME is more efficient, in both time and movement, than the TA and PVC.[7, 8, 48] In studies measuring time to remove the facemask, the FME required significantly more time than the AP, screwdriver and a Quick Release (QR) system.[43, 51] The QR is a prototype, spring loaded nut and bolt system that, to date, is not available on the market.[43]

The FME comes with instructions for three possible techniques. Method A places the notched end of the FME against the loop strap. Method B places the notch around the bar of the facemask. Method C calls for making two cuts in the loop strap while the notch rests on the bar of the facemask.[54, 55] In a study where ATCs were allowed to choose the method, most preferred method C.[54] In a related study comparing the three methods recommended by the manufacturer, Method C was found to be the most effective method with respect to time.[55]

Anvil pruner

The AP is effective in removing the facemask (Figure 2-20). In 1997, Knox et al. found the AP to be significantly faster than screwdriver in cutting individual loop straps, however it was slower than the screwdriver and TA in total time to remove the facemask. They concluded this was due to the residual anterior portion of the loop strap.[6] Similar studies have shown the AP to be faster than the PVC cutter and TA.[6, 8] However, in the one study using video based 3D motion analysis, the AP caused more motion to the helmet than the FME or TA.[41] When taking time and motion into consideration, the AP was as efficient as the FME but more efficient than the TA or PVC cutter.[8] Measuring deviations in center of pressure readings, Knox et al. also found the AP caused less motion when compared to the TA.[6] In a study investigating the effect of grip strength and hand size, the AP was significantly faster for all subjects.[49, 53]

When comparing three temperature conditions (cold loop straps, room temperature loop strap and warm loop straps) the results showed the AP took less time to cut warm or room temperature loops straps, then the TA. However, when the loop straps were cold, the AP took significantly more time than the TA.[56]

The AP can be modified to have a groove for stabilizing against the facemask bar while cutting the loop straps (Figure 2-21). However, there is no uniform method for modifying the AP. Therefore some researchers have chosen to leave the AP unmodified for research purposes.[8] This could explain the differing efficiency results from various studies

Time Studies

Previous research can be categorized by those investigating only time efficiency and those looking at both time and amount of movement. With the exception of the few studies previously mentioned, the majority of research on facemask removal has concentrated on the time to remove the facemask. Many of the studies measuring time have examined other factors that could influence the efficiency of facemask removal, including type of loop straps, hand size, grip strength, gender, hand placement patterns, level of training and practice.

Comparing three types of loop straps, Block et al. found that there was a significant difference in the time to remove the facemask. When using both the AP and TA, the Schutt Armor Guard loops straps took significantly less time to cut through than did the Maxpro Shockblocker II and the Riddell loop straps.[23] In a similar study, the AP cut through the Schutt loops straps faster than Bike loop straps. However, the TA was faster when cutting the Bike loop straps.[57] Finally, when comparing the Schutt Armor Guard to the Riddell Kra-lite system, Fuchs et al. found the Kra-lite was more difficult to cut therefore a screwdriver was the faster tool. However, the AP was faster on the Schutt loop straps.[34] These results would indicate that the most efficient tool may depend on the loop straps used.

Several studies have examined specific techniques while using various tools. It has been demonstrated that there is a correlation between the techniques employed to use a tool and the time to remove the facemask. Tools that can do not require the use of both hands or to be set down during facemask removal are more time efficient.[41, 48] The FME and AP are less likely to require two hands or be set down during facemask removal. [41, 48] Those tools that require fewer cuts to remove the facemask are also more time efficient. [38] The FME and TA require the least number of cuts to remove the facemask. [38]

Several studies have investigated how the level of training or experience affects the efficiency of facemask removal. In 1995, Knox et al compared ATCs, athletic training students and EMTs using TA, AP and screwdriver to remove the facemask. Although they did not find any significant difference in time to remove the facemask, the ATCs demonstrated significantly more head movement than the students.[36] This illustrates the need for ATCs to practice the skill of facemask removal. In two previous studies, a significant improvement in performance was demonstrated, with both the AP and TA, when the subjects practiced the skill.[50, 58] However, this improvement only occurs when the skill is practiced with the specific tool to be used. The practice effect does not appear to transfer to other tools.[58] ATCs must learn and practice the skill of facemask removal with the tool they will use on the field.[59] However, care must be taken not to dull the blade, which would adversely affect the tools ability to cut through the loop straps.[52]

Another aspect of concern is that of facemask retraction verses removal. The IATF recommends facemask removal from the helmet prior to transporting the athlete.[4] More sagittal plane motion to the neck is theorized to occur during retraction, therefore less movement will result if the facemask is removed rather than being retracted.[60] When comparing time to remove verses time to retract, Kleiner et al found significant difference when using the TA but not when using the AP.[60] However, in a similar study, O'Sullivan et al found removal to be significantly faster than retraction with all tools tested (TA, AP, PVC and FME).[39]

Motion Studies

Conclusions from previous studies have eliminated the utility knife, PVC cutters and bolt cutters as practical tools for facemask removal. Data have been inconclusive as to which of the remaining tools is most efficient. To determine a tool's efficiency, both time and motion factors must be considered. Few studies have compared tools accounting for both time and motion. Majority of facemask studies have only measured time factors when comparing tools. Although the outcomes of these motion studies are promising, there are limitations to the studies that leave the results inconclusive.

Knox et al. was the first to consider motion in comparing tools, using a force plate to measure the movement of center of pressure and calculated an efficiency rating (time x movement/10) that has been used by researchers in more recent motion studies.[6, 36] Tools examined were the TA, AP, screwdriver and utility knife (which was removed after injuring a subject).[36] Using a force plate to measure movement is not a direct method to analyze neck motion during facemask removal.

In two similar studies, Ray et al. compared screwdrivers, TA and pocket mask insertion using optoelectric sensors to measure motion.[5, 9] Lack of variety in the tools examined in this study is a limitation. Instead the focus was on comparing facemask removal to an experimental method of establishing and airway which does not require facemask removal.

In 2000, Surace et al. used a video based 2-D motion analysis to examine movement in the sagittal plane during facemask removal. Tools examined were TA, AP and screwdriver. In this study markers digitized were place on the helmet.[42] Thus, actual head and neck motion were not measured. Rather they were inferred from the data collected about the helmet motion. Limitations of this research were both the examination in only one plane and the measurement of helmet motion rater than head and neck motion. .

Swartz et al.[7, 8, 41, 61] have performed the most comprehensive motion analysis of facemask removal. In several recent studies, they used 3-D video based motion analysis to compare movement among PVC cutters, AP, TA and FME. Although 3-D motion analysis is the most appropriate method to detect minute amounts of motion such as seen in facemask removal, these studies also have serious limitations. Markers measured were placed on the helmet and shoulder pads.[7, 8, 41, 61] Thus the measurements made were of helmet motion compared to torso rather than actual head or neck motion. Also, only a 25 second portion of the facemask removal was digitized. Rationale for this sampling was to only measure the direct effect of the tool cutting the loop straps. [61] However, the performance of the tool will affect the beginning and end motions of the process to remove the facemask. The goal of proper facemask removal is to limit all head and neck motion, not just the motion while the loop straps are being cut.

Although a few studies have measured motion of the helmet, to the best this author's knowledge, no study comparing facemask removal tools has examined actual skull or spinal motion. Thus, the previous research has not definitively shown which method is the most effective. Those studies that did include motion analysis have inferred skull and spine motion from the helmet data. In a properly fit helmet, the head and helmet should move as one unit. However, in a study by McGuine et al.[62], fitting errors on average of 2.04 of 7 criteria were found in helmets tested in Wisconsin schools. Although it is assumed that head movement results in spine movement, the research in this area is limited.[61]

The current study compared helmet motion to the motion of the skull. This determined how much motion an injured athlete is subjected to during facemask removal. By also collecting fluoroscopic images of the spine in motion while the subject is wearing the football equipment, a mathematical model comparing skull and spine motion can be used to estimate the amount of spine motion occurring while the facemask is removed. Results can also be applied to previous studies to estimate the actual spinal motion. In addition, if a direct relationship between cervical spine motion and the motion of the helmet is found future kinematic studies will be able to estimate spinal motion, without the need for radiographic imaging.

Clinical significance of this project is to determine if current emergency management protocols are truly limiting spinal motion. Results have the potential to modify and improve the guidelines for the safe care and transport of the spine-injured athlete. By measuring skull motion during facemask removal using various tools, the most effective method can be determined and this information is valuable to sports medicine professionals.

Table 2-1. Cervical cord injuries occurring between 1977-2002.

Year	Sandlot	Pro/Semipro	High School	College	Total
1977	0	0	10	2	12
1978	0	1	13	0	14
1979	0	0	8	3	11
1980	0	0	11	2	13
1981	1	0	6	2	9
1982	1	1	7	2	11
1983	0	0	11	1	12
1984	1	0	5	0	6
1985	0	0	6	3	9
1986	0	0	4	0	4
1987	0	0	9	0	9
1988	0	0	10	1	11
1989	0	1	12	2	15
1990	0	0	11	2	13
1991	0	1	1	0	2
1992	0	1	6	0	7
1993	0	1	8	0	9
1994	0	0	1	1	2
1995	0	0	8	1	9
1996	0	0	6	3	9
1997	0	1	7	1	9
1998	0	0	4	0	4
1999	1	0	7	1	9
2000	0	0	6	2	8
2001	0	0	6	0	6
2002	0	0	5	1	6
Total	**4**	**7**	**188**	**30**	**229**

Note: Adapted from Boden BP, Tacchetti RL, Cantu RC, Knowles SB, Mueller FO. Catastrophic cervical spine injuries in high school and college football players. *American Journal of Sports Medicine.* June 30, 2006;34(8):1223-1232.

Table 2-2. IATF guidelines for appropriate care of the spine-injured athlete.

General

1. If spinal injury is suspected, athlete should not be moved and should be managed as though a spinal injury exists.
2. Assess the athlete's airway, breathing and circulation, neurological status and level of consciousness.
3. Do not be move athlete unless absolutely essential to maintain airway, breathing and circulation.
4. If the athlete must be moved to maintain airway, breathing and circulation, the athlete should be placed in a supine position while maintaining spinal immobilization.
5. When moving a suspected spine injured athlete, the head and trunk should be moved as a unit. One accepted technique is to manually splint the head to the trunk.
6. Activate emergency medical services.

Facemask Removal

1. Remove the facemask prior to transportation, regardless of current respiratory status.
2. The tools for facemask removal must be readily available.

Football Helmet Removal

Only remove the helmet and chin strap if..

1. The helmet and chin strap do not hold the head securely, such that immobilization of the helmet does not also immobilize the head.
2. The design of the helmet and chin strap is such that even after removal of the facemask the airway can not be controlled, or ventilation be provided.
3. The facemask can not be removed after a reasonable period of time.
4. The helmet prevents immobilization for transportation in an appropriate position.

Helmet Removal

1. Spinal immobilization must be maintained while removing the helmet.
2. Helmet removal should be frequently practiced under proper supervision.
3. In most circumstances, it may be helpful to remove cheek padding and/or deflate air padding prior to helmet removal.

Equipment

1. Appropriate spinal alignment must be maintained.
2. The helmet and shoulder pads elevate an athlete's trunk when in the supine position.
3. Should either be removed, or if only one is present, appropriate spinal alignment must be maintained.
4. Open the front of the shoulder pads to allow access for CPR and defibrillation.

Note: Adapted from Kleiner DM, Almquist JL, Bailes J, et al. Prehospital Care of the Spine Injured Athlete. Dallas: Inter-Association Task Force for the Appropriate Care of the Spine Injured Athlete; 2001.

