A Comparison of Cervical Spine Motion After Immobilization With a Traditional Spine Board and Full-Body Vacuum-Mattress Splint

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Background: The National Athletic Trainers' Association (NATA) advocates for cervical spine immobilization on a rigid board or vacuum splint and for removal of athletic equipment before transfer to an emergency medical facility.

Purpose: To (1) compare triplanar cervical spine motion using motion capture between a traditional rigid spine board and a full-body vacuum splint in equipped and unequipped athletes, (2) assess cervical spine motion during the removal of a football helmet and shoulder pads, and (3) evaluate the effect of body mass on cervical spine motion.

Study Design: Controlled laboratory study.

Methods: Twenty healthy male participants volunteered for this study to examine the influence of immobilization type and presence of equipment on triplanar angular cervical spine motion. Three-dimensional cervical spine kinematics was measured using an electromagnetic motion analysis system. Independent variables included testing condition (static lift and hold, 30° tilt, transfer, equipment removal), immobilization type (rigid, vacuum-mattress), and equipment (on, off). Peak sagittal-, frontal-, and transverse-plane angular motions were the primary outcome measures of interest.

Results: Subjective ratings of comfort and security did not differ between immobilization types ($P > .05$). Motion between the rigid board and vacuum splint did not differ by more than 2° under any testing condition, either with or without equipment. In removing equipment, the mean peak motion ranged from 12.5° to 14.0° for the rigid spine board and from 11.4° to 15.4° for the vacuum-mattress splint, and more transverse-plane motion occurred when using the vacuum-mattress splint compared with the rigid spine board (mean difference, 0.14 deg/s [95% CI, 0.05-0.23 deg/s]; $P = .002$). In patients weighing more than 250 lb, the rigid board provided less motion in the frontal plane ($P = .027$) and sagittal plane ($P = .030$) during the tilt condition and transfer condition, respectively.

Conclusion: The current study confirms similar motion in the vacuum-mattress splint compared with the rigid backboard in varying sized equipped or nonequipped athletes. Cervical spine motion occurs when removing a football helmet and shoulder pads, at an unknown risk to the injured athlete. In athletes who weighed more than 250 lb, immobilization with the rigid board helped to reduce cervical spine motion.

Clinical Relevance: Athletic trainers and team physicians should consider immobilization of athletes who weigh more than 250 lb with a rigid board.

Keywords: cervical spine; equipment removal; immobilization; football

A catastrophic cervical spine injury occurs in 15 football participants per year at the high school and collegiate levels.[1] A 13-year epidemiology study has revealed that a majority of catastrophic spine injuries occurred during game participation and involved defensive players.[1] Most injuries involved the subaxial spine and resulted in paraplegia.[1] Because the frequency of these injuries remains high, it is important that the sports medicine physician be familiar with the appropriate acute management of these injured athletes.

After an injury, immobilization of the cervical spine is important to reduce or prevent spinal cord compression and protect the athlete's airway. The National Athletic Trainers' Association (NATA) has recommended immobilization with either a traditional spine board or a full-body immobilization device.[13] The NATA specifically mentions the use of a full-body vacuum splint to improve comfort for the immobilized athlete and reduce the irritation of bony

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prominences.[13] This recommendation was based on previous studies that have shown improved comfort and less cervical spine extension and lateral bending in a full-body vacuum splint.[3,5]

Cervical spine immobilization of a football player is complicated by the presence of a helmet, facemask, and shoulder pads. Previously, the NATA had recommended the maintenance of equipment until transport to the emergency department.[13] The rationale for deference of on-field equipment removal was based on preventing unwanted movement of the cervical spine. However, these recommendations were largely made based on inconsistent or limited-quality patient-oriented evidence.[13] A previous cadaveric study[4] and a patient study[11] showed increased cervical spine sagittal motion, documented with fluoroscopy, while removing equipment. Acceptable alignment of the cervical spine when both the helmet and shoulder pads were present provided further evidence to maintain on-field equipment.[15,16] However, the recently updated NATA consensus statement now advocates for the removal of equipment under the appropriate conditions before transfer to an emergency medical facility.[10] The NATA noted the advancement of equipment technology, expertise in removing equipment by athletic trainers, and expedited access to the athlete (specifically the chest) as rationales for early equipment removal.[10]

