Journal of Athletic Training 2002;37(3):246–251

www.journalofathletictraining.org

Removal Tools are Faster and Produce Less Force and Torque on the Helmet Than Cutting Tools During Face-Mask Retraction

Heather L. Jenkins*; Tamara C. Valovich†; Brent L. Arnold‡; Bruce M. Gansneder§

*University of Richmond, Richmond, VA; †Arizona School of Health Sciences, Mesa, AZ; ‡Virginia Commonwealth University, Richmond, VA; §University of Virginia, Charlottesville, VA

Heather L. Jenkins and Tamara C. Valovich, MS, ATC, CSCS, contributed to conception and design; acquisition and analysis and interpretation of the data; and drafting, critical revision, and final approval of the article. Brent L. Arnold, PhD, ATC, contributed to conception and design; analysis and interpretation of the data; and drafting, critical revision, and final approval of the article. Bruce M. Gansneder, PhD, contributed to analysis and interpretation of the data and critical revisions and final approval of the article.

Address correspondence to Tamara C. Valovich, MS, ATC, CSCS, Department of Sports Health Care, Arizona School of Health Sciences, 5850 E. Still Circle, Mesa, AZ 85206. Address e-mail to tvalovich@ashs.edu.

Objective: To investigate the retraction time, forces, and torques applied to the football helmet during removal of the face mask with different face-mask removal tools.

Design and Setting: Subjects retracted the face mask of a football helmet mounted to a force platform in a laboratory setting. They removed a standard face mask by cutting or removing (or both) the lateral plastic loop straps using 4 different tools: the Trainer's Angel (TA), FM Extractor (FM), power screwdriver (SD), and Quick Release System (QR) in a counterbalanced fashion.

Subjects: Eighteen certified athletic trainers participated in this study.

Measurements: We started measuring time when the subject picked up the tool and ended when the face mask was in a fully retracted position. Maximum forces and torques were measured from the force platform during the retraction process.

Results: The SD and QR retracted the face mask significantly faster than the TA and FM. Forces producing superior-inferior translation were least with the SD. The SD and QR produced less lateral translation and rotation and lateral flexion moment than the TA and FM. The FM produced less torque in the lateral flexion moment than the TA.

Conclusions: Tools that removed the loop straps (SD, QR) were faster and produced less force and torque on the helmet than the tools that cut through the loop straps (TA, FM).

Key Words: cervical spine injury, loop straps, equipment removal

One of the most critical situations certified athletic trainers (ATCs) face today is managing a football player with a suspected cervical spine injury. Currently, football is responsible for the largest number of cervical spine injuries in athletics.[1] Also, the skills that are required in the sport, such as tackling, can place the neck in a vulnerable position for injury if not performed correctly.[2] For example, forces that place the neck in an axial loaded position have been found to cause catastrophic cervical spine injury.[3–6]

The current standard of practice in managing a football athlete with a possible spinal injury, as recommended by the Inter-Association Task Force for Appropriate Care of the Spine-Injured Athlete, is to first stabilize the head and neck, then gain access to the victim's airway.[7,8] In-line stabilization is extremely important to prevent further injury to the spinal cord. Currently, the degree of head movement needed to result in neurologic deficit with a spinal injury is unknown. However, it is estimated that as little as 1 to 2 mm of helmet displacement reduces the amount of space for the spinal cord in the spinal canal, possibly damaging the cord itself.[9] Because 25% of spinal injuries with neurologic deficit were caused by improper handling of the victim during transport, the goal for the ATC should be to limit motion as much as possible during the immobilization process.[7,10,11]

After the athlete's head and neck have been stabilized, the rescuer should gain access to the victim's airway by removing the face mask from the helmet. The plastic loop straps that attach the face mask to the helmet can be cut with a sharp instrument or removed by unscrewing the screws that holds the straps in place. In either case, the task should be performed quickly and with little jarring of the head to decrease the risk for further injury.[12–14]

