Removal of the Cervical Spine Collar from Alpine Extrication and Evacuation Skiing Rescue Spinal Motion Restriction Protocols: A Biomechanical Controlled Study in Real-Life Mountain Conditions with a High-Fidelity Mannequin

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Abstract

Background: Alpine skiing rescues are unique because of the mountainous environment and risks of cervical spine motion (CSM) induced during victims' extrication (EX) and downhill evacuation (DE). Current pre-hospital guidelines recommend the application of full spinal immobilization using various orthotic devices such as cervical collars (CC) when mobilizing and transfer+ring a victim with a suspected spine injury. The biomechanical benefits of applying CC in terms of spinal motion restriction during simulated alpine rescue are undocumented.

Methods: Observational design of CSM measurement on a high-fidelity simulation mannequin with a motion sensors-instrumented cervical spine during simulated alpine skiing EX and DE. A total of 32 EXs and 4 DEs on different slope conditions were performed by six experienced active ski patrollers at a Canadian ski resort. The primary outcome was the 3D excursion vector (Peak$\Delta\theta$) of the mannequin's head. The secondary objectives were the time to extrication completion (tEX) depending on CC use and to identify which EX event is more likely to induce CSM.

Results: Peak$\Delta\theta$ recorded during flat terrain EX using CC was 11.71° +/- 3.61° compared to 16.00° +/- 7.93° using MILS, and 18.29° +/- 9.78° for CC versus 17.90° +/- 4.16° using MILS on a steep slope. Peak$\Delta\theta$ with CC or using MILS during EXs were equivalent according to a 10 degrees non-inferiority hypothesis testing. Time to extrication completion (tEX) was significantly higher using CC as opposed to MILS for both flat and steep terrain conditions (100.6s vs. 219.2s and 106.2s vs. 268.8s longer respectively, 95% confidence interval). During DEs, CSM with and without CC across all terrain conditions were negligible (<5°). Task analysis during EX showed that when CC is used, its installation induces the highest CSM. When EXs are done using MILS without CC, the logroll initiation is the manipulation inducing the highest risk of CSM.

Conclusion: For experienced ski patrollers, the biomechanical benefits of motion restriction provided by CC over MILS during alpine skiing rescues were found to be at best marginal and CC use negatively affected rescue time. Systematic use of CC during alpine rescue should be reconsidered.

Introduction

After road traffic accidents and falls, sport accidents are the most frequent cause of traumatic spinal injuries (TSI) (1), with alpine winter sports representing about 20% of these (2–4) and the cervical spine being implicated in about 50% of cases (5, 6). Worldwide, the overall incidence of TSI is approximately 10.5 cases per 100 000 persons annually and around 37.3% of these have an associated spinal cord injury (SCI) (7, 8). Considering the potentially serious sequelae of TSI, historical pre-hospital and hospital guidelines recommend the application of full spinal immobilization using various orthotic devices (e.g. cervical collars (CC), sandbags, straps, backboards, splints, vacuum mattresses, etc.) during mobilizations and transfers of individuals with a suspected TSI (5, 9–14).

Recent data suggests the aim of pre-hospital care should be to achieve spinal motion restriction (SMR) rather than full immobilization (13). SMR objective is to reduce motion which may be achieved using manual in-line stabilization (MILS) without the addition of a cervical collar. Orthotic devices may be used as well but are not mandatory considering data now shows that the proposed benefits of full immobilization do not always outweigh the related risks (10, 15–19). Spinal immobilization with a CC may lead to serious complications such as pressure ulcers, airway difficulties, increased intracranial pressure, increased imaging and radiation exposure (14, 20–27); neurologic aggravations in ankylosing spondylitis (28, 29) and elderly patients (30, 31); and increased mortality in penetrating trauma patients (18, 32). Moreover, CCs installation requires precious time as well as winter clothing and helmet removal, inducing higher risks of CCs inappropriate use, victim cold exposure, and other hazardous events (33).

The prehospital benefits of cervical collar (CC) use for the application of SMR in wilderness settings remain thus strongly debated in clinical guidelines, which affect practices in the field. The Canadian ski patrol follows the National Institute for Health and Care Excellence (NICE) guidelines (5). According to these, ski patrollers should use a CC for rescues unless they can safely clear the C-spine before the victim extrication by assessing the risk factors for C-spine injuries. This is partly in line with the recommendations by the Wilderness Medical Society (17) which despite its main recommendation in favor of the cervical collar, mentions that in some situations "[the cervical collar] should not be considered necessary if adequate immobilization can be accomplished by other means" which include manual in-line stabilization (MILS) (17). Kornhall, D.K. et al. recently published prehospital Norwegian Guidelines emphasizing the limited evidence on CCs efficacy and supporting a selective approach to achieve timely rescues (10). The First Aid Task Force in their 2020 revised recommendations on cervical motion restriction and manual in-line stabilization suggests against the use of cervical collars by first aid providers (weak recommendation, very low-quality evidence) and concluded that there is insufficient evidence for or against manual in-line stabilization (34).