Because of the current recommendations of both a rigid spine board and vacuum-mattress splint in the management of a suspected cervical spine injury, the current study aimed to compare cervical spine motion between a traditional rigid spine board and a full-body vacuum splint. In light of the recommendation to remove athletic equipment in a prehospital setting, the secondary aim of this study was to investigate the influence of football equipment, and the process of equipment removal, on cervical spine motion using each immobilization type. Last, this study evaluated the influence of weight on cervical spine motion under each of the above conditions. We hypothesized that immobilization with a rigid board or vacuum splint, the presence of equipment, or weight would not influence cervical spine motion. However, we hypothesized that increased cervical spine motion would occur in removing equipment from the immobilized athlete.

METHODS

Design and Participants

Twenty healthy male participants volunteered for this crossover study to examine the influence of immobilization type and presence of equipment on triplanar angular cervical spine motion. Independent variables included testing condition (static lift and hold, 30° tilt, transfer, equipment removal), immobilization type (rigid, vacuum-mattress), and equipment (on, off). Peak sagittal-, frontal-, and transverse-plane angular motions were the primary outcome measures of interest. Secondary outcomes included perceived feelings of comfort and security during immobilization. Participants with a history of head or neck injuries were not included in this study. To maintain a representative sample of phenotypes, participants were enrolled into 4 groups based on body weight: 150-200 lb, 201-250 lb, 251-300 lb, and >300 lb. The final sample included 5 participants in each weight group. The institutional review board of the University of Virginia approved this study, and all participants provided written informed consent before enrollment.

Motion Capture

Three-dimensional cervical spine kinematics was measured using an electromagnetic motion analysis system (trakSTAR; Ascension Technology Corp) controlled by MotionMonitor software (version 8; Innovative Sports Training Inc) at a sampling rate of 144 Hz. The trakSTAR system is accurate to 1.4 mm and 0.5°.

Participant Preparation

Three electromagnetic sensors were fixed to each participant's lumbar spine (lumbar vertebrae 4/5), midsternum, and custom mouthpiece as previously described.[9] Using double-sided tape, sensors were secured using adhesive (Leukotape; Beiersdorf and Smith & Nephew Medical) to minimize aberrant motion during testing (Figure 1). The occiput of the skull, C7, and T12 were digitized to 3-dimensionally reconstruct the spine. Once digitized, participants were fit with a football helmet (Revolution; Riddell Sports Group Inc) and shoulder pads (Power; Russell Brands LLC) by experienced certified athletic trainers and immobilized to either a rigid backboard (CombiCarrierII; Hartwell Medical Corp) or vacuum-mattress splint (EVAC-U-SPLINT Vacuum Mattress; Hartwell Medical Corp) (Figure 2).

Procedures

Testing was conducted during a single study visit using both immobilization types within each weight group (Figure 3). A team of certified athletic trainers with more than 10 years of collegiate football experience (n = 2), orthopaedic sports

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Ethical approval for this study was obtained from the University of Virginia's Institutional Review Board for Health Sciences Research (FWA No. 00006183).

Figure 1. (A) Immobilization on the rigid spine board. (B) Immobilization in the vacuum splint.

Figure 2. (A) Vacuum-mattress splint and (B) rigid spine board.