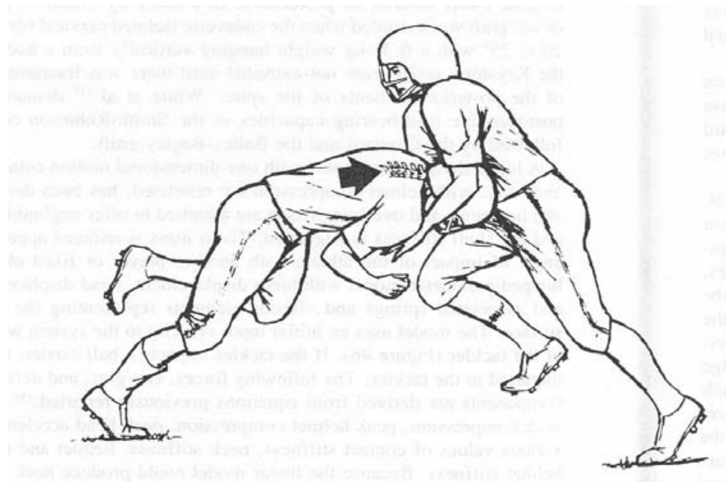


Figure 2-1. Spearing is the use of one's head to make initial contact with an opponent. [Reprinted with permission from Sances, et.al. The Biomechanics of Spinal Injuries. *CRC Critical Reviews in Biomedical Engineering.*11(1): 52 (Figure 46)]

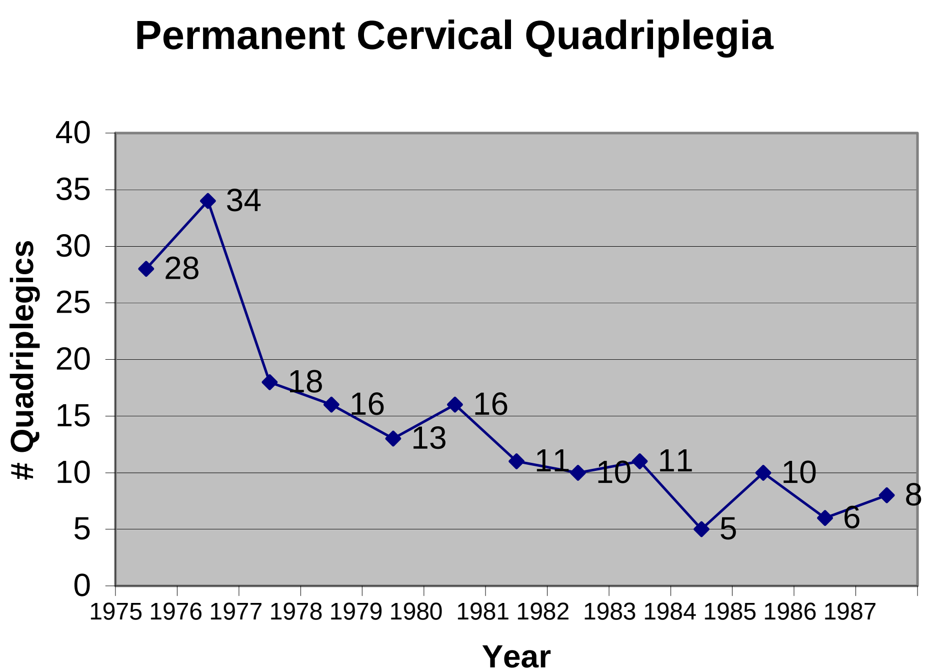


Figure 2-2. Yearly incidence of cervical quadriplegia for all levels of competition (1975-1987) decreased dramatically in 1977 after prohibiting spearing.[Adapted from Torg JS, Vegso JJ, O'Neill MJ, Sennett B. The epidemiologic, pathologic, biomechanical, and cinematographic analysis of football-induced cervical spine trauma. *American Journal of Sports Medicine.* 1990;18(1):50-57.]

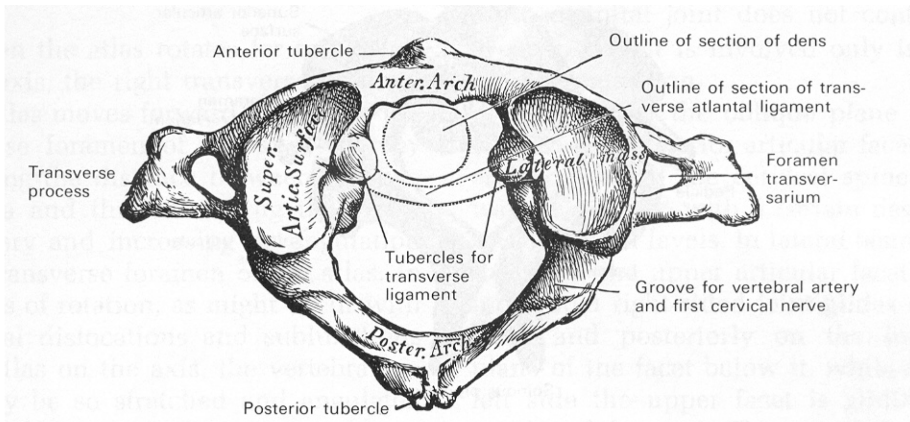


Figure 2-3. First cervical vertebra is also called the atlas and articulates with the occipital condyles of the skull. [Reprinted with permission from Torg JS. The epidemiologic, pathologic, biomechanical, and cinematographic analysis of football-induced cervical spine trauma and its prevention. In: Torg JS, ed. *Athletic Injuries to the Head, Neck, and Face*. second ed. St. Louis: Mosby; 1991:97-109.]

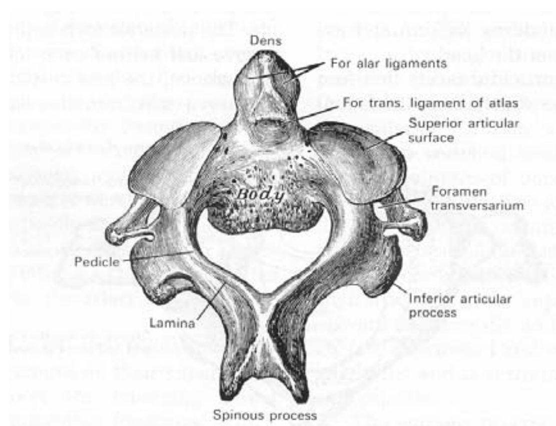


Figure 2-4. Second cervical vertebra is called the axis and articulates with the atlas both at the superior articular surface and the odontoid process. [Reprinted with permission from Johnson RJ. Anatomy of the cervical spine and its related structures. In: Torg JS, ed. *Athletic Injuries to the Head, Neck, and Face*. second ed. St. Louis: Mosby; 1991:374 (Figure 27-3)]

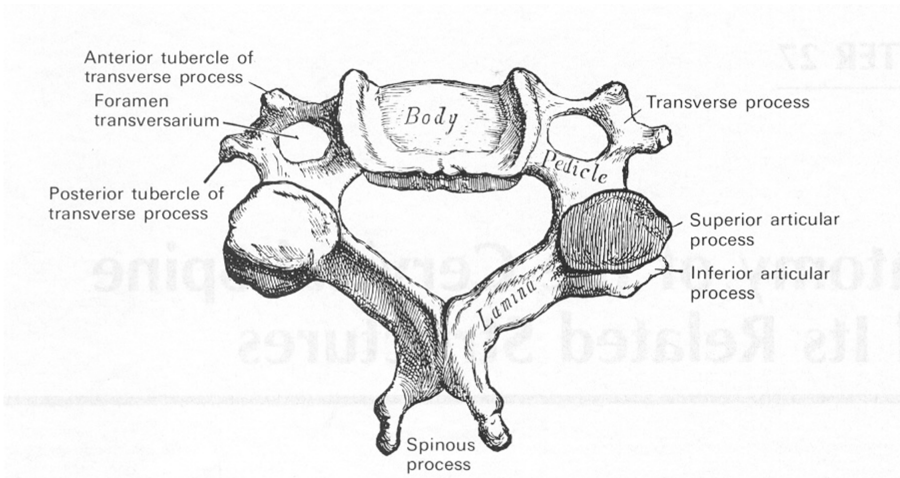


Figure 2-5. Typical cervical vertebra found at levels C3-7. [Reprinted with permission from Johnson RJ. Anatomy of the cervical spine and its related structures. In: Torg JS, ed. *Athletic Injuries to the Head, Neck, and Face*. second ed. St. Louis: Mosby; 1991:372 (Figure 27-1)]

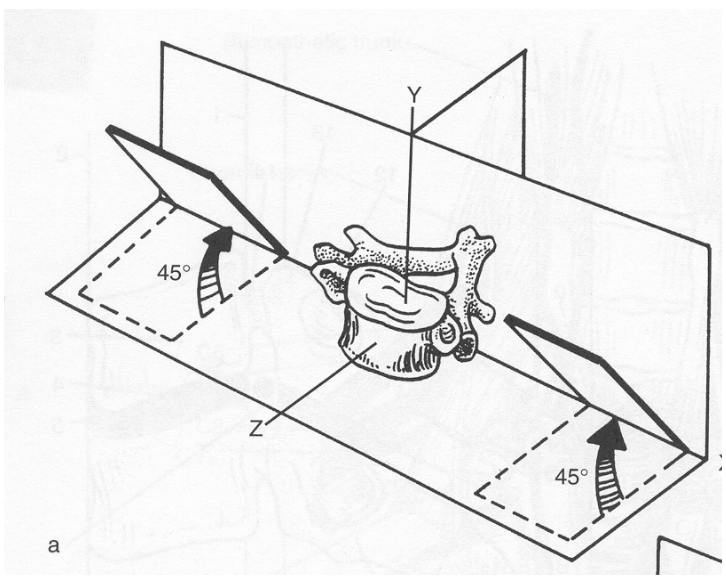


Figure 2-6. Articular facets of the cervical vertebra are oriented at a 45°angle to allow for rotation. [Reprinted with permission from Whiting WC, Zernicke RF. *Biomechanics of Musculoskeletal Injury*. first ed. Champaign, IL: Human Kinetics; 1998.]

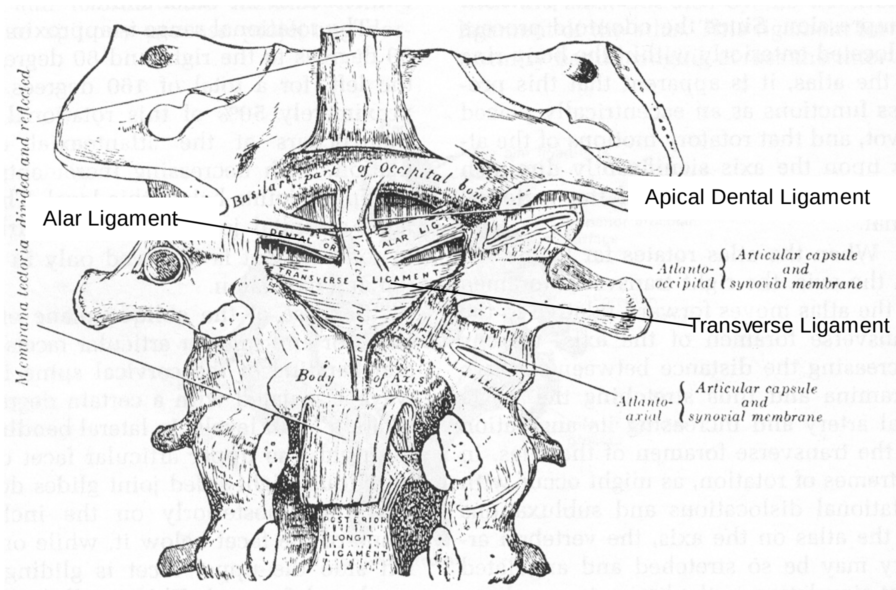


Figure 2-7. Ligament of the upper cervical spine as viewed from behind. [Reprinted with permission from Johnson RJ. Anatomy of the cervical spine and its related structures. In: Torg JS, ed. *Athletic Injuries to the Head, Neck, and Face*. Second ed. St. Louis: Mosby; 1991:376 (Figure 27-4)]

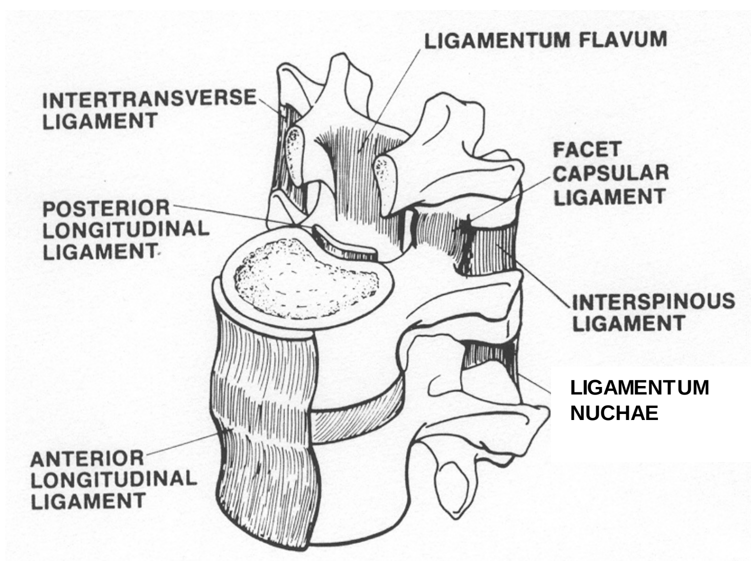


Figure 2-8. Ligaments of the spine that connect one vertebra to another. [Reprinted with permission from White A, Panjabi M. *Clinical Biomechanics of the Spine*. 2nd ed. Philadelphia, PA: JB Lippincott; 1990: 20 (Figure 1-13)]