Tools such as a Trainer's Angel ([TA], Trainer's Angel, Riverside, CA), a power screwdriver (SD), and an FM Extractor ([FM], Sports Medicine Concepts, Geneseo, NY) have been examined for their effectiveness in face-mask removal. The TA was the first tool specifically designed to cut through the plastic loop straps that attach the face mask to the helmet.[12] In previous research, the TA has been found to remove the plastic loop straps significantly faster than a manual screwdriver and an anvil pruner.[12,14] Although the TA allowed fast access to the victim's airway, it was associated with significantly more helmet movement than the other tools tested.[12,14]

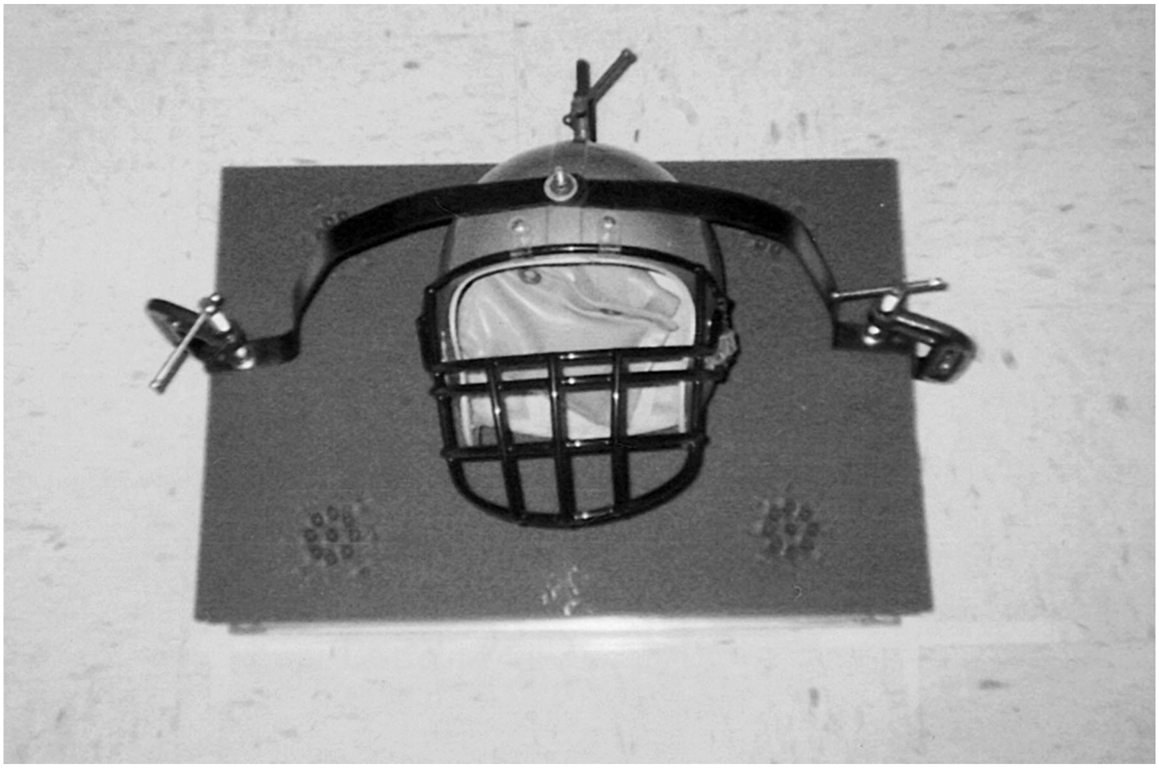

Figure 1. The helmet mounted on the forceplate.

