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Cervical Spine Motion During Football Equipment-Removal Protocols: A Challenge to the All-or-Nothing Endeavor

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Context: The National Athletic Trainers' Association position statement on acute management of the cervical spine-injured athlete recommended the all-or-nothing endeavor, which involves removing or not removing both helmet and shoulder pads, from equipment-laden American football and ice hockey athletes. However, in supporting research, investigators have not considered alternative protocols.

Objective: To measure cervical spine movement (head relative to sternum) produced when certified athletic trainers (ATs) use the all-or-nothing endeavor and to compare these findings with the movement produced using an alternative pack-and-fill protocol, which involves packing the area under and around the cervical neck and head with rolled towels.

Design: Crossover study.

Setting: Movement analysis laboratory.

Patients or Other Participants: Eight male collegiate football players (age = 21.4 ± 1.4 years; height = 1.87 ± 0.02 m; mass = 103.6 ± 12.5 kg).

Intervention(s): Four ATs removed equipment under 4 conditions: removal of helmet only followed by placing the head on the ground (H), removal of the helmet only followed by pack-and-fill (HP), removal of the helmet and shoulder pads followed by placing the head on the ground (HS), and removal of the helmet and shoulder pads followed by pack-and-fill (HSP). Motion capture was used to track the movement of the head with respect to the sternum during equipment removal.

Main Outcome Measure(s): We measured head movement relative to sternum movement (translations and rotations). We used 4 × 4 analyses of variance with repeated measures to compare discrete motion variables (changes in position and total excursions) among protocols and ATs.

Results: Protocol HP resulted in a 0.1 ± 0.6 cm rise in head position compared with a 1.4 ± 0.3 cm drop with protocol HS ($P < .001$). Protocol HP produced 4.9° less total angular excursion ($P < .001$) and 2.1 cm less total vertical excursion ($P < .001$) than protocol HS.

Conclusions: The pack-and-fill protocol was more effective than shoulder pad removal in minimizing cervical spine movement throughout the equipment-removal process. This study provides evidence for including the pack-and-fill protocol in future treatment recommendations when helmet removal is necessary for on-field care.

Key Words: National Athletic Trainers' Association position statement, pack and fill, motion analysis, helmet removal

Key Points

- The pack-and-fill protocol resulted in less overall motion than removal of the helmet and shoulder pads followed by placing the head on the ground, which is currently endorsed by the National Athletic Trainers' Association.
- Using pack and fill, the athletic trainers could position the head at release in, on average, nearly the identical position as at initiation.
- Removal of the helmet and shoulder pads resulted in a drop in linear and angular head position, placing the cervical spine into increased extension.

American football has the highest number of catastrophic cervical spine injuries of all sports in the United States.[1] Although still of major concern, the incidence of catastrophic cervical spine injuries has declined over the past 35 years, and the rate is now less than 1 per 100 000 exposures.[2] Much of this decline has been attributed to a 1976 rule change making it illegal to spear, or lower the head to butt or ram an opponent.[2] Given the force applied at the front and top of a player's helmet, spearing has long been associated with the axial-load mechanism of injury that results in catastrophic cervical spine injury.[3] However, despite a focus on player safety, researchers[4–6] have suggested that the incidence of spearing or other axial head impacts may be as prevalent in American football in the United States today as before the 1976 rule change. Instead, improved prehospital care and on-field management of equipment-laden athletes with potential spine injuries possibly also has led to a reduction in catastrophic cervical spine injuries by reducing the number of cervical spine injuries that result in catastrophic outcomes. This possibility needs to be documented, and research pertaining to prehospital care protocols and management techniques that may affect catastrophic spinal cord injury outcomes in American football needs to continue.