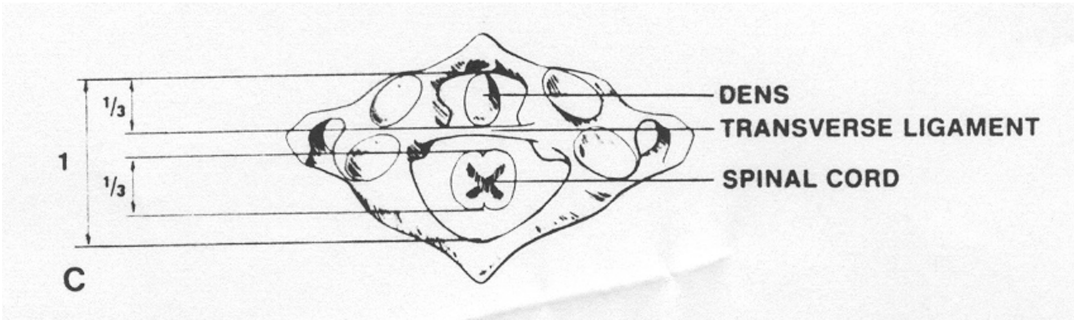
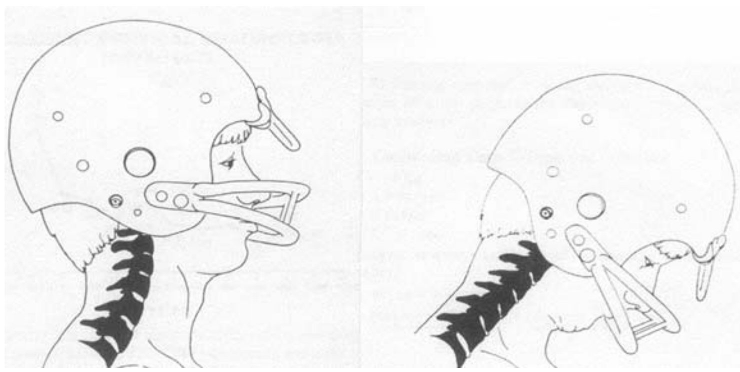


Figure 2-9. Steele's rule of thirds, where one third of the vertebral space is occupied by the odontoid structure, leaving one third for the cord and the remaining one third for the fluid. [Reprinted with permission from White A, Panjabi M. *Clinical Biomechanics of the Spine*. 2nd ed. Philadelphia, PA: JB Lippincott; 1990: 204 (Figure 4-21)]



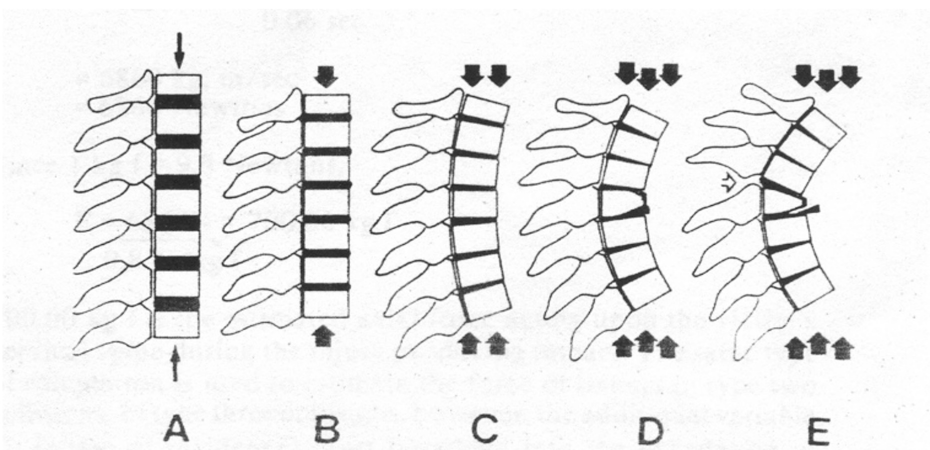


Figure 2-10. When the neck is flexed 30E, the normal lordotic curve is lost and the cervical spine is converted into a segmented column. Axial loading of a segmental column results first in compression deformation of the intervertebral discs (A&B). As energy input continues, maximum compressive deformation is reached, and angular deformation and buckling occur. The spine fails in a flexion mode(C) with resulting fracture, subluxation or dislocation (D&E). [Reprinted with permission from Torg JS, Vegso JJ, O'Neill MJ, Sennett B. The epidemiologic, pathologic, biomechanical, and cinematographic analysis of football-induced cervical spine trauma. *American Journal of Sports Medicine.* 1990;18(1):99-100 (Figures8-1,8-2,8-3)]

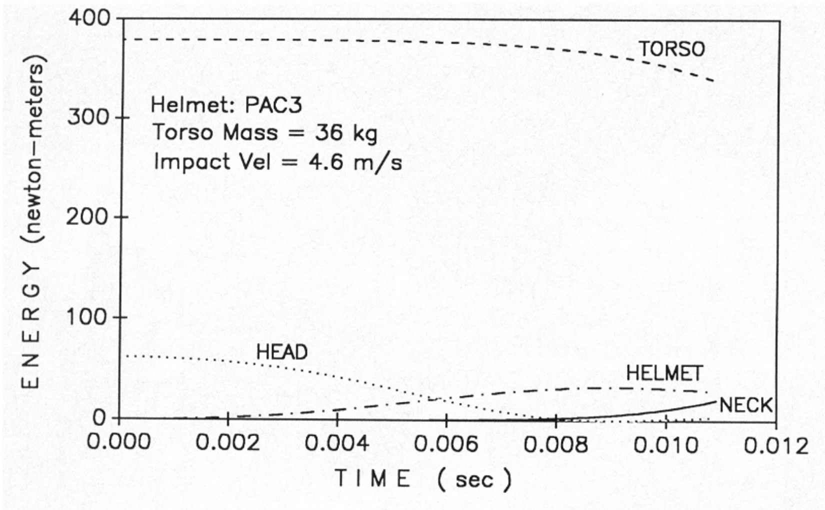


Figure 2-11. Immediately after impact the kinetic energy of the head is transferred to the helmet which bottoms out and subsequently, the kinetic energy of the torso must be absorbed by the neck. [Reprinted with permission from Otis JC, Burstein AH, Torg JS. Mechanics and pathomechanics of athletic injuries to the cervical spine. In: Torg JS, ed. *Athletic Injuries to the Head, Neck, and Face*. St.Louis: Mosby; 1991:452 (Figure 31-14)]

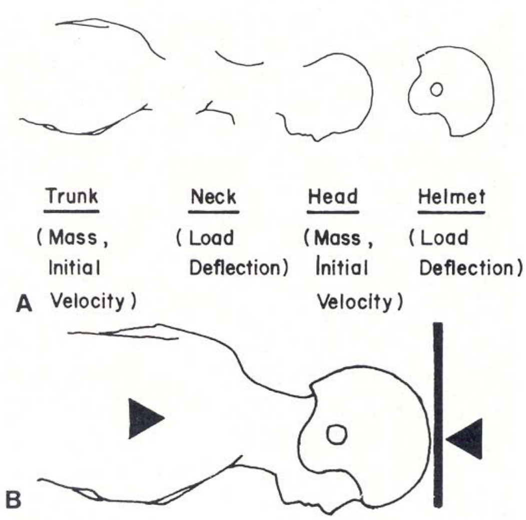


Figure 2-12. Axial load injury condition illustrates how the cervical spine is trapped between the abruptly decelerating head and the continued momentum of the torso, requiring the spine to absorb 90% of the kinetic energy. [Reprinted with permission from Otis JC, Burstein AH, Torg JS. Mechanics and pathomechanics of athletic injuries to the cervical spine. In: Torg JS, ed. *Athletic Injuries to the Head, Neck, and Face*. St.Louis: Mosby; 1991: 448 (Figure31-9)]

Sample calculation, Case 1—type 1 collision:

$$\begin{aligned} Wt &= 84 \text{ kg} \\ V_i &= 4.9 \text{m/sec} \\ V_f &= 0 \text{ m/sec} \\ t &= 0.06 \text{ sec} \end{aligned}$$

According to Newton's second law and the concept of conservation of momentum,

$$F_1 = m_1 a_1 = F_2 = m_2 a_2$$

$$= \frac{(m_1 v_{i1}) - (m_1 v_{f1})}{t} = \frac{(m_2 v_{i2}) - (m_2 v_{f2})}{t}$$

$$\because v_{f1} = 0 = v_{f2}$$

$$\therefore F1 = \frac{m_1 v_{i1}}{t} = F2 = \frac{m_2 v_{i2}}{t}$$

$$\text{Therefore, } F = \frac{(84 \text{ kg})\ (4.9 \text{ m/sec})}{0.06 \text{ sec}}$$

$$= 6{,}860 \text{ kg, m/sec}^2$$

$$= 6{,}860 \text{ newtons}$$

Since 1 kg f = 9.8 newtons,

$$F = \frac{6{,}860 \text{ N}}{9.8 \text{ N/kg f}} = 700.00 \text{ kg f}$$

700.00 kg f is the estimated axial force acting upon the victim's cervical spine during the injury-producing impact. The same type of calculation is used to estimate the force of impact in type 2 collisions. In type 3 collisions, however the additional variable 0_i (angle of incidence) must be added into the calculation of momentum.

Figure 2-13. Sample calculation using the law of conservation of momentum to estimate the force of impact values. [Reprinted with permission from Torg JS, Vegso JJ, O'Neill MJ, Sennett B. The epidemiologic, pathologic, biomechanical, and cinematographic analysis of football-induced cervical spine trauma. *American Journal of Sports Medicine.* 1990;18(1):106 (Figure 8-8)]

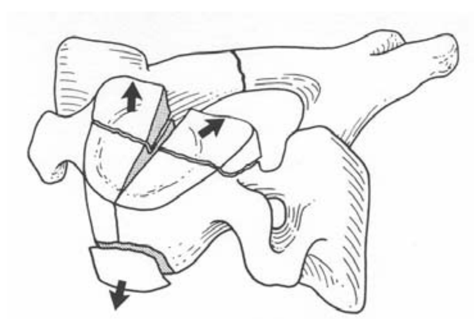


Figure 2-14. Orientation of common fracture planes and directions of fragment displacements commonly occurring in cervical vertebra. . [Reprinted with permission from White A, Panjabi M. *Clinical Biomechanics of the Spine*. 2nd ed. Philadelphia, PA: JB Lippincott; 1990: 173 (Figure 4-2)]

Figure 2-15. Plastic loop straps attach the facemask to the helmet using a screw and t shaped nut.

Figure 2-16. The facemask is retracted when only the two lateral loop straps are removed.

Figure 2-17. EMT Shears

Figure 2-18. Trainers' Angel was the first tool specifically designed for facemask removal.

Figure 2-19. The FM Extractor was designed to remove the facemask.

Figure 2-20. Anvil pruners have been shown to be an effective tool for facemask removal.

Figure 2-21. Anvil pruners can be modified to have a groove for stabilizing against the facemask bar while cutting the loop straps

CHAPTER 3
MOTION ANALYSIS OF HEAD AND NECK WHILE WEARING FOOTBALL EQUIPMENT

Approximately 10,000 catastrophic cervical spine injuries occur in the United States each year.[10, 11] Of patients who sustain an upper cervical injury, 25-40% die prior to receiving medical care.[11] Football has most frequently been cited as having the highest incidence of cervical spine injury among organized sports, second only to recreational diving.[1] Football also poses greater difficulty to healthcare providers because the protective equipment worn by the athlete can hinder the management of a potential cervical spine injury. Cervical spine injuries occurring in football have the potential for catastrophic results, including quadriplegia or death. Therefore, medical professionals in prehospital settings must be trained and prepared to properly manage potential cervical spine injuries in athletes.