The clips are attached to the helmet with a T-bolt, washer, and screw; therefore, manual and power screwdrivers have also been used for face-mask removal. However, manual screwdrivers take significantly longer to use,[12,14] and at times, the bolt inside the helmet turns without loosening the screw, rendering the screwdriver ineffective.[12,13]

In recent years, new tools have come onto the market for the purpose of face-mask removal, such as the FM and the Quick Release System ([QR], Jo Silken, ATC, San Mateo, CA). The FM is a tool that cuts through the fastener between the loop strap and the fixed screw end of the plastic clip. It also has features that enable the face mask to be used as a lever to aid in the cutting process. The QR is another innovative face-mask removal device. It uses a spring-loaded nut-and-bolt system to secure the loop strap onto the helmet. With this system, only a flat-head screwdriver is needed to turn the screw that attaches the face mask to the helmet. With just a quarter turn, the spring-loaded system releases and the entire loop strap can be removed, leaving the face mask unattached to the helmet and easily removed or retracted.

Most previous research on the effectiveness of face-mask removal tools measured the time taken for removal and retraction of the face mask. Few investigators have attempted to study the motion of the helmet during the removal process.[12,15] The purpose of our study was to investigate the effectiveness of 4 face-mask removal tools (TA, SD [Craftsman, Sears, Hoffman Estates, IL], FM, and QR) on the time required for retraction and the forces and torques applied to the helmet during retraction of the face mask. We hypothesized that the QR and SD would retract the face mask in a shorter period of time and with less force and torque applied to the helmet.

METHODS

Subjects

Eighteen athletic trainers certified by the National Athletic Trainers' Association Board of Certification (age = 24.6 ± 2.4 years old [range, 22–32 years], 2.1 ± 2.3 years certified [range, 0.42–9.2 years], 2.6 ± 2.3 years of football experience [range, 0–10 years]) volunteered to participate in this study. All subjects read and signed an informed consent approved by the university institutional review board (which also approved the study) before participating.

Instrumentation

The face-mask removal tools in this investigation included the TA, SD, FM, and QR. A flat-head screwdriver was used in conjunction with the QR. A Bertec force platform (Bertec Corp, Columbus, OH) and the DataPac 2000 (Run Technologies, Laguna Hills, CA) were used for collection of the force and torque data.

In the testing area, a standard football helmet was mounted onto a force platform. This was accomplished by bolting 3 brackets to the helmet (Figure 1). Two brackets were attached to each side of the helmet and ran laterally, and the third bracket was attached to the posterior aspect of the helmet's crown and ran posteriorly to the force platform. These brackets were then attached to the force platform using standard C clamps. The C clamps were applied with a firm force to prevent slippage. In addition, the clamps were standardized and tightened to the same level for each participant. A cuff weight of 3.4 kg (7.5 lbs), the approximate weight of an adult head,

Time, Force, and Torque Means (±SDs) for Each Tool*

	Trainer's Angel	FM Extractor	Power Screwdriver	Quick Release System
Time (s)	98.6 ± 50.5	71.74 ± 28.8	34.1 ± 7.9	20.9 ± 9.0
Force (N)				
Superior-inferior translation	76.9 ± 17.3	47.11 ± 27.9	24.7 ± 28.1	38.2 ± 57.8
Lateral translation	64.1 ± 17.1	57.34 ± 19.4	30.5 ± 14.4	36.2 ± 17.3
Anterior-posterior translation	135.6 ± 102.2	180.98 ± 152.2	95.5 ± 112.5	137.8 ± 222.8
Torque (Nm)				
Rotation moment	7.2 ± 4.3	5.93 ± 7.1	0.65 ± 1.02	1.9 ± 2.3
Flexion-extension moment	18.0 ± 18.6	22.02 ± 22.3	12.4 ± 15.9	16.7 ± 29.4
Lateral-flexion moment	12.4 ± 4.1	9.40 ± 3.9	4.3 ± 2.7	4.1 ± 1.8

SD indicates standard deviation; s, seconds; N, Newtons; and Nm, Newton-meters.

was placed in the helmet once it was secured to the platform. The forceplate was then zeroed before each trial so that the only forces being measured were from movement associated with retraction of the face mask.

