INVESTIGATION OF AIRWAY ACCESS TECHNIQUES IN MEN'S LACROSSE WITH RELATION TO HELMET FIT

Alexis Ann Altier

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Approved by:

Meredith Petschauer

Kevin Guskiewicz

Barnett Frank

Ashley Littleton

Nina Walker

ABSTRACT

ALEXIS ANN ALTIER: Investigation of Airway Access Techniques in Men's Lacrosse with Relation to Helmet Fit
(Under the direction of Meredith Petschauer and Kevin Guskiewicz)

Objective: Determine effect of helmet fit (athletic trainer-AT vs. player-PF) and airway access technique (helmet removal-HR vs. facemask removal-FR) on cervical spine (C-spine) motion. **Results:** Interaction effect for integrated motion in frontal plane ($F_{1,17}$= 8.052, P=0.011) and peak displacement in sagittal ($F_{1,17}$= 12.336, P=0.003) and transverse planes ($F_{1,17}$= 11.118, P= 0.004). Main effect of airway access technique in all planes for peak displacement and integrated motion; HR resulted in more motion than FR. Main effect of fit for transverse plane peak displacement and frontal plane integrated motion; AF resulted in more motion than PF. **Conclusion:** These findings suggest an increase in c-spine motion with HR compared to FR; HR is a faster method of airway-access. FR is the current guideline for airway access technique, but HR should be considered as a viable option, especially when time is important. **Word Count:** 138

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LIST OF ABBREVIATIONS

AT	Certified athletic trainer
C-spine	Cervical spine
AF	AT fit helmet condition
PF	Player fit helmet condition
HR	Helmet Removal
FR	Facemask Removal

CHAPTER 1

INTRODUCTION

Lacrosse is a rapidly growing sport in the United States, with 41% expansion in collegiate men's lacrosse teams since 1988 (Dick, Romani, Agel, Case, & Marshall, 2007). An increase in participation represents a call for establishing evidence-based practice regarding proper emergency management of a potential catastrophic event, such as a head or neck injury, which can result in permanent disability or potential fatality as a consequence of improper care. Due to specialized training and experience in equipment removal in addition to nature of professional role; athletic trainers (AT) and other sports medicine professionals remain as the primary party responsible for proper management of potential cervical spine (c-spine) injuries in competitive athletic events. Unfortunately, very few studies have examined emergency airway access procedures specific to men's lacrosse equipment, (Bradney & Bowman, 2013; Higgins, Tierney, Driban, Edell, & Watkins, 2010; Petschauer, Schmitz, & Gill, 2010; Sherbondy, Hertel, & Sebastianelli, 2006; Waninger, Richards, Pan, Shay, & Shindle, 2001) with limited evidence regarding best practice for proper removal technique to ensure athlete safety and c-spine integrity. This is alarming due to the fact that since 1982, 22 catastrophic neck and spine injuries have been recorded in high school men's lacrosse and 13 catastrophic injuries have been recorded in collegiate men's lacrosse (Mueller, 2011). Thus, to ensure that future injuries to the brain and/or spinal cord are handled in the safest, most efficient and effective manner, further research is warranted.

Men's lacrosse is a fast paced, and high contact sport, (Diamond & Gale, 2001) with 11.7% of recorded game injuries and 6.2% of recorded practice injuries involving the head and neck from 1988 to 2004 (Dick et al., 2007). Improper handling of c-spine injuries can result in outcomes as dire as spinal cord disruption such as transverse myelopathy, which results in a loss of spinal function below the level of injury. Although improvement of one spinal level above the lesion may be seen when primary swelling subsides, subsequent loss of function is seldom reversed. Furthermore, spinal cord injuries can transpire even when spinal cord continuity is maintained; hemorrhage or ischemia can block impulse transmission, thus it is imperative that correct management procedures are established to minimize potential for injury due to subsequent mishandling of a c-spine injury (Bailes, Petschauer, Guskiewicz, & Marano, 2007).

To minimize additional hemorrhage or ischemia associated with c-spine injuries, current guidelines are in place in regards to airway access and emergency management to prevent excessive movement (Bailes et al., 2007). These guidelines are critical to individuals who will be first to the scene of a catastrophic injury. US Lacrosse Sports Science and Safety states that current guidelines are; "the helmet and shoulder pads of an injured lacrosse athlete should be left in place until they can be removed in a controlled environment" (*Lacrosse Helmet Facemask/Chinguard Removal Hints for Certified Athletic Trainers*) based upon findings from Sherbondy, Hertel, and Sebastianelli's 2006 study (Sherbondy et al., 2006). These guidelines have given rise to controversy for many reasons. The first debate stems from the fact that often times the medical personnel most familiar with equipment being used by the athletes are on-site. Athletic trainers and the sports medicine team immediately involved at the scene have a better understanding of equipment removal procedures than emergency room clinicians who may have no training in helmet removal methods (Banerjee, Palumbo, & Fadale, 2004b). The second argument is due to that fact that the research upon which these guidelines are based only found minimal movement in the area of occiput-C2 in a helmet removed airway access situation and found no movement in the area of C2-C7, where most injuries occur (Higgins et al., 2010). Additionally, previous research has revealed that airway access in a men's lacrosse athlete via helmet removal, while leaving shoulder pads in place, did not affect space available for the spinal cord, (Higgins et al., 2010) which is critical in avoiding tissue disruption. Lastly, it was revealed that a men's lacrosse athlete laying supine experiences an increase in cervical spine extension of 6 degrees as compared to an athlete with no equipment on while placed in the neutral position (Sherbondy et al., 2006).

Another concern regarding the current guidelines in place is the fact that improperly fit men's lacrosse helmets do not provide the adequate security needed for airway access using an in-line stabilization of the c-spine with clinicians securing the helmet (Petschauer et al., 2010; Sherbondy et al., 2006). Previous literature states that equipment should be removed if the helmet and chin straps do not stabilize the head securely such that immobilization does not also immobilize the head (Bailes et al., 2007; Kleiner, 2003; Swartz et al., 2009). Evidence suggests that a large population of men's lacrosse athletes do not wear properly fitted helmets (Petschauer et al., 2010), thus the clinical utility of the current guidelines established using properly fit helmets may be limited due to lack in external validity of previous research. In addition, men's lacrosse helmets do not afford the same customizable fitting options seen in those of football helmets, and even with a properly fitted men's lacrosse helmet it has been observed that the helmet does not effectively stabilize the athletes head to a spine board (Petschauer et al., 2010). Furthermore, the same study reported that only limited prevention of neck flexion and extension was afforded with the addition of extra padding provided to adjust fit with no additional restrictions in the other planes of motion (Petschauer et al., 2010). Petschauer et al.'s 2010 findings afford the notion that removing the helmet to access an airway in an emergent situation may be the optimal technique to access a men's lacrosse player's airway safely, resulting in the least c-spine motion, until a men's lacrosse helmet that properly stabilizes the head can be designed and proper fit can consistently be ensured (Petschauer et al., 2010).

The issue of airway access in men's lacrosse is consistently debated. While there are guidelines in place, they do not go uncontested. Although the current guidelines suggest that it is the least deleterious to leave the athlete in their helmet and simply remove the facemask to gain airway access prior to reaching the controlled environment of the hospital (Sherbondy et al., 2006), the concern that the head is not adequately stabilized in the helmet despite the status of its fit gives rise to concern over establishing practices to safely stabilize the athlete's head and neck (Petschauer et al., 2010). In addition, it has been observed that there is not adverse cervical extension in a helmet removed condition with men's lacrosse as seen in football due to the much less dramatic thoracic elevation provided by the much slimmer men's lacrosse shoulder pads as compared to bulky football shoulder pads (Higgins et al., 2010). Lack of adequate in-line stabilization and lack of deleterious cervical extension compounded by the fact that athletic trainers and the sports medicine staff immediately involved at the scene of the injury, in general, have more specialized training in equipment removal as compared to emergency medical technicians or emergency room technicians lends the question: why shouldn't the helmet be removed on-site if there are qualified personnel available? However, the effect of c-spine motion in the act of removing the helmet to access the airway has not been researched (Higgins et al., 2010). Therefore the purpose of this study is to evaluate the effects of helmet fit and equipment removal technique on c-spine motion during airway access in collegiate men's lacrosse players.

VARIABLES

Independent

1. Airway access technique
    a. Facemask removal (FR)
    b. Helmet removal (HR)
2. Fit
    a. AT Fit (AF)
    b. Player Fit (PF)

Dependent

1. Angular Motion
    a. Head-to-thorax cervical rotation in the transverse plane
    b. Head-to-thorax cervical flexion/extension in the sagittal plane
    c. Head-to-thorax cervical lateral flexion in the frontal plane
        i. Measured in:

1. Change in peak displacement

2. Integrated motion in Each Plane

2. Time to completion

RESEARCH QUESTIONS

RQ_1: What is the interaction effect between helmet fit and airway access technique on c-spine change in peak displacement during airway access in collegiate men's lacrosse players?

RQ_{1A}: What is the effect of helmet fit on c-spine change in peak displacement during airway access in collegiate men's lacrosse players?

RQ_{1B}: What is the effect of airway access technique on c-spine change in peak displacement during airway access in collegiate men's lacrosse players?

RQ_2: What is the interaction effect between helmet fit and airway access technique on total c-spine motion in each plane during airway access in collegiate men's lacrosse players?

RQ_{2A}: What is the effect of helmet fit on total c-spine motion in each plane during airway access in collegiate men's lacrosse players?

RQ_{2B}: What is the effect of airway access technique on total c-spine motion in each plane during airway access in collegiate men's lacrosse players?

RQ_3: What is the effect of airway access technique on time to completion?

HYPOTHESES

Alternate

AH_1: There will be an interaction effect on c-spine motion involved in airway access technique in player fit men's lacrosse helmet as compared to airway access technique in AT fit men's lacrosse helmet.

AH_{1A}: There will be less c-spine motion during airway access in a men's lacrosse athlete wearing a player fit men's lacrosse helmet as compared to an AT fit men's lacrosse helmet.

AH_{1B}: There will be a greater effect on c-spine motion during facemask removal than during helmet removal.

AH_2: There will be an interaction effect on total c-spine motion in each plane involved in airway access technique in player fit men's lacrosse helmet as compared to airway access technique in AT fit men's lacrosse helmet.

AH_{2a}: There will be a smaller effect on total c-spine motion in each plane during airway access in a men's lacrosse athlete wearing a player fit men's lacrosse helmet as compared to an AT fit men's lacrosse helmet.

AH_{2b}: There will be a greater effect on total c-spine motion in each plane during facemask removal than during helmet removal.

AH_3: Time to completion will not be significantly different based upon airway access technique.

Research

RH_1: There will be no interaction effect of helmet fit and equipment removal technique on c-spine motion during airway access in collegiate men's lacrosse players.

RH_{1A}: There will be no effect of helmet fit on c-spine motion during airway access in men's lacrosse athletes.

RH_{1B}: There will be no effect of helmet removal technique on c-spine motion during airway access in men's collegiate lacrosse athletes.

RH_2: There will be no interaction effect of helmet fit and equipment removal technique on total c-spine motion in each plane during airway access in collegiate men's lacrosse players.

RH_{2a}: There will be no effect of helmet fit on total c-spine motion in each plane during airway access in men's lacrosse athletes.

RH_{2b}: There will be no effect of helmet removal technique on total c-spine motion in each plane during airway access in men's collegiate lacrosse athletes.

RH_3: Time to completion will be significantly shorter during the helmet removal airway access technique.