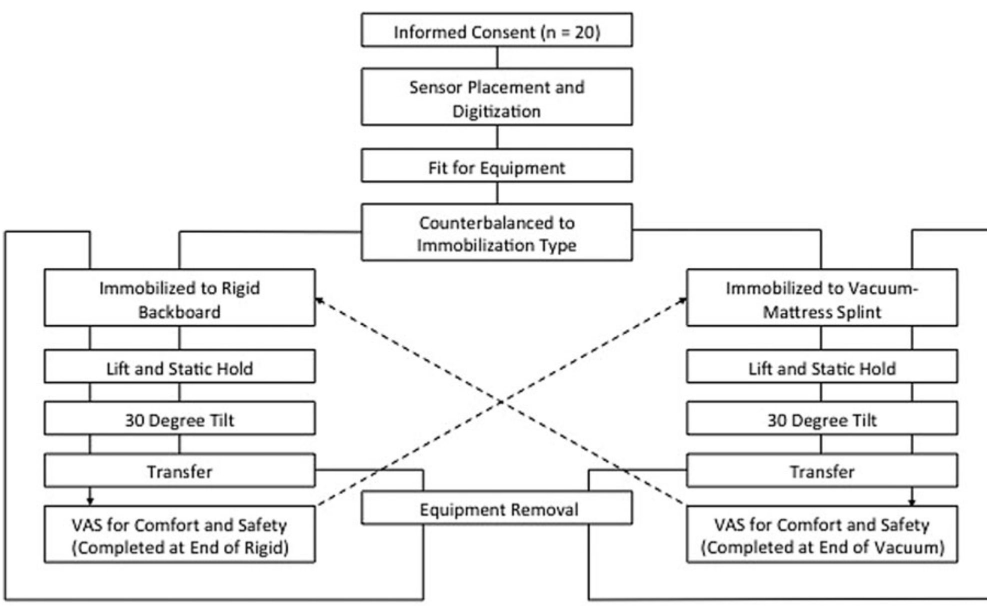

Figure 3. Flow diagram for athlete immobilization testing. VAS, visual analog scale.

medicine fellows (n = 3), and fellowship-trained sports medicine orthopaedic surgeons (n = 2) participated in all aspects of testing. Once fit for equipment and immobilized, participants were asked to relax with their arms placed at their side (vacuum-mattress) or folded over their stomach (rigid). When immobilized to the rigid backboard, foam blocks were placed on either side of the head or helmet, and tape was placed over the forehead region (of the head or helmet) and chin to provide support. When immobilized to the vacuum-mattress splint, foam blocks and tape were not used, and the splint was manually formed around the head to provide support (Figure 1).

Lift and Hold, Tilt, and Transfer Conditions

An athletic trainer was positioned behind the head (lead), with 2 additional personnel positioned on either side of the participant during the lift and static hold, 30° tilt, and transfer conditions. On the count of the lead, all personnel lifted the participant to standing height and held in place for 3 seconds (Figure 4A). The participant was then tilted to 30° side to side (relative to the ground surface) and held in place for 3 seconds. The 30° tilt test was used to simulate the possible tilt that could occur in a real-world scenario (miscommunication between staff members, stumble of a staff member, etc). Participants