Proper prehospital on-field medical care of the athlete with a spine injury, including equipment management, may be critical in limiting secondary cervical spine injury while also allowing access to the airway and chest compressions. The National Athletic Trainers' Association (NATA) position statement on the acute management of the cervical spine-injured athlete[7] includes the all-or–nothing technique, which discourages independent removal of the helmet or shoulder pads in American football or ice hockey when an athlete has a potential cervical spine injury. This specific NATA recommendation is based on several studies[8–11] in which the researchers measured vertebral positioning or spinal cord space before and after equipment removal and showed that when the football helmet is removed while the shoulder pads remain in place, cervical alignment can be compromised as the head and neck fall backward into extension.

However, a gap exists in the body of evidence used to support this recommendation, as no authors of supporting studies have addressed the use of fillers (eg, rolled towels) to stabilize the head and cervical spine after removing only the helmet and leaving the shoulder pads on the athlete. This technique, termed *pack and fill*, would fill the void of the missing helmet by placing rolled towels around and beneath the posterior head, cervical spine, and surface of the spine board or ground to prevent the head and cervical spine from moving into extension during performance of critical-care tasks. Although the NATA position statement[7] mentions this technique as a possibility for an athlete whose helmet is dislodged or shoulder pads are not removed easily, pack and fill could be an alternative clinical practice when removal of the helmet is necessary to provide safe access to the airway (eg, inability to remove the facemask efficiently or a poorly fitted football helmet creating instability of the head and cervical spine within the helmet). Decoster et al[12] recently demonstrated that pack and fill can effectively maintain a neutral sagittal cervical alignment after helmet removal.

Another gap in these supporting studies is that they were based on static imaging and, therefore, did not account for the amount of head and neck movement that occurs during the equipment-removal process. In the case of shoulder-pad removal, this could be substantial. Therefore, the purposes of our study were to address these 2 gaps by measuring cervical spine movement (head with respect to sternum) throughout the removal process and to compare this movement among several possible removal protocols. We hypothesized that removal of the helmet combined with the pack-and-fill technique would result in less overall movement than removal of both the helmet and shoulder pads.

METHODS

Removal Protocols

We analyzed 4 helmet-removal protocols: (1) removal of the helmet only followed by placing the head on the ground (H), (2) removal of the helmet only followed by packing the area under and around the head with towels (HP), (3) removal of the helmet and shoulder pads followed by placing the head on the ground (HS), and (4) removal of the helmet and shoulder pads followed by packing the area under and around the head (HSP). Protocols H and HS represent portions of the all-or-nothing principle, with HS endorsed over H. Protocol HP represents the alternative pack-and-fill technique mentioned previously, and protocol HSP was included for comparison purposes.

Participants

A total of 8 male collegiate football players (age = 21.4 ± 1.4 years; height = 1.87 ± 0.02 m; mass = 103.6 ± 12.5 kg) volunteered. Four practicing athletic trainers (ATs) certified by the Board of Certification performed the equipment removal as part of the study team. The ATs worked in pairs, with one acting as the equipment remover and the other acting as the head stabilizer. All participants provided written informed consent, and the study was approved by the institutional review boards of Mercyhurst University and Hamot Hospital.

Procedures

Several different sizes of Riddell Revolution (Elyria, OH) helmets and commercially manufactured shoulder pads were used. An AT fitted the appropriately sized helmet and shoulder pads to participants based on the manufacturers' fitting recommendations. We detached all helmet facemasks and cut and removed the anterior portions of the shoulder pads so as not to impede the camera's view of the reflective markers placed on the football athletes. A total of 10 retroreflective markers, 6 mm in diameter, were affixed to the participants' heads and torsos with double-sided tape. Two marker triads were located on the bridge of the nose and on the manubrium just below the jugular notch (Figure 1). These locations were chosen for their visibility and stability (minimal soft tissue artifact). In addition, 2 markers were placed just anterior to the ear orifices, and 2 markers were placed on the acromioclavicular joints, approximating the proximal (atlanto-occipital joint) and distal (C7–T1 articulation) ends of the cervical chain. These were used only for a neutral calibration trial and were removed before the helmet and shoulder pads were donned.