OPERATIONAL DEFINITIONS

1. *AT Fit (AF) Helmet*- helmet that meets all of the following qualifications per manufacturers fitting guidelines (Cascade, 2013b):

a. The back of helmet should be in uniform firm contact with the back of the athlete's head.
b. The skin of the athlete's forehead should move with helmet when helmet is moved anterior to posterior and side-to-side; helmet should not be able to slip over head.
c. The helmet should not gap at athlete's forehead when anterior force is applied to occiput segment of helmet.
d. When pressure is applied anteromedially and posteromedially to either parietal area of helmet, skin on the athlete's forehead should move with helmet and liner should bunch cheeks. The helmet should not slide towards the athlete's nose.
e. Clearance from end of the athlete's nose to facemask should be at least 2-3 finger widths.

2. *Player fit (PF) helmet*- fit of helmet in which subject arrives wearing and wears consistently at practice as well as in games
3. *C-spine motion*- degrees of motion of the head relative to the thorax, in the sagittal, frontal, and transverse planes (Mihalik, Beard, Petschauer, Prentice, & Guskiewicz, 2008; Toler et al., 2010); measured by change in peak displacement and integrated motion in each plane.
4. *Helmet Removal*- the act of in-line stabilization and two-person helmet removal with towel placed under athlete's head
5. *Facemask removal*- the act of in-line stabilization and facemask removal with a cordless screwdriver and/or back-up anvil pruner if necessary

6. *Change in peak displacement*- the absolute difference between maximum values of rotation of sensor on left temple in one direction and rotation in the other as compared to sensor on the sternum
7. *Integrated motion in each plane*- the absolute difference between maximum values of rotation in one direction and rotation in the other using Simpson's integration normalized to time
8. *Time to completion*- time in which it takes to complete each airway access technique trail based upon the following:
    a. Each helmet removal trial will begin when AT secures head and will end when the research assistant places towel under head after complete helmet removal.
    b. Each facemask removal trial began as soon as AT secured head in in-line stabilization and ended when the facemask was placed on the ground next to the subject.

ASSUMPTIONS

1. Flock of Birds is reliable and valid in modeling c-spine motion through analyzing motion between the head and the thorax.
2. The Cascade® R is a widely used helmet.
3. The movement of the head relative to the thorax accurately represents cervical motion.
4. The subjects will follow the instructions given.
5. The subjects and researchers will be consistent in conducting airway access techniques.

DELIMITATIONS

1. Only the Cascade® R men's lacrosse helmet is used.
2. No goalie helmets were tested.
3. This study only studied c-spine motion in relation to airway access
4. The only measurement of c-spine motions was head motion in relation to the thorax.

LIMITATIONS

1. College aged athletes may not represent all athletes helmet fit.
2. Measurements taken in lab are representative of on-field c-spine motion that would occur during the airway access techniques being used in the study.
3. There may be inconsistencies in conductance of airway access techniques.
4. Even in the properly fit condition, not all helmets may fit exactly the same.
5. Study limited to evaluation of facemask and helmet removal airway access techniques in male collegiate lacrosse players.

CHAPTER 2

INTRODUCTION

Although uncommon, catastrophic injury is an unfortunate risk associated with participating in contact sports like men's lacrosse. Although catastrophic injury is not completely preventable, ensuring adequate immediate treatment of cervical spine injuries lends to a more positive outcome (Banerjee, Palumbo, & Fadale, 2004a; Banerjee et al., 2004b). It is important that immediate treatment of potential c-spine injuries be handled in a manner in which unnecessary head and neck motion is avoided in order to decrease chances of exacerbating a potential injury already sustained (Bailes et al., 2007; Waninger et al., 2001). Incorrectly managed c-spine injuries have the potential to lead to devastating outcomes including compromised cardiac and respiratory status as well as irreversible neurologic damage leading to permanent disability (Banerjee et al., 2004a, 2004b).

With the consequences of improper potential c-spine injury management being so deleterious, it is important that competent health care professionals establish a comprehensive pre-hospital protocol prior to the initiation of a men's lacrosse athletics program. It is essential that this plan entail specifics in regards to airway access. Prior to transportation of an athlete with suspected c-spine injury to an emergency facility, access to an unobstructed airway needs to be maintained in case of respiratory status deterioration (Bailes et al., 2007). Health care professionals must establish and practice a standard emergency action plan with the most beneficial course of actions for the athletes' health. (Banerjee et al., 2004b)

EPIDEMIOLOGY

Catastrophic injuries in athletics are most prevalent in contact sports (Bailes et al., 2007). Men's lacrosse is a contact sport that has exhibited 45.9% of injuries stemming from contact with another player (Dick et al., 2007). Additionally, it has been recorded that 11.7% of recorded game injuries and 6.2% of recorded practice injuries involve the head and neck (Dick et al., 2007). The men's lacrosse rate of head injury prevalence comes secondary only to football (Lincoln, Caswell, Almquist, Dunn, & Hinton, 2013). It was found that men's lacrosse athletes sustain concussions 47% of the time in a head down position while attempting to pick up a ground ball (Lincoln et al., 2013). This is concerning due to the compromised position of the c-spine in a flexed neck arrangement.

Men's lacrosse is also a rapidly growing sport yielding an expansion of 71 NCAA programs from the years of 1988-2004. In conjunction, the number of NCAA students participating grew from 4805 to 7100 in those years as well (Dick et al., 2007). With this increase in participation comes an increase in need for evidence-based practice regarding proper emergency management of a potential catastrophic event, such as a head or neck injury that can result in permanent disability or potential fatality as a consequence of improper care.

NORMAL AND PATHOLOGICAL ANATOMY

Normal Anatomy

A catastrophic injury is defined by Mueller and the National Center for Catastrophic injury as a sport injury that results in a brain, spine, spinal cord, or skull injury (Mueller, 2011). The c-spine is a critical element of human anatomy. It is made up of precise segments that each offer a unique contribution to movement and stabilization. In addition, c-spine anatomy is organized in such a manner that small deviations from normality can result in adverse effects in spinal anatomy and surrounding structures. For these reasons, there are increasingly specific guidelines that must be followed to ensure the best outcome possible when caring for potential c-spine injures.

The human c-spine consists of 4 bony sections (Bogduk & Mercer, 2000). The most superior segment is the atlanto-occipital joint. This joint is made up by the articulation of the occiput of the skull and the superior facets of the atlas. The convex shape of the occiput in relation to the concave superior surface of the atlas allows for movement in the sagittal plane to occur (Bogduk & Mercer, 2000). Moving inferiorly, the next section of the c-spine is created by the atlanto-axial joint. The atlanto-axial joint is made up of the superior projection of the axis, or the dens, articulating superiorly through the atlas. The shape of the dens and its positioning within the axis allow for rotational head movements to occur (Bogduk & Mercer, 2000). The next section of the human c-spine is identified at the C2-C3 joint. This joint is the joint at which motion begins to be classified as c-spine motion rather than head movement (Bogduk & Mercer, 2000). This joint also marks the start of uniformity among c-spine vertebrae. With that being said; the C2-C3 joint is not, in it of itself, uniform. The C2-C3 joint is made up of the inferior aspect of the axis (C2) and the superior aspect of the C3 vertebrae. The axis (C2) is unique such that it not only extends superiorly into the atlas, but also extends inferiorly to articulate C3 in a distinct manner. This inferior projection works to serve as an anchor for head movement. The inferior anchor of the axis also creates a unique facet joint between the C2-C3 vertebrae; affording the joint a medial orientation in addition to the superior and posterior orientation revealed in all other c-spine facets. The non-uniformity at this joint lends to a difficulty in determining the articulation's specific function (Bogduk & Mercer, 2000). Following the C2-C3 joint inferiorly to the C6-C7 joints, uniform bony segments are found. Typical cervical segments are made up of vertebral bodies and intervertebral discs (Bogduk & Mercer, 2000). The cervical intervertebral discs are oriented obliquely in relation to the long axes of the vertebral bodies due to the surface of vertebral bodies; a unique feature of the c-spine. The vertebral bodies in the c-spine are also curved laterally and medially, which give them qualities similar to that of an ellipsoid joint. This arrangement allows for sagittal plane rocking motion. Frontal plane motions is blocked by the oblique angulation previously mentioned (Bogduk & Mercer, 2000). Due to the motion afforded by these unique bony elements the importance of considering special precautions in the care suspected c-spine bony pathologies is warranted.

Aside from a unique bony anatomy and the resultant arthrokinematics and osteokinematics, the human c-spine possesses soft tissue mechanisms to resist forces that are also unique from other musculoskeletal structures. Initially, the human c-spine is protected circumferentially starting at the foramen magnum by osseoligamentous structures, which continue inferiorly to cover the entirety of the c-spine (Banerjee et al., 2004a). The most stable aspect of the cervical spine is the anterior aspect due to the way in which the annulus fibrosus is situated in the intervertebral disc. Whereas in other aspects of the spine, the annulus fibrosus forms concentric rings surrounding the entire nucleus pulposus to form an intervertebral disc; in the c-spine the annulus fibrosus is nearly absent laterally and posteriorly (Bogduk & Mercer, 2000). Although the c-spine vertebral discs are different than other intervertebral discs, they still work to resist compressive loads in the spine. An unequal annulus fibrosus leads to an unequal force distribution. In conjunction with the role of resisting and dispersing compressive loads, the annulus fibrous is also the c-spine's main barrier to tensile forces (Banerjee et al., 2004a). The longitudinal ligaments, supraspinous ligaments, and interspinous ligaments offer additional resistance to tensile forces to aid the annulus fibrosus. The paraspinal ligaments and musculature aid in resisting shear forces as well as distraction (Banerjee et al., 2004a).

The individual characteristics of each c-spine segment lend themselves to an organization pattern that is only found in the c-spine. Most easily observed, is the lordotic curve that the annulus fibrosus, supporting ligaments, and supporting musculature create in the human c-spine. This lordotic posture is the position in which all stabilizing and force distributing structures are in their optimal alignment. Not so easily observed is the intrinsic organization of the c-spine. The c-spine vertebrae possess the largest vertebral openings most superiorly; the vertebral opening decreases in diameter between the levels of C4 and C7. This natural stenosis is complicated by the fact that the spinal cord itself increases in diameter as it moves inferiorly through c-spine segments. The average diameter of the spinal cord at mid-cervical levels ranges between 8 and 9 mm whereas the average diameter of the spinal cord at lower cervical ranges between 14 and 23 mm.

Between the levels of C4 and C7 the spinal cord fills approximately 75% of all space available in the vertebral space (Banerjee et al., 2004a). This characteristic anatomically explains the phenomenon that spinal cord damage rarely occurs in the upper cervical spine (C1-C4); there is greater space available within the vertebral canal (Banerjee et al., 2004a).

Pathological Anatomy

There are a variety of different maladies that can arise from injuries to and/or around the cervical spinal cord. Despite the subsequent symptoms and impairment, neurological injury does not take place only when direct damage to the spinal cord is caused. Neurological injury can be caused by disruption of the spinal cord transmission in the form of ischemia stemming from hemorrhage or edema from an alternate injury (i.e. c-spine vertebrae fracture or dislocation) or from damaged vessels that supply the spinal cord with blood and nutrients. Compression and ischemia of the spinal tracts contents can be predicted when the vertebral canal's diameter becomes less than 10mm (Banerjee et al., 2004a). This physiological secondary injury can cause the same extensive injuries as primary anatomic injury to the spinal cord and is more common (Bailes et al., 2007).