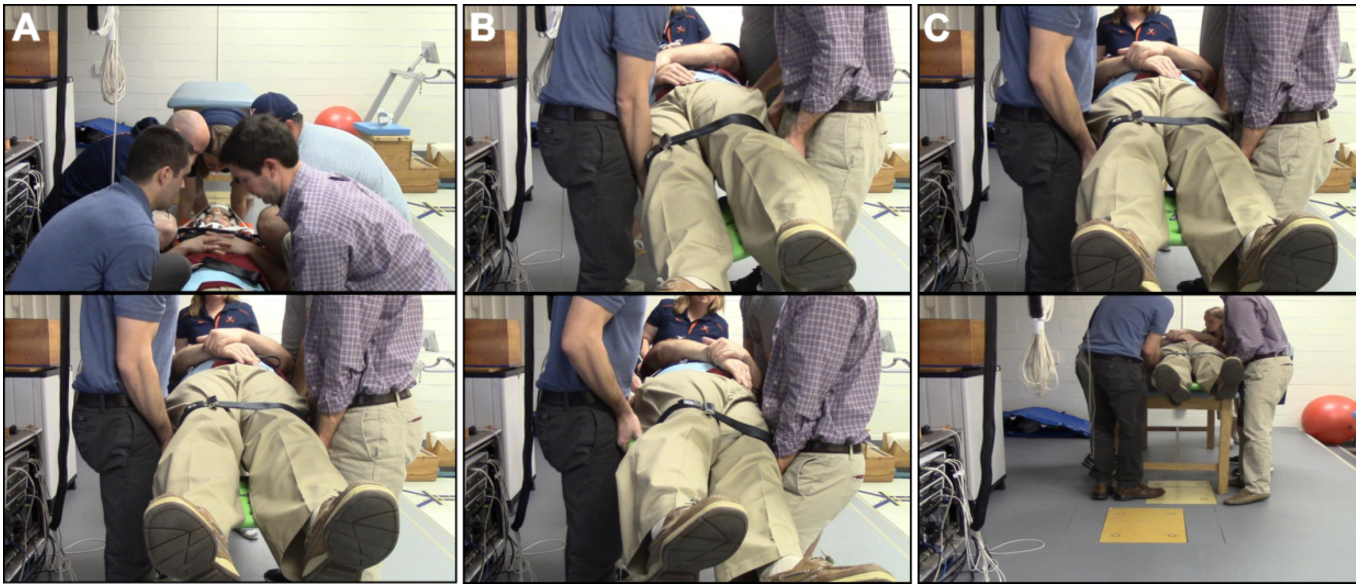

Figure 4. Demonstration of athlete testing: (A) static position (top) and lift and hold position (bottom), (B) tilt test, and (C) transfer.

were tilted in each direction, and a sixth member of the research team verified each 30° tilt using an inclinometer at the base of the rigid backboard or vacuum-mattress splint (Figure 4B). Last, the participant was transferred approximately 2 m to a padded treatment plinth (Figure 4C). Cervical spine kinematics was captured separately during the entire process for each of the above conditions. All conditions were completed in succession as a single task, and only 1 successful trial for each condition was collected and used for analysis. Once each condition was recorded with the equipment on, the process of equipment removal was recorded.

Equipment Removal

An athletic trainer was positioned behind the head to provide in-line cervical stabilization with the helmet on the participant. The facemask of the helmet was removed for all testing. Jerseys, which would have to be cut off during a real-life scenario, were not worn for testing. The second athletic trainer proceeded to cut the shoulder pads over the sternum. For the purposes of repeated testing, we secured the chest region of the shoulder pads with Leukotape between uses. Additional straps were subsequently released. The chinstrap was removed next. The orthopaedic surgeon or fellow then reached under the shoulder pads and inside the helmet to position their hands around the head and neck of the participant and maintained in-line cervical stabilization. The athletic trainer positioned behind the head then removed the helmet and shoulder pads in a cephalic manner and re-established control of the head and neck, while a rigid cervical collar was put in place. Once secured in the cervical collar, the recording was stopped. Cervical spine kinematics was captured for the entire process of removal, and only 1 trial was used for analysis. After equipment removal, participants were immobilized using the next immobilization type in the same fashion as described above.

Perceived Comfort and Security

All participants were asked to self-report their perceived level of comfort and security during all phases of testing after each immobilization type using a 10-cm visual analog scale (VAS). Higher values indicated feelings of greater comfort and security (0 = least comfortable/secure, 10 = most comfortable/secure).

Statistical Analysis

Descriptive statistics were used to quantify peak sagittal-, frontal-, and transverse-plane cervical spine kinematics for all conditions. Data were averaged over the first 10 frames recorded during the 3 seconds of data collection before the onset of each condition and used as a baseline for each individual participant. Paired t tests were used to compare cervical spine motion between immobilization types with the equipment on and off to examine the influence of immobilization type. Paired t tests were also used to compare cervical spine motion with the equipment on and off for each immobilization type separately to examine the influence of equipment. All analyses were performed within each testing condition (eg, static, tilt, transfer, removal). Cervical spine kinematics was expressed as raw (degrees) and time to peak normalized peak angular motion (deg/s) during equipment removal to assess the influence of duration of equipment removal on cervical spine motion. Cohen d effect sizes were calculated to determine the magnitude of difference in cervical spine motion using each immobilization technique during equipment removal only. A separate 1 (immobilization type) × 3 (plane of motion) analysis of variance was used to identify differences between planes of motion for each condition. Bivariate Pearson r correlation coefficients were used to examine the relationship between cervical spine motion and weight based on