The current protocol for treatment of potential cervical spine injuries in football was delineated by the Inter-Association Task Force for the Care of the Spine Injured Athlete (IATF) in 2001 and has been approved by most allied health professions. It includes leaving the helmet and shoulder pads in place and removing the facemask from the helmet prior to transport.[4] To remove the facemask from a football helmet, the four plastic loop straps attaching the facemask to the helmet must be cut or removed. Several tools are available that accomplish this task and many have been the focus of previous research.

However, only a few of the previous studies have actually examined motion of the head/helmet during facemask removal. Most of these studies have utilized external markers to measure the amount of helmet motion that occurs. To the best of this author's knowledge, no study has examined the segmental spinal motion in the cervical region during facemask removal. This is probably due to the logistical limitations and high costs of measuring segmental vertebral motion, while performing facemask removal. However, if a mathematical model relating cervical spine motion to that of head movement is available, it can be used in facemask removal studies to estimate the segmental motion at the cervical level.

Methods for measuring C-spine motion include both external and internal procedures. The most basic form of external ROM measurement is the use of a goniometer. Goniometry is convenient and well accepted for clinical screening because it demonstrates good reproducibility and reliability.[67] Goniometers are designed to measure relative rotations of a joint. To accurately measure a joint's rotation, the center of rotation of the goniometer must match the joint's center of rotation.[67] This is difficult to accomplish in the cervical spine due to the coupled motion with multiple joints acting together to produce the motion at the neck. Therefore, goniometers lack precision and the ability to measure segmental motion in the cervical spine.

Perhaps the best external measurement methods involve 3-D kinematic analysis using optoelectric devices, including camera-based systems utilizing passive reflectors or active infrared emitting diodes, as well as electromagnetic motion analysis systems. Such motion measurement systems are well-accepted procedures for measuring total functional ROM of the cervical spine. However, they rely on external surface or skin markers. One must employ a mathematical technique to correlate these surface markers with the motion of the individual vertebral segments.[68] Therefore, 3-D kinematic analysis alone does not allow one to measure segmental motion of the cervical vertebrae.

Internal measures of cervical motion can be obtained using CT or MRI scans, x-rays or video fluoroscopy. The use of plain x-rays to study cervical motion is the simplest and most widely used method as evident in the previous research. The procedure usually involves measuring vertebral displacement in a series of radiographs taken at various points of the ROM. Measurement techniques can vary quite significantly and include measuring canal size, functional motion of the neck, vertebral displacement, and centers of rotation for each vertebra. However, similar methods developed by Dimnet, Panjabi, and Dvorak have become widely accepted and reproduced or modified throughout the literature. These methods all require marking of lines tangential or perpendicular to anatomical landmarks on the vertebral body (Figure 3-1).[69, 70] From these lines, various measurements can be made between successive extension/flexion x-rays. Plain x-rays limit the examination of the sagittal and frontal planes only, as transverse views of the cervical spine are not accessible.

According to Lim et al.,[71] CT is a better measurement technique because the use of plain x-rays for measuring sagittal plane translation can produce false positive or false negative values in a clinical setting. CT and MRI can provide a 3-dimensional view of both osseous and soft tissue structures, as an image slice can be taken in any plane. ROM studies using CT and MRI technology are not common for several reasons. Technology is expensive and difficult to use in the research setting. CT sometimes requires the use of ionizing radiation contrast agents, which have potential side effects [68] MRI requires the subject to remain motionless for long periods of time. MRI is not a reliable measure when the subject is wearing football equipment because the metal in the football helmet and shoulder pads can cause too much artifact.[72]

Cineradiography is an excellent choice for ROM studies. Unlike plain x-rays, the entire range of motion can be viewed dynamically. Cineradiography began by using roentenography with motion picture technology. Modern methods, like fluoroscopy, use a special cathode ray tube and image intensifier to produce a clear image with minimal exposure to the subject.[68] Video fluoroscopy exposes the subject to approximately 50% less radiation for a comparable view than conventional radiographs.[73]

The current study used video fluoroscopy to quantify the segmental motion of the cervical vertebrae. The purpose of this study was to establish a mathematical relationship between the motion of C4 and C5 and the motion of the skull.

Methods

Subjects

Twenty-seven healthy male volunteers, between the ages of 18-30 years, were recruited from the community to serve as subjects. This population represents the age and health characteristics of those participating in competitive football. All subjects were free of orthopedic and neurological conditions that would influence normal neck motion. Therefore, subjects were excluded if they had any history of neck injury/pathology prior to data collection.

Instrumentation

Motion of the neck was recorded using video fluoroscopy. In separate trials, anterior-posterior and lateral radiographic views of the spine and opaque markers attached to a mouthpiece were obtained using an OEC-Diasonics Series 9800 Fluoroscope (OEC- Diasonics, Salt Lake City, UT) (Figure 3-2). The fluoroscopic images were used to determine motion of the skull and cervical spine.

Procedures

Prior to participation, each subject read and signed a written informed consent statement approved by the Institutional Review Board. After consent was given, each subject was fitted with a football helmet, according to manufacturer specifications. The subject was also fitted with a mouthpiece consisting of a plastic dental impression tray lined with dental wax to insure proper fit. An opaque marker attached to the mouthpiece was visible in the fluoroscopic view (Figure 3-3). During the data collection the subject lied supine on an examination table, with his shoulders on a 2.5cm thick pad (Figure 3-4). This pad was made from the posterior portion of set of shoulder pads, simulating the proper neutral alignment of the cervical spine while wearing the helmet. Once the subject was properly positioned, a lead apron was draped over the subject's abdomen. The C-Arm of the fluoroscope was positioned at the head of the table such that the C-Arm arc could easily be rotated between an anterior-posterior view of the skull and a lateral view (Figure 3-2).

Fluoroscope recorded DICOM images continuously. Before experimental trials, a lateral view and an anterior-posterior view of the mouthpiece markers and cervical spine at the neutral position were recorded. Radiation physicist (Mayo Clinic Jacksonville) was consulted to assess radiation exposure and ensure the dosages were minimized. Estimated total radiation dose for each trial was slightly greater than a single cervical plain X-ray.

The majority of football related cervical injuries occur between C4 andC6. Therefore, two-dimensional lateral and anterior-posterior fluoroscopic images recorded were centered to optimally capture the motion at C4/5 and the opaque mouth marker in the same view. Cervical rotation was not included in this study because it cannot be measured directly using fluoroscopy. Once the subject was positioned on the table, a test image was recorded to ensure proper centering of the image intensifier. When the subject was properly positioned, the image intensifier rested against the superior margin of his shoulder for the lateral view. Image intensifier was rotated inferiorly and was positioned under the exam table for the A-P view.

Two experimental trials were conducted in a data collection session. During the first trial, the subject's head and neck were placed in a neutral position. His head was moved passively through flexion/extension ROM while the fluoroscope captured a lateral view of the cervical vertebrae. Once the ROM was completed, the fluoroscope was turned off and positioned for the second trail. During the second trial, the subject's head and neck was placed in a neutral position and moved through the lateral flexion ROM. To minimize exposure to the subject's thyroid, static images were captured as the subject was passively moved to five preset positions throughout the lateral ROM. The first position was a neutral starting position. Next the subject was positioned at two points in either direction, midway through the ROM and at the endpoint of lateral flexion. A physician operated the fluoroscope and the investigator performed the passive motion. Both the physician and the investigator wore protective lead shields.

Data Reduction

Fluoroscopic DICOM file of each trial was processed and saved as an AVI file using ImageJ software (Rasband, W.S., ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA, http://rsb.info.nih.gov/ij/, 1997-2007). Hu-m-an® software package (HMA Technology, Inc., King City, Ontario, Canada) was utilized to obtain x- and y-coordinates of selected landmarks. A marker (20 mm diameter) on the opaque mouthpiece allowed the Hu-m-an® software to determine a conversion factor between actual and radiographic measurements. Two points on the opaque mouthpiece were digitized to calculate the orientation (angular location) of the skull during the passive motion. Bodies of C4 and C5 were digitized using a modified Dvorak procedure described by Ordway, et al.[74](Figure 3-1). The intersection of 4 lines tangent to the vertebral body defined the corners of the body. A line was drawn from the midpoint between the anterior corners to the midpoint between the posterior corners on the lateral view. On the A-P views, a line was drawn from the midpoint of the right side corners to the midpoint of the left side corners. These lines were used to calculate the angular location of the vertebra during the passive motion.

Statistical Analyses

Descriptive statistics (Mean±SD) were calculated for the subjects' age, height, mass and neck size. The motion occurring at C4/5 was correlated with the motion occurring at the skull marker, using a Pearson correlation. In addition, a regression analysis was performed plotting the angular location of C4/5 vs. the angular location of the skull for each subject. The best –fit polynomial equation was used to determine the relationship between the two angular locations.

Results

Twenty-six males (18-30 years), completed participation in the study. One male was excluded from the study due to failure to properly fit the helmets available for the study. The mean age of subjects was 25.6±3.2 years. The height range for subjects was between 165.1cm and 193cm, with a mean of 180.3±8.1cm. Subject mass range was 63.5kg to 127kg, with a mean weight of 86.5±13.4kg. Neck sizes for subjects ranged from 34.5cm to 45.7cm, with a mean of 39.1±2.8cm.

Mean flexion/extension ROM was 8.3º ± 2.4º at C4/5 and 34.4º ± 8.7º for the head. Mean lateral flexion ROM was 7.7º ± 2.8º at C4/5 and 48.1º ± 7.5º for the head. Pearson correlation coefficient between the head and C4/5 motion was $r = -.466$ ($p < .0001$) in the lateral view (flexion) and $r = -.722$ ($p < .0001$) in the A-P views (lateral flexion). Polynomial Equation 3-1 from the regression analysis reveals a linear relationship between the head and neck in both flexion and extension (Figure 3-5). The relationship between the head and neck in lateral flexion is also linear (Figure 3-6) and is identified in Equation 3-2.

$$C4/C5_{FLX} = (-0.13 * \text{head}) + 35.24; \; (R^2 = 0.217) \tag{3-1}$$

$$C4/C5_{LAT} = (0.14 * \text{head}) + 0.25; \; (R^2 = 0.521) \tag{3-2}$$

Discussion

Large numbers of structures, articulations and soft tissue attachments make the cervical spine an extremely complex arrangement. Motion occurring at the cervical level of the spine is spread across eight joints. Therefore, correlating the motion of the head with that of the lower cervical vertebra is difficult.

Many range of motion (ROM) studies have evaluated both the functional or total range of cervical motion and the segmental ROM of each cervical vertebra. Analysis of head and neck motion is complicated by the fact that the spherical shape of the head does not provide good landmarks and the head moves in combined axes.[74] Predominate motion of the cervical spine is flexion and extension in the sagittal plane.[70] Also, coupled motion in the transverse and frontal planes is incorporated in lateral bending and axial rotation.[65] Previous studies have found that the greatest amount of motion and stress occurs at C5/6 during flexion and C4/5 during extension.[75] In a simplified single plane examination, Dvorak, et al.[70] used x-rays to quantify intervertebral rotations, translation and centers of rotation in flexion and extension. Results showed that from C2/3 to C6/7 the centers of rotation moved progressively higher, from the middle of the vertebral body to the superior end plate. Limits of ROM in the sagittal and frontal plane for C4/5 and C5/6 are 13-29º and 0-16º respectively. In the transverse plane, the limits for C4/5 are 1-12º and 2-12º is the range for C5/6.[65]

Nearly 50% of head/neck flexion and extension occurs at the atlanto-occipital articulation, with the rest of the motion divided among the cervical vertebra. [25] Aside from the atlanto-occipital complex, the greatest mean segmental rotation in the sagittal plane was found at C5/6, and followed by C4/5.[70] In a study by Ordway et al.[74], also using single plane radiographs, the greatest mean sagittal ROM was found to be at C4/5 and C5/6, with the exception of the atlanto-occipital complex, which had the greatest mean value. It is interesting to note that C4-6 is the most common site for cervical fractures in athletes.[76] This division of the motion among the atlanto-occipital and the vertebral joints during flexion/extension could explain why our results showed the correlation between the head and neck in the sagittal plane motion was not as strong as the correlation in the frontal plane motion.