Current guidelines advising for or against the use of CC offer mostly weak recommendations based on low-quality evidence that is often not specific to the context of alpine rescue (14, 15, 18, 22, 32, 35–37). Thus, more data is needed and should be collected in real-life alpine skiing rescue situations to strengthen evidence and acknowledge geographic and meteorological conditions unique to their harsh environment.

Best practices studies on SMR application can be performed from an epidemiological perspective using observational design (cross-sectional surveys, cohort, or case-control studies), or in the form of biomechanical, pre-experimental, simulation-based studies with simulated patients, cadavers, or mannequins. Gathering accurate cervical spine motion (CSM) data during SMR application in a simulated patient, in a safe and convenient manner is challenging (38, 39). Various 3D motion capture technologies exist including optical motion capture, magnetic tracking systems, and inertial movement systems (40–43). Optical systems remain the gold standard but require a clear sightline to markers, making it technically difficult to use in situations with multiple rescuers crowding the victim. Magnetic systems operated under constrained volumes are not ultra-responsive to fast motion and might be affected by ferrous elements around the area (44, 45). Both optical and magnetic systems are almost inoperable in outside field conditions and are limited to a fixed experimental volume. Wearable Inertial measurement units (IMU) offer more flexibility to study SMR under field conditions (46–48), have good accuracy for short data recordings (45), but require a sensor to body calibration (IMUs' record orientation in a global coordinate system that is not anatomically aligned with a specific joint coordinate system) which can affect their accuracy. In this study, we used a high-fidelity humanoid simulation mannequin with a 4-segment mechanical cervical spine instrumented with motion sensors to accurately capture CSM.

The aim of this study was to evaluate CSM variations occurring in alpine skiing rescues depending on the use or not of a cervical collar (CC versus MILS) during simulated extrications (EXs) and downhill evacuations (DEs) on real-life ski mountain terrains with this high-fidelity simulation mannequin.

Methods

Design and participants

This was a biomechanical pre-experimental simulation-based study. Data was collected on February 22nd and 23rd 2020 at the Mont-Orford Ski Resort in Quebec, Canada. Funding was provided by a *Université de Sherbrooke*, surgery department research grants and the FREOS (*Fondation de recherche et d'enseignement d'orthopédie de Sherbrooke*). Ethic approval to conduct this study was received from the local ethics board ("*Comité d'éthique de la recherche du CIUSSS de l'Estrie – CHUS*"). Six volunteer active ski patrollers of the Quebec's Eastern Townships Region Canadian ski patrol were recruited to participate in this study. Participants were aged between 30 and 56 years old and had between 9 and 21 years of ski patrol rescue experience. All participants were informed of the risks associated with real-life conditions data collection and provided informed consent before data collection.

High fidelity mannequin and motion capture system

The high-fidelity mannequin used to collect CSM during alpine rescue simulations was developed by our group based on previous c-spine management best practice research (46–48). The mannequin measures 175cm and weighs 82 proportionally distributed kilograms. It has a full humanoid silicone-based shape with an articulated internal skeleton reproducing the physiological range of movements and inertia of body segments (see supplemental file). The cervical spine consists of a 4-segment mechanical structure reproducing head motion in all anatomical planes (49). Linear optical encoders (sensor that encodes a position and can measure motion as changes in position over time) with an accuracy of 0,073 deg (resolution of 5000 counts per revolution over 360 degrees) are positioned in each segment, daisy-chained, and linked to an IoT board sampling their data at 100Hz and transmitting it wirelessly to a tablet device for real-time and asynchronous head motion data analysis. Head motion derived from the motion recorded by the linear optical encoders is divided into three elementary axes: 1) flexion/extension; 2) lateral motion, and 3) rotation (see figure 1). A 3-dimensional magnitude vector angle is calculated to depict the overall head motion.

Data collection: Manipulations and Terrains

Figure 2 summarizes the mountain rescue steps. The first step is the extrication (EX), in which the mannequin is mobilized from its initial trauma location to a rescue toboggan. It is further divided into steps (a. to g.) according to the protocol used and culminates with the transfer to the toboggan. The downhill evacuation (DE) phase starts the moment the mannequin is secured in the toboggan and ends when it reaches the base of the mountain.

To understand alpine geography's impact on the ability to maintain an appropriate cervical alignment, EXs were tested on two different terrains: A) flat terrain; B) steep slope (≥ 40% grade). In a similar manner, DEs were executed on four different inclinations trails, from an easy regular descent <25% to a ≥40% mogul descent. All events were completed an equal number of times with a CC and with MILS control (no CC).

Technique standardization

At the beginning of every rescue simulation, the mannequin was positioned supine with the head in the neutral position and dorsal spine aligned with the head. It was dressed and geared as a typical alpine skiing victim, including a helmet, ski goggles, and a neck warmer. When using a CC, ski patrollers first removed this equipment to achieve proper CC positioning. When no CC was used, the equipment was kept in place and MILS was applied until the mannequin was transferred to the toboggan. Regarding the MILS technique (head squeeze vs trap squeeze) the choice was left to each patroller. Although the lift & slide technique to position the victim into the vacuum mattress might be more effective (46, 50–52), the log roll technique was used in this study considering most first aid providers are familiar with it and have the advantage to require fewer people to be properly executed.