The most extreme case of spinal cord injury is a transverse myelopathy in which the entirety of the spinal cord is affected at a specific cross section. A transverse myelopathy results in complete loss of spinal function below the level of spinal injury (Bailes et al., 2007). An array of other spinal cord injuries result from a partial blockage of neural transmission and partial loss of spinal function. Central cord syndrome is a condition in which loss of motor function in upper extremities is more severe than that in lower extremities. It results from injury to the corticospinal tract, which is the area of the spinal cord that is responsible for voluntary control of muscle contraction (Martini, Timmons, & Tallitsch, 2009). It is thought that the upper extremity function is more severely impacted than that of the lower extremity function due to the more medial placement of upper extremity motor neurons (Bailes et al., 2007). Another spinal cord malady is anterior spinal cord syndrome, which is classified as injury to the anterior section of the spinal cord that's blood supply is controlled by the anterior spinal artery. Neurologic deficits include complete loss of spinal motor function at every level inferior to that of injury as well as sensory deficits, because the anterior spinal artery provides nourishment for both the corticospinal tract and spinothalmic tract (Bailes et al., 2007). The spinothalmic tract is responsible for transmission of sensation signals such as pain and temperature (Martini et al., 2009). Anterior spinal cords syndrome's mirror image is posterior spinal cord syndrome in which the area of the spinal cord supplied by the posterior spinal artery is affected. Posterior spinal cord syndrome is observed clinically to a lesser extent than that of anterior spinal cord syndrome. Posterior spinal cord syndrome is also objectively less traumatic than anterior spinal cord syndrome due to the entities that the posterior spinal artery serves; the corticospinal tract and spinothalmic tract do not rely on blood from the posterior spinal artery and are thus unaffected (Bailes et al., 2007). Finally, Brown-Sequard Syndrome results from damage to a sagittal half of the spinal cord; lateral corticospinal tracts and spinothalmic tracts. Resulting motor function loss is seen on the ipsilateral half of the body as compared to the hemisection of damage to the spinal cord, whereas resulting sensory function loss is seen on the contralateral side (Bailes et al., 2007). This is due to the fact that crossover in the central nervous system takes place in two different locations for the spinothalmic and corticospinal tracts.

Spinothalmic crossover occurs at the axon of the second-order neuron located in the spinal cord or brain stem meaning that any damage superior to that spinothalmic crossover will affect the contralateral side (Martini et al., 2009). Lateral corticospinal tracts crossover occurs in the medulla oblongata of the brain; therefore, any lateral damage occurring in the spinal cord will affect the same side (Martini et al., 2009).

Physiological and/or anatomical damage to the spinal cord can take place in many forms and cause different neurological outcomes. The aforementioned syndromes have been found clinically independent of one another as well as in conjunction with one another (Bailes et al., 2007). Minimizing c-spine movement in emergent care is essential not only to prevent anatomical spinal cord damage, but also prevent further injury to the surrounding structures limiting the risk of secondary injury to the greatest capacity possible.

MECHANISM OF INJURY

In athletic activities there are a number of ways in which the spinal cord can be harmed. However, in contact sports there has been a distinct mechanism observed in which c-spine injuries are most prevalent. In football and ice hockey serious cervical injury occurs when a large compression vector is applied to the top of the head and slightly less often when a large flexion vector is applied to the head (Banerjee et al., 2004a). However, the most common c-spine injury is seen when a compression and flexion vector are applied at once (Bailes et al., 2007; Banerjee et al., 2004a).

Cervical flexion increases the severity of a compressive load on the c-spine because it decreases the effectiveness of force distributing mechanisms in the c-spine by disturbing the normal lordotic curve (Bailes et al., 2007). Cervical flexion disrupts the normal length tension relationship in paraspinal muscles and limits the function of the surrounding stabilizing musculature; leaving the spinal column to withstand forces all on its own (Banerjee et al., 2004a). Additionally, the spine is most stable anteriorly due to the situation of the annulus fibrosus; flexion stresses the annulus fibrosus posteriorly where it is most weak (Bogduk & Mercer, 2000).

When the ability to distribute force is decreased, an increased amount of stress is placed on bony structures. This is why a compression-flexion mechanism has the capacity to lead to c-spine vertebrae fracture and/or dislocation. C-spine fractures and/or dislocations are the leading causes of spinal cord trauma in athletics. Unstable fractures are often times the most severe because they cause the c-spine to become unable to support even physiological loads without potentially damaging the spinal cord or nerve roots (Banerjee et al., 2004a). Compression, or "burst", fractures may also compromise the spinal cord. When a "burst" fracture occurs, osseous fragments have the potential to infiltrate the vertebral canal and damage the spinal cord (Banerjee et al., 2004a).

Unlike other athletic injuries, individuals are not at a predetermined risk based upon anatomical factors for c-spine fractures/dislocations. Individuals are at risk for c-spine injuries based upon nature of sport and use of technique. Hitting an opponent or being hit on the crown of the head while in a cervical flexion position is the main predictor of c-spine injury (Bailes et al., 2007). Therefore, education in any contact sport program is key in avoiding c-spine injuries (Banerjee et al., 2004b).

GUIDELINES FOR SUSPECTED C-SPINE INJURIES

Management of Cervical Spine Injury

Health care practitioners must practice the utmost caution in avoiding unnecessary head movement in order to refrain from exacerbating any possible current injury when a c-spine injury is suspected. Initial arrival to the scene of a suspected c-spine injury should begin with the primary survey consisting of: airway access and maintenance, ventilatory assessment and treatment if necessary, and circulatory assessment and treatment if necessary (Bailes et al., 2007; Banerjee et al., 2004b). All actions taken during the primary survey need to be conducted with the individual held in manual c-spine neutral (in-line stabilization) in order to minimize head motion and the potential for secondary injury.

If no immediate life-threatening condition is detected, then a neurological screening can commence to determine c-spine involvement. Mid-line neck pain, altered sensation, paresthesia, and weakness should all be evaluated in a conscious individual (Bailes et al., 2007). If any of the above signs and symptoms are in the neurologic screening, or the individual is unconscious, transportation to the hospital will be required and should be done so very carefully while maintaining in-line stabilization in order to prevent further c-spine injury (Bailes et al., 2007; Banerjee et al., 2004a). In a conscious individual a cognitive and cranial nerve screening can take place while waiting for emergency personnel to arrive at the scene (Bailes et al., 2007).

Men's Lacrosse Airway Access Guidelines

In helmeted sports, such as men's lacrosse, it is essential that an unobstructed airway is established in individuals with suspected c-spine injury prior to transportation to emergency facility regardless of respiratory status at the time of transportation (Banerjee et al., 2004b; Kleiner, 2003; Swartz et al., 2009). The current guidelines, per US Lacrosse Sport and Safety, is that only the facemask of an injured athlete should be removed prior to transportation in emergency vehicle and all other equipment should be left in place until taken off upon arrival to hospital (*Lacrosse Helmet Facemask/Chinguard Removal Hints for Certified Athletic Trainers*). Men's lacrosse helmets also add the additional challenge of a chinguard as an airway obstruction. US Lacrosse Sport and Safety instructs that the chinguard must also be removed prior to transportation (*Lacrosse Helmet Facemask/Chinguard Removal Hints for Certified Athletic Trainers*).

Upon Reaching Hospital

In making a plan for a men's lacrosse c-spine emergency, planning does not stop when the injured individual leaves the field in emergency vehicle. Prior to emergent situation, emergency transportation that will take individual to medical facility capable of treating c-spine injuries needs to be identified (Banerjee et al., 2004b). If possible, a team physician or athletic trainer should accompany the individual to medical facility to provide continuity of care and assistance in further equipment removal. Equipment removal is routinely a part of the sideline team physicians' and athletic trainers' annual training, therefore, the task is more familiar to them as compared to emergency room employees. As the guidelines currently stand, all equipment except for the facemask will be in place when individual arrives at emergency medical facility and emergency medical clinicians may not be familiar with proper removal, whereas the sports medicine staff must be familiar with these protocols (Banerjee et al., 2004b).

Facemask Removal With Cordless Screwdriver

There are a multitude of different tools that can be used to remove a men's lacrosse facemask. Tools include a: cordless screwdriver, the Face Mask Extractor®, the Trainer's Angel®, and modified pruning shears (Bailes et al., 2007; Bradney & Bowman, 2013; *Lacrosse Helmet Facemask/Chinguard Removal Hints for Certified Athletic Trainers*). Bradney and Bowen (2013) found that of these four tools, the cordless screwdriver is the fastest and easiest to use for men's lacrosse facemask removal (Bradney & Bowman, 2013). It was discovered that although the cordless screwdriver and the pruning shears are statistically the most efficient tools to use, practically, the cordless screwdriver far surpassed the pruning shears in efficiency by taking an average of 32 seconds to remove a facemask to the pruning shears 68 seconds average (Bradney & Bowman, 2013). Additionally, the cordless screwdriver was given the lowest rate of perceived exertion by individuals operating all 4 possible implements (Bradney & Bowman, 2013). Therefore, if looking only at the measurements of time and difficulty of use, the cordless screwdriver is the most beneficial tool for facemask removal purposes.

Men's Lacrosse as Compared to Football and Ice Hockey

Football and ice hockey are two other contact sports in which participants wear helmets. Football equipment removal and airway access is the most researched realm of equipment removal to date. Current guidelines for football airway access are consistent with that of men's lacrosse helmet removal (Decoster et al., 2012; Swartz, Belmore, Decoster, & Armstrong, 2010). This guideline stems from extensive research demonstrating antalgic effects of helmet removal and ability of helmet to secure head.

In football it has been proven that complete helmet removal with the shoulder pads still in place produces an adverse c-spine lordosis and is discouraged while not at a medical facility (Decoster et al., 2012). If, however, a situation arises in which it is completely necessary for the helmet to be removed, it has been found that placing a towel underneath the individuals head will limit lordosis associated with helmet removal (Decoster et al., 2012). Further equipment removal should be avoided in the pre-hospital setting (Decoster et al., 2012).

Facemask removal in football, like men's lacrosse, is recommended to be performed with a cordless screwdriver. In the case of faulty equipment it is recommended that sports medicine personnel be prepared with a back-up cutting tool in the event of cordless screwdriver failure, such as the Trainer's Angel®, FMX Extractor®, and/or anvil pruning shears (Swartz et al., 2010). Additionally, if football helmets are equipped with a Quick Release system, that has been found to be just as efficient as using a cordless screwdriver; taking 15 seconds less on average to perform the task. It has been displayed that the Quick Release system does not increase head motion or difficulty of task completion when compared to use of a cordless screwdriver; therefore, the Quick Release system's ability to decrease time to facemask removal makes it more favorable (Swartz et al., 2010; Toler et al., 2010).

In relation to ice hockey airway access and equipment removal there is significantly less research in which to base emergency equipment removal and airway access practice. Although research is limited, one study observed that helmet removal in ice hockey similarly results in antalgic c-spine lordosis if shoulder pads are left in place (Laprade, Schnetzler, Broxterman, Wentorf, & Gilbert, 2000). Additionally it has been reported that ice hockey helmets are unable to ensure that the head and the helmet will move as one entity; even in a manufacturer recommended fit condition (Mihalik et al., 2008).

Due to the fact that there is a significantly less amount of airway access and equipment removal research pertaining specifically to ice hockey and men's lacrosse, it is evident that recommendations for both sports are established based upon research conducted in relation to football equipment. This is problematic due to the fact that both ice hockey and lacrosse helmets have very different designs than that of a football helmet. Additionally, shoulder pads worn in all three sports are of different widths and make, with football shoulder pads commonly displaying an increased width. This shoulder pad discrepancy is notable due to the lordosis that is subsequently caused in a helmet removed situation; this phenomenon has been shown to be not as extreme while equipped with lacrosse shoulder pads (Higgins et al., 2010). These disparities alone give rise to the fact that findings within one sport's equipment should not be generalized among all three.