Procedures

The subjects first attended a short training session in which they were verbally and visually instructed in how to use each of the face-mask removal tools according to the manufacturer's guidelines through a standard lecture and demonstration. Subjects were then given 10 minutes to familiarize themselves with each tool and complete face-mask retractions until they were satisfied that they understood how the tool worked and how to retract the face mask under each condition. After the practice time, subjects were individually escorted to the testing area.

When the subject entered the testing area, the testing procedure was explained. The subject was instructed to retract the face mask by cutting or removing (or both) the 2 lateral loop straps (Bike Athletic Co, Knoxville, TN) and retracting the face mask using the anterior fasteners as a hinge. The subject was told to retract the face mask quickly and with as little movement as possible.

One of the 4 face-mask removal tools was then placed on the floor next to the force platform. Time began when the subject first touched the tool and ended when the face mask was in a fully retracted position. The timing device was activated manually by one of the investigators (H.L.J.). After the subject retracted the face mask, one of the researchers (H.L.J.) fit the helmet with new fasteners, and the procedure was repeated until the subject performed the task 8 times (twice with each tool). The order of tools was counterbalanced.

Data Analysis

Time. Time was recorded on the DataPac 2000 from the moment the subject picked up the tool until the face mask was in a fully retracted position.

Forces and Torques. All force and torque data were analyzed and interpreted with the assumption that the motion of the helmet would translate to the motion of the head. However, it should be emphasized that in field situations, not all torques may be transferred to the head due to some shift in the fit of the helmet on the athlete's head. Raw data from the force platform were transferred to the Data Pac program and analyzed using the DataPac 2000 software. We set an event for the entire length of the trial, and the raw output was processed into Newtons and Newton-meters using the calibration matrix of our force platform. The calibration matrix was used to calculate the appropriate gain value to convert raw voltage signals from the forceplate to the appropriate Newtons of force and Newton-meters of torque. The absolute maximum values for 3 forces (superior-inferior, lateral, and anterior-posterior) and for torques producing a rotational, flexion-extension, or lateral-flexion moment were recorded. The absolute maximum value was chosen as the largest amount of force or moment applied during that trial. Torque values were adjusted from the raw torque values to account for the torque's being applied to the center of the helmet, not the center of the forceplate. The center of rotation for the helmet was measured at 13.75 cm above the center of the forceplate, in line with the ear holes of the football helmet, where the axis of rotation of the cervical spine would lie. The maximum values for the 2 trials of each tool were averaged to determine the force and torque applied with each tool.

Statistical Analysis. All statistical analyses were performed with Statistical Package for the Social Sciences software (version 10.0, SPSS Inc, Chicago, IL). We used a multivariate analysis of variance to analyze differences among tools for time, the 3 forces, and the 3 torques. Univariate, repeated-measures analysis of variance was then calculated for time, force (superior-inferior, lateral, and anterior-posterior), and torque (rotational, flexion-extension, and lateral-flexion moment) to determine significant differences among the 4 tools. Significant differences were investigated further using the Tukey Honestly Significant Difference test. Alpha was set a priori at .05.

RESULTS

Means and standard deviations for time, forces, and moments are presented in the Table. Results of the multivariate analysis of variance demonstrated significant differences among the dependent measures ($F_{21,129.8} = 7.06$, $P = .0001$, $\beta = 1.0$). Violations of assumed sphericity were found for all measures, except for forces producing lateral translation. This violation of assumed sphericity indicates that our samples demonstrated unequal variances and unequal correlations, which can make the results of the F test seem somewhat liberal.[16] It is for this reason that we report the F values associated with the Huynh-Feldt test, an adjustment to more accurately reflect the P value, with the exception of the lateral force.