TABLE 1
Participant Demographics and Perceived Level of Comfort and Security for the Rigid Backboard and Vacuum-Mattress Splint[a]

	Mean ± SD
Age, y	27.7 ± 6.6
Height, cm	187.8 ± 8.8
Weight, kg	112.7 ± 22.6
Body mass index, kg/m^2	32.0 ± 6.6
VAS score for comfort	
Rigid board	6.4 ± 1.8
Vacuum splint	6.5 ± 2.0
VAS score for security	
Rigid board	7.1 ± 2.2
Vacuum splint	7.4 ± 1.8

[a]VAS, visual analog scale.

TABLE 2
Triplanar Raw Angular Motion During Static Lift and Hold, 30° Tilt, and Table Transfer Conditions Using a Rigid Backboard and Vacuum-Mattress Splint With and Without Football Equipment[a]

	Equipment		No Equipment	
Condition	Rigid Board	Vacuum Splint	Rigid Board	Vacuum Splint
Static				
Sagittal	3.1 ± 1.8	3.2 ± 2.9	2.3 ± 1.2[b]	4.3 ± 3.4[b]
Frontal	4.2 ± 2.7	3.1 ± 1.7	3.6 ± 2.3	3.5 ± 2.1
Transverse	3.3 ± 1.4	3.1 ± 2.3	2.5 ± 1.4	3.5 ± 3.1
Tilt				
Sagittal	3.5 ± 2.1[b]	1.9 ± 0.9[b]	3.2 ± 1.1[b]	2.4 ± 1.6[b]
Frontal	4.6 ± 3.2	4.9 ± 2.5	4.9 ± 2.2	5.0 ± 2.3
Transverse	3.6 ± 2.1[b]	2.3 ± 1.7[b]	3.4 ± 2.0	2.6 ± 1.6
Transfer				
Sagittal	2.8 ± 2.5	2.7 ± 2.8	3.4 ± 3.5	3.0 ± 2.4
Frontal	1.9 ± 0.9	2.6 ± 1.5	2.3 ± 1.1[b]	3.7 ± 2.3[b]
Transverse	2.8 ± 1.4[c]	2.5 ± 1.7	1.9 ± 0.7[c]	2.5 ± 2.2

[a]Values are presented as mean ± SD in degrees. Statistically significant at $P \leq .05$.

[b]Different between rigid board versus vacuum splint (equipment and no equipment compared separately).

[c]Different between equipment versus no equipment (rigid board only).

immobilization type and presence of equipment for each condition. Cervical spine motion was further compared by immobilization type and equipment between participants who were ≤250 lb or >250 lb. The level of statistical significance was set a priori at $P \leq .05$. All statistical analyses were performed using SPSS (version 20.0; IBM Corp).

RESULTS

Participant demographics are presented in Table 1. Subjective ratings of comfort and security did not differ between immobilization types ($P > .05$).

Influence of Immobilization Type and Equipment

Results for immobilization type and equipment are presented in Table 2. In the equipped athlete, less sagittal-plane (mean difference, 1.6° [95% CI, 0.7°-2.5°]; $P = .007$) and transverse-plane (mean difference, 1.3° [95% CI, 0.3°-2.3°]; $P = .041$) cervical spine motion occurred during the 30° tilt condition only when using the vacuum-mattress splint compared with the rigid spine board. In the unequipped athlete, more sagittal-plane motion occurred during the static lift and hold condition when using the vacuum-mattress splint compared with the rigid spine board (mean difference, 2.0° [95% CI, 0.6°-3.3°]; $P = .025$), but less sagittal-plane motion occurred during the 30° tilt condition (mean difference, 0.8° [95% CI, 0.1°-1.5°]; $P = .027$). When using the rigid spine board during the transfer condition, more transverse-plane motion occurred in the equipped athlete compared with the unequipped athlete (mean difference, 0.9° [95% CI, 0.3°-0.8°]; $P = .036$).