A full-body, first-aid-provider vacuum mattress, instead of a long spine board was used because growing evidence supports that it is at least as efficient as the spinal board and has fewer associated complications (15, 53–55). When the CC was used, it was left in place on the victim throughout the steps of the transfer to the vacuum mattress and toboggan. Prior to the transfer to the toboggan, the vacuum mattress was molded around the mannequin's shoulders, head, and neck using the vacuum. The CC used was a Ambu Perfit ACE Extrication Collar and the toboggan was a CATT model IV. Special care was taken to avoid learning bias: CC use and non-use were alternated between trials, and patrollers' positions and roles were rotated after each EX to make sure that all patrollers had equal head stabilization repetitions.

Data analysis

Figure 1 demonstrates an example of raw data collected from a single EX. The main value extracted from each repetition is the peak 3D excursion angle vector (Peak$\Delta\theta$). The Peak$\Delta\theta$ is the highest head motion variation recorded during a whole EX. As described previously, EXs are further subdivided into manipulations and the highest 3D excursion angle vector ($\Delta\theta$) for each of these is also extracted to assess which manipulation is at the highest risk of inducing CSM. Data analysis was conducted using IBM SPSS Statistics Version 26. Shapiro-Wilk test demonstrated non-normal distribution. Differences in

PeakΔθ recorded between conditions (CC, MILS) during EX and DE were assessed using Mann-Whitney U non-parametric tests with a 10 degrees non-inferiority hypothesis testing. P values < 0,05 were considered significant. No *a priori* power estimation was performed, though as many repetitions as possible were executed during our two-day experimentation.

Results

A total of 32 Extrications (EXs) were performed. Out of these, 20 were on a flat area and 12 on a 40% grade slope (see figure 2). In addition, four Downhill Evacuations (DEs)were executed. An equal number of repetitions was done with and without a CC for both EXs and DEs.

Cervical spine motion during extrication

Figure 3 shows the CSM (PeakΔθ) recorded during each EX, depending on CC or MILS use, and on terrain conditions. Extrications with CC on a flat terrain induced a mean PeakΔθ of 11.71° +/- 3.61° compared to a mean PeakΔθ of 16.00° +/- 7.93° during EXs using MILS without a cervical collar. Further CSM during EXs on a steep slope using a CC reached a mean PeakΔθ of 18.29° +/- 9.78° whereas on the same terrain using MILS the mean PeakΔθ is 17,90° +/- 4,16°. CSM during EXs with CC and MILS are equivalent according to a 10 degrees non-inferiority hypothesis testing (p<0,01).

Time to extrication completion

Mean extrication time on flat terrain with a CC was 6 m 33 s (5 m 28 s; 7 m 40 s) compared to 3 m 53 s (3 m 31 s; 4 m 16 s) when no CC is used (p<0.05) (see figure 4). The mean difference is -2 m 40 s (-1 m 41 s; -3 m 39 s, p=0.001). A similar result was obtained when EXs were performed on a steep slope with a mean difference of -3 m 07 s (-1 m 47 s; -4 m 29 s, p=0.02).

Cervical spine motion during a downhill evacuation

Figure 5 shows the continuous data gathered for each DE performed. Despite testing on various terrains including an easy slope (<25% grade), an intermediate slope (25-40% grade), a steep slope (≥40% grade) and an expert mogul slope (≥40% grade), the PeakΔθ never reached a value above 5°, with little variation over time both with and without a cervical collar. CSM recorded during DEs across all experimental conditions were thus clinically negligible. There were no differences between PeakΔθ recorded during EXs with CC and without CC during EXs.

Manipulations' cervical spinal motion (CSM) risk

To identify which manipulation induces the highest CSM risk, EXs were divided into the following events: a) equipment removal, b) CC installation, c) logroll from supine to lateral decubitus, d) logroll from lateral decubitus back to supine on the mattress, e) translation on the mattress, f) immobilization on the mattress, g) transfer on the toboggan. Figure 6 demonstrates the means of each manipulations' highest 3D excursion angle vector (Δθ). This data suggests a trend towards an increased motion risk during CC installation when EXs are done using a CC. For trials without CC the logroll to lateral decubitus appears to generate the most motion.

Discussion

This controlled biomechanical study performed in real-life conditions with experimented patrollers suggests the following key points regarding the use of a cervical collar for alpine skiing rescues: 1) Cervical spine motion during extrications with CC compared to MILS without CC are equivalent according to a 10 degrees non-inferiority hypothesis testing ($p<0,01$); 2) Time to extrication completion is increased by a mean of 2 m 40 s and 3 m 07 s depending on terrain conditions ($p=0,001$, $p=0,02$); 3) Downhill evacuations produce small cervical motion (< 5 degrees); 4) When using MILS without CC, special care should be taken at the initiation of the logroll as it showed a higher risk of causing CSM(45).