DISSENSION REGARDING CURRENT GUIDELINES

There is currently dissension in the men's lacrosse emergent care community as to airway access guidelines as they currently stand. Current guidelines state that emergency airway access should be obtained by facemask removal only (*Lacrosse Helmet Facemask/Chinguard Removal Hints for Certified Athletic Trainers*). Many arguments stem from the fact that the issue of helmet fit is not addressed in the guidelines and there is no assurance during play of individual's wearing properly fitted helmets. Additionally, there are a multitude of different men's lacrosse helmets on the market; not only is the manner in which the facemask is removed inconsistent, the integrity of the helmet in a facemask removed condition changes based upon helmet design.

Issue of fit

A component that is largely missing from the current men's lacrosse airway access guidelines is the course of action that needs to be taken if an individual is wearing an incorrectly fit helmet. Even though the current guidelines recommend helmet removal if immobilization of the helmet does not result in immobilization of the head, the guidelines fail to address how to assess for head immobilization. (Bailes et al., 2007). Additionally, it has been found that men's lacrosse athletes do not wear their helmets fitted to manufacturer's standard (Evan Boyd Allen, 2010; Petschauer et al., 2010); in two different studies conducted on men's lacrosse athletes it was found that 100% of subjects reported with incorrectly fit helmets. Most men's lacrosse athletes fail to adequately tighten chinstraps and/or insert additional padding when necessary to improve the fit of the helmet (Evan Boyd Allen, 2010; Petschauer et al., 2010).

In conjunction, even when men's lacrosse helmets are properly fitted per manufacturer's guidelines, they do not provide adequate head stabilization. A thesis project conducted by Boyd et al. (2010) investigated helmet-to-thorax and head-to-thorax motion in a prone log roll technique in order to assess disparities between helmet motion and head motion within the helmet in three different helmet conditions: 1) Competition fit, 2) Properly fit, and 3) Helmet removed. This study found that a men's lacrosse athlete wearing a properly fit helmet displayed greater head-to-thorax transverse plane head movement than an athlete in a helmet removed condition, 33.82 ± 6.59 and 28.63 ± 7.67

degrees respectively. Another finding in this study was that head to helmet movement was statistically significant in both the properly fitted helmet condition and competition during the prone log roll tasks despite the fact that all of the competition fit helmets were classified as "improperly fit" per manufacturer guidelines. This speaks to the fact that although men's lacrosse helmets may be fit to the manufacturers guidelines, they do not adequately stabilize the athlete's head inside the helmet.

Lastly, Petschauer et al. (2010) investigated the effects of three helmet conditions (improperly fit, properly fit, and helmet removed) on available c-spine range of motion when secured to a spine board. The results from this study revealed that in both the improperly fit condition and properly fit condition, available c-spine range of motion was greater in the sagittal, transverse, and frontal planes than in the helmet removed condition. The only plane of motion in which differences were found between the improperly fit helmet and the properly fit helmet was the sagittal plane. Both of these finding signify that the aforementioned condition of necessary helmet removal is met even when men's lacrosse helmets are properly fitted.

The only research available to dispute the findings of Boyd et al. (2010) and Petschauer et al. (2010) is a study done by Waninger et al. in 2001. They studied the relative motion between the head and the helmet in a properly fitted football helmet, ice hockey helmet, and men's lacrosse helmet while secured to a spine board. Their study did not observe any significance in allowed motion between the 3 helmet types. However, their study did not actual look at any c-spine motion and did not take into account an athlete fitted condition (Waninger et al., 2001).

Spinal Cord Involvement When Helmet is Removed

A distinct point of contention when men's lacrosse helmet removal is discussed is the fact that antalgic c-spine lordosis may be created as a result of thorax elevation stemming from shoulder pads. However, Higgins et al. (2010) used magnetic resonance imaging to investigate the difference in space available for the spinal cord as well as cervical thoracic angle in supine men's lacrosse athlete under three conditions: 1) helmet and shoulder pads worn, 2) shoulder pads only, and 3) no equipment. It was observed that while in a shoulder pads only condition, space available in the vertebral canal for the spinal cord remained unchanged as compared to normal (Higgins et al., 2010). Although through visual observation and MRI measure the cervical thoracic angles changes in a helmet removed condition as opposed to helmet worn condition, c-spine movement is kept in mid-range due to the minimal thoracic elevation provided by men's lacrosse shoulder pads; 5.23 $\pm$ 1.3 mm in a no equipment condition at the level C7 as compared to 5.29 $\pm$ 1.5 mm in a shoulder pads only condition (Higgins et al., 2010). This proves that c-spine motion is not nearly as deleterious in men's lacrosse helmet removal as what has been found in football helmet removal studies.

A study performed by Sherbondy et al. (2006) used a CT scan to investigate men's lacrosse athletes' sagittal c-spine alignment, at C0-C7, C0-C2, and C2-C7, in the supine position in three conditions: 1) helmet and shoulder pads in place, 2) helmet removed and shoulder pads in place, and 3) no equipment. Their findings were unexpected with the no significant effect between the lower cervical angle in condition 1 or 2 (16.3 and 17.2 degrees respectively) and actually a significantly smaller angle was observed in the upper cervical angle in the shoulder pads only condition as compared to the helmet and shoulder pads in place condition (59.2 and 63.9 degrees respectively). Although it was found that removing the helmet in a supine men's lacrosse athlete may put the athlete in a more optimal c-spine position, the authors argue that any movement in the c-spine may be deleterious and should be avoided. However, helmet removal will not remain avoidable forever. At some point the athletes' helmet will have to be removed in order to receive imaging or further medical care, having the most qualified personnel perform this task would prove to be most beneficial for outcome; current guidelines prevent that.

Although these studies on fit and cervical spine alignment provide evidence that removing the lacrosse helmet rather than just the facemask, may be more effective in an emergent situation, guidelines remain unchanged. This is because a significant piece of information is missing; how is the c-spine affected in the act of helmet removal. This study will help fill that void.

LACROSSE HELMET DESIGN

Helmet Fit

Companies that manufacture lacrosse helmets set forth guidelines for correct fitting of their helmet. Fitting guidelines are in place to ensure that helmet is providing maximal protection for athlete. Cascade® is a widely used men's lacrosse helmet company, and their helmets will be used in this study. Cascade's current fit guidelines are as follows (Cascade, 2013b):

a. Back of helmet should be in uniform firm contact with the back of the athlete's head.

b. The skin of the athlete's forehead should move with helmet when helmet is moved anterior to posterior and side-to-side; helmet should not be able to slip over head.
c. The helmet should not gap at athlete's forehead when anterior force is applied to occiput segment of helmet.
d. When pressure is applied anteromedially and posteromedially to either parietal area of helmet, skin on the athlete's forehead should move with helmet and liner should bunch cheeks. The helmet should not slide towards the athlete's nose.
e. Clearance from end of the athlete's nose to facemask should be at least 2-3 finger widths.

If an athlete is wearing a helmet that does not satisfy all of the above guidelines then they are wearing a helmet deemed incorrectly fit per manufacturers standards and are not being offered optimal protection.

Helmet Choice

There are several different men's lacrosse helmets available for purchase and use. The individual designs of the helmets may affect the ability to access the airway in a suspected c-spine injury. In a study done by Bradney and Bowen (2013) the Brine Triumph and the Cascade CPX were more quickly removed than the other models (Onyx Lacrosse Riddell Revolution, Cascade CPX, Warrior Venom, and Cascade Pro7) with times of 72.89 $\pm$ 70.17 seconds and 72.75 $\pm$ 74.67 seconds respectively. Ease of facemask removal was also ranked similarly for the two models, rated as 3.84 $\pm$ 1.21 and 3.66 $\pm$ 1.37 respectively on a 6-point Likert scale. The two helmets significantly differed in failure rate with the Brine Triumph registering 8 out of 56 as failed attempts and the Cascade CPX only registering 3 out of 56 as failed attempts. This study revealed that the Cascade CPX can be most quickly and efficiently removed in an airway access situation. This disparity in findings between helmets strengthens contention with the current recommendations for airway access due to the fact that practitioner familiarity with every make plays a large key in successful completion.

Difficulty in other helmet designs

Bradney and Bowen (2013) observed that the Cascade Pro7 helmet required the most time for successful facemask removal (159.57 $\pm$ 132.30), over twice as long as both the Cascade CPX and Brine Triumph. The authors cite many difficulties in removal based upon helmet and facemask design. The Cascade Pro7's chinguard is pop riveted to the shell of the helmet; this prevents the facemask and the helmet from being removed as one unit using a cordless screwdriver as is possible in other helmet designs. In alternate designs of the Cascade Pro7 the chinguard can be removed with a cordless screwdriver because screws are used instead of pop rivets; however, they require 5 screws to be removed whereas most other helmets require only 3. Additionally, this discontinuity between the exact same helmet model increases the obscurity of airway access in men's lacrosse. Another design difficulty in the Pro7 is the placement of the T-nut that holds the side loop strap. In the Pro7 the T-nut is placed extremely close to the helmet shell, which makes it difficult to remove once the screw holding the side loop strap is removed. Finally, there is a metal ball on each side of the facemask in the Cascade Pro7 that is placed there to hold the side loop straps in place, however, this makes using a cutting tool increasingly difficult.

Due to the difficulty in removing the Cascade Pro7 facemask, full helmet removal may be warranted if managing an athlete wearing a Cascade Pro7 in attempting airway access. Equipment removal is warranted if the facemask cannot be removed to gain airway access (Bailes et al., 2007).

MEASUREMENT OF C-SPINE MOTION

Measurement of c-spine motion in this study will be obtained by using the Flock of Birds with Motion Monitor Software. This system has the capability to measure movement at a rate of 144 Hz in 6 degrees of freedom with accuracy of 0.5 degrees in relation to angular acceleration and 0.07 degrees in static posture ("Ascension Technology Corporation,"). This measurement tool has been validated and found reliable (Koerhuis, Winters, van der Helm, & Hof, 2003). Also, there have been past studies that use a landmark on the head and landmark on the sternum in order to adequately assess cervical motion (Koerhuis et al., 2003; Toler et al., 2010).

Koerhuis, Winters, van der Helm, and Hof (2003) found that after appropriate calibration the Flock of Birds system is able to properly measure 3-D angles involved in neck mobility. They cited that subjects' movements were minimally obstructed so angles could be adequately measured and translated into practical tasks. Their study matched actual human subjects with 'dummy heads' in order to assess reliability. A receiver was mounted on the human subjects sternum and forehead while their nosebridge, chin midpoint, xiphoid process, internal jugular, external occipital protuberance, spinous process of C7, and spinous process of T8 were digitized using a stylus. Koerhuis et al. observed that the Flock of Birds system is able to accurately quantify neck motion with a maximal error of 2.5° over a range of 180°.

Toler et al. (2010) similarly used the Flock of Birds as a measurement tool to collect c-spine motion data. In this study the MotionMonitor® software V8.0 (Innovative Sport Training, Inc, Chicago, IL) calculated not only head-to-thorax range of motion, which was used to quantify c-spine motion, but also head to helmet motion. A sensor was placed on the subjects' left temple and distal sternum as well as on the crown of the helmet.

The purpose of this study is to evaluate c-spine motion in relation to airway access technique and helmet fit condition on men's lacrosse athletes. The measurements used in order to obtain c-spine motion will be angular motion in the frontal, sagittal, and transverse planes of the subjects' head in relation to their thorax. The Flock of Birds with MotionMonitor software has been shown to not only adequately measure angular motion ("Ascension Technology Corporation,"), but also be reliable in the representation of c-spine motion (Koerhuis et al., 2003).