Many studies have shown similar results for the mean ROM at the C4/5 and C5/6 levels. Using planar radiographs, Miller et al. found that the mean ROM was greatest for flexion at the C6 level (10.5º)[75]. While in extension, the mean ROM was greatest at the C4 level (12.3º).[75] Bhalla and Simmons found the greatest total motion occurred at the C4/5 complex.[74] Lind et al. reported similar findings in their study using both frontal and lateral radiographs and clinical examinations. They found the largest ROM in the sagittal plane occurred at C4/5 (16º±6º) and C5/6 (15º±8º) In the same study, using external measures, the means for total ROM in each plane were reported for males and females. Mean sagittal, lateral and transverse plane motions in females were 76º, 45º, and 139º respectively and in males 68º, 45º, and 145º respectively.[77]

Mean lateral flexion ROM at the C4/5 level, in the present study, were within the limits reported in previous research. White and Punjabi found the maximum flexion angle to be between 13-29º and the maximum lateral flexion angle to be between 1-12º at the level of C4/5.

Mean flexion/extension angles were considerably less than that reported previously. This limitation in motion was most likely due to the restrictions of the football equipment. Also, the difference in measurement technique, namely the supine position of the subject and passive motion used in the current study, could explain some of the reduced motion. In the majority of previous studies subjects were tested in a seated or standing posture.

Conclusion

Results from this study indicate that the relationship between the angular motion of the head and the angular motion between C4 & C5, while wearing football equipment, is a linear relationship, in both the sagittal and frontal planes. However, the correlation is much stronger when examining the motion in the frontal plane, perhaps due to the fact that lateral flexion is more evenly distributed across all the vertebral joints, whereas the majority of flexion/extension occurs in atlanto-occipital complex. This difference between the two planes of motion is reflected in the polynomial equations generated by the regression analysis. Using these equations, motion of the head can be used to predict vertebral motion at the level of C4 and C5. These results will make it possible for future facemask removal studies to estimate vertebral motion using a similar skull marker system.

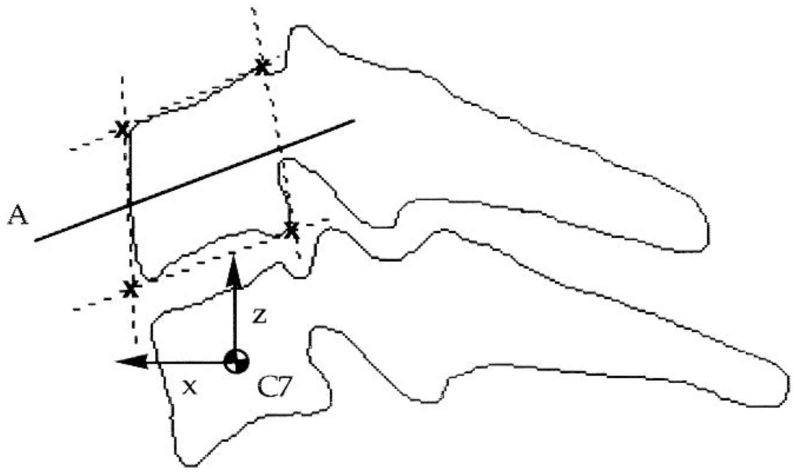


Figure 3-1. Modified Dvorak procedure for calculating segmental motion of vertebrae. The intersections of four tangent lines define the corners of the vertebral body. The midpoint between the anterior corners and the midpoint between the posterior corners define a line (Line A) that is used to calculate the angle of rotation of a body with respect to the global coordinate system defined at C7. [Reprinted with permission from Ordway NR, Seymour RJ, Donelson G, Hojnowski LS, Edwards WT. Cervical flexion, extension, protrusion and retraction : A radiographic segmental analysis. *Spine.* February 1999;24(3)(Figure 3)]

Figure 3-2. Experimental set up with the fluoroscope positioned for a lateral view of cervical spine.

Figure 3-3. Lateral view fluoroscopic image of cervical spine of an individual wearing a football helmet. The opaque marker connected to the mouthpiece can be seen at the bottom left.

Figure 3-4. Pad placed under subject's shoulders to maintain neutral alignment of the spine

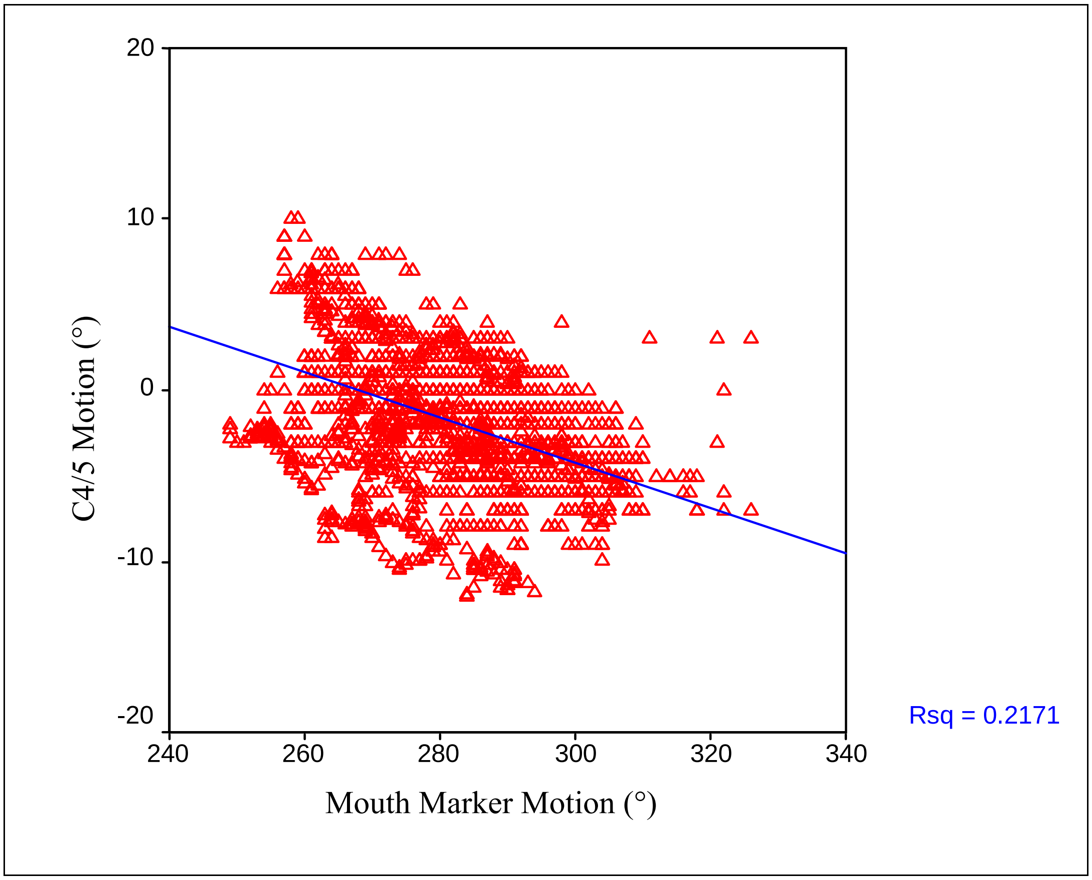


Figure 3-5. Linear relationship between head and neck in lateral fluoroscopic view.

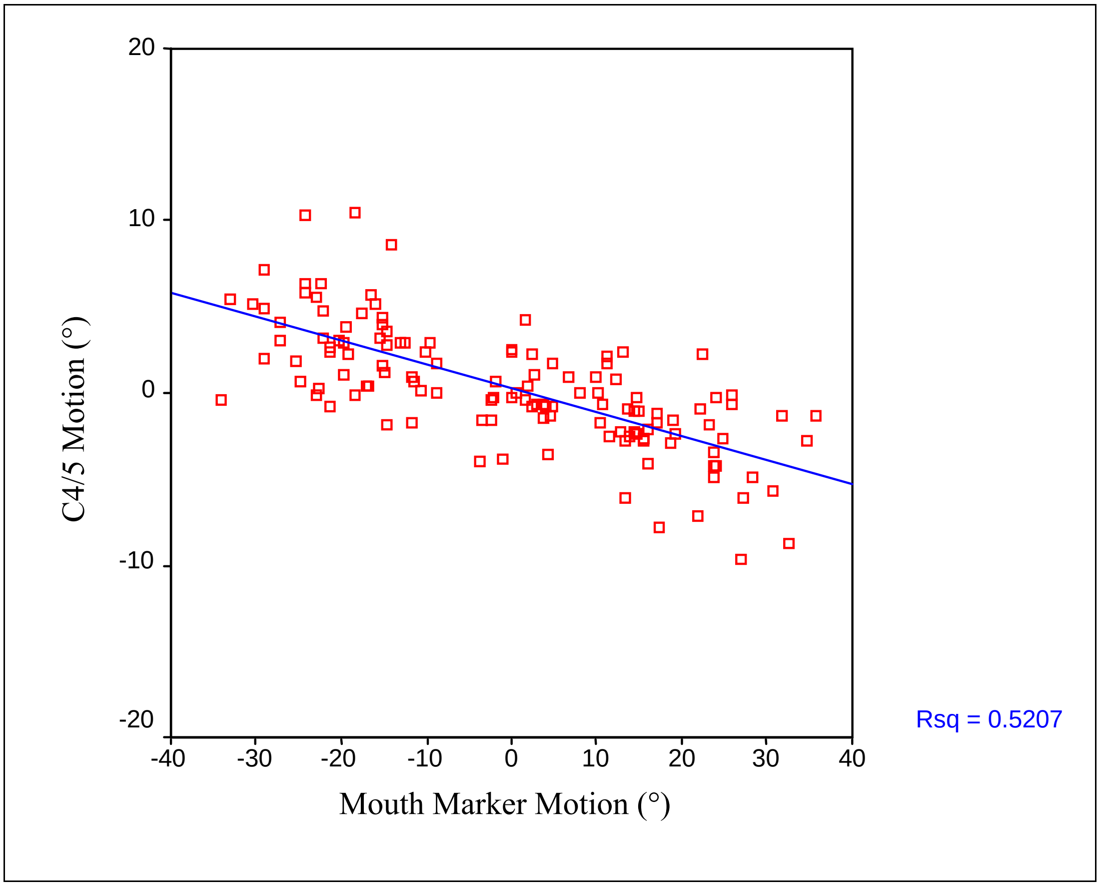


Figure 3-6. Linear relationship between head and neck in A-P fluoroscopic view.