Time

The univariate analysis for time ($F_{3,51} = 36.12$, $P = .0001$, $\beta = 1.0$) and a subsequent Tukey analysis revealed signifi-

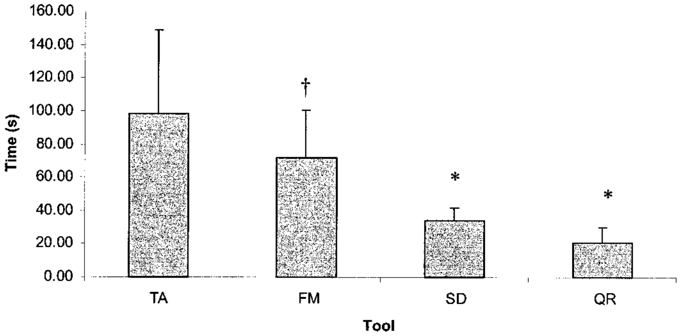

Figure 2. Mean time, in seconds, for removal of the face mask with the 4 tools. TA indicates Trainer's Angel; FM, FM Extractor; SD, screwdriver; and QR, Quick Release System. Error bars represent standard deviations. *SD and QR took significantly less time than TA and FM. †FM took significantly less time than TA ($P < .05$).

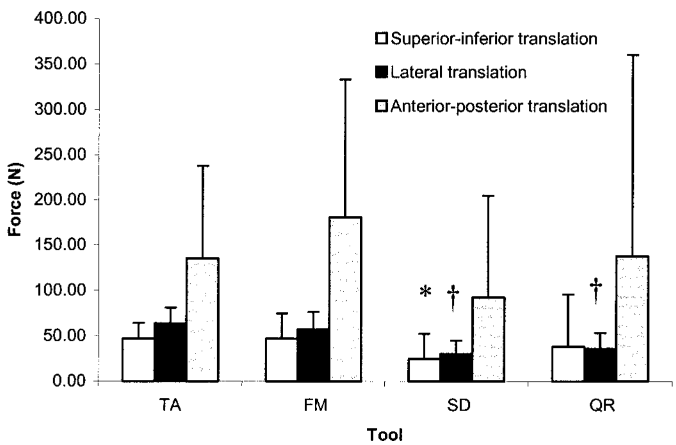

Figure 3. Mean force, in Newtons, applied to the helmet during removal with the 4 tools. TA indicates Trainer's Angel; FM, FM Extractor; SD, screwdriver; and QR, Quick Release System. Error bars represent standard deviations. *SD produced significantly less force than TA and FM. †SD and QR produced significantly less force than TA and FM ($P < .05$).

cantly faster removal times for the SD compared with the TA and FM, the QR compared with the TA and FM, and the FM compared with the TA (Figure 2).

Forces

Significant main effects were found for superior-inferior force ($F_{3,51}$ = 3.576, P = .02, β = .76) and lateral force ($F_{3,51}$ = 32.04, P = .0001, β = 1.0) (Figure 3). On post hoc analysis, we found that the SD produced less superior-inferior force than the TA and FM and that the SD and QR produced less lateral force than both the TA and FM. No differences were found among the various tools in producing anterior-posterior force ($F_{3,51}$ = 2.79, P = .069, β = .64).

Moments

Figure 4 illustrates the significant main effects for the rotation moment ($F_{3,51}$ = 10.79, P = .0001, β = .99) and lateral-flexion moment ($F_{3,51}$ = 34.05, P = .0001, β = 1.0). Post hoc analysis for the rotational moments showed that the SD produced significantly less torque than the TA and FM, and the QR produced significantly less torque than the TA and