The neutral calibration trial was performed with participants lying supine in a comfortable position, aligned with the long axis of the laboratory reference frame and with a 2-cm-thick spacing block placed under the occiput. This was based on the neutral cervical spine position recommendation of De Lorenzo et al,[13] and it also conveniently matched closely the occiput elevation when shoulder pads and helmets were worn. Four tripod-mounted Vicon M2 cameras (Oxford, United Kingdom), which were positioned circumferentially above the participants, were used to track the positions of the markers at 30 Hz during the neutral trial and for the subsequent equipment-removal trials. Camera calibration residuals for the small volume (approximately 2 m long × 1 m wide × 1.5 m high) were less than 0.4 mm. Video cameras were also used to record all trials for quality assurance and presentation purposes.

After the neutral calibration trial, participants donned the equipment, and the equipment-removal trials began. Participants lay supine in the same location and orientation as in the neutral calibration trial and were instructed not to

Figure 1. Experimental setup. One athletic trainer worked as the remover, and one worked as the stabilizer. The motions of the head and torso were monitored using motion-capture technology throughout 4 different protocols.

assist the ATs during the removal process. Between removal trials, participants were instructed to actively reposition the head to the same approximate orientation as in the neutral calibration trial. A total of 16 trials were performed for each participant. The removing AT performed each of the 4 removal protocols and then switched places with the stabilizing AT, who repeated the 4 protocols. Next, the second AT pair repeated the same process. The AT pairs remained the same throughout the study. The order of the removal processes was randomized among participants and ATs.

Data Analysis

Data were processed using Visual 3D software (C-Motion, Inc, Rockville, MD). Marker trajectories were smoothed using a low-pass Butterworth filter with a 3-Hz cutoff. Local reference frames were created for the head and torso from the neutral calibration trials. The origin of the head was located at the midpoint between the 2 ear markers, and the origin of the torso was located at the midpoint between the 2 acromioclavicular joint markers. Axes for both reference frames were aligned with the laboratory reference frame. The 6-degrees-of-freedom motion of the head and torso reference frames were then tracked in the equipment-removal trials by the marker triads on the nose and manubrium, respectively. Angles between the 2 segments were calculated using an Euler/Cardan rotation sequence with the following order: (1) flexion-extension, (2) lateral flexion, and (3) rotation. Translations were calculated in each anatomic plane as the distance between reference frame origins relative to the original neutral calibration position.

The removal process was differentiated by the events of initiation and release. These events were defined manually based on visual inspection of the motion-capture data and the time-synchronized video. *Initiation* was defined as 1 frame before the first sign of helmet-removal motion by the removing AT, and *release* was defined as 1 frame after complete release of the head by the stabilizing AT. Several discrete measures of cervical (head relative to torso) motion were then chosen for statistical comparisons and consisted of (1) the change in relative position from initiation to release measured as both angles and translations and (2) the total angular and linear excursions between the 2 events (maximum − minimum throughout the removal process). Each angular and linear measure consisted of 3 components (ie, 3 planes of movement). These 12 dependent variables were compared among removal techniques (primary independent variable with 4 levels) and among ATs (secondary independent variable with 4 levels) using 4 × 4 analyses of variance (ANOVAs) with repeated measures on both factors followed by Bonferroni pairwise comparisons (familywise error $\alpha = .05$) when main effects were found. Statistical analysis was performed using the maximum likelihood mixed procedure in SAS (version 9.2, SAS Institute Inc, Cary, NC), treating AT as a fixed factor; because the ATs worked in pairs, they were treated as 4 levels. Multiple ATs were included to investigate possible interactions between AT and protocol and not to make main-effect comparisons among the ATs.