CHAPTER 4
MOTION ANALYSIS OF THE HEAD AND FOOTBALL HELMET DURING FACEMASK REMOVAL

Spinal cord injury is possibly the most devastating traumatic injury anyone can survive. According to the National Spinal Cord Injury Data Research Center, sports related injuries accounted for 15% of all spinal cord injuries reported between 1973-1981. Ninety-five percent of those involved permanent neurological deficit.[1] Cervical spine injuries account for approximately 2-3% of all sports related injuries and can occur in virtually any sport.[12] However, sports such as diving, football, wrestling and gymnastics have historically had higher incidence of neurological injuries than other sports activities.[12] Football is second only to recreational diving and has the highest incidence of spinal cord injuries in organized sports.[1] Between 1976 and 2000, there were 229 cervical spine injuries in football resulting in incomplete neurological recovery.[20] Advances in the modern football helmet have been cited as a reason for high cervical injury rates in the early 1970s. As the helmet has progressively provided better protection to the head, athletes became more comfortable using the crown of the head to make contact with an opponent, which can cause an axial loading of the cervical spine. Research by Torg et al.[13] resulted in rule changes forbidding spearing which have reduced the incidence of catastrophic spine injuries in football to single digits in recent years. In 2002, there were six cervical spinal cord injuries reported involving incomplete neurological recovery.[20]

While the incidence of spinal cord injuries is low when compared to exposure rate, 0.44 per 100,000 participants, the topic still demands significant attention from the sports medicine community due to the permanent and profound effects of these traumatic injuries.[20] The sports medicine team must prevent secondary injury with immediate and proper evaluation, transport and treatment of cervical spine injuries.[12] Improper handling and transport in the prehospital environment can increase the risk of causing secondary injury to the athlete.[6, 12, 78-80] The incidence of secondary cervical spine injury from improper care has been estimated to be 10-25%.[5] However, the amount of force and motion necessary to cause secondary injury to a potential spine injured athlete is difficult to determine. Individual differences in anatomy, cervical spine orientation at time of force application and cervical level involved would need to be considered in such a determination. However, it is possible that as little as 1mm of movement in the cervical spine could cause significant secondary damage.[6] Therefore, the accepted gold standard of care is that little to no motion of the head and neck is ideal when a cervical injury is suspected.[5, 6]

Although protective equipment is designed to prevent and minimize injuries to the athlete, serious injuries do occur. When an athlete is injured, the protective equipment can be a hindrance to the medical team evaluating and treating the injury. This is most prevalent in collision sports such as football, hockey and lacrosse, where a helmet, with a facemask attached, limits the access to the head and face. Football helmet and shoulder pads have been the focus of many biomechanical studies because of their potential to cause secondary injury to the spine when removed. Researchers have observed significant motion in the head and neck when the helmet is removed.[32] In addition, when the helmet is removed and the shoulder pads remain, the neck is forced into an extension position (Table4-1). These findings led the Inter-Association Task Force for the Appropriate Care of the Spine Injured Athlete (IATF) to recommend protocol changes. Current protocols require leaving the helmet and shoulder pads in place and removing only the facemask.[4]

Several authors have evaluated the tools and techniques for facemask and helmet removal in an effort to determine the best, most efficient method to gain access to the injured athlete's airway. It is important to consider both time and movement elements when considering which technique/tool is most effective.[6] There are several tools and methods that may be employed to accomplish facemask removal. Tools specifically designed to remove the facemask, such as the Trainers' Angel (TA) and FM Extractor (FME) have regularly been tested in research studies. In addition, various implements are capable of cutting through or removing the plastic loop straps that hold the facemask in place. However, previous research has been inconclusive as to which method is most effective with respect to both time and movement.

Objective of the current study was to determine the amount and nature of head motion during football helmet facemask removal. This motion was measured directly, not inferred from the helmet motion. In addition, the project aims to compare helmet motion to the amount of head motion while using various tools to remove the facemask from a football helmet.

Clinical significance of this project is to determine if current emergency management protocols are truly limiting skull motion. results may have the potential to improve the guidelines for the safe care and transport of the spine-injured athlete. By analyzing motion during facemask removal using various tools, the effectiveness of different methods can be evaluated and the findings may provide valuable information to sports medicine professionals.

Methods

Subjects

Two groups of individuals were used in this study. Twenty-six athletic training students (AT), 8 male and 18 female, ranging in age from 20-26 years old, were recruited from local university population to serve as subjects. Facemask removal is an entry level athletic training skill, however, there is no way to control for experience with the tools among Certified Athletic Trainers. We have accounted for this by using AT students from the same educational program to perform the task of cutting the loop straps. All the AT students had similar education and training with the various tools. Additionally, 20 male students, 18-30 years in age, were recruited from the University of Florida population to serve as models. This population represented the age and gender of those individuals participating in organized football. Procedures were explained to all subjects/models and they signed an IRB approved informed consent form prior to participation. Each subject participated in one data collection session, consisting of four trials. Some models participated in more than one data collection session. All subjects/models were free to withdraw from the study at any time.

Instrumentation

Five Hawk digital cameras (Motion Analysis Corp., Santa Rosa, CA) collecting at 100 Hz, positioned two in front of and one on each side of the model (Figure 4-1), and a radio telemetry EMG system (MESPEC 4000) collecting at 900Hz were used for data collection. EMG data were evaluated subjectively to ensure the model did not actively resist any motion caused from facemask removal. Pairs of Ag/AgCl surface electrodes (Blue Sensors type M-00-S[h]) of 3.4mm diameter were attached over the model’s right and left sternocleidomastoid and right upper trapezius muscles. Skin surfaces were cleansed with alcohol and shaved if necessary prior to electrode placement. Electrode attachment was in accordance with Cram et al.[81] over the bellies of the each muscle, parallel to the line of action, with center-to-center distance of 2.5cm. The EMG signals were pre-amplified with a gain of 500 and band pass filtered at 8-1500Hz (CMRR>130dB) near the electrodes and telemetrically transmitted to a central receiver (gain=1, Butterworth filter, 8-500Hz band pass). Amplified EMG signals were sampled at 900 Hz using EvaRT 4.6 motion analysis software (Motion Analysis Corp., Santa Rosa, CA).

The 3-D motion analysis positional data of reflective markers on the helmet and mouthpiece were used to determine the amount of helmet and head motion during facemask removal. Object space calibration errors in the X, Y and Z directions were below 0.5% for all data collections.

The system was calibrated prior to each testing session according to the manufacturer specified procedures.

Each model wore a standard football helmet and shoulders pads (running back), which were properly fitted according to manufacturer specifications. Seven reflective markers (1.0cm in diameter) were placed on the surface of the helmet (Figure 4-2). Subjects were fitted with a mouthpiece consisting of plastic disposable dental impression tray lined with dental wax to insure proper fit. Attached to this mouthpiece was a T-shaped array with four reflective markers extending outside the mouth (Figure 4-3). These markers were visible through the facemask. A facemask with an interior bar removed was used to facilitate the view of mouthpiece markers (Figure 4-2).

Tools

Many tools are available to accomplish facemask removal. This study focused on the most widely used tools and the ones that have previously been investigated, including the Trainers' Angel (TA), the FM Extractor (FME) and two types of anvil pruners (AP)(Figure 4-4). Subjects were instructed to use the tools as the manufacturer recommends. The FME comes with three possible methods for removing the facemask (Table 2-4). Subjects were instructed to use Method C, as it has been shown in previous studies to be the most preferred and efficient method.[55] The AP and RAP do not come with instructions for removing a facemask, so the subject was instructed to use them in a similar manner to the FME. Tool use order was randomly assigned. Each AT used all four tools, thus removing a total of four facemasks.

Procedures

In a separate session, prior to data collection, the AT subjects attended a lecture about the prehospital care of the spine injured athlete. On the day of testing, the subjects were given instructions on the use of each tool and watched an instructional DVD. They were given practice time with the tools, removing two facemasks with each tool prior to data collection. Each model was fit with a mouthpiece lined with dental wax, to which the markers were attached. Two pairs of disposable Ag/AgCl surface electrodes (Blue Sensors type M-00-S) EMG electrodes were attached to the SCM and upper trapezius muscles of the model.

During the data collection the model lied supine on the floor and was instructed not to assist in restraining their head movement. EMG activity of the model's neck muscles were monitored to ensure that they were not actively restraining the head. The EMG data were reviewed after each trial. If qualitative analysis of the EMG data showed the model was not completely relaxed, the trial was repeated. Two trials were restarted due to loss of contact with the electrodes.

The AT subject knelt above the model's head and was instructed to remove the facemask as quickly as possible while limiting the amount of motion to the head and neck. To simulate in-line stabilization of the models head, Ferno™ blocks were used similar to if the patient were secured to a backboard. One of four tools was used to make two cuts through the plastic loop-straps, which secure the facemask to the helmet, parallel to the facemask bar. This created a channel opening slightly wider than the diameter of the facemask bar. This process was repeated until all four loop-straps were cut. The facemask could then be carefully freed from the helmet. It is essential that this task be completed as quickly as possible to access the airway of an athlete who has stopped breathing. The task should take approximately 1-2.5 minutes to perform. Each subject performed the facemask removal four times, using each of the four commercially available tools. Tools were honed between trials to keep the blades sharp. Tool order was completely randomized.

Data Reduction

Each reflective marker was digitized and scaled positional data were smoothed using EVaRT software package (Motion Analysis Corp., Santa Rosa, CA). Angular kinematic data for the helmet and skull in the sagittal, frontal and transverse planes were calculated from the positional data using KinTrak 6.2 software (Motion Analysis Corp., Santa Rosa, CA) (Appendix A). Planar range of motion (ROM) for the skull and helmet was calculated from the maximum and minimum angles in each plane and can be described as limits of angular motion. Six angular measures were calculated for the ROM data; Helmet Flexion, Helmet Rotation, Helmet Lateral Flexion, Skull Flexion, Skull Rotation and Skull Lateral Flexion. Total movement (TMT) was calculated by summing the absolute angular displacement between consecutive video fields and can be described as the total angular displacement, in three planes of motion, during the time of facemask removal.

Additional Measures

In addition to the angular kinematic data of the helmet and head, the time for facemask removal was measured. Removal times were calculated, using the EvaRT 4.6 motion analysis software (Motion Analysis Corp., Santa Rosa, CA), from the number of frames collected during each trial. Removal time began when the AT picked up the tool and ceased when the facemask was successfully freed from the helmet. Time and motion data were used to determine an efficiency ratio (EFF) for each tool (Equation 4-1).[6] At the conclusion of the data collection session, the AT was asked to choose which tool they would most like put in their athletic training kit.

$$\text{EFF} = \text{Time} \times \text{ROM}/100 \tag{4-1}$$

Statistical Analysis

An a priori sample size analysis was performed based on the following parameters: α level of .05, power level of .80 and expected effect sizes ranging from 0.50-0.75. This analysis produced a recommended sample size of 18-25 subjects. Demographic data (mean ± SD) of the subjects were calculated for age, gender, amount of experience, and number of football seasons worked. A one-way MANOVA with 4 levels with repeated measures was used to analyze the ROM, TMT, time and EFF data ($\alpha = .05$). Pairwise comparisons were performed using LSD post hoc analysis. Pearson's correlation coefficient was calculated between kinematic measures of the helmet and skull motion.

Results

The AT subjects reported enrollment in athletic training program for 1-3 years, with a mean of 1.85±0.55 years. They reported having worked in a football environment a mean of 1.05±0.75 seasons. Thirteen subjects reported having some experience with at least one tool, 7 in lecture situation, 4 in a workshop, and 10 in practice/lab sessions.

Of the 26 AT subjects, two were unable to complete the facemask removal in the allotted time. Therefore, the data reflect only 8 minutes of their efforts. Erroneous data were found for the skull lateral flexion angles in 4 trails. This information was excluded from calculation of the MANOVA. Results for ROM, TMT, EFF and Time are reported in the means table (Table 4-2). Multivariate analysis revealed statistically significant differences among flexion ROM (helmet markers), rotational ROM (skull markers), TMT, time and EFF ratio. Pair wise comparisons for helmet marker ROM data show the FME and RAP caused significantly less flexion/extension than the TA. For skull marker ROM data, the FME caused significantly less rotational motion than both the TA and AP. Time data pair wise comparison revealed the FME took significantly less time to remove the facemask than all other tools. Also, the RAP performed significantly better than the TA with respect to time. The TMT for the FME was significantly less than all other tools and the TMT for the TA was significantly more than all other tools. The EFF ratio for the FME was significant less than the AP and TA.

Pearson product correlation revealed significant correlation between the helmet markers and skull markers for flexion ($r = .525$; $p < .001$) and rotational movement ($r = .539$; $p < .001$), but not for lateral flexion ($r = .134$; $p = .178$).

When asked to choose their tool preference after the testing sessions, 20 AT subjects chose the FME. Four subjects chose the AP and 2 chose the RAP. None of the subjects preferred the TA.

Discussion

Primary objective of this study was to determine if one cutting tool performed better with respect to time and motion. In addition, by comparing markers located both on the helmet and attached directly to the skull via dental tray, we hoped to determine whether the helmet motion was a valid measure of the amount of head motion. Many researchers have examined tool efficiency from a time aspect. Few studies have measured motion occurring during facemask retraction. Only a handful of recent studies have included both time and motion variables during facemask removal.

While the previous researchers have all considered time in removing the facemask, a limited number have investigated the amount of motion occurring. Of those, none have measured the motion of the head or neck, instead they have inferred head and neck motion from helmet motion.[5-9] While a properly fit helmet should move as one unit with the head, helmets are not always properly fit.[62] Therefore one cannot assume the head and neck will move the same magnitude as the helmet does. Waninger, et al. evaluated head movement in football hockey and lacrosse athletes immobilized to a backboard. Using a similar set of markers to those used in the current study they extrapolated the amount of head motion within the helmet by calculating the difference between the head markers ROM and the helmet markers ROM. Results from the Waninger study indicated that a properly fitted football helmet allowed less than 5°of head motion within the helmet.[82] Results from the current study are consistent with the Waninger study. Significant correlations were found between the helmet and head motion in both sagittal and transverse planes. Lateral flexion did not significantly correlate between the helmet and head. This is most likely due to erroneous data in the skull lateral flexion calculations.

