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Quality of chest compressions performed on mannequins in toboggans on a ski slope: a crossover study

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Objective: When sudden cardiac arrest occurs on ski slopes, rescuers can perform cardiopulmonary resuscitation (CPR) with the patient on snow, a stationary toboggan, or a moving toboggan. We examined the quality of chest compressions performed in each of these settings.

Methods: Seven prehospital healthcare professionals performed straddling CPR for 1 minute under three conditions: a moving ski-patrol toboggan, a stationary ski-patrol toboggan, and flat snow-covered terrain. Various parameters (average compression depth, rate, recoil, and correct hand position) were measured to assess the quality of chest compressions. The paired Student t-test was utilized for statistical analysis.

Results: The deepest chest compressions during CPR were observed on the snow (4.7±1.0 cm), followed by those on a stationary toboggan (4.6±0.8 cm), and on a moving toboggan (4.2±0.5 cm). There was no statistically significant difference in the depth of chest compressions among the three conditions. The participants performed compressions within the American Heart Association's recommended rates (112.0±5.4 beats per minute on flat snow, 111.4±4.5 on stationary toboggan, and 114.1±4.1 on moving toboggan, respectively). High-quality recoiling was achieved under all three conditions (0.0±0.0 cm on flat snow, 0.0±0.0 on stationary toboggan, and 0.1±0.0 on moving toboggan). A higher tendency to perform compressions on the right side of the chest was noted in the moving toboggan condition (41.0%±22.9%) compared to the other two conditions (stationary toboggan, 5.6%±12.6%; difference: −35.40% [95% confidence interval, −66.53% to −4.33%]; P=0.03; flat snow, 4.0%±10.6%; difference: 37.00% [14.16% to 59.84%]; P=0.01).

Conclusion: The depth of chest compressions was insufficient during straddling CPR performed on a ski slope, whether directly on snow or on a moving or stationary toboggan.

Keywords: Wilderness medicine; Heart arrest; First responder

INTRODUCTION

Out-of-hospital cardiac arrest (OHCA) is associated with high mortality rates worldwide [1]. Adult OHCAs in residential and public settings represent approximately 75% and 16.3% of all OHCAs, respectively [2], while sports- and exercise-induced sudden cardiac arrest (SCA) accounts for 0.3% of all OHCAs [3]. SCA can occur in any location and during any sport, including snow sports. In a 10-year study conducted in the French Alps, researchers identified 136 OHCA cases, with 24.3% resulting from trauma and 69.9% from cardiac causes [4]. Additionally, 369 deaths (190 traumatic and 179 nontraumatic) were recorded on Austrian ski slopes [5].

In cases of trauma-induced cardiac arrest, the survival rate remains quite low even when resuscitation is performed on site [4,6,7]. The benefits of on-scene cardiopulmonary resuscitation (CPR) must be carefully weighed against those of transportation. In cases of trauma-induced cardiac arrest, it is crucial to address the major reversible causes immediately, such as controlling hemorrhage with tourniquets, treating tension pneumothorax with needle decompression, and managing airway emergencies before transportation. However, in Japan, the scope of practice for first responders limits the performance of advanced life support procedures. This study focused on the care of nontraumatic OHCAs. Early recognition and defibrillation are essential for improving the survival rates of patients with SCA [8]. It is also important to provide high-quality CPR, which the American Heart Association (AHA) defined as a chest compression depth of 5–6 cm, rate of 100–120 beats per minute (bpm), full recoil, and minimal interruption [9].

It has been reported that ski-on-slope-specific OHCA typically occurs in patients with an average age of 56 years, which is approximately 10 years younger than the average age of 66 years for other OHCAs. Bystander CPR is administered immediately, and shockable rhythms are twice as likely to appear in this group than in non-slope and non-ski-resort OHCAs [4]. The average time to defibrillation for on-slope patients has been reported to be 7.5 minutes [4]. When SCA occurs on a ski slope, several transportation options are available, including helicopters, snowmobiles, and toboggans. Performing CPR on toboggans presents challenges, and rescuers often employ alternative CPR techniques, such as the straddling position [10]. Abrams and Torfason are the only researchers who have studied the quality of chest compressions in toboggans. Although the compression depths and rates in their study were in accordance with the guidelines from the International Liaison Committee on Resuscitation, shallow compressions were observed when the procedure was performed while both the patients and rescuers were in motion [10].