RESULTS

No interactions between AT and protocol were noted in any of the ANOVAs (F range, 1.03–1.79; $P > .08$) as protocol differences were similar across all ATs. The static changes in sagittal-plane angular positions from initiation to release showed a difference among protocols ($F_{3,84} = 92.8$; $P < .001$), and all pairwise comparisons were significant (Figure 2A). Protocol H resulted in the greatest angular change: 11.0° of extension. In the opposite direction, protocol HSP resulted in a mean change of 5.4° of flexion. Protocols HP and HS showed more modest changes in angular positioning from initiation to release, with protocol HP (0.1° of flexion) causing less change than protocol HS (3.2° of extension) (Table).

Changes in vertical linear positions were also different among protocols ($F_{3,84} = 496.9$; $P < .001$), and all pairwise comparisons were significant (Figure 2B). Linear trends mirrored angular trends, and again, the greatest change occurred in protocol H (mean drop of 3.4 cm in relative head position). Protocol HP resulted in a mean rise of just 0.1 cm; protocol HS, a drop of 1.4 cm; and protocol HSP, a rise of 1.7 cm.

We found small changes in coronal- and transverse-plane angles (< 2°) and in mediolateral and longitudinal translations from initiation to release (< 0.7 cm). For brevity, they are not presented.

Vertical linear- and sagittal-angular excursions (maximum − minimum) during removal were larger than the static position changes described (Figure 3). On average, we noted an additional 8.0° of angular movement during the removal process compared with the change in position measurement (compare Figures 2A and 3A) and an additional 1.9 cm of translation (compare Figures 2B and 3B). Angular excursions ranged from 8.7° for protocol HP to 16.8° for protocol H (Figure 3A), and all pairwise comparisons were significant (main effect, $F_{3,105} = 27.3$; $P < .001$). Vertical linear excursions ranged from a minimum of 2.2 cm for protocol HP to 4.5 cm for protocol H (Figure 3B). Protocol HS was not different from protocol H, but all other pairwise protocol comparisons were significant (main effect, $F_{3,84} = 113.4$; $P < .001$).