This study reinforces emerging guidelines previously discussed supporting the removal of systematic cervical collars use from first-aid protocols to save critical time (9–11, 15, 17, 18, 34). According to our results, the motion reduction expected with a CC (less than 10 degrees) is probably not clinically significant as it would be unlikely to cause significant neurological complications. Any presumed benefit from CC use would have to outweigh its drawbacks, particularly its required installation time (approximating a 60% longer total extrication time), aside from the victim's cold exposure, possible airway complications, pressure ulcers, etc. In the wilderness prehospital care, cervical collar use should therefore be considered an available tool to achieve Spinal Motion Restriction (SMR) rather than a requirement. A caveat to this is that our results, while obtained in real ski rescue conditions on two different surfaces including a 45-degree slope, can't be generalized to all rescue conditions and environments. There might be a protective effect of using CC for ski rescue performed under more complex and hostile environments. As such, cervical collar application should be individually assessed depending on each rescue situation, according to the terrain, weather, urgency, health care providers available, etc.

Presently, there is no known established amount of movement of an injured cervical spine that would lead to neurological injuries and this question is likely to remain unanswered. The 10 degrees non - inferiority threshold selected to compare the effect of using a CC or MILS in our data analysis can be construed as somewhat arbitrary yet it is aligned with the current paradigm shift of spinal motion restriction as opposed to full spinal immobilization (13) and takes into consideration the reported spinal motions and their variations recorded in published studies on the application of SMR for similar scenarios. For instance, a recent study published by McDonald et al. on real victims with a suspected traumatic spinal injury equipped with inertial measurements units (IMUs) underlined the wide range of multi-plane head-neck motion (from 7,2° to 82,1°) (56). No study had previously objectively measured CSM on real trauma patients during prehospital care. Their results suggest that our < 10° threshold is a conservative value considering the overall range of CSM recorded. Remarkably, despite a low participant number, multiple motion restriction devices were used in this study and the authors outlined that there was no significant CSM difference recorded among them. They stated that patient compliance (anxiety, intoxication, pain, etc.) was significantly more related to CSM recorded than the motion restriction protocol used.

Our study stands out owing to its use of a high-fidelity mannequin and real-life situation data collection. Few biomechanical studies on spinal stabilization are designed in real-life settings and these are essentially focused on ambulance transport or vehicle extrication (57, 58). There is no study on spinal stabilization completed in real mountain rescue geographic and meteorological conditions that we are aware of. A thorough sample of slope grades for both EXs and DEs were also carefully chosen to realistically portray the average alpine skiing rescues happening in Northeastern America. The high-fidelity mannequin used in this study is also an interesting tool to further study cervical spine motion restriction devices and protocols. Cervical spine motion studies are known to be challenging for convenient accurate data collection (41). Current literature relies on data obtained with conscious volunteers or with cadavers using various external motion capture systems. Healthy volunteer studies mostly evaluate the efficacity of collars according to their reduction of active movements. In these cases, volunteers are asked to flex and rotate the head as much as possible which is not representative of the usual compliant trauma victim (16, 59). Cadaveric studies enable the possibility to surgically induce a cervical instability prior to spinal stabilization tests. However, they are not suitable for real-life situations data collection. As for external motion capture systems they have practicality issues for real life situation data collection that are not present when using an integrated system. For future perspectives, this mannequin could also be used for prehospital health care providers training through high-fidelity simulations.

Some limitations of this study must be outlined. First, ski patrollers were all volunteers and experts with more than 9 years of experience. One might fairly argue that some less experienced patrollers could induce more movements when stabilizing the cervical spine without the assistance of a cervical collar. However, the same could be true for hazardous motion during the cervical collar installation which would void its benefits. Also, we consider that, in such rescue situations, cervical spine stabilization is usually the role of the most experienced patroller. Second, as a limitation it should be noted that our data collection could not be blinded, and patrollers were vulnerable to the Hawthorne effect as they were indeed aware of the use or not of the collar and knew they were observed. Third, our number of repetitions and Peak$\Delta\theta$ values remain small (EX = 32), however as discussed previously the data collected demonstrated that both immobilization techniques were statistically equivalent within a 10 degrees margin, and it is believed that any difference less than 10 degrees would most likely not be clinically significant.

Conclusion

The biomechanical benefits of cervical collars in terms of spinal motion restriction (SMR) during a simulated alpine rescue in comparison to MILS are marginal at best. Considering the difficulties of applying cervical collars under these rescue conditions and the marginal benefits observed, systematic use of the cervical collar by first aid providers during alpine skiing rescues cannot be supported. With experienced ski patrollers, the application of MILS during alpine ski rescues can achieve similar levels of SMR to what is observed with a cervical collar.

Declarations

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Availability of data and materials. The data presented in this study are available on request from the corresponding author

Ethics approval and consent to participate. The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board of the CIUSSS de l'Estrie-CHUS. Informed consent was obtained from all subjects involved in the study.