Equipment Removal

Results for cervical spine motion observed during equipment removal are presented in Table 3. Raw cervical spine motion did not differ between immobilization types or by plane within each immobilization type (all $P > .05$). The mean peak motion that occurred ranged from 12.5° to 14.0° for the rigid spine board and from 11.4° to 15.4° for the vacuum-mattress splint. When normalized to the time taken to reach peak motion, more transverse-plane motion occurred when using the vacuum-mattress splint compared with the rigid spine board (mean difference, 0.14 deg/s [95% CI, 0.05-0.23 deg/s]; $P = .002$). The total time taken for equipment removal (58.1 ± 10.3 vs 63.9 ± 9.2 seconds, respectively; $P = .043$) and the time to peak transverse-plane motion (40.3 ± 14.1 vs 47.4 ± 10.2 seconds, respectively; $P = .050$) were shorter when using the vacuum-mattress splint compared with the rigid spine board.

Influence of Weight

In the equipped athlete, body weight was negatively correlated ($r = -0.503$, $P = .024$) with sagittal-plane motion during the 30° tilt condition when using the rigid spine board only. In the unequipped athlete on a rigid spine board, body weight was negatively correlated to frontal-plane motion ($r = -0.495$, $P = .027$) during the static lift and hold condition, sagittal-plane ($r = -0.470$, $P = .036$) and frontal-plane ($r = -0.558$, $P = .011$) motion during the 30° tilt condition, and sagittal-plane motion ($r = -0.698$, $P = .001$) during the transfer condition but positively related to transverse-plane motion ($r = 0.450$, $P = .046$) during the tilt condition. In the unequipped athlete on a vacuum-mattress splint, body weight was positively correlated with sagittal-plane motion in the static lift and hold ($r = 0.611$, $P = .004$) and transfer ($r = 0.511$, $P = .021$) conditions (Figure 5).

In athletes weighing more than 250 lb, the rigid board provided more cervical spine stability when equipment was removed. Specifically, less frontal motion (3.7° vs 5.9°,

TABLE 3
Triplanar Angular Motion During Football Equipment Removal Using a Rigid Backboard and Vacuum-Mattress Splint[a]

	Rigid Board		Vacuum Splint		
	Raw[b]	Normalized[c]	Raw[b]	Normalized[c]	Effect Size (95% CI)[d]
Sagittal	14.0 ± 7.7	0.30 ± 0.18	13.3 ± 6.1	0.31 ± 0.14	–0.1 (–0.6 to 0.4)
Frontal	12.5 ± 5.3	0.46 ± 0.45	11.4 ± 5.2	0.64 ± 0.99	–0.2 (–0.7 to 0.3)
Transverse	12.6 ± 4.9	0.28 ± 0.12[e]	15.4 ± 6.9	0.42 ± 0.22[e]	–0.7 (–1.2 to –0.1)

[a]Values are presented as mean ± SD unless otherwise specified. Statistically significant at $P \leq .05$.
[b]Raw angular motion in degrees.
[c]Angular motion normalized by time to peak motion in degrees per second (deg/s).
[d]Cohen *d* effect size with 95% CI calculated using normalized angular motion between rigid board and vacuum splint (rigid board used as control). Negative value indicates more motion under vacuum splint.
[e]Different between rigid board versus vacuum splint.