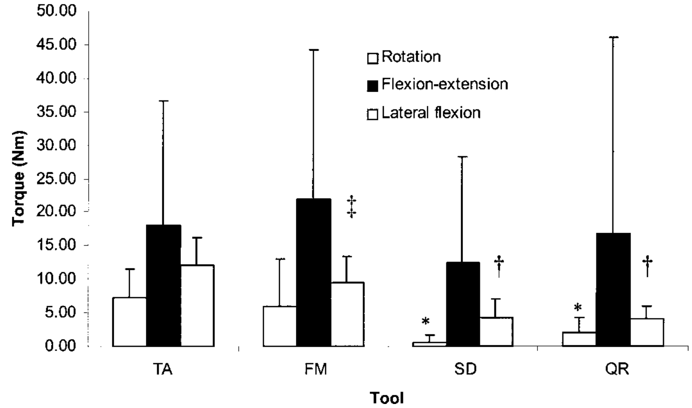

Figure 4. Mean torque, in Newton-meters, applied to the helmet during removal with the 4 tools. Error bars represent standard deviations. TA indicates Trainer's Angel; FM, FM Extractor; SD, screwdriver; and QR, Quick Release System. *SD and QR produced less torque than TA and FM. †SD and QR produced significantly less torque than TA and FM. ‡FM produced significantly less torque than TA ($P < .05$).

FM. The post hoc analysis for the lateral-flexion moment revealed that less torque was produced by the SD compared with the TA and FM, the QR compared with the TA and FM, and the FM compared with the TA. No differences were found among tools for the torque produced in the flexion-extension moment ($F_{3,51}$ = 2.23, P = .117, β =. 45).

DISCUSSION

In general, face-mask retraction techniques have not been the subject of a great deal of research; however, this is the area in which ATCs need to be the most proficient and have the best tools available in order to effectively care for a cervical spine–injured athlete. Therefore, the purpose of our study was to evaluate several means of face-mask retraction, both newly developed and previously tested, to determine which retracted the face mask the fastest and with minimal force applied to the head. The SD and QR generally allowed for faster retraction of the face mask with less force and torque applied to the helmet than the cutting tools, TA and FM.

Previous Research

It was difficult for us to compare our results with those of previous researchers because 2 of our 4 tools (SD and QR) had not yet been examined for time of removal, and 3 of our tools (QR, SD, FM) had not yet been examined in terms of force or torque. However, our results tend to agree with previous findings (ie, that the SD is faster[15] and produces less head motion than tools that cut through the loop strap).[12,15]

Removing the plastic loop strap completely via the SD or QR was quicker and produced significantly less force and torque than the cutting tools. Our findings support previous results in which the manual screwdriver produced less head movement but took the same amount of time for removal as the TA.[12] Similarly, Ray et al[14] found that neither the manual nor power screwdriver provided a clear advantage in speed or movement. Motion analysis of head movement while using the TA, SD, and anvil pruner demonstrated that the SD took significantly less time (36.6 seconds) to remove the mask than the anvil pruner (77.95 seconds) and the TA (84.4 seconds).[15]

In addition, head motion produced by the SD (2.35°) was significantly less than that produced by the anvil pruner (3.01°) and the TA (3.31°). Therefore, our results support previous findings that the SD can be effective in removing the face mask more quickly and with less application of force compared with cutting tools. However, one must be aware of the potential limitations of the effectiveness of the SD. Our observations were consistent with previous findings that the T-bolt spun instead of the screw.[12–14] If this occurs, the SD is ineffective, and the face mask must be removed by another tool. If no other tool is available, the helmet must be removed, exposing the athlete to an increased risk of further injury due to head and cervical spine motion. We found an 8% incidence of screw spinning, similar to the 7% incidence reported by Knox and Kleiner.[12] Although Ray et al[14] did not mention the specific incidence of spinning in their investigation, they did report spinning, which should be a concern for those using the SD as the primary removal tool. Overall, we agree with the past literature and the Inter-Association Task Force for Appropriate Care of the Spine-Injured Athlete that the SD should not be used as the primary means of face-mask retraction or removal.[7]

Recent investigators have examined the FM to determine the amount of time required for face-mask removal. Three different methods suggested by the manufacturer of the FM, to retract the face mask by resting the semicircular notch on top of the face-mask bar, locking the semicircular notch onto the face-mask bar, and placing each end of the tool on the loop strap, demonstrated time intervals of 98.94, 109.55, and 135.23 seconds, respectively.[17] Another recent investigation compared the FM with the TA and anvil pruner and found the anvil pruner to be a faster removal tool (32.04 seconds) than both the TA (75.91 seconds) and FM (63.10 seconds). The latter 2 tools did not differ significantly from one another.[18]

The QR seems to be a promising new method of attaching the face mask to the helmet and was found effective in the face-mask retraction process. This device enabled subjects to remove the face mask significantly faster than the TA and FM and with less lateral translation and rotational and lateral-flexion moment.