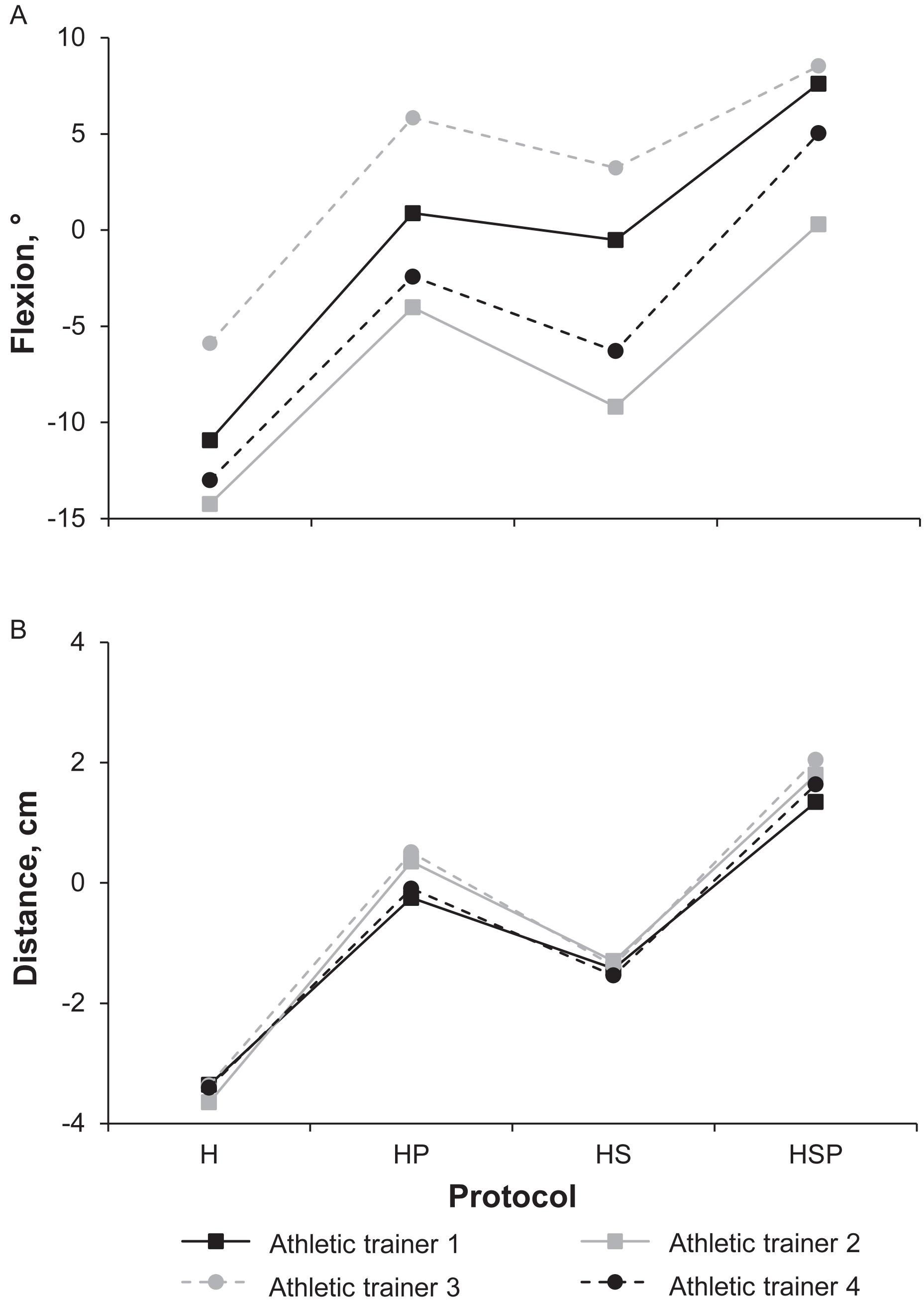

Figure 2. Mean changes in head relative to torso position between initiation and release. A, Cervical flexion (+) /extension (–). All pairwise protocol comparisons were different ($P < .008$). B, Vertical position (up [+]/down [–] relative to neutral calibration). All pairwise protocol comparisons were different ($P < .008$). We found no protocol-athletic-trainer interactions. Abbreviations: H, removal of the helmet only followed by placing the head on the ground; HP, removal of the helmet only followed by packing the area under and around the head with towels; HS, removal of the helmet and shoulder pads followed by placing the head on the ground; and HSP, removal of the helmet and shoulder pads followed by packing the area under and around the head.

Table. Protocol Values Pooled Across Athletic Trainers (Mean ± SD)[a]

	Protocol			
Variable	H	HP	HS	HSP
Angular position change, °	–11.0 ± 4.1	0.1 ± 2.3	–3.2 ± 2.9	5.4 ± 2.5
Linear position change, cm	–3.44 ± 0.36	0.13 ± 0.62	–1.41 ± 0.31	1.71 ± 0.64
Angular excursion, °	16.8 ± 3.6	8.7 ± 1.6	13.5 ± 3.6	12.5 ± 2.4
Linear excursion, cm	4.54 ± 0.32	2.16 ± 0.27	4.29 ± 0.33	3.43 ± 0.45

Abbreviations: H, removal of the helmet only followed by placing the head on the ground; HP, removal of the helmet only followed by packing the area under and around the head with towels; HS, removal of the helmet and shoulder pads followed by placing the head on the ground; HSP, removal of the helmet and shoulder pads followed by packing the area under and around the head.
[a] Indicates that all pairwise comparisons with the exception of linear excursions (H with HS) were different ($P < .008$).