Competing interests. The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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Figures

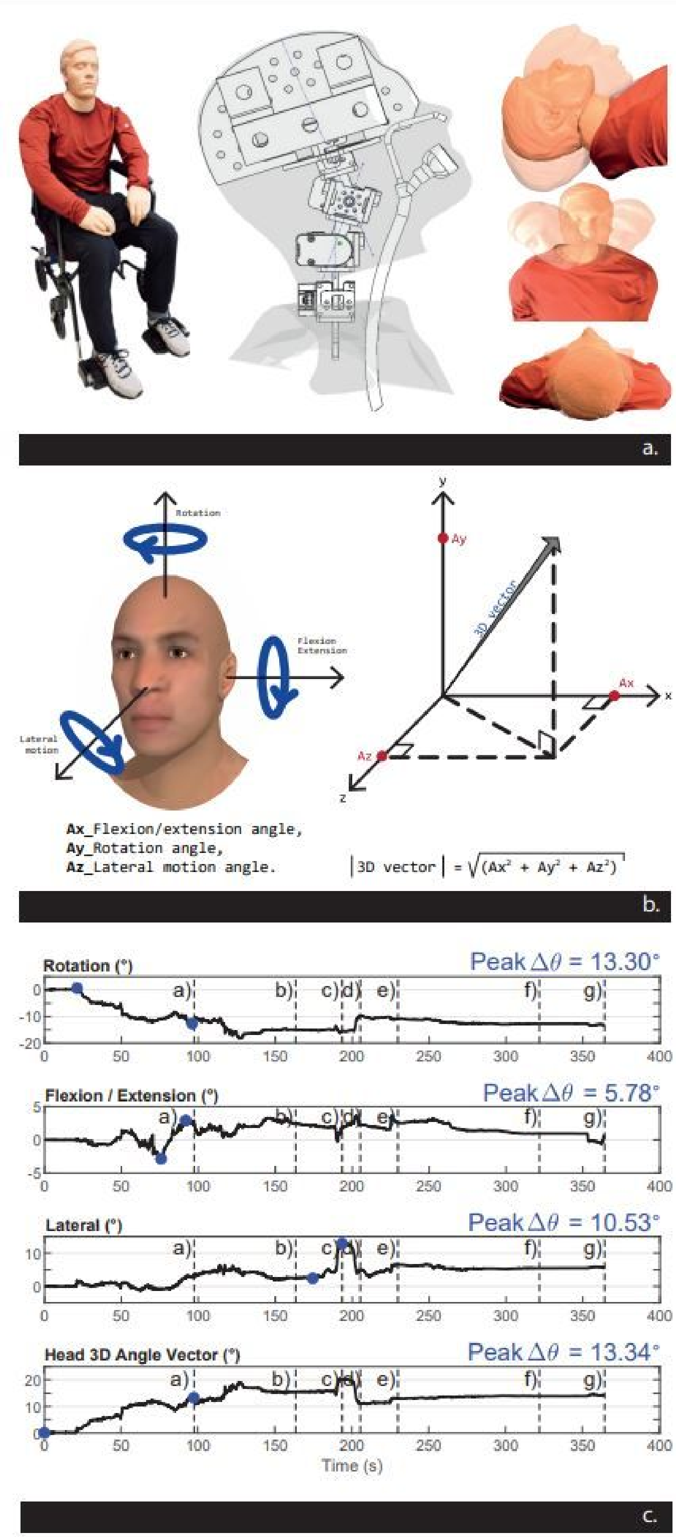

Figure 1

High-fidelity mannequin with integrated cervical spine motion capture system. Legend: a) High-fidelity mannequin morphology and integrated motion capture system; b) Head motion elementary axes and 3D angle vector calculation; c) Continuous raw data obtained from a single extrication using a cervical collar. Vertical lines mark the extrication's manipulation divisions (see figure 2).