SIGNIFICANCE OF STUDY

There is a limited amount of research currently available that specifically pertains to men's lacrosse airway access. Current guidelines instruct on-field personnel to remove the facemask as the sole means of gaining airway access. However, it has been illustrated that some men's lacrosse helmets have high failure rates with facemask removal and inadequate necessary quickness of removal (Bradney & Bowman, 2013). Additionally, it has been demonstrated that even properly fit men's lacrosse helmets fail to provide adequate in helmet stabilization during emergency procedures (Evan Boyd Allen, 2010; Petschauer et al., 2010). Both of these inadequacies provide grounds for complete helmet removal for airway access in an emergent situation (Bailes et al., 2007). Finally, there is evidence that a supine men's lacrosse athlete in a helmet removed and shoulder pads in place condition does not experience antalgic c-spine angles in resting position (Higgins et al., 2010; Sherbondy et al., 2006).

The only information missing in the argument that complete helmet removal should be the standard of care in men's lacrosse airway access rather than facemask removal is the c-spine motion that takes place during the actual act of removing the helmet. The aim of this study is to determine if deleterious motion occurs in the c-spine of a men's lacrosse athlete during best practice helmet removal. Correct helmet removal maintains spinal immobilization (Kleiner, 2003; Swartz et al., 2009) and we hypothesize that this study will identify best practice in men's lacrosse emergency airway access and clarify the disparity against current men's lacrosse airway access guidelines.

CHAPTER 3

METHODOLOGY

The purpose of this study is to evaluate the effects of helmet fit and equipment removal technique on c-spine motion and time to removal during airway access in collegiate men's lacrosse players. This is pertinent to current clinical practice due to the fact that deleterious motion occurring in the c-spine of a men's lacrosse athlete during correct helmet removal as compared to facemask removal in order to access an airway has not yet been studied. This information may lead to a change in current guidelines and standard of on-field emergency care. This study used a two-way within subject design. The independent variables are airway access technique (facemask removal vs. helmet removal) and fit condition (AT Fit vs. Player Fit). The dependent variables are time to completion and angular c-spine motion in the transverse, sagittal, and frontal plane measured in change in peak displacement and integrated motion in each plane.

SUBJECTS

A total of 18 subjects participated in this study in order to counterbalance testing. This method was used in previous research (Evan Boyd Allen, 2010; Mihalik et al., 2008; Petschauer et al., 2010). Subjects were members of the University of North Carolina at Chapel Hill's men's lacrosse team and ranged in ages from 18-22 years old (height = 184.46 ± 6.15 cm, mass = 90.49 ± 6.81 kg). Subjects were excluded if they were currently experiencing or had a history of neck pain or any past traumatic neck injury (Mihalik et al., 2008; Petschauer et al., 2010). All participants completed and signed an informed consent form approved by the Institutional Review Board of The University of North Carolina at Chapel Hill.

EQUIPMENT

The helmet used in all testing scenarios was a Cascade® R (Cascade Lacrosse, Liverpool, NY). The subjects were asked to bring the helmet and shoulder pads worn during lacrosse practices and games. Subjects practiced in helmets for at least 3 weeks prior to data collection to ensure that they had time to make personal adjustments to their helmets. Players' helmets were used for the player fit (PF)_conditions, while a separate Cascade® R helmet provided by the researchers was used for the athletic trainer fit (AF) conditions.

A TrackStar (Ascension Technologies, Burlington, VT) electromagnetic motion analysis system, controlled by the Motion Monitor software (Innovative Sports Training Inc Chicago, IL), was used to collect data. Kinematic data was collected at 144 Hz.

For facemask removal a cordless screwdriver with the ability to orient at 90 degrees or 180 degrees was used and a manual screwdriver was available if additional torque was necessary to remove screw.

PROTOCOL

Subjects arrived to lab with personal Cascade® R helmet and shoulder pads. Subjects were tested using a repeated measure, counterbalanced design in one of two helmet conditions and one of two airway access techniques (Table 3.1). For the AF condition, a Cascade® R helmet (separate from the PF helmet) was fitted by a research assistant according to the Cascade® helmet safety guidelines (Cascade, 2013b).

Table 3.1 Counterbalance Design of Data Collection

Subjects	Testing Order			
	First	Second	Third	Fourth
1,7,13	AF; Facemask Removal	AF; Helmet Removal	PF; Facemask Removal	PF; Helmet Removal
2,8,14	AF; Helmet Removal	AF; Facemask Removal	PF; Helmet Removal	PF; Facemask Removal
3,9,15	PF; Facemask Removal	PF; Helmet Removal	AF; Facemask Removal	AF; Helmet Removal
4, 10, 16	PF; Helmet Removal	PF; Facemask Removal	AF; Helmet Removal	AF; Facemask Removal
5, 11, 17	AF; Facemask Removal	AF; Helmet Removal	PF; Facemask Removal	PF; Helmet Removal
6, 12, 18	PF; Facemask Removal	PF; Helmet Removal	AF; Facemask Removal	AF; Helmet Removal

The AT left the room for all PF helmet assessment and AF helmet adjustment for blinding purposes. For the AF conditions, the subject was asked to place the research assistant provided helmet on their head. Once in place, the research assistant ensured that the back of the helmet was in uniform contact with the back of the head. If the helmet was too loose, the HardTail SPRfit™ technology (Cascade Lacrosse, Liverpool, NY) was tightened until uniform contact around the entire head was reached. After making this adjustment, the research assistant applied an anterior pressure over the occiput of the helmet to ensure that there was not gapping at the subjects' forehead. In addition, the research assistant applied rotational forces on either side of the athlete's head in order to assess if the skin on the subjects' forehead moved with the helmet, verifying fit per manufacturer's guidelines (Cascade, 2013b). If the helmet moved independently of the subjects' head in during any of the fitting assessment the HardTail SPRfit™ technology was attempted to be tightened again in order to further secure helmet (Figure 3.1).

Finally, the facemask was inspected to ensure a 2-3 finger width clearance from the subjects' nose (Cascade, 2013b).

The same inspection was conducted on the PF helmet. Data would not have been collected if the PF helmet fit all the conditions necessary in the AF condition, but none of our subjects presented with PF helmets that fit the AF helmet criteria. The AT returned to the room following PF helmet assessment and AF helmet adjustment and assessed both helmet conditions with subject supine in order to assess ability to judge difference in helmet fit.

Figure 3.1 Cascade® R Lacrosse Helmet and HardTail SPRfit™ Technology

(Cascade, 2013a)

Three electromagnetic sensors were fit to each of the subjects. One was fit on the crown of the helmet, left temple, and distal sternal notch of the thorax. Similar receiver arrangement has been used in previous research studies (Toler et al., 2010). After the receivers were properly secured, the subjects sat upright in order to digitize anatomical landmarks with a wooden stylus. The anatomical landmarks identified include: T12/L1, xiphoid process, proximal sternal notch, T8, C7, chin, bridge of nose, and occiput. After digitization the subjects lay supine.

The starting position was standardized; supine with subject instructed to lie motionless at all times. Subjects were instructed not to assist in maintaining head posture in any way. One certified athletic trainer (AT) and one research assistant who had been taught and practiced proper airway access techniques for managing on-field men's lacrosse spine injuries, performed both helmet removal and facemask removal techniques. For each helmet removal technique, the AT maintained control of the subjects' head inferiorly as the research assistant removed the chinstrap followed by the helmet; following complete helmet removal the research assistant placed towel under subjects head (Figure 3.2). Each helmet removal trial began when the AT secured the head and will end when the research assistant placed a towel under the head after complete helmet removal. In the facemask removal technique, the research assistant performed the facemask removal and the AT stabilized the head superiorly (Figure 3.3). Each facemask removal trial began as soon as AT secured head in in-line stabilization and ended when the facemask was placed on the ground next to the subject. Initiation of task was signified by verbal cue of "stabilized" and termination of task was signified by verbal cue of "removed". A 9V trigger was used to define the beginning and end of each task. Each airway access technique was performed three times under both helmet fit conditions.

Figure 3.2 Helmet Removal

Figure 3.3 Facemask Removal

In order to prevent a learning effect, both the AT and research assistant performed pilot testing. Pilot test subjects were fit with helmets using the AT Fit guidelines and an unused set of lacrosse shoulder pads. Pilot subjects were outfitted with the same receiver set as test subjects. Pilot testing occurred until facemask removal and helmet removal time no longer showed significant decreases using a paired samples t-test.

DATA REDUCTION

Euler angles were used to record c-spine motion of the head and helmet relative to the fixed sternum. A world axis system was established using a right-hand rule with right lateral flexion about positive z-axis, left rotation about positive x-axis, and flexion about positive y-axis. Data was filtered with a 14.5 Hz low-pass Butterworth.

C-spine motion was defined as the displacement occurring between the receivers on the left temple in relation to motion of the receiver on the distal sternal notch. Change in peak displacement was measured as the absolute difference between maximum and minimum angles in each plane for each trial. These were then averaged to create one change score for each plane and each condition. Additionally, integrated motion in each plane was measured using Simpson's integration, which was then normalized to time throughout the entire trial for each individual plane of motion. Lastly, time to completion was compared as a separate variable using the length of the trial.

Data was exported from the Motion Monitor v8.0 (The Motion Monitor, Chicago Il.) system and reduced using a LabView program customized for this study. A 9V trigger was used to define the beginning and end of each task.

STATISTICAL ANALYSIS

All data was analyzed using Mauchley's test of sphericity to ensure equal variance and assess skewness and kurtosis; all out-liers were removed. Six 2 (fit) x 2 (removal technique) analyses of variance (ANOVA) were used to assess the differences in c-spine motion in the sagittal, frontal, and transverse planes for both change in peak displacement and integrated motion (Table 3.2). Another 2 (fit) x 2 (removal technique) ANOVA for time to completion was used (Table 3.3). Our level of significance was set a prior at an alpha level of 0.05. If a significant omnibus ANOVA is revealed, a pairwise comparison with a Bonferroni correction (adjusted p-value of .0125) was completed in order to determine which conditions caused significant alteration in the dependent variable of c-spine motion. Lastly, time was compared as a separate variable using a paired samples t-test for airway access technique. All statistical analysis will be performed using SPSS Statistics 20 (SPSS, Chicago, IL).

Table 3.2 Visual Representation of ANOVA Study Design (one table for both change in peak displacement and integrated motion)

	Helmet Removal			Facemask Removal		
	Frontal	Sagittal	Transverse	Frontal	Sagittal	Transverse
AT Fit						
Player Fit						

Table 3.3 Visual Representation of 2-way within subjects ANOVA for time to completion

	Helmet Removal	Facemask Removal
AT Fit		
Player Fit		

CHAPTER 4

OVERVIEW

Objective: To determine the effect of lacrosse helmet fit (athletic trainer-AT fit vs. player fit-PF) and airway access technique (helmet removal-HR vs. facemask removal-FR) on cervical spine (C-spine) motion. **Subjects:** Eighteen college-level varsity male lacrosse players (age range 18-22; height = 184.46 ± 6.15 cm, mass = 90.49 ± 6.81 kg). **Methods**: C-spine motion and time to completion were recorded during both airway access techniques under both helmet fit conditions. C-spine motion was defined as change in peak displacement and total excursion in each plane. Seven 2-way within subjects ANOVA were conducted: one for each plane (sagittal, transverse, and frontal) for both C-spine motion variables, and one for time to completion. **Results:** There was an interaction effect for integrated motion in the frontal plane ($F_{1,17} = 8.052$, $P = .011$) and for change in peak displacement in the sagittal ($F_{1,17} = 12.336$, $P = .003$) and transverse planes ($F_{1,17} = 11.118$, $P = .004$). AFHR resulted in greater motion than AFFR for peak displacement and integrated motion in all three planes. PFHR resulted in greater motion than PFFR for peak displacement in the transverse plane and for integrated motion in the frontal plane. AFHR resulted in greater motion than PFHR for peak displacement in the transverse plane and integrated motion in the frontal plane. There was a main effect of airway access technique in all three planes of motion for change in peak displacement (sagittal: $F_{1,17} = 21.878$, $P < .05$, transverse: $F_{1,17} = 26.144$, $P < .05$, frontal: $F_{1,17} = 28.720$, $P < .05$) and integrated motion in all three planes of motion (sagittal: $F_{1,17} = 68.655$, $P <$