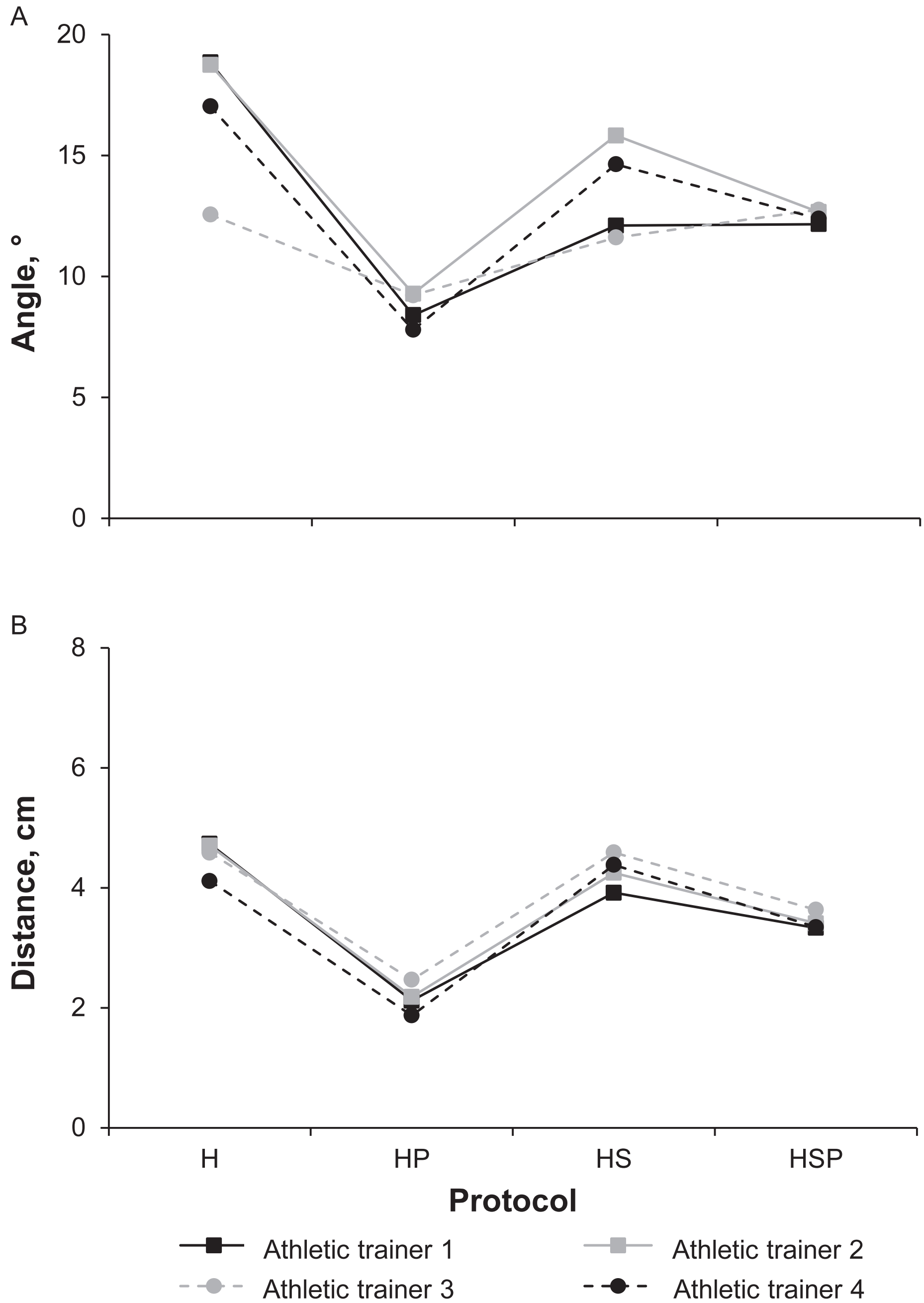

Figure 3. Total excursion throughout the removal process (maximum – minimum). A, Cervical flexion/extension excursions. All pairwise comparisons were different ($P < .008$). B, Vertical linear excursions. With the exception of the comparison between protocols H and HS, all pairwise protocol comparisons were different ($P < .008$). We found no protocol-athletic trainer interactions. Abbreviations: H, removal of the helmet only followed by placing the head on the ground; HP, removal of the helmet only followed by packing the area under and around the head with towels; HS, removal of the helmet and shoulder pads followed by placing the head on the ground; and HSP, removal of the helmet and shoulder pads followed by packing the area under and around the head.