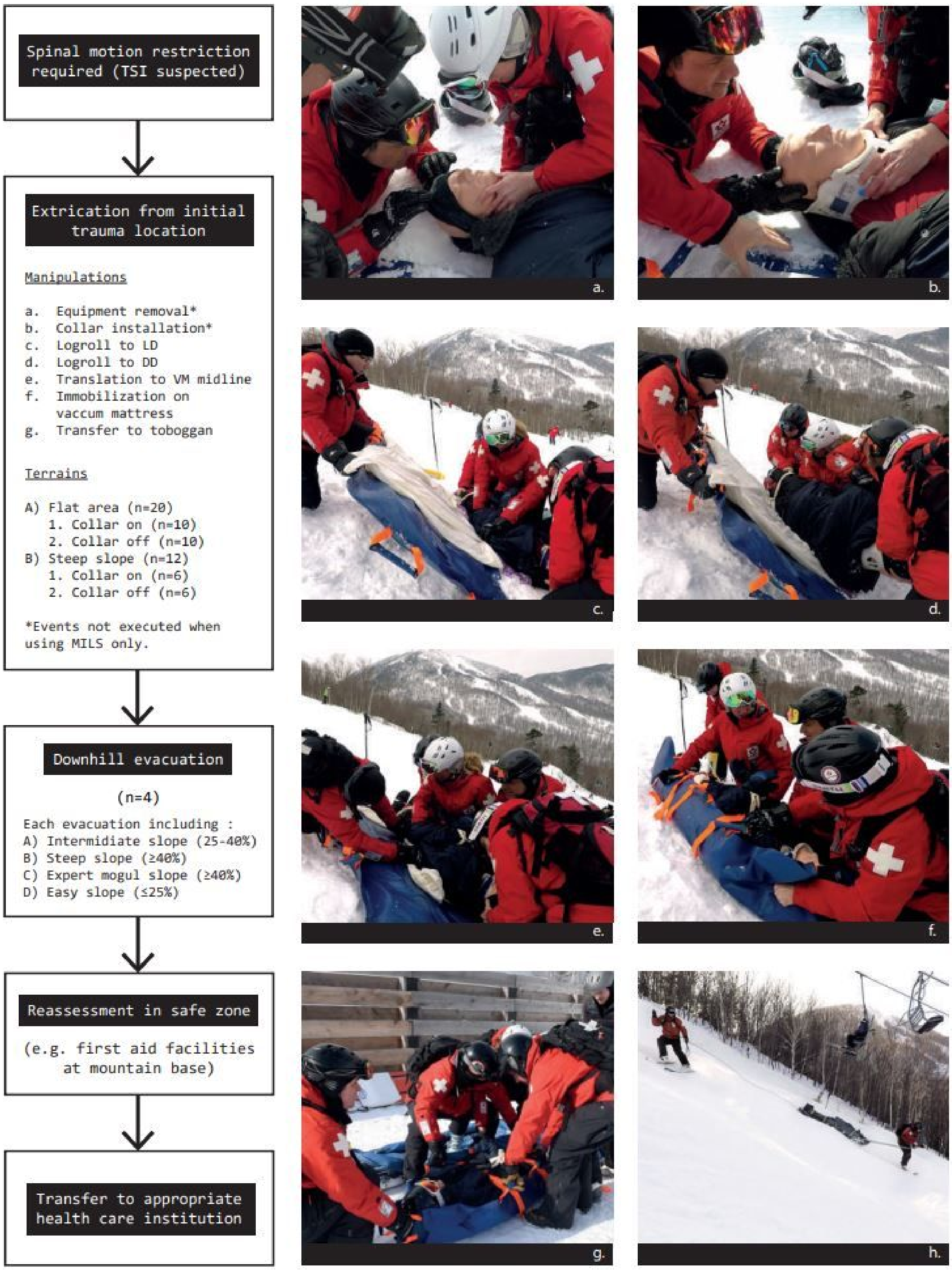

Figure 2

Alpine skiing rescue process and description of terrains. Legend: a) Winter clothes removal and b) cervical collar installation (flat terrain); c) Preparing logroll to lateral decubitus and d) preparing logroll back to supine (steep slope); e) Preparing to move to vacuum mattress midline and f) Immobilization on the vacuum mattress (steep slope) (note that head and cervical spine are included in the vacuum mattress immobilization), g) Preparing transfer to toboggan, h) Downhill evacuation (expert mogul slope). LD: Lateral Decubitus, DD: Dorsal Decubitus, VM: Vacuum mattress, MILS: Manual in Line Stabilization, TSI: Traumatic Spine Injury.