Therefore, we aimed to examine and compare the quality of chest compressions performed on a moving downhill toboggan, a stationary toboggan, and flat snow-covered terrain. We hypothesized that the quality of CPR would be reduced when performed during downhill movement.

METHODS

Participants

We recruited seven prehospital healthcare professionals, including emergency medicine physicians and paramedics, who did not regularly participate in snow emergency management. We assessed whether the quality of CPR performed on snow and moving toboggans varied among participants accustomed to performing CPR in urban environments. The inclusion criteria required participants to be certified CPR instructors with prior experience in snow mountain emergency management training. We excluded individuals who had sustained upper or lower extremity injuries within 6 months prior to the study. Snow mountain emergency management training is incorporated into a 4-year paramedic training program and includes a 4-day course specifically focused on winter snow emergency management, taught by experienced paramedics and ski patrols. The training covers the treatment of fractures and trauma on ski slopes, full spinal immobilization, performing CPR on ski slopes, and coordination with rescue helicopters, including the management of toboggans. Participants also engage in rescue drills and training exercises in collaboration with ski patrols, and they receive instruction in off-piste rope rescue and search and rescue techniques.

In Japan, most ski patrollers work part-time, and not all are certified by the Ski Association of Japan (SAJ). Those who are certified have completed a program with a structured curriculum. It is possible to work as a ski patroller without certification, and training can vary across different ski areas. Given that many are part-time, enhancing the quality of CPR performed by ski patrollers is crucial. In our study, we utilized prehospital healthcare providers who frequently perform chest compressions in the field as subjects. During data collection, SAJ-certified ski patrollers were tasked with transporting the mannequins and participants using ski-patrol toboggans downhill. All participants were equipped with skis, gloves, and boots throughout the data collection process. This study received approval from the Institutional Review Board of Kokushikan University (approval number: 22032).

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Instruments

As illustrated in Fig. 1, chest compression quality data were measured using a Saveman Pro LM-119P mannequin (Koken Co., Ltd.) weighing 23 kg and measuring 175×57×25 cm (length×width ×height) [8]. This mannequin is capable of monitoring and recording various chest compression variables such as depth, recovery, rhythm, hand position, chest compression fraction, duty cycle, and ventilation volume. Additionally, the mannequin's mechanism includes a digital event recorder for reviewing CPR quality [11]. To protect the mannequin's delicate mechanical components, a curing tape that does not interfere with CPR performance was applied, and an original soft case was used to shield the mannequin from snow. To create a realistic scenario, the mannequin was dressed in two layers of winter clothing: a base layer and an outer layer. The outer layer was removed to facilitate chest compressions, leaving only the base layer to protect the mannequin from snow. Details of our aluminum toboggan are as follows: length, 216 cm; inner width, 38 cm; outer width at the center, 60 cm; total weight, 27 kg; rails and edges made of steel; and bases made of aluminum [12]. A toe strap was used to prevent the participants from sliding, as recommended by Abrams and Torfason [10].

Procedure

This study was conducted on the Main Bahn slope of the Zao Sunrise Gelande, located in the Zao Onsen ski area in Yamagata, Japan. This slope, designed for beginners, was machine-groomed [13]. Verbal informed consent was obtained from all participants. Before the crossover study commenced, participants were given time to familiarize themselves with the equipment. As a safety measure, participants who performed CPR under specific conditions were required to execute chest compressions for one minute using the straddle method. This was done under three different conditions, determined by a randomization allocation sheet: (1) moving toboggan condition-CPR was performed while a ski patrol toboggan moved down a ski slope. The head of the mannequin was positioned uphill; (2) stationary toboggan condition-CPR was performed while the mannequin was on a ski-patrol toboggan that was stopped on flat but snowy terrain (Fig. 1); and (3) flat snow condition-CPR was performed with the mannequin positioned directly on flat snow-covered terrain. All participants took part in condition 1 first. Subsequently, based on randomization; three participants took part in condition 2 and then condition 3, and the remaining four participants carried out CPR in conditions 3 and 2, sequentially. There was a 15-minute break between trials. As a safety precaution, several individuals skied both behind and in front of the moving toboggan during data collection.