Many previous facemask removal studies involved subject ratings of tool performance. In one study, the TA was the tool of choice for 54% of the ATCs surveyed. However, in the same study it was discovered that only 12% of those ATCs used the technique recommended by the manufacturer, 60% needed to use two hands to operate a TA, 58% were unable to complete the task on the first attempt and 68% reported never practicing the use of a TA.[47] In several studies, the TA has received a lesser rating of satisfaction by the participants.[6, 49, 58, 60]

When considering time alone in tool performance, studies have shown the TA to be faster than some tools in removing the facemask. However, several studies have shown it to be significantly slower than the anvil pruner (AP). [6-8, 39, 42, 48-51] In fact, a sharp TA has been shown to be less effective than a dull AP.[52] When compared to the FME, the TA has been shown to demonstrate comparable or slower times for removal.[7, 8] Limited number of studies comparing the amount of motion caused to the helmet have illustrated that the TA produces significantly more motion than other available tools, including the AP and FME. [6, 8, 9] Consistent with previous research, in the current study the TA performed significantly worse than all other tools with respect to time, ROM, TMT and EFF rating. During data collection, many subjects needed to use 2 hands to operate the TA and several reported hand fatigue. The TA was the only tool with which subjects were unable to complete the task in the allotted time.

The FME is a tool designed more recently and specifically for facemask removal. The FME has been shown to be an effective tool in removing the facemask. More specifically, the FME has been found to create less motion than the other available tools.[7, 8] Also, in previous studies, the FME took less time than the TA and PVC pipe cutter[7, 8, 48] and significantly more time than the AP [43, 51] to remove the facemask. Our results contradict the previous time data. In the current study, the FME performed significantly better than all tools when comparing time for removal and TMT. Also, the FME caused less motion than the TA or AP and had a better EFF rating than either the TA or AP. The only significant differences between the FME and the RAP were in time and TMT, which is a function of time.

The AP has produced high satisfaction ratings by subjects [6, 49, 53, 58, 60] although the results of previous studies conflict in some areas. Several studies have shown the AP to be significantly faster than other tools, including the TA.[6-8, 39, 42, 48-51, 53, 56] However, Knox and Kleiner[6] reported that the use of AP resulted in a slower time for removal of the facemask when compared to the TA and screw driver. While Knox and Kleiner[6] found the AP caused less motion than the TA, Swartz et al.[8] found the use of AP resulted in more motion than the FME and TA. When both the time and motion were considered, the AP was comparable to the FME and more efficient than the TA or PVC pipe cutter.[8]

There are many different manufacturers of APs. In addition, the AP can be modified to have a groove for stabilizing against the facemask bar while cutting the loop straps (Figure 2-21). However, there is no uniform method for modifying the AP. Therefore some researchers have chosen to leave the AP unmodified for research purposes.[8] This could partly explain the differing efficiency results from various studies.

The current study used unmodified AP and RAP tools, purchased from a national retail chain. Results show the AP caused more motion in the transverse plane and took longer to remove the facemask than the FME. The AP also performed worse than the FME with respect to TMT and EFF rating. The only tool the AP outperformed was the TA, in the time measurement.

Conclusion

When evaluating a cutting tool for the removal of the facemask from a football helmet, it is important to consider both motion and time factors. Results of this study have shown the FME to be the most effective tool, of those compared, when measuring ROM excursion, total cumulative movement, time, and efficiency rating. The FME either performed superiorly or had no significant difference from the AP, RAP or TA. In contrast, the opposite was true of the TA. The TA had the worst performance in both time and motion measurements.

When considering a tool for use, the ATC needs to take many factors into consideration and then chose the tool that is right for them. The FME would be a wise choice solely based on the results from this study. However, the FME costs a great deal more to purchase than the other tools. For the ATC in a colligate division 1 institution or with a professional team, cost is probably not an issue. However, there are far more ATCs in small colleges or high schools that may not have the budget to afford a $350.00 tool. The RAP performed equally well in many areas of the study, with time being the only differentiating factor. Research has revealed that practice with a specific tool can greatly improve the time to remove the facemask.58 Therefore, if an ATC chose a quality RAP and practiced with the tool, on the equipment at their location, it is this researcher’s opinion that the RAP could perform the task, within he IATF guidelines, at a substantial cost savings. Finally, the results of this study show that utilizing helmet markers to measuring head motion is valid, assuming the helmet is properly fit to the individual.

Table 4-1 Vertebral sagittal alignment values with no equipment (control), shoulder pads only (SH) and helmet and shoulder pads (SH/H)

Test Situation	Occ-C2	C2-C7	Occ-C7
Control	60.2°	22.5°	81.6°
SH/H	60.9°	25.3°	86.6°
SH	59.4°	32.8°	92.4°
Larger value= more cervical lordosis			

Note : Adapted from Swenson TM, Lauerman WC, Blanc RO, Donaldson WF, Fu FH. Cervical spine alignment in the immobilized football player: Radiographic analysis before and after helmet removal. *American Journal of Sports Medicine.* 1997;25(2):226-230.

Table 4-2. Means ± SD for ROM (helmet markers), ROM (skull markers), Time, TMT, and EFF ratio using four tools to remove the facemask from a football helmet.

Dependant Variable	AP	FME	RAP	TA
Time (s)	221.0 ± 98.0	153.8 ± 56.4 [a,c,d]	200.2 ± 98.0 [d]	280.1 ± 126.2
Helmet Flexion (°)	12.8 ± 5.3	11.7 ± 3.1 [d]	11.6 ± 4.5 [d]	15.1 ± 5.0
Helmet Rotation (°)	11.6 ± 6.3	9.9 ± 6.0	9.6 ± 3.7	12.2 ± 6.8
Helmet Lat. Flexion (°)	26.2 ± 14.9	25.1 ± 17.4	39.7 ± 7.4	31.9 ± 20
Skull Flexion (°)	13.2 ± 6.4	11.3 ± 3.9	11.2 ± 5.0	14.5 ± 9.3
Skull Rotation,(°)	17.5 ± 10.5	12.2 ± 5.9 [a,d]	14.6 ± 9.7	16.5 ± 6.2
Skull Lat. Flexion (°)	53.0 ± 17.9	50.39 ± 17.1	47.4 ± 24.5	53.5 ± 15.8
TMT, (°)	8022.3 ± 479	5192.4 ± 2122 [a,c]	8711.2 ± 7171	14780.9 ± 3444 [a,b,c]
EFF ratio	113.6 ± 71.2	69.8 ± 44.3 [a,d]	122.1 ± 167.9	179.5 ± 145.4

[a]Significantly different from AP ($p<.05$)
[b]Significantly different from FME ($p<.05$)
[c]Significantly different from RAP ($p<.05$)
[d]Significantly different from TA ($p<.05$)

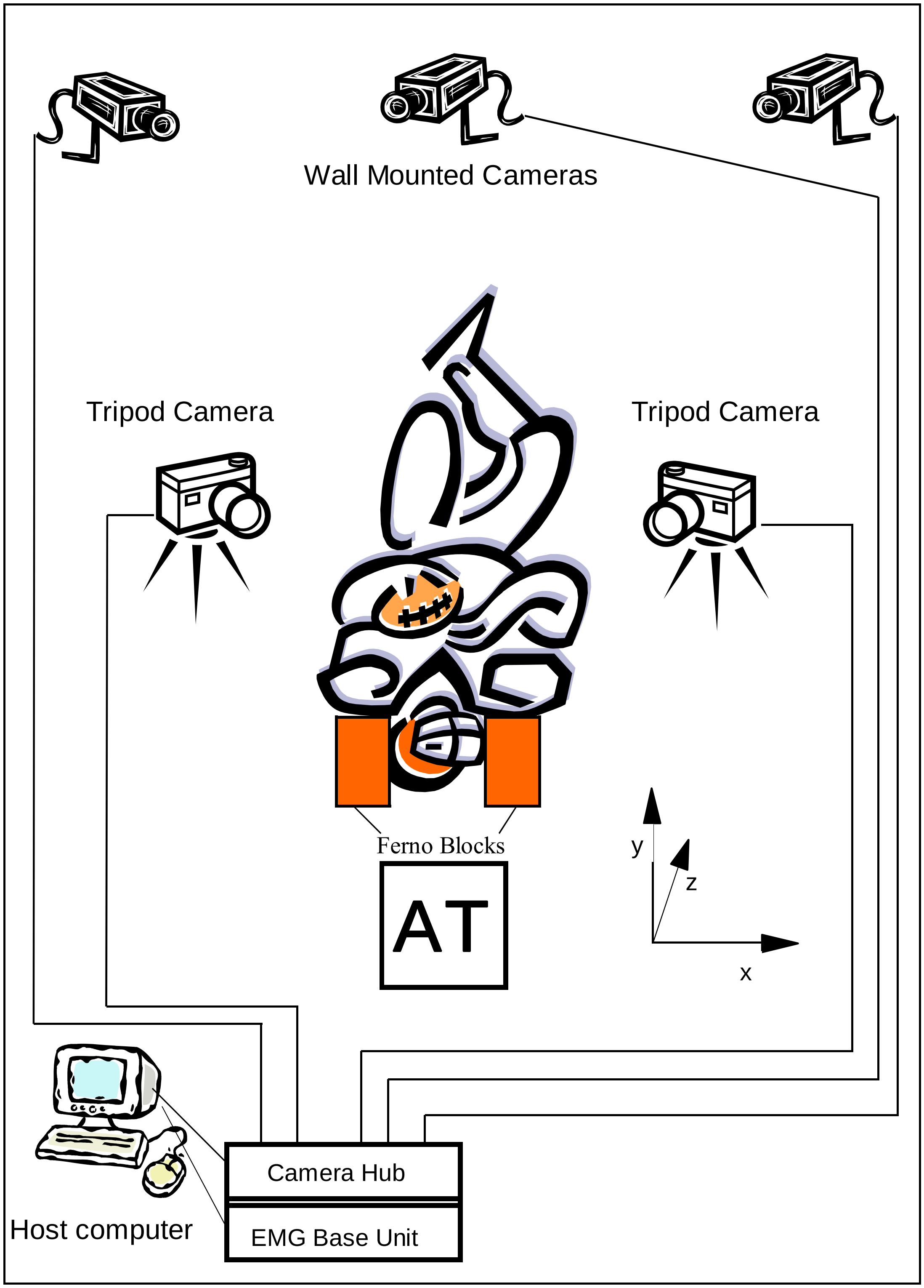


Figure 4-1. Overhead view of experimental set up.

Figure 4-2. Football helmet with reflective markers attached to the surface. One interior bar of the facemask has been removed to facilitate the view of the mouth markers.

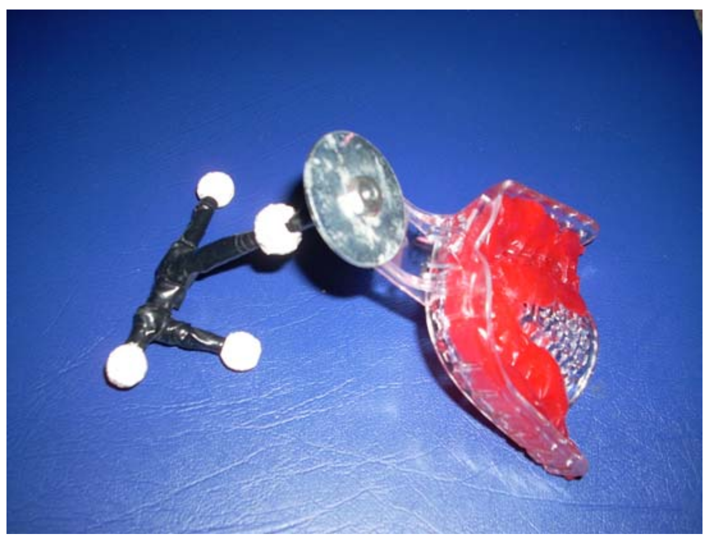


Figure 4-3. Dental tray lined with wax to ensure proper fit. The T-shaped array with four reflective markers, will protrude from the subjects mouth and be visible through the facemask of the helmet.