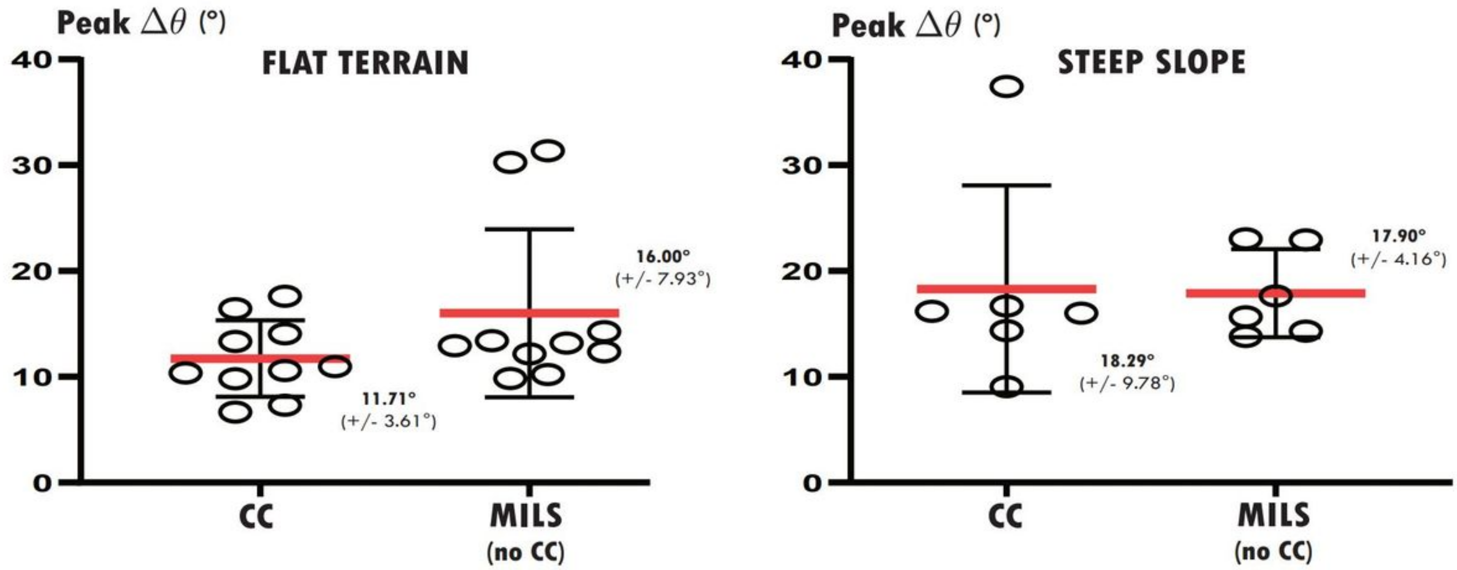

Figure 3

Peak 3D excursion angle vectors during EX trials on flat terrain and steep slope. Legend : Left: Peak 3D excursion vectors on a flat terrain depending on the use or not of a cervical collar; Right: Peak 3D excursion vectors on a steep slope (>40% grade) depending on the use or not of a cervical collar. PeakΔθ: peak 3D excursion vectors, CC: Cervical collar, MILS: Manual in-line stabilization

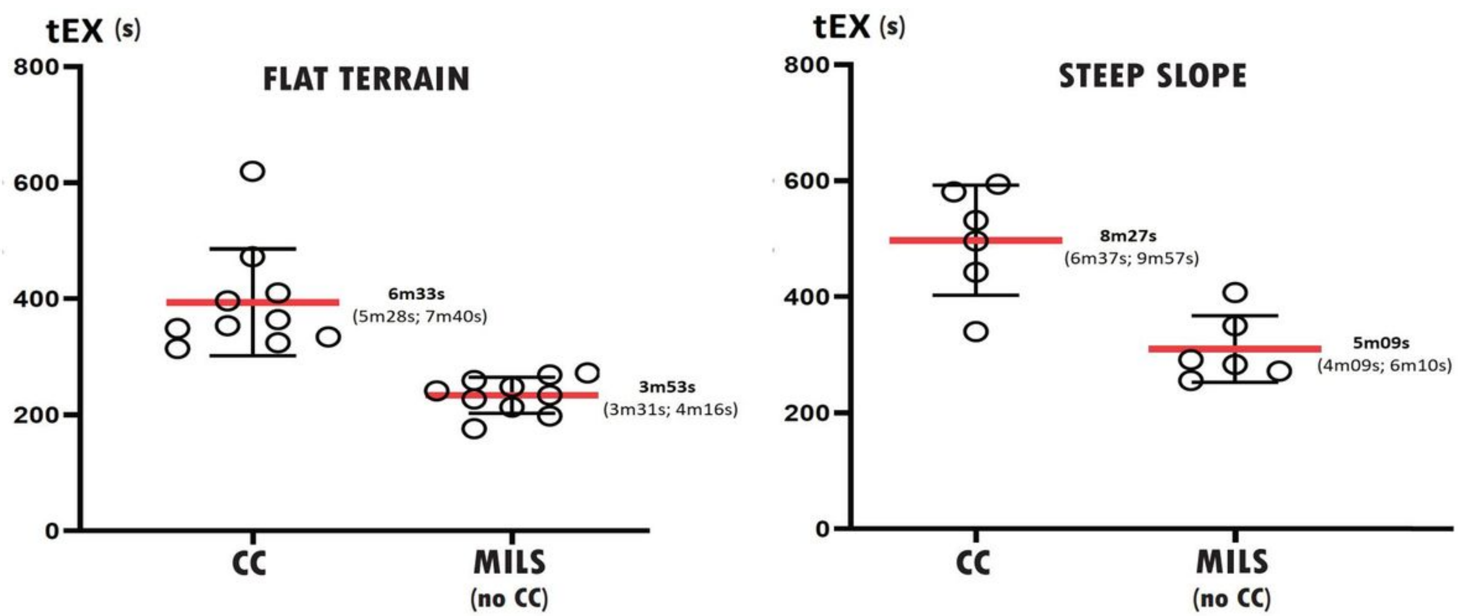

Figure 4

Time to extrication completion depending on the collar use and terrains. Legend : Left: Time to extrication completion on a flat terrain depending on the use or not of a cervical collar; Right: Time to extrication completion on a steep slope (>40% grade) depending on the use or not of a cervical collar. tEX: time to extrication completion (seconds), CC: Cervical collar, MILS: Manual in-line stabilization