While performing CPR on moving toboggans, we positioned the mannequins with their heads uphill. Meta-analyses of head-up CPR have shown improved outcomes in animal studies; however, only one observational study has been conducted to date [14-16]. In head-up CPR, gravity assists in expelling blood from the brain, reducing intracranial pressure, enhancing cerebral perfusion, and improving the neurological prognosis for patients with SCA [17].

Fig. 1. Images of a mannequin wearing a base layer (A) and a mannequin wearing a base layer in a stationary toboggan position (B).

Measurement of outcomes

The primary outcome of the study was the quality of chest compressions, which included average compression depth (cm), rate (bpm), recoil (cm), and correct hand position (%). The hand positions assessed were center, upper, lower, right, and left, as illustrated in Fig. 2. These variables were measured using a manikin. The recoil measurements in this study were based on the distance the manikin's chest did not return to its original position. A shallow measurement (closer to 0 cm) indicates full recoil, while a deeper measurement suggests incomplete recoil.

Statistical analyses

Variables are presented as means and standard deviations. The paired Student t-test was used for statistical analyses. The two-tailed alpha level was set at 0.05. Differences and 95% confidence intervals (CIs) were calculated for all three conditions. Due to the potential for type I errors resulting from multiple comparisons, the findings from our outcome analyses should be considered exploratory. Data were analyzed using JMP Pro version 17.0.0 (SAS Institute).

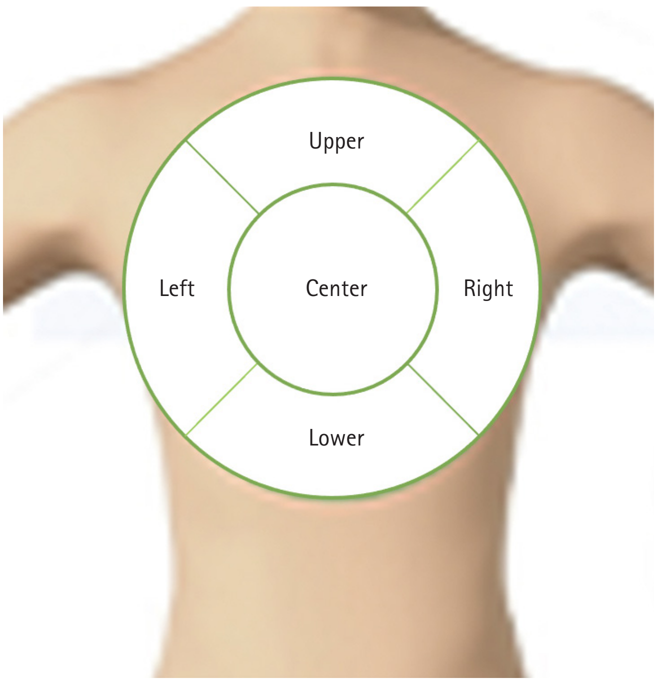

Fig. 2. Image of the hand position.

RESULTS

No potential participants met the exclusion criteria. The study included seven participants: one emergency medicine physician and six paramedics (six men and one woman). All participants successfully completed all three conditions.

CPR quality measurements are presented in Table 1. During data collection, the weather was cloudy with temperatures ranging between a high of 1.2 °C and a low of –0.7 °C. The terrain was covered with fresh snow from the previous night. On the piste-covered slope, the snow cover was adequate, consisting of fresh snow, and the slope had been groomed by a machine. None of the compressions performed under the three conditions met the 2020 AHA guidelines, which recommend a depth of 5–6 cm. The deepest compressions occurred on flat snow, followed by those on stationary and moving toboggans (4.7±1.0, 4.6±0.8, and 4.2±0.5 cm, respectively). No statistically significant differences were observed between the three conditions. The compression rates under all three conditions fell within the 2020 AHA guidelines of 100–120 bpm. No significant differences were found among the conditions (112.0±5.4 bpm on flat snow, 111.4±4.5 on stationary toboggan, and 114.1±4.1 on moving toboggan, respectively). The quality of the compression recoil was good under all conditions (0.0±0.0 cm on flat snow, 0.0±0.0 on stationary toboggan, and 0.1±0.0 on moving toboggan, respectively).