Coronal- and transverse-plane excursions were not a major focus of the study but were included in the analysis to investigate whether any substantial out-of-plane movement was present during the removal process. A few statistical differences were noted among protocols, but for brevity, statistics are not presented. Most noteworthy for angular excursions, we found a general increase as the protocol complexity increased (ie, from protocol H to protocol HP, protocol HS, and protocol HSP), with mean coronal-plane excursions ranging from 4.1° for protocol H to 6.2° for protocol HSP and mean transverse-plane excursions ranging from 3.1° for protocol H to 4.6° for protocol HSP. No pairwise differences were noted in either plane between HP and HS. The same general increase was noted for mediolateral and longitudinal linear excursions. Mediolateral excursions ranged from 0.8 cm for protocol H to 1.1 cm for protocol HSP, whereas longitudinal excursions ranged from 1.1 for protocol H to 2.0 for protocol HSP. Significant pairwise differences in longitudinal excursions between the shoulder-pad–removal protocols (HS, HSP) and the helmet-only protocols (H, HP) were noteworthy.

DISCUSSION

In this study, we used motion-capture technology and an alternative pack-and-fill protocol to address gaps in the literature used to create the recent NATA position statement.[7] Our results supported our hypothesis that protocol HP would result in less overall motion than protocol HS, which is currently endorsed by the NATA. Using HP, the ATs were able to position the head at release in, on average, nearly the identical position as at initiation (Figure 2). This is consistent with the results of Decoster et al.[12] Protocol HS resulted in a drop in linear and angular head position, placing the cervical spine in increased extension. This linear drop was approximately equal to the difference in thickness between the helmet and shoulder pads. Perhaps most importantly, the additional motion from the actual removal process (difference between Figures 2 and 3) was greater for protocol HS than for the other 3 protocols. This appeared to be because the AT could not stabilize the head and neck to anticipate or compensate for the sudden torso drop when the shoulder pads were removed. This resulted in increased cervical flexion or protraction immediately after shoulder-pad removal, followed by a large angular and linear excursion to position the head in extension on the floor. In addition, a slight increase in longitudinal movement of the trunk toward the head occurred as the shoulder pads were sometimes pulled with considerable effort during removal, likely increasing cervical spine compression.

The use of motion-capture technology allowed us to track the motion of the head and torso throughout the removal process rather than relying on static analysis alone. We are aware of only one other study in which the researchers[14] evaluated cervical movement during the equipment-removal process. However, the authors did not report total excursions; they only reported values at limited, discrete points in the process. In addition, the equipment was removed with the torso elevated, which is a scenario not likely to be duplicated on the field. Although we performed our study in a laboratory setting, we attempted to duplicate on-field conditions. Beyond the need to avoid bumping or blocking cameras while reaching for towels, feedback from the ATs suggested that the laboratory conditions did not affect their ability to perform the removal protocols. The lack of a facemask may have increased the flexibility of the helmet, making it slightly easier to remove. However, the head was supported by the stabilizing AT during helmet removal, and it is unlikely that a stiffer helmet would increase vertical or lateral translations more than a minimal amount and more likely that it would increase longitudinal traction. Conversely, the torso was unsupported during shoulder-pad removal and appeared to fall unconstrained when the pads were extracted.