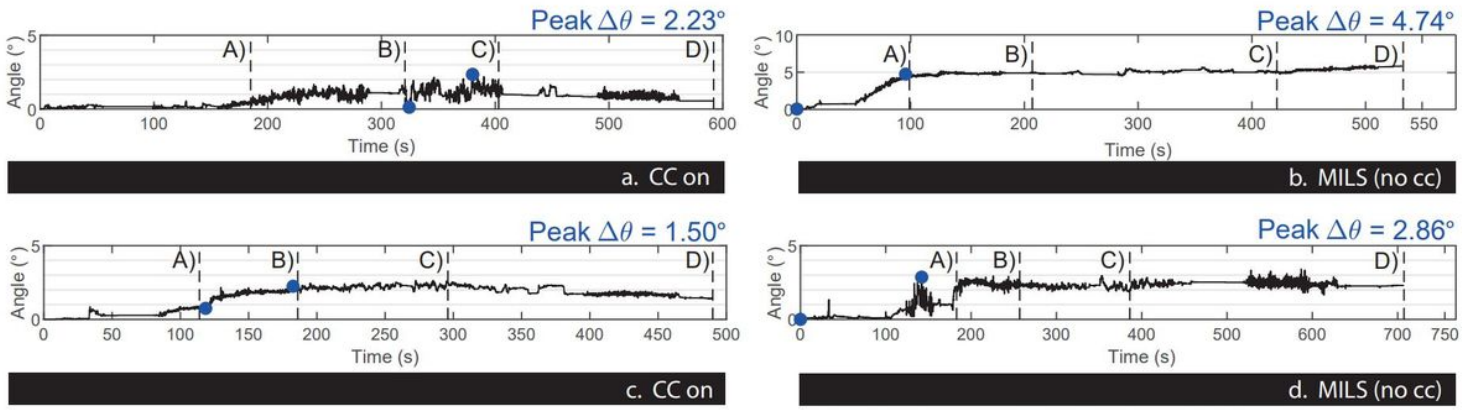

Figure 5

Continuous data collected during downhill evacuations depending on terrain conditions and cervical collar use. Legend: a) First downhill evacuation executed with a cervical collar; b) Second downhill evacuation executed with manual in-line stabilization; c) Third downhill evacuation executed with a cervical collar; d) Fourth downhill evacuation executed with manual in-line stabilization. Vertical lines mark the slope terrain transitions: A) Intermediate slope (25-40% grade), B) Steep slope (≥40% grade), C) Expert mogul slope (≥40% grade), D) Easy slope (<25% grade). PeakΔθ: peak 3D excursion vectors, CC: Cervical collar, MILS: Manual in-line stabilization

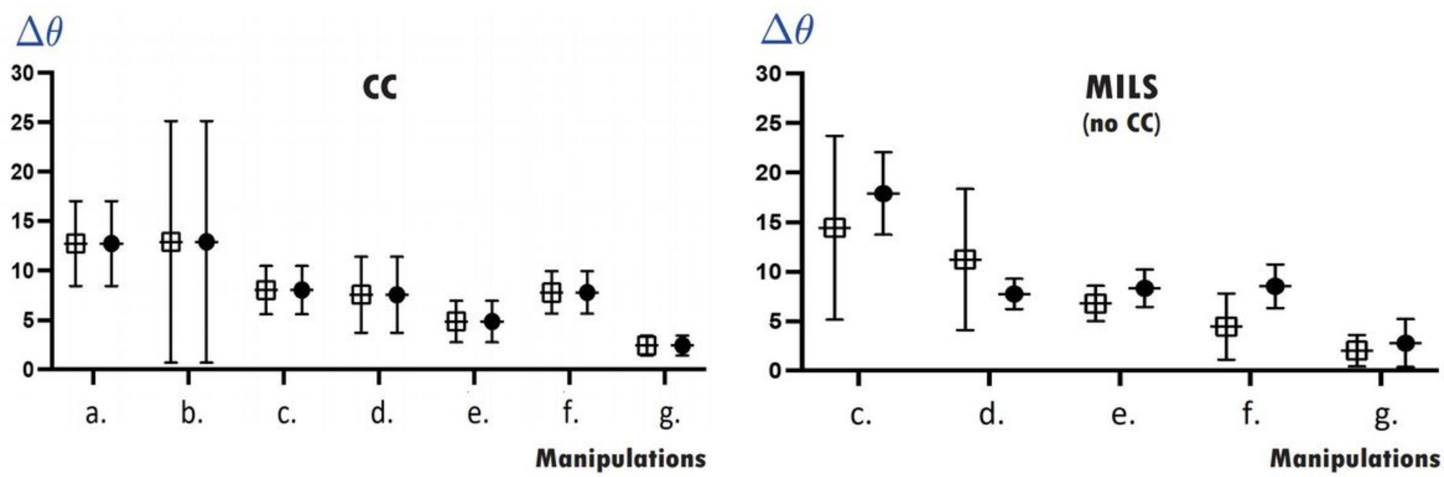

Figure 6

Means of excursion 3D vectors depending on extrication manipulations and cervical collar use. Legend : Left: Excursion 3D vectors' means recorded when using a cervical collar (all terrains included) depending on the manipulation executed; Right: excursion 3D vectors' means recorded when using manual in-line stabilization (all terrains included) depending on the manipulation executed. a) Winter clothes removal, b) Cervical collar installation, c) Logroll to lateral decubitus, d) Logroll back to supine, e) Move to vacuum mattress midline, f) Immobilization on the vacuum mattress, g) Transfer to toboggan. •_Flat area, □_Steep slope

Supplementary Files

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