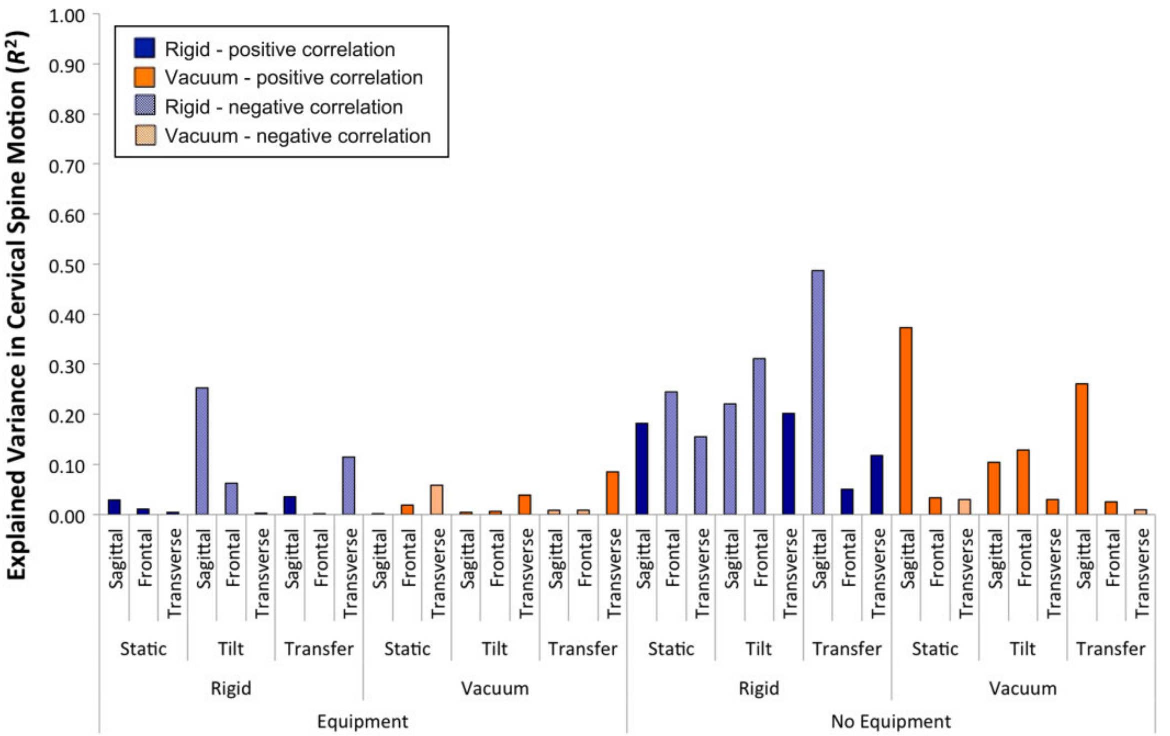

Figure 5. The effect of weight on cervical spine motion on a rigid board versus a vacuum splint.

respectively; $P = .027$) and less sagittal motion (1.6° vs 4.9°, respectively; $P = .030$) were seen with immobilization on the rigid board compared with the vacuum splint during the tilt condition and the transfer condition, respectively. Furthermore, the rigid board provided less sagittal motion compared with the vacuum splint (2.6° vs 6.3°, respectively; $P = .013$) during the static lift and hold condition.

DISCUSSION

In the current study, during immobilization with equipment, increased motion occurred in the sagittal and transverse planes when using a rigid board compared with a vacuum splint. Conversely, after equipment removal, increased motion in the sagittal and frontal planes occurred when using the vacuum splint compared with the rigid board. Previous authors[5-7] have compared rigid immobilization boards to vacuum-mattress splints. Two previous studies showed that rigid backboards and vacuum-mattress splints provided similar degrees of immobilization.[5,6] In contrast, Luscombe and Williams[7] found the vacuum splint to provide more stability. The above studies used rudimentary measuring techniques: patient alerts, flexible metal arms, rigid metal wire arms, inclinometers, and goniometers. The current study is the first to use 3-dimensional motion analysis to quantify triplanar cervical spine motion in a comparison of immobilization boards.

Despite small but significant differences in cervical spine motion between board types, neither board with an immobilized equipped or unequipped athlete had cervical spine motion greater than 5° when moved and turned in the different testing conditions. Furthermore, motion between the board types was limited to 2° or less, irrespective of equipment or testing condition. These small movements in cervical spine motion did not surpass a previous established minimal important difference: 5° of flexion and extension and 3° of lateral bending and rotation.[2,14]

Previous studies have criticized rigid immobilization for patient discomfort and perceived instability.[3,5,6] The current study showed equivocal VAS scores for comfort and security. This change in scores from the established literature can be attributed to the improved ergonomics of the modern, contoured, plastic rigid board compared with the antiquated, flat, wooden rigid board. Both the rigid board and vacuum-mattress splint provide adequate, comfortable, and clinically equal immobilization for a suspected cervical spine–injured football player.