.05, transverse: $F_{1,17} = 6.025$, $P = .025$, frontal: $F_{1,17} = 52.447$, $P < .05$), with HR resulting in more motion than FR. There was a main effect of fit for the transverse plane in change in peak displacement ($F_{1,17} = 9.733$, $P = .006$) and for integrated motion in the frontal plane ($F_{1,17} = 8.371$, $P = .010$), with AF resulting in more motion than PF. **Conclusion:** Data from this study suggests that there is an increase in c-spine motion with helmet removal. It also displays that helmet removal is a faster method of airway access technique as compared to facemask removal. Despite the fact that facemask removal is the current guideline for airway access technique, helmet removal as an airway access technique should be considered as a viable option that may take place on the field. **Word Count:** 406

MANUSCRIPT

Lacrosse is a rapidly growing sport in the United States, with 41% expansion in collegiate men's lacrosse teams since 1988 (Dick et al., 2007). An increase in participation represents a call for establishing evidence-based practice regarding proper emergency management of a potential catastrophic event, such as a head or neck injury, which can result in permanent disability or fatality as a consequence of improper care. Unfortunately, very few studies have examined emergency airway access procedures specific to men's lacrosse equipment, (Bradney & Bowman, 2013; Higgins et al., 2010; Petschauer et al., 2010; Sherbondy et al., 2006; Waninger et al., 2001). It is alarming that there is limited research examining best practice for proper airway access in cervical spine injuries in men's lacrosse, because since 1982, 22 catastrophic neck and spine injuries have been recorded in high school men's lacrosse and 13 catastrophic injuries have been recorded in collegiate men's lacrosse (Mueller, 2011). Thus, to ensure that future injuries to the brain and/or spinal cord are handled in the safest, most efficient and effective manner, further research is warranted.

Spinal cord injuries can transpire even when spinal cord continuity is maintained. Secondary injuries, including hemorrhage or ischemia can also result in neurological disorders if handled improperly. Thus, it is imperative that correct management procedures are established to minimize potential for injury due to subsequent mishandling of a c-spine injury (Bailes et al., 2007). To minimize additional risk of hemorrhage or ischemia associated with c-spine injuries, US Lacrosse Sports Science and Safety has set forth guidelines for the proper airway access technique when c-spine injury is suspected. "The helmet and shoulder pads of an injured lacrosse athlete should be left in place until they can be removed in a controlled environment" (*Lacrosse Helmet Facemask/Chinguard Removal Hints for Certified Athletic Trainers*).

These guidelines have given rise to controversy for many reasons. The first debate stems from the belief that, often times, the medical personnel most familiar with the equipment being used by the athletes are the athletic trainers on-site. Athletic trainers (AT) and the sports medicine team immediately involved at the scene have a better understanding of equipment removal procedures than emergency room clinicians who may have no training in helmet removal methods (Banerjee et al., 2004b). Additionally, one study demonstrated that there was only minimal movement in the area of occiput-C2 in a helmet removed airway access situation and no movement in the area of C2-C7, where most injuries occur (Higgins et al., 2010). Furthermore, cervical extension in a men's lacrosse athlete with his helmet removed but shoulder pads still in place does not affect space available for the spinal cord as is seen in football equipment (Higgins et al., 2010). This decrease in cervical extension is a product of the much less dramatic thoracic elevation provided by the much slimmer men's lacrosse shoulder pads (Higgins et al., 2010). Also, men's lacrosse helmets do not provide adequate head immobilization when clinicians secure the helmet to a spine board (Petschauer et al., 2010; Sherbondy et al., 2006). C-spine care guidelines state that equipment should be removed if the helmet and chin straps do not stabilize the head securely such that immobilization does not also immobilize the head (Bailes et al., 2007; Kleiner, 2003; *Lacrosse Helmet Facemask/Chinguard Removal Hints for Certified Athletic Trainers*; Swartz et al., 2009). Lastly, clinical utility of these guidelines have been questioned as evidence suggests that a large portion of men's lacrosse athletes do not wear properly fitted helmets (Petschauer et al., 2010); therefore, research that these guidelines are based on may be lacking external validity because they are based on properly fit men's lacrosse helmets.

The issue of airway access in a potentially c-spine injured men's lacrosse athlete is also a debated topic. While there are guidelines in place, they do not go uncontested. Although the current guidelines instruct athletic trainers at the site of the injury to only remove the facemask, this action has not been compared to the alternate airway access technique of complete helmet removal. For this reason, the effect of c-spine motion in the act of removing the helmet to access the airway needs to be researched (Higgins et al., 2010). Therefore, the purpose of this study was to evaluate the effects of helmet fit and equipment removal technique on c-spine motion (measured in change in peak displacement and integrated motion in each plane) and time to completion of the task during airway access using helmet removal and facemask removal in collegiate men's lacrosse players.

METHODS

Participants

A total of 18 collegiate men's lacrosse athletes (age range 18-22; height = 184.46 ± 6.15 cm, mass = 90.49 ± 6.81 kg) volunteered to participate. Subjects were excluded if they were currently experiencing or had a history of neck pain or any past traumatic neck injury (Mihalik et al., 2008; Petschauer et al., 2010). All participants completed and signed an informed consent form approved by the IRB at the University of North Carolina – Chapel Hill.

Equipment

The helmet that was used in all testing scenarios was a Cascade® R (Cascade Lacrosse, Liverpool, NY). The subjects were asked to bring their helmet and shoulder pads that they wear during lacrosse practices and games. Subjects had been practicing in the helmets for at least 3 weeks prior to data collection to ensure that personal adjustments that are commonly made will be made throughout the season were as consistent with data collection as possible.

A TrackStar (Ascension Technologies, Burlington, VT) electromagnetic motion analysis system, controlled by the Motion Monitor software (Innovative Sports Training Inc Chicago, IL), was used to collect data. Kinematic data were collected at 144 Hz. For facemask removal a cordless screwdriver with the ability to orient at 90 degrees or 180 degrees was used and a manual screwdriver was available if additional torque was necessary to remove screw.

Protocol

Subjects arrived to the lab with their personal Cascade® R helmet, which acted as the player fit (PF) helmet, and shoulder pads. Subjects were tested using a repeated measures, counterbalanced design in one of two helmet conditions and one of two airway access techniques. For the athletic trainer fit (AF) helmet condition, a Cascade® R helmet (separate from the PF helmet) was fit by a research assistant according to the Cascade® helmet safety guidelines (Cascade, 2013b). Prior to helmet assessment and adjustment for the AF and PF conditions, the lead investigator left the room for blinding purposes, and returned to the room immediately following helmet assessment and adjustment.

For the AF condition, a research assistant placed the AF helmet on the subjects' head. Once the helmet was in place, a research assistant ensured that the back of the helmet was in uniform contact with the back of the subject's head. If the helmet was too loose, a researcher tightened the HardTail SPRfit™ technology (Cascade Lacrosse, Liverpool, NY) until uniform contact around the entire head was reached. After making this adjustment, a research assistant applied an anterior pressure over the occiput of the helmet to ensure that there was not gapping at the subjects' forehead. In addition, a research assistant applied rotational forces on either side of the subject's head in order to assess if skin on the forehead moved with helmet, which verifies fit per manufacturer's guidelines (Cascade, 2013b). If the helmet slipped over the head in either of those conditions, a research assistant attempted to tighten the HardTail SPRfit™ technology. Finally, a research assistant inspected the facemask to ensure a 2-3 finger width clearance from the subjects' nose (Cascade, 2013b). These conditions were assessed on the PF helmet and if the PF helmet met all the conditions necessary in the AF condition, the subjects' data were not collected.

Three electromagnetic TrackStar receivers were fit to each of the subjects; one on the crown of the helmet, left temple, and distal sternal notch of the thorax. After the receivers were properly secured, the subjects were digitized using the following anatomical landmarks: T12/L1, xiphoid process, proximal sternal notch, T8, C7, chin, bridge of nose, and occiput. Starting position was standardized; supine with subject instructed to lie motionless at all times. Subjects were instructed not to assist in maintaining head posture in any way. One AT and one research assistant, who had been taught and practiced proper airway access techniques, performed both helmet removal and facemask removal techniques. For each helmet removal technique, the AT maintained control of the subjects' head inferiorly, which signaled the start of the trial, as the research assistant removed the chinstrap followed by the helmet. Following complete helmet removal the research assistant placed towel under subjects head, which indicated the end of the trial. The towel was folded to the thickness perceived to eliminate deleterious c-spine extension following helmet removal. For the facemask removal technique, the research assistant performed the facemask removal and the AT stabilized the head superiorly by grasping both sides of the helmet. Each facemask removal trial began as soon as the AT secured head in in-line stabilization and ended when the facemask was placed on the ground next to the subject. A second research assistant pressed a 9V trigger to signify the start and end of each trial.. Each airway access technique was performed three times under both helmet fit conditions.

In order to prevent a learning effect, both the AT and the research assistant performed pilot testing. Pilot testing occurred until facemask removal and helmet removal time no longer showed significant decreases using a paired samples t-test.

DATA REDUCTION

Euler angles were used to record c-spine motion of the head and helmet relative to the fixed sternum. A world axis system was established using a right-hand rule with right lateral flexion about positive z-axis, left rotation about positive x-axis, and flexion about positive y-axis. Data were filtered with a 14.5 Hz low-pass Butterworth.

C-spine motion was defined as the displacement occurring between the receivers on the left temple in relation to motion of the receiver on the distal sternal notch. Change in peak displacement was measured as the absolute difference between maximum and minimum angles in each plane for each trial. These absolute differences between maximum and minimum angles in each plane for each trial were then averaged to create one change score for each plane and each condition. Additionally, integrated motion in each plane was measured using Simpson's integration, which was then normalized to time throughout the entire trial for each individual plane of motion. Lastly, time to completion was compared as a separate variable using the length of the trial.

Data were exported from the Motion Monitor v8.0 (The Motion Monitor, Chicago Il.) system and reduced using a LabView program customized for this study.

STATISTICAL ANALYSIS

Six 2 (fit) x 2 (removal technique) analyses of variance (ANOVA) were used to assess the differences in c-spine motion in the sagittal, frontal, and transverse planes for both change in peak displacement and integrated motion. Another 2 (fit) x 2 (removal technique) ANOVA for time to completion was used. Our level of significance was set a prior at an alpha level of 0.05. If a significant omnibus ANOVA is revealed, a pairwise comparison with a Bonferroni correction (adjusted p-value of .0125) was completed in order to determine which conditions caused significant alteration in the dependent variable of c-spine motion. All statistical analysis were performed using SPSS Statistics 20 (SPSS, Chicago, IL).

RESULTS

Change in Peak Displacement and Integrated Motion

All results are presented in Table 4.1. There was a significant interaction effect for airway access technique and helmet fit in the sagittal ($F_{1,17} = 12.336$, $P = .003$) and transverse plane ($F_{1,17} = 11.118$, $P = .004$) for change in peak displacement, and an significant interaction effect in the frontal plane ($F_{1,17} = 8.052$, $P = .011$) for integrated motion (Figure 4.1, Table 4.2, and Table 4.3, respectively). Post hoc testing revealed that in the AF conditions, helmet removal resulted in more motion than facemask removal for peak displacement in the sagittal ($t_{17}= 9.900$, $P < .0125$) and transverse planes ($t_{17}= 4.959$, $P < .0125$) and integrated motion in the frontal plane ($t_{17}= 7.741$, $P < .0125$). For the PF conditions, helmet removal resulted in more motion than facemask removal for peak displacement in the transverse plane ($t_{17}= 4.058$, $P = .001$) and integrated motion in the frontal plane ($t_{17}= 3.150$, $P = .006$) . For the helmet removal conditions, the AF helmet resulted in more motion than the PF helmet for peak displacement in the transverse plane ($t_{17}= 3.398$, $P = .003$) and integrated motion in the frontal plane ($t_{17}= 2.968$, $P = .009$).