Forces and Moments

One unique aspect of our study was the measurement of the forces applied to the helmet and the torques created about the axes of motion during the removal process. These measurements are important to our understanding of the face-mask removal process and in the clinical practice of removing the loop straps and retracting the face mask. We noted several trends in our force and torque data. For all 4 tools, greater forces were applied in the anterior-posterior direction (directly down into the forceplate) than forces applied in either the superior-inferior or medial-lateral directions. Additionally, the moments about the flexion-extension axis were greater for all 4 tools than the moments about the rotational or lateral-flexion axes. These findings agree when we consider the location of the loop straps on the helmet. The loop straps are located anterior to the medial-lateral axis of the head, and as one pushes harder into the forceplate (anterior-posterior translation), a larger torque about the flexion-extension moment should be created. These results indicate that the ATC providing cervical stabilization of a suspected spine-injured athlete should be aware of greater torque and possible motion about the flexion-extension axis.

In general, the use of the SD was associated with the least amount of force and moment about all 3 axes, demonstrating less potential movement of the helmet. However, one must consider the SD's limitations as previously described and in the recommendations of the Inter-Association Task Force.[7]

Limitations

Our study differed in several ways from past research, which could have limited the validity of our results. By using the data from the force platform, we were able to analyze the maximal forces and torques applied to the helmet. However, it is unclear how these correlate with the actual head and spinal movements of an athlete. How much the clinician can move the head and not cause further injury to the athlete is currently unknown. Therefore, it is recommended that any movement of the head and cervical spine be minimal. No conclusions can be drawn as to whether these values represent a safe removal process.

A second potential limitation was that there was no live model occupying the testing helmet. This created a system lacking the counterstability of bony and soft tissue neck anatomy. Without these natural restraints, the subjects might have moved the helmet more than if an actual person was wearing the helmet. This design could have also affected the subjects' mindset during the testing procedure. Without a human model, the subjects may have been more inclined to use greater force with the tool than if they were in an actual injury situation. This is especially the case with the cutting tools, TA and FM, and may explain why these tools had such elevated force and torque values compared with the SD and QR.

The final limitation to our study deals with the design of the modified testing helmet that was used in the procedure. In order to attach the helmet to the force platform, 3 brackets were bolted to the helmet (2 laterally and 1 posteriorly). We used this design to standardize the stabilization of the helmet, both within and between subjects, by using clamps tightened the same amount throughout the study. However, because of the alignment of one of the lateral brackets, 2 subjects did not have direct access to one of the face-mask loop straps. This limitation affected their use of the TA during the testing procedure in that these subjects had to make several attempts to cut the strap with the TA. This limitation could account for the longer time to remove the loop straps with the TA.

Clinical Relevance

A great deal more research is needed in the area of football face-mask removal to determine which tool is the most helpful to the athletic trainer in this critical situation. Overall, we feel that this study adds new insight into the forces and torques applied to the helmet during retraction of the face mask with various means. We also feel that it potentially establishes a new method of attaching the face mask to the helmet (ie, Quick Release System). However, we should emphasize that the Quick Release System is a prototype device and, as currently designed, may not represent a final marketable product. Despite this, we believe that the design has merits because it was easy to install and easy to operate, requiring only a screwdriver. Our results suggest that, indeed, this is the case, and that new alternative designs to face-mask retraction and removal are worth considering. This device performed as well as, or better than, the other standard face-mask removal devices with respect to time, force, and torque. Even though the Quick Release System and power screwdriver produced similar results in the measures we collected, the Quick Release System did not have any factors that limited its effectiveness, such as the spinning that occurred with the screwdriver.