For all measurements, participants performed chest compressions using the straddling CPR method. The rate of accurately

Table 1. Chest compression quality ratings under the three different conditions

Variable	Stationary toboggan, mean±SD (n=7)	Moving toboggan, mean±SD (n=7)	Flat snow, mean±SD (n=7)	Stationary toboggan vs. moving toboggan		Moving toboggan vs. flat snow		Flat snow vs. stationary toboggan	
				Diff (95% CI)	P-value	Diff (95% CI)	P-value	Diff (95% CI)	P-value
Depth (cm)	4.6±0.8	4.2±0.5	4.7±1.0	0.46 (–0.13 to 1.12)	0.10	–0.57 (–1.52 to 0.38)	0.19	0.77 (–0.46 to 0.60)	0.75
Rate (bpm)	111.4±4.5	114.1±4.1	112.0±5.4	–2.71 (–8.98 to 3.55)	0.33	2.14 (–4.56 to 8.84)	0.46	0.57 (–1.74 to 2.89)	0.57
Recoil (cm)	0.0±0.0	0.1±0.0	0.0±0.0	NA	NA	NA	NA	NA	NA
Hand position (%)									
Center	15.0±36.7	2.9±7.6	4.0±10.6	12.14 (–14.79 to 39.08)	0.31	–1.14 (–14.08 to 11.80)	0.84	–11.0 (–49.95 to 25.95)	0.49
Upper	58.3±42.6	55.1±21.0	57.1±45.2	3.14 (–29.30 to 35.59)	0.82	–2.00 (–53.69 to 49.69)	0.93	–1.14 (–59.02 to 56.74)	0.96
Lower	0.0±0.0	0.0±0.0	0.1±0.4	NA	NA	NA	NA	NA	NA
Right	5.6±12.6	41.0±22.9	4.0±10.6	–35.40 (–66.53 to –4.33)	0.03	37.00 (14.16 to 59.84)	0.01	–1.57 (–17.21 to 14.07)	0.81
Left	21.1±38.9	2.4±6.0	34.7±47.3	18.70 (–19.06 to 56.49)	0.27	–32.29 (–77.92 to 13.35)	0.13	13.57 (–21.74 to 48.88)	0.38

SD, standard deviation; Diff, difference; CI, confidence interval; bpm, beats per minutes; NA, not applicable.

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delivering compressions to the central part of the mannequin's chest was extremely low across all conditions (stationary toboggan, 15.0% ± 36.7%; moving toboggan, 2.9% ± 7.6%; flat snow, 4.0% ± 10.6%). However, more than 50% of the compressions were administered to the upper part of the chest (stationary toboggan, 58.3% ± 42.6%; moving toboggan, 55.1% ± 21.0%; flat snow, 57.1% ± 45.2%). No statistical differences were noted between compressions to the central and upper parts of the chest under any condition. However, there was a significantly higher tendency to compress the right side of the chest under the moving toboggan condition (41.0% ± 22.9%) than under the other two conditions (stationary toboggan: 5.6% ± 12.6%, difference: –35.40% [95% CI, –66.53% to –4.33%], P = 0.03; flat snow: 4.0% ± 10.6%, difference: 37.00% [95% CI, 14.16% to 59.84%; P = 0.01). Conversely, the second most common compression position was on the left side of the chest under the stationary toboggan and flat snow conditions (21.1% ± 38.9% and 34.7% ± 47.3%, respectively). An extremely low rate of compression was observed on the lower part of the chest, occurring only under the flat snow condition, which did not involve a toboggan (0.1% ± 0.4%).

DISCUSSION

The number of CPR studies conducted on snow is limited due to environmental factors and manpower requirements. Performing CPR in a wilderness setting, such as straddling CPR, presents significant challenges. To our knowledge, only one previous study has evaluated CPR performed on toboggans [10]. In this study, under three different conditions, participants performed within the normal range of the 2020 AHA guidelines in terms of rate (100–120 bpm) and recoil. However, the compression depths were shallower than those recommended by the 2020 AHA guidelines. Emergency action plans vary based on the ski resort and the local availability of transportation. Helicopters, snowmobiles, and toboggans are the primary methods of transportation at most ski resorts, where CPR must be continuously performed regardless of the location. While mechanical CPR devices are beneficial, they are not practical for use or transport in ski resorts. In such scenarios, manual CPR should be performed, even in constrained environments. Standard CPR, which involves chest compressions from one side of the patient, is the most commonly performed type, and its quality is well characterized. However, alternative CPR methods can be challenging, and the quality of their compressions is not as well documented. One study showed that straddling CPR resulted in a higher number of compressions but with inadequate depth [18].