Figure 4-4. Facemask removal tools: Trainers' Angel (top left), FM Extractor (top right), anvil pruner (bottom left), and anvil pruner with ratchet handle (bottom right)

CHAPTER 5
GENERAL DISCUSSION AND CONCLUSIONS

Although the frequency of cervical spinal injuries in football has declined over the past decades, the ramifications of such a catastrophic injury dictate that all medical personnel involved need to be familiar and practiced in protocols for the prehospital care of these athletes. Handling of athletic equipment worn by the athlete must be addressed by the protocols. Therefore, it is important that all entry level ATCs understand the importance of the task of removing the facemask from a football helmet and be competent and practiced with the tools used to accomplish this.

Guidelines have been developed by the IATF for care of the spine injured athlete, including removing the football facemask prior to transport and leaving the helmet and shoulder pads in place. The NATABOC does not include the task of facemask removal in the competencies all athletic training students must master. Since there are many ways to accomplish the task, the competencies do not specify any one method that should be used. Because of this, facemask removal is not tested on a certification exam.

Previous research examining which facemask removal tools are most efficient has been inconclusive. Most researchers have only measured time to remove the facemask. Few studies measuring both time and motion have only measured motion of the helmet. Motion of the skull and vertebra has not been examined during facemask removal. Therefore, it is difficult to conclude which tools are truly accomplishing the task in the most efficient manner.

The purpose of this study was to determine which facemask removal methods could accomplish the task quickly while truly limiting the motion of the cervical vertebra. By examining the relationship between head motion and vertebral motion, measuring actual skull motion while comparing various tools, and merging the results we hoped to accurately determine which tool(s) limited spinal motion and thus should be used for facemask removal. Determining the best method(s) for facemask removal would allow the NATABOC to adopt specific techniques to be taught in educational programs. With a standard set for the education of the task, it could then be objectively evaluated on a certification exam.

Results from Study I have shown there is a linear relationship between head and neck motion while wearing football equipment. This yielded a prediction equation with which to reliably compare the two motions. Results from Study II, measuring skull motion while removing a facemask illustrated that the FME is a superior tool, performing better than at least one other tool with respect to flexion/extension motion, rotation of the skull, total amount of motion, and efficiency rating.

Applying the regression equation to the raw motion data from Study II, then calculating MIN and MAX angles to determine the C4/C5 ROM, integrated the results from both studies. Resulting means for each tool were much smaller than the ROM means in Study II (Table 5-1). Calculated means were then compared using MANOVA. Results showed no significant difference among tools in flexion and lateral flexion ROM. This is due to the fact that motion of the head is the result of combined motion at the eight joints. Therefore the corresponding motions at C4/5 ROM were much smaller than skull ROM.

Considering the difference in motion between the skull and C4/5, the results of previous facemask removal studies are hard to interpret. While previous researchers have found tools to be significantly more efficient when measuring the helmet motion, would their conclusions remain the same if the vertebral motion were considered? It is possible that when comparing vertebral motion, the differences among tools are minimal. Therefore, there could be more tools than previously thought that are effective in removing the facemask in a timely manner while minimizing spinal motion.

Limitations

In light of the results from this study, a limitation to all previous studies is sample size. In order to detect a difference in small amount of vertebral motion, the sample size must be increased. In addition, the current study had several limitations. Tools used were all cutting tools. Also two of these, AP and RAP, have no standard manufacturer. The AP and RAP used in this study were purchased at a national hardware chain, however other pruners and modified pruners could perform differently. Another limitation to the tools was that the same tool was used throughout the study. To minimize a dulling effect, a separate tool was used for practice and testing and each tool was honed between trial sessions. Equipment used was only one style of helmet and shoulder pads. There are several manufacturers of football equipment, and each makes several different styles of equipment. By using only one type, the results are limited to the specific equipment. Also, to standardize the effects of external stabilization, the models head was only restrained by Ferno™ blocks whereas in a clinical situation, a member of the medical team would provide in –line stabilization to the head while the facemask was removed. Therefore, our result could possibly show much greater motion then would occur in an actual rescue situation. Also, AT subjects were confined to the space above the model's head as to not interfere with camera positioning. In a clinical situation, the ATC would probably be positioned next to the athlete while removing the facemask. Finally, the subjects used were inexperienced students, rather than ATCs. This was done to standardize the amount of previous experience each subject had prior to the study. This inexperience may have caused longer removal times and more motion than studies using experienced individuals.

Recommendations

Recommendations for further investigation include correcting limitations from this study. Namely, using a new tool for each trial, testing several different helmets/loop straps, and using either more experienced ATCs or allowing for extra practice and training with students. Another recommendation for future research is to conduct facemask removal under fluoroscopy. This would give actual vertebral motion rather than estimated or calculated values.

Conclusions

These studies have shown the relationship between head and neck motion can be quantified and provide us with a better understanding of previous research on facemask removal. This relationship demonstrates that the motion of the lower cervical vertebra is markedly less than that of the head. Therefore, many of the tools previously shown to be less effective, may truly be safe to use in the clinical setting. However, until research is performed examining directly the motion of individual vertebrae during facemask removal, we must rely on the larger ROM data from external head markers. With this in mind, results from Study II show the FME to be a significantly better tool. The FME was designed specifically for facemask removal and has been shown to be significantly better to other cutting tools in previous studies as well.[7, 8, 48] Therefore, if the NATABOC were to adopt a standard method for facemask removal, the FME would be an excellent choice.

Table 5-1. Means ± SD for flexion/extension and lateral flexion ROM for skull markers and estimated C4/5 vertebral motion using four tools to remove the facemask from a football helmet.

Dependant Variable	AP	FME	RAP	TA
Skull Flexion, deg	13.2 ± 6.4	11.3 ± 3.9	11.2 ± 5.0	14.5 ± 9.3
Skull Lat. Flexion, deg	53.0 ± 17.9	50.39 ± 17.1	47.4 ± 24.5	53.5 ± 15.8
C4/5 Flexion, deg	1.65 ± 0.7	1.46 ± 0.5	1.44 ± 0.7	1.88 ± 1.2
C4/5 Lat. Flexion, deg	7.52 ± 2.3	7.06 ± 2.4	6.63 ± 3.4	7.66 ± 2.3

** Significant difference (p >.05)*

APPENDIX A
ANGULAR CALCULATIONS IN KINTRAK

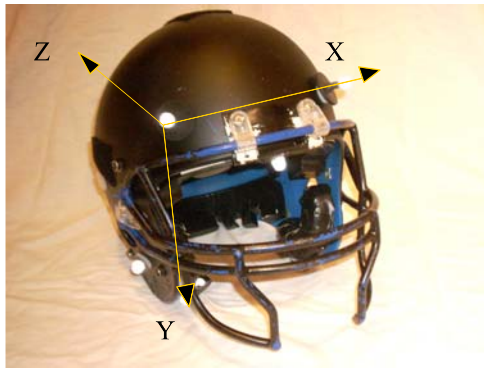
A three-point segment was created for the helmet using the markers on the top right and left and the center forehead marker. This created a local coordinate system (HCS)(Figure A-1) in which the top right marker became the origin. The line between the top right and top left markers represents the x-axis. The y-axis is perpendicular to the x-axis in the direction of the center marker, but not intersecting it.

A three-point segment was created for the mouth marker using the left, center and right markers. This created a local coordinate system (MCS)(Figure A-2) in which the right marker became the origin. The line between the right and left markers represents the x-axis. The y-axis is perpendicular to the x-axis in the direction of the center marker, but not intersecting it.

Vectors from these segments are then projected onto a plane to calculate the angular displacements. These angles are formed between a reference axis and a plane for projection. The marker coordinates were transformed to the lab coordinate system (Figure A-3) by pairing the reference axis from the lab coordinate system with the corresponding projection plane from the helmet or mouth coordinate system (Table A-1).

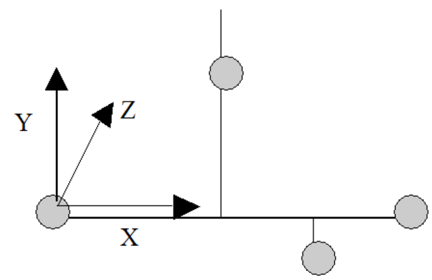
Table A-1. Projection planes

Reference axis	LCS Projection plane	HCS Projection plane	MCS projection plane
X (Flexion)	yz	xz	xz
Y (Rotation)	zx	zy	yz
Z (Lateral Flexion)	xy	yx	xy



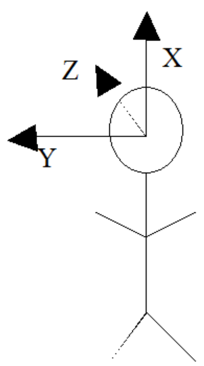
Helmet Marker Coordinate System

Figure A-1. Local coordinate system for helmet markers.



Mouth Marker Coordinate System

Figure A-2. Local coordinate system for mouth markers.



Lab Coordinate System

Figure A-3. Lab coordinate system.

APPENDIX B
SUBJECT QUESTIONAIRE

Data Collection Questionnaire Subject #______

Tool Order

1______ Date______

2______ Time______

3______

4______

Age______

Male or Female

Years as ATC:_______

Football seasons as ATC_______

Have you ever had formal training/education with any of these tools? Y or N

If yes, which one(s): TA FME AP RAP *(circle all that apply)*

What was the nature of that training:

Workshop

Lecture

Practice session

Other____________________

What tool(s) do you currently carry in you kit for face mask removal:

____

After participation in this study, which of these tools would you most likely use to removal a face mask? ____________________________

____

IRB
APPROVED
ON 3/31/03
cl

IRB# 364-2002

APPENDIX C
RADIATION SAFETY COMMITTEE APPROVAL

RADIATION SAFETY COMMITTEE

MAYO CLINIC JACKSONVILLE/ST. LUKE'S HOSPITAL

August 18, 2005

Michael Osborne, M.D.
Davis E-4B
Physical Medicine & Rehab

George Joseph
IRB
MCJ

Angela Dean
Clinical Research
MCJ

The Mayo Clinic Jacksonville Radiation Safety Committee approved by a vote of 8-For, 0- Against, 0-Abstentions, a protocol submitted by Dr. Osborne entitled, **"Motion Analysis of Head and Neck While Wearing Football Equipment"**. This study will involve 30 healthy adult male volunteers ages 18-30. Each participant will receive an AP and lateral fluoro scan to image the segmental motion of the cervical spine. A lead apron will cover the participant's chest and abdomen to reduce primary and secondary scatter while undergoing the exams. Total effective dose from this procedure is estimated to be 17 millirem. Recommended participant radiation risk consent form language is as follows:

Participant Exposure (H(e), >100 mrem)
"The amount of radiation the participant will receive from participation in this study is well below the levels that result in significant risk of harmful effects."

Pregnancy Statement
Not required

If you have any questions, contact Dr. Nelson at 904/953-8978.

Omer L. Burnett, M.D.
Chair, MCJ Radiation Safety Committee

Kevin L. Nelson, Ph.D.
Radiation Safety Officer, Mayo Clinic Jacksonville

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BIOGRAPHICAL SKETCH

Christine Ensch Norton was born on March 16, 1971 in San Diego, California. The youngest of three daughters of a career naval officer, she grew up primarily in San Diego, CA, however also lived in Alexandria, VA and Jacksonville, FL, Key West, FL and Pensacola, FL. She graduated from University City High School, in San Diego, CA in 1989.

She earned her B.S. in physical education/athletic training from Western Illinois University in 1994. In 1994, she completed a semester internship working as an athletic trainer at he U.S. Naval Academy. After graduating, Christine passed the NATABOC certification exam and became a certified athletic trainer (ATC). In 1997, she completed her M.S. in athletic training from Ohio University (OU). While attending OU, she also worked as an athletic trainer for the intercollegiate athletic department, working with field hockey, swimming and golf.

In 1997, Christine moved to Jacksonville, FL and worked in an outpatient rehab center. In 1998, she took a position as a visiting instructor at the University of North Florida (UNF), teaching in the Athletic Training-Sports Medicine education program. The one-year position at UNF allowed her to teach and mentor future athletic trainers. These experiences lead to the realization that she wanted to teach in an athletic training education program in a mare permanent position. This led her to the University of Florida to pursue a PhD in biomechanics.

Christine has been married for six years to Christopher Norton, a physical therapist/ATC at Mayo Clinic Jacksonville. They have a four-year-old daughter, Emily