While immobilized, cervical spine motion was limited to 5° or less, irrespective of helmet and shoulder pad equipment or rigid board or vacuum-mattress splint. However, when removing equipment, cervical spine motion ranged from 11° to 15°. An increase in transverse-plane motion was detected with the use of the vacuum-mattress splint when taking into account the time to reach peak motion. Interestingly, equipment removal took less time when using the vacuum-mattress splint than the rigid spine board. Because the time taken to complete this process differed between immobilization types, we felt that it was appropriate to normalize by time to peak motion. Despite this normalization, peak motion occurred faster in the transverse plane for the vacuum-mattress splint, which may have contributed to the observed difference between immobilization types. Motion during the removal of equipment exceeded the minimal important difference established by Swartz et al[13] and accepted by Boissy et al.[2] Previous authors[4] have noted 18° of motion by fluoroscopy while removing football equipment in an injured cadaveric model. Using motion capture, this study confirms the movement of the cervical spine during equipment removal.

It is not established what amount of movement of an injured cervical spine would lead to neurological injuries. McGuire et al[8] have noted the possibility of neurological injuries with a greater than 2-cm anterior-posterior displacement of the cervical spine. Other authors have previously established radiographic spinal instability with as little as 14° of motion.[17] However, more recent data have found greater than 20° of fluoroscopic cervical spine motion in asymptomatic patients.[12] Regardless of these radiographic parameters, the goal of cervical spine motion in the suspected injured athlete is zero. Despite the idealistic circumstances, the current study showed cervical spine motion while removing football equipment. Real-life clinical scenarios involving unqualified health care professionals attempting to remove equipment could lead to unwanted neurological sequelae. Sports medicine physicians and athletic trainers should continue to lead the process of equipment removal. Their expertise in protecting the cervical spine–injured athlete cannot be overstated. Additional research is needed to specify a clinical threshold of cervical spine movement in the immobilized athlete.

This is the first study to evaluate the effect of weight on cervical spine motion during simulated cervical spine immobilization and transfer. The correlations in Figure 5 confirm the importance of considering the weight of the athlete and the presence of equipment when choosing the immobilization type. In general, patients with a greater weight had less movement on the rigid board compared with the vacuum splint. Specifically, heavier, unequipped athletes experienced less cervical spine motion when immobilized to a rigid backboard (sagittal, frontal, and transverse planes). Furthermore, the presence of equipment protected against movement in both the rigid board and vacuum splint. We postulate that the equipment may normalize the body mass by distributing the mass over a fixed surface. When athletes weighing over 250 lb were analyzed, the vacuum splint allowed motion greater than the 5° clinical threshold, whereas the rigid board reduced cervical spine motion to within the 5° threshold.

Limitations

The current study is not without limitations. Cervical spine motion was captured in a healthy, noninjured athlete. The conditions of the experiment were in a controlled environment without distractions. Real-life clinical scenarios could show increased cervical spine motion. As the spine-boarded athletes in our study did not suffer a cervical spine injury, the involuntary contracture of the paraspinal musculature in the tested participants could have led to an underestimation of cervical spine motion. Furthermore, testing was only performed on male football players. These data may not be applicable to other helmeted athletes (hockey, lacrosse, etc) or female athletes. Nevertheless, we believe that the current study supports the use of a rigid board or vacuum-mattress splint in the immobilized football player.

CONCLUSION

The current study confirms the statistically significant but clinically insignificant motion with the vacuum-mattress splint compared with the rigid backboard in varying sized, equipped, or unequipped athletes. Significant cervical spine motion occurs when removing a football helmet and shoulder pads, at an unknown risk to the injured athlete. Qualified health care providers such as certified athletic trainers and team physicians should be intimately involved in equipment removal. In immobilized athletes with a weight greater than 250 lb, immobilization with the rigid board with equipment present helped to reduce cervical spine motion compared with the vacuum-mattress splint.

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