Straddling CPR and the use of mechanical devices are viable options for patients being transported on toboggans. However, participants in this study delivered chest compressions of inadequate depth, suggesting that performing straddling CPR on a moving toboggan may not be optimal. The study also noted variability in the types of toboggans used across ski areas. Straddling CPR is also commonly employed in urban settings during transportation on stretchers and hospital beds when mechanical devices are not available. A study reported a compression depth of 5.1 cm and 100% correct hand positioning during straddling CPR on a stretcher moving at a speed of 70 m/min [19]. Nonetheless, we hypothesized that stretchers and toboggans present fundamentally different conditions. In our study, four participants achieved a compression depth of 5 cm on flat snow, two reached this depth on a stationary toboggan, and none managed to do so on a moving toboggan. Abrams and Torfason observed compression depths greater than 5 cm in both moving and stationary conditions, with significantly deeper compressions in the stationary setting [10]. Although the 2020 AHA guidelines recommend a compression depth of 5 cm, the highest survival rates in a study conducted in Alabama, Dallas/Fort Worth, Milwaukee, Ottawa, Pittsburgh, Portland, San Diego, Seattle/King County, and Toronto were observed with compressions of 4.6 cm [20]. A recent study reported that the highest survival rate was obtained with a combination of 107 bpm heart rate and 4.7 cm compression depth [21]. To summarize, previous reports have indicated that it is possible to save a patient's life in clinical practice even if the 5 cm depth guideline is not met.

We also observed that the hand position deviated from the center of the chest. In contrast, a stretcher-based study reported 100% correct hand positioning [19]. Factors such as wilderness settings, movement, and winter outfits or ski boots may limit the quality of chest compressions. During data collection, all participants wore ski gloves while performing CPR, which could have influenced their ability to maintain the correct hand position. Straddling CPR has been associated with more incorrect hand positions compared to the standard and overhead methods [18].

This study has several key limitations. First, we conducted a simulation using a realistic whole-body mannequin weighing 23 kg, which does not accurately represent a real human body. As a result, chest compression performance may differ under real-world conditions. Second, the sample size was small, with only one of the seven participants being female. We recruited prehospital healthcare providers instead of ski patrollers, which may not reflect the experience of trained ski patrollers, especially since this may have been the first time most participants performed straddling CPR. Third, the study was conducted in a controlled environment, which means the quality of CPR could vary in different weather conditions, snow types, and slope angles. Additionally, the outside temperature could have affected the manikin's stiffness, as it is largely made of plastic, potentially impacting compression depth. Fourth, each participant performed compressions for only one minute, which is a relatively short duration. Fifth, regarding the order of data collection, condition 1 was always performed first for all participants. Sixth, the characteristics of the snow surface were not formally documented, although it was groomed and not ice-like. Future studies should assess the quality of CPR delivery using larger sample sizes.

We concluded that chest compression depth was inadequate during straddling CPR performed by non-ski patrol prehospital healthcare providers on a ski slope, whether directly on snow or on a moving or stationary toboggan. The shallowest compression depth occurred during CPR on a moving toboggan. If compressions on a moving toboggan are inadequate, the potential benefits of the procedure may not justify the associated risks. Our study confirms that a stay-and-play approach to CPR on a slope is advisable; however, when transportation by toboggan is necessary, rescuers must be cautious about hand positioning on a moving toboggan. Further research could explore ways to alert rescuers about this tendency and potentially mitigate the issue.

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CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

AUTHORS' CONTRIBUTIONS

Conceptualization: ST, KN; Data curation: ST, KN; Formal analysis: ST, KN; Investigation: ST, TK, YK, KK, KT, SG, KO, MS; Methodology: ST, KN, TK; Project administration: Hiroyuki Takahashi, Hideharu Tanaka; Resources: HI, SS, TK, YK, KK, Hiroyuki Takahashi; Software: HI; Supervision: Hideharu Tanaka; Validation: ST, KN; Visualization: ST, KT; Writing–original draft: ST; Writing–review & editing: all authors.

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