With motion capture, our ability to evaluate individual cervical joints or spinal cord space was limited. However, the cervical spine is a closed chain connecting the head and torso, and our conclusions were drawn by analyzing the relative angular and linear motion between these segments. Although pure rotation without linear translation can occur at the proximal end of the chain in the atlanto-occipital joint, which acts as a hinge due to the depth of the atlantal sockets,[15] the presence of translations indicates movement of the cervical vertebrae. Small translations without rotation can occur between vertebrae, primarily at the distal end of the chain (C5–7),[16] but these are extremely small compared with the translation of the head relative to the torso when the cervical chain (C1–7) moves collectively in the sagittal plane (ie, cervical spine flexion-extension). We did not attempt to statistically analyze differences among the limited number of ATs, but the separated but parallel lines in the angular variables suggested small variations in atlanto-occipital manipulation by each AT (Figures 2A and 3A). Conversely, the extremely consistent and nearly identical linear variables suggested that these measures were relatively unaffected by the AT.

Application

Our results can be applied directly to current clinical management. Ideally, in the prehospital setting, the cervical spine should be immobilized in its neutral position to prepare the patient for transport to the emergency department.[7] Exceptions to manual realignment include the following: movement causes pain to the patient, neurologic symptoms arise, movement could jeopardize the patient's airway, performing the movement is too difficult, or the patient is uncomfortable or resists.[7] Maintaining the spine in a neutral position provides the maximal amount of space within the vertebral foramen, protecting the injured cervical spine from unnecessary additional trauma and reducing the likelihood of secondary injuries.[11] Anatomically, when the cervical spine is flexed, the dorsal sagittal space available for the spinal cord is widened, the ventral sagittal space available for the spinal cord is decreased, and the overall size of the spinal cord space is decreased due to a change in shape.[17] Conversely, in extension, the ventral sagittal space increases and the dorsal sagittal space decreases in size, again resulting in a decrease in spinal cord space. When the spinal cord space decreases in flexion or extension, the chance of injury to the facet joints, discs, and spinal cord is greater.[18,19]

In an equipment-laden athlete, Tierney et al[11] suggested that immobilization with equipment intact provides the best chance for a neutral alignment (eg, the head is elevated slightly more than the torso). We also do not advocate the unnecessary removal of protective equipment. However, in many cases, helmets and shoulder pads can impede ATs from providing sufficient on-field care.[20] If the helmet alone is removed and the head is placed in extension on the ground or spine board, cervical lordosis and spinal cord space decrease.[21,22] Gastel et al[20] reported a 10° decrease in lordosis in a helmet-only condition contrasted with a 14° increase in lordosis with a shoulder-pad–only condition. In our study, protocol H resulted in an average 11° increase in extension (Figure 3A) and a 4-cm drop in head position (Figure 3B), values that were larger than that for any other protocol. This supports the NATA's position of discouraging this practice in American football. With protocol HS, we noted a smaller 3° increase in extension and a 2-cm drop in head position; yet, total excursion throughout the removal process increased to 13° and 4 cm and was not statistically different from that of protocol H. Although the NATA position statement[7] suggested using fillers when the shoulder pads cannot be removed easily, our findings suggest that shoulder-pad removal may rarely be performed without extraneous movement in an athlete lying supine. Applying protocol HP was a substantial improvement in limiting head movement during the removal process (approximately 5° less angular movement and 2 cm less linear movement than protocol HS) and in maintaining a more neutral position.

In this study, we focused specifically on American football players, and the applicability of the results to other sports will likely depend on the specific equipment used.[21] Our methods may be applied to future research on sport-specific or manufacturer- or model-specific equipment to assess the potential benefits of the pack-and-fill method with other protective athletic equipment. Another future direction is investigation of the different segments of the entire treatment process from initial assessment through spine boarding. The recent modification of the traditional first-responder protocol of airway, breathing, and circulation to circulation, airway, and breathing[23] directly affects the sequence of care rendered to an athlete with a potential cervical spine injury. This new protocol changes the prioritization of the specific care rendered and, in turn, may lead to further research related to minimizing cervical spine movement for the prehospital care of the athlete with a spine injury.

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