There was a main effect of airway access technique in all three planes of motion for both peak displacement and integrated motion, with the facemask removal technique consistently taking longer than the helmet removal technique. There was a main effect of helmet fit in the transverse plane for change in peak displacement ($F_{1,17} = 9.733$, $P = .006$) and in the frontal plane for integrated motion ($F_{1,17} = 8.371$, $P = .010$), with the AF resulting in more motion than the PF fit in both conditions (Figure 4.4 and Figure 4.5 respectively).

Table 4.1 Results of Statistical Analysis

Measure	Plane	Fit	Facemask Removal (FR) Mean ± SD	Helmet Removal (HR) Mean ± SD	Fit*Removal Technique Interaction	Main Effect: Fit	Main Effect: Airway Access Technique
Peak Displacement	Sagittal	AF PF	17.48±4.39 16.53±6.91	22.36±7.53 20.37±12.72	$F_{1,17}$ = 12.336 P = .003*[a]	$F_{1,17}$ = 3.304 P = .087	$F_{1,17}$ = 21.878 P <0.005‡
	Transverse	AF PF	8.38±1.74 8.41±3.10	22.42±11.80 14.97±6.41	$F_{1,17}$ = 11.118 P = .004*[a,b,c]	$F_{1,17}$ = 9.733 P =.006†	$F_{1,17}$ = 26.144 P <0.005‡
	Frontal	AF PF	10.67±3.41 11.99±5.07	19.24±7.48 19.10±11.06	$F_{1,17}$ =.368 P = .552	$F_{1,17}$ = .090 P = .768	$F_{1,17}$ = 28.720 P <0.005‡
Integrated Motion	Sagittal	AF PF	1.42±0.90 1.72±0.97	4.43±1.74 4.12±3.01	$F_{1,17}$ = .557 P = .466	$F_{1,17}$ = .000 P = .988	$F_{1,17}$ = 68.655 P <0.005‡
	Transverse	AF PF	2.14±1.55 2.15±1.01	3.59±1.88 4.03±4.90	$F_{1,17}$ = .159 P = .695	$F_{1,17}$ = .139 P = .714	$F_{1,17}$ = 6.025 P= .025‡
	Frontal	AF PF	1.74±0.60 1.68±0.58	4.39±1.36 2.90±1.54	$F_{1,17}$ = 8.052 P = .011*[a,b,c]	$F_{1,17}$ = 8.371 P = .010†	$F_{1,17}$ = 52.447 P <0.005‡
Time to completion	Not applicable	AF PF	29.04±2.97 30.35±5.31	17.11±2.73 19.16±2.72	$F_{1,17}$ = .219 P = .646	$F_{1,17}$ = 6.063 P = .025†	$F_{1,17}$ = 179.646 P < 0.005Ω

AF= Athletic trainer fit; PF= Player fit; FR= Facemask removal; HR= Helmet removal
* = Significant interaction effect at the 0.05 alpha level
[a] = AFHR > AFFR
[b] = PFHR > PFFR
[c] = AFHR > PFHR
† = AF > PF, statistically significant at the 0.05 alpha level
‡ = HR > FR, statistically significant at the 0.05 alpha level
Ω = FR > HR, statistically significant at the 0.05 alpha level

Figure 4.1 Interaction effect between helmet fit and airway access technique in the sagittal plane for change in peak displacement

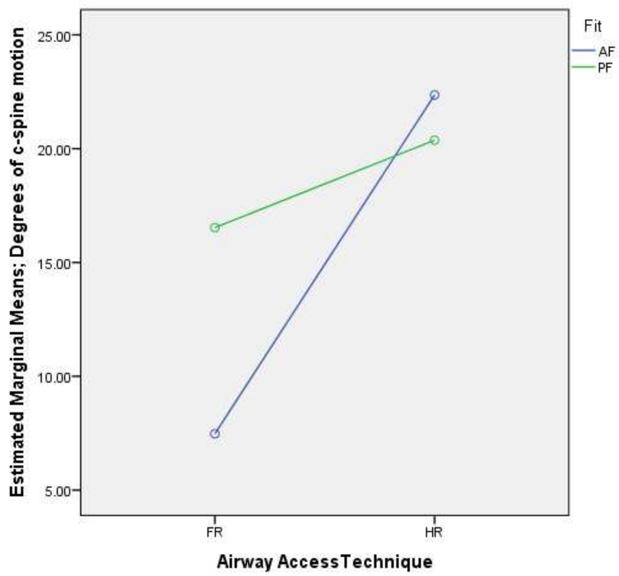


Figure 4.2 Interaction effect between helmet fit and airway access technique in the transverse plane for change in peak displacement

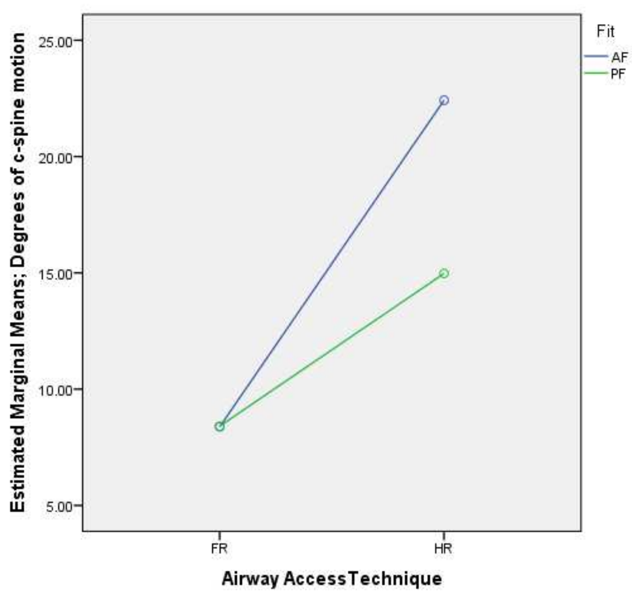


Figure 4.3 Interaction effect between helmet fit and airway access technique in the frontal plane for integrated motion

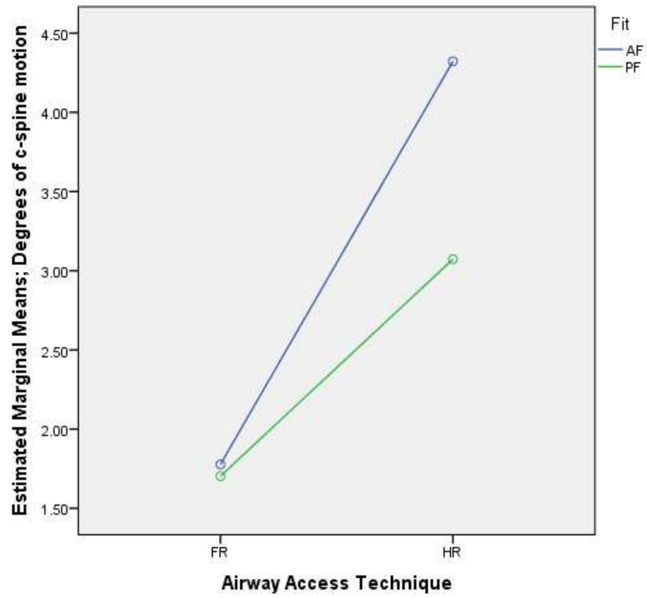


Figure 4.4 Change in peak displacement for all four testing conditions in the sagittal, transverse, and frontal planes

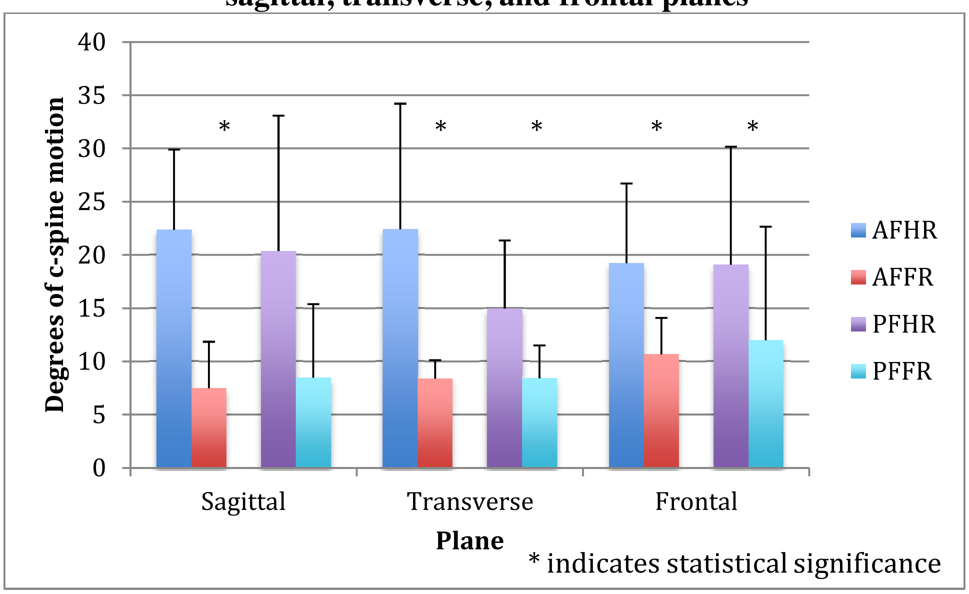
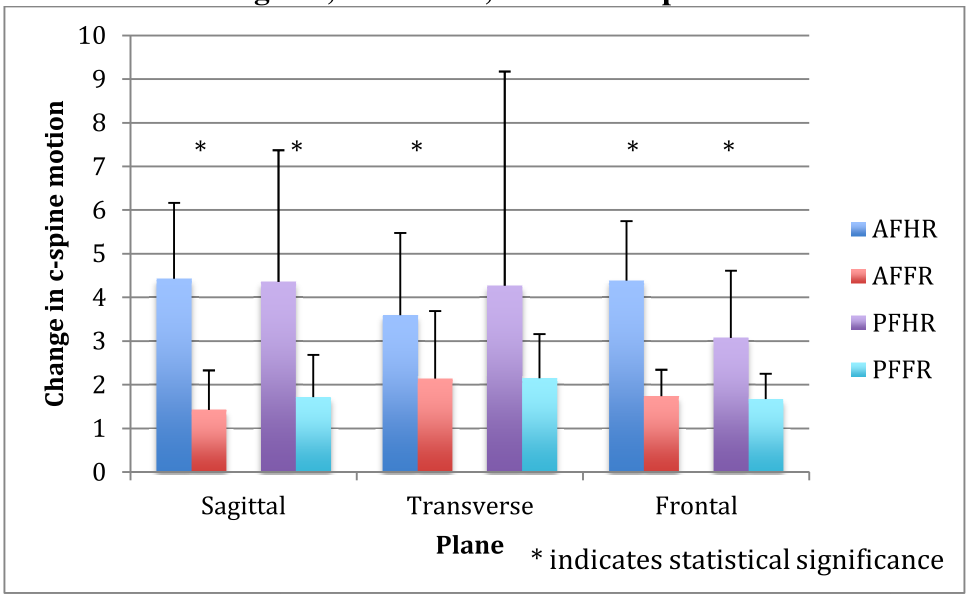