Also of concern for the ATC are the directions of the greatest force and moment found in our study. Regardless of the tool used to retract the face mask, the largest force was in the anterior-posterior direction and the largest torque was along the flexion-extension moment. The ATC responsible for stabilizing the injured athlete needs to be aware of the potential for these large forces and moments and stabilize accordingly.

ACKNOWLEDGMENTS

We thank Jo Silken, ATC, for donating the Quick Release System; the Riddell Corporation (Elyria, OH) for the donation of the loop straps; and the Building and Grounds Department at Virginia Military Institute (Lexington, VA) for help with construction of the helmet-mounting brackets. We also thank Sara E. Wilson, PhD, for her help with the analysis and conversion of the torque data.

REFERENCES

1. Bailes JE, Hadley MN, Quigley MR, Sonntag VK, Cerullo LJ. Management of athletic injuries of the cervical spine and spinal cord. *Neurosurgery.* 1991;29:491–497.
2. Mueller FO. Fatalities from head and cervical spine injuries occurring in tackle football: 50 years' experience. *Clin Sports Med.* 1998;17:169–182.
3. Albright JA. Cervical spine injuries in football. *Conn Med.* 1976;40:677–679.
4. Bailes JE, Maroon JC. Management of cervical spine injuries in athletes. *Clin Sports Med.* 1989;8:43–58.
5. Torg JS. Epidemiology, pathomechanics, and prevention of athletic injuries to the cervical spine. *Med Sci Sports Exerc.* 1985;17:295–303.
6. Torg JS, Vegso JJ, O'Neill MJ, Sennett B. The epidemiologic, pathologic, biomechanical, and cinematographic analysis of football-induced cervical spine trauma. *Am J Sports Med.* 1990;18:50–57.
7. Inter-Association Task Force for Appropriate Care of the Spine-Injured Athlete. *Prehospital Care of the Spine-Injured Athlete.* Dallas, TX: National Athletic Trainers' Association; 2001.
8. Denegar CR, Saliba E. On the field management of the potentially cervical spine injured football player. *Athl Train J Natl Athl Train Assoc.* 1989;24:108–111.
9. American Academy of Orthopaedic Surgeons. *Emergency Care and Transportation of the Sick and Injured.* 7th ed. Boston, MA: Jones and Bartlett; 1999:706–709.
10. Cloward RB. Acute cervical spine injuries. *Clin Symp.* 1980;32:1–32.
11. Riggins RS, Kraus JF. The rise of neurologic damage with fractures of the vertebrae. *J Trauma.* 1977;17:126–133.
12. Knox KE, Kleiner DM. The efficiency of tools used to retract a football helmet face mask. *J Athl Train.* 1997;32:211–215.
13. Putman LA. Alternative methods for football helmet face mask removal. *J Athl Train.* 1992;27:170–172.
14. Ray R, Luchies C, Baxuin D, Farrell RN. Airway preparation techniques for the cervical spine-injured football player. *J Athl Train.* 1995;30:217–221.
15. Surace AF, Goldfuss AJ, Hauth JM, Wagner LE. Effect of selected tools on face mask removal time and head motion [abstract]. *J Athl Train.* 2000;35:S62.
16. Glass GV, Hopkins KD. *Statistical Methods in Education and Psychology.* 3rd ed. Needham Heights, MA: Simon and Schuster Co; 1996.
17. Angotti DD, Hoenshel RW, Kleiner DM. The most efficient technique for using the FM Extractor [abstract]. *J Athl Train.* 2000;35:S60.
18. Hoenshel RW, Angotti DD, Kleiner DM. An objective evaluation of the FM Extractor [abstract]. *J Athl Train.* 2000;35:S61.