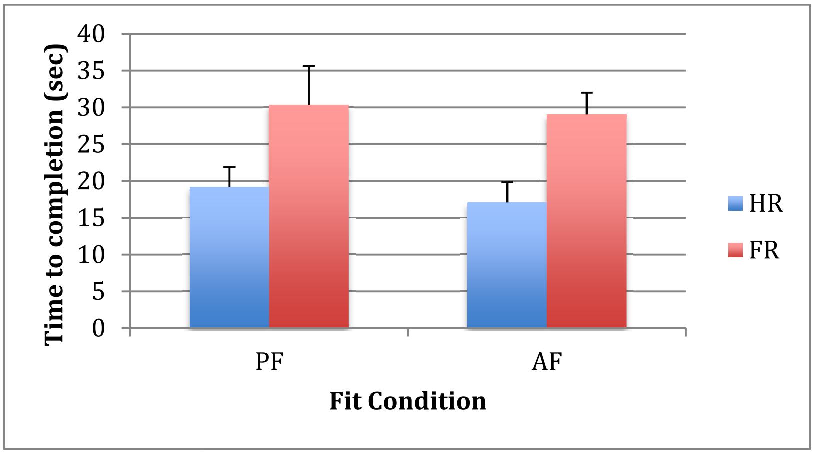
Figure 4.5 Integrated motion in each plane for all four testing conditions in the sagittal, transverse, and frontal planes



Time to Completion

There was not a significant interaction effect for airway access technique and helmet fit ($F_{1,17}$ = .219, P = .646) for time to completion. There was a main effect for airway access technique ($F_{1,17}$ = 179.646, P < 0.005) for time to completion with FR taking longer than HR. There was also a main effect for helmet fit ($F_{1,17}$ = 6.063, P = .025) for time to completion with AF displaying a decreased time to completion as compared to PF (Figure 4.6).

Figure 4.6 Time to Completion (sec)



Helmet Fit

All 18 subjects arrived to our lab for testing with ill-fitted PF helmets when assessed using manufacturers standards: 55% of the subjects did not wear their helmets in uniform contact with the back of their head, 78% of subjects' helmets gapped at their foreheads, 78% of subjects' helmet slid over forehead when rotational forces were applied, and 89% of subjects wore helmets with chin straps that were too loose to stabilize helmet to head.

DISCUSSION

To our knowledge, we are the first to investigate helmet removal for airway access in men's lacrosse. Our results suggest that helmet removal may cause more motion than facemask removal, but helmet removal is also faster than facemask removal. Furthermore, athletic trainer fit helmets cause more motion during helmet removal than ill-fitted player helmets. All lacrosse players in this study were participating in both practice and competition daily with helmets that were not fitted according to manufacturer's guidelines.

Minimizing cervical spine motion and accessing the airway quickly are both emphasized in the care of a men's lacrosse athlete with a suspected spinal cord injury (Swartz et al., 2009). The cervical spine must be immobilized in a proper manner in order to avoid secondary spinal cord injury (Bailes et al., 2007). Additionally, individuals with spinal cord injuries may deteriorate quickly, so an airway should be accessed quickly and prior to the need of an airway arising (Bailes et al., 2007). Due to the need to limit cervical spine motion and to access the airway as quickly as possible, medical professionals may struggle with agreeing on the middle ground for airway access technique in regards to a suspected c-spine injured athlete.

Change in Peak Displacement and Integrated Motion

In our study, helmet removal consistently resulted in more motion than facemask removal. We speculate that the increase in c-spine motion during helmet removal may occur because of the cervical extension caused by tilting the lacrosse helmets posteriorly during helmet removal in order for the chin-guard to clear the athlete's nose. Unfortunately, to date, there is no objective number in which to gauge potential damage to the c-spine injury in regards to motion (Higgins et al., 2010; Sherbondy et al., 2006; Swartz et al., 2009), or at which level the motion occurs (Banerjee et al., 2004a). However, it is accepted that athletes should be transported in a position in which a neutral spine is obtained to ensure optimal outcome (Banerjee et al., 2004b; Kleiner, 2003; Swartz et al., 2009). Current equipment removal guidelines for men's lacrosse airway access are closely based off of the football helmet removal guidelines that state only the facemask of a helmet may be removed due to the antalgic extension removing the helmet would cause in relation to the athletes shoulder pads (Swartz et al., 2009). Conversely, in men’s lacrosse equipment, athletes are in a position closer to c-spine neutral in a helmet-removed condition as compared to full equipment condition.

We observed that helmet fit had minimal effects on the motion that occurred during airway access. Consistent with other studies (Evan Boyd Allen, 2010; Petschauer et al., 2010), our sample all reported with ill-fitting helmets compared to manufacturers standards. Consistent findings of men’s lacrosse athletes wearing helmets that are not properly fit reveal a cultural trend within the sport (Evan Boyd Allen, 2010; Petschauer et al., 2010). In our study, fit of helmet only had a significant effect during helmet removal conditions and only on the change in peak displacement in the transverse plane and integrated motion in the frontal plane. Fit did not affect any other measures or planes of motion. These findings may be because even well-fitted men’s lacrosse helmets do not provide adequate stabilization for an athlete’s head when they are laying supine, causing properly fitted helmets to be removed as easily as ill-fitted helmets.

Health care professionals as well as coaches and manufacturers can start aiding in the safety of their athletes by educating athlete on proper fitting techniques. If c-spine injury is suspected it is integral that the athlete is secured to a spine board in order to prevent unnecessary movement during transportation to further medical care (Bailes et al., 2007; Kleiner, 2003; Swartz et al., 2009); this cannot be accomplished in an ill-fitted helmet or a helmet that does not allow for neutral alignment of the c spine. While properly fit helmets is certainly a start toward aiding in the safety of men’s lacrosse athletes, men’s lacrosse helmets do not afford the same customizable fitting options seen in those of football helmets. The addition of extra padding inserted into a men’s lacrosse helmet to adjust fit only limits neck flexion and extension with no additional restrictions in the other planes of motion (Petschauer et al., 2010). These compounding factors afford the notion that removing the helmet to access an airway in an emergent situation in which the c-spine may be injured may be the optimal technique to access a men's lacrosse player's airway safely, resulting in neutral alignment and the least c-spine motion during transportation, until a men's lacrosse helmet that properly stabilizes the head can be designed and proper fit can consistently be ensured (Petschauer et al., 2010).

Time to Completion

Facemask removal consistently took longer than helmet removal, by approximately 11 seconds (11.19 in player fit helmets, and 11.93 seconds in athletic trainer fit helmets). Accessing an airway in an expedient manner is a point of emphasis in the current emergency care standard of care (Swartz et al., 2009). According to the American Red Cross one round of cardiopulmonary resuscitation (CPR) should take 20-24 seconds. Thirty chest compression at the proper rate should take approximately 18 seconds and 2 rescue breaths should fill the remaining 2-6 seconds ("American Red Cross," 2007). This means that removing a helmet will allow for nearly half a round of CPR to be performed even prior to the facemask removal being completed. These findings suggest that helmet removal may provide oxygen in a more expedient manner to a potentially c-spine injured athlete. A faster airway access technique also means that an athlete may be transported quicker. A faster transportation time is optimal and allows a c-spine injured athlete to reach a spine surgeon's care in a more expedient manner (Banerjee et al., 2004b). Current men's lacrosse guidelines for airway access account for the minimization of c-spine movement by recommending facemask removal exclusively; however, they do not address a consequent action if time to task completion is becoming extensive (*Lacrosse Helmet Facemask/Chinguard Removal Hints for Certified Athletic Trainers*)

We speculate that difficulty of unhooking the chin-guard in the Cascade® R (Figure 4.7) contributed to increased facemask removal time. This finding may even be exacerbated in men's lacrosse helmets that would require pop rivets, t-nuts, or loop straps (Bradney & Bowman, 2013) to be cut/removed such as the: DeBeer Identity, Cascade® CPX, Cascade® CLH2, Cascade® PRO7, and Cascade® CS (*Lacrosse Helmet Facemask/Chinguard Removal Hints for Certified Athletic Trainers*). The Cascade® R only requires the unscrewing of 3 screws via cordless screwdriver, which is relatively minor in comparison to other more difficult helmets (Bradney & Bowman, 2013). Helmet designs that are different from the Cascade® R may also affect airway access itself (Bradney & Bowman, 2013). Some men's lacrosse helmets have chinguard pieces that do not come off when the facemask is removed; they stay affixed to the helmet (i.e. The DeBeer Identity) and must be cut off if causing an obstruction to the airway (*Lacrosse Helmet Facemask/Chinguard Removal Hints for Certified Athletic Trainers*), this variability has been shown to cause difficulty with facemask removal (Bradney & Bowman, 2013). Additionally, the large variability in men's lacrosse helmets means that allied healthcare professionals that initially arrive at the scene of a men's lacrosse injury must maintain current knowledge of most popular helmet styles and techniques in removing the facemask. This also supports the argument that the most qualified professional to remove equipment are the athletic trainers immediately on scene as they will be most familiar with the current equipment.

Figure 4.7 Image of Cascade® R

Limitations

There are acknowledgeable limitations to this study. First, the AT and the research assistants were very familiar with the Cascade® R facemask removal process, which may have made facemask potentially easier and decreased c-spine motion. Second, measurement instrumentation of this study also did not allow for exact c-spine motion to be measured. Measurements were taken with an electromagnetic capture system with sensors affixed to the subjects' sternum and left temple; this means that helmet removal had the potential to cause more sensor motion than facemask removal as a product of skin movement underneath sensor and/or helmet pulling on sensor while being removed. Movement of the temple sensor may not have been indicative of actual c-spine motion.

Future Research

Future studies with inter-clinician facemask removal should be conducted in order to further strengthen or contest this study's findings. Additionally, as improvements in motion capture technology arise further investigation should be done in order to better assess actual c-spine motion related to helmet removal in the absence of extraneous motion. Furthermore, future studies may look into the c-spine motion and timeliness associated with complete facemask removal followed by complete helmet removal. If a lacrosse helmet is constructed in such a way that when the facemask is removed, the chin-guard comes off (as is the Cascade® R), then removing the facemask prior to helmet removal may expunge the additional c-spine motion associated with helmet removal. Lastly, the disadvantages of the c-spine motion caused when removing a helmet needs to be compared to the disadvantages of transporting an athlete while not in c-spine neutral in order to further examine the current men's lacrosse airway access guidelines. Though this study lays the ground work for discussion about altering current men's lacrosse airway access guidelines in a potentially c-spine injured athletes, there is further research warranted to make concrete suggestions. Further research will benefit not only clinicians performing emergency airway access, but also the athlete receiving care.

Conclusion

Emergency medical care is an extremely important area and can mean the difference in the outcome of a dire situation. Evidence based practice must be implemented, yet there is a lack of research examining the best airway access techniques in men's lacrosse athletes. Standard of care for health professionals tending to the needs of athletes wearing helmets states that if a facemask malfunction renders the facemask unable to be removed or if the facemask is unable to be removed in a timely manner than helmet removal needs to take place (Kleiner, 2003; Swartz et al., 2009). Additionally, the standard of care calls for specific guidelines in place to help facilitate helmet removal (Kleiner, 2003). Although data from this study suggests that there is an increase in c-spine motion with helmet removal, it also displays that helmet removal is a faster method of airway access as compared to facemask removal. Therefore, men's lacrosse governing bodies and health professionals associated with the sport need to further investigate men's lacrosse helmet removal as an airway access technique in order to develop guidelines. Despite the fact that facemask removal is the current guideline for airway access technique (*Lacrosse Helmet Facemask/Chinguard Removal Hints for Certified Athletic Trainers*); helmet removal as an airway access technique should be considered as a viable option that may take place on the field.

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