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Assessing Firefighters' Tourniquet Skill Attainment and Retention: A Controlled Simulation-Based Experiment

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Original Research

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Abstract

Background: The aim of this study was to train and assess firefighters' skill attainment in the use of tourniquets, and to assess their skill retention after 3 mo. The purpose is to show if firefighters can successfully apply a tourniquet after a short course based on the Norwegian national recommendation for civil prehospital tourniquet use.

Methods: This is a prospective experimental study. The study population were firefighters, and the inclusion criterion was any on-duty firefighter. The first phase consisted of baseline precourse testing (T1), a 45-min course, followed by immediate retesting (T2). The second phase consisted of retesting of skill retention after 3 mo (T3).

Results: A total of 109 participants at T1, 105 at T2, and 62 participants at T3. The firefighters achieved a higher proportion of successful tourniquet applications at T2 (91.4%; 96 of 105) as well as T3 (87.1%; 54 of 62) compared with 50.5% at T1 (55 of 109) ($P = 0.009$). Mean application time was 59.6 s (55.1-64.2) in T1, 34.9 s (33.3-36.6) in T2 and 37.7 s (33.9-41.4) in T3.

Conclusion: A sample of firefighters can successfully apply a tourniquet after a 45-min course based on the 2019 Norwegian recommendation for civil prehospital tourniquet use. Skill retention after 3 mo was satisfactory for both successful application and application time.

Tourniquets are simple, portable, and cheap instruments for controlling exsanguinating extremity hemorrhage. Controversy surrounding the effectiveness and safety of tourniquets has impeded its implementation in civilian prehospital care. The landmark articles by Kragh et al. on military tourniquet use demonstrated that the tourniquet's capacity to save lives far outweighed its risks.[1,2] Implementation of civilian prehospital tourniquet use was recommended by The American College of Surgeons Committee on Trauma and the Hartford consensus in 2013-2014.[3,4] Several descriptive retrospective studies have supported its use,[5–11] and recently Teixeira et al. demonstrated that prehospital tourniquet application was independently associated with a 6-fold mortality reduction in patients with peripheral vascular injuries compared with similarly matched no-tourniquet patients (adjusted odds ratio [OR], 5.86; $P = 0.0015$).[12] The Norwegian National Advisory Unit on Trauma published the first recommendation for civilian prehospital tourniquet use in Norway in 2019.[13] To this point, there has only been sporadic use of tourniquets in Norway among both emergency medical services and fire services. Statistics from the Norwegian Directorate for Civil Protection revealed that firefighters were first on site in 54.8% of instances where all 3 emergency services were activated,[14] and firefighters usually arrive in numbers several times the number of emergency medical personnel. Their primary objective is to deal with fires and/or chemical, biological, radiological, and nuclear (CBRN) threats, but their secondary objective is to assist emergency medical services in evacuation and treatment. Application of a tourniquet is a technical skill which only requires basic medical knowledge. Consistent with the recommendations on tourniquet use, we believe that firefighters are qualified to apply tourniquets with proper training and exercise. The aim of this study is to train and assess firefighters' skill attainment in the use of tourniquets, and to validate the skill retention after 3 mo. The purpose of this study is to show whether firefighters can successfully apply a tourniquet after a short tourniquet course consistent to the Norwegian national recommendations for prehospital tourniquet use.

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Methods

This is a prospective experimental study of firefighters' tourniquet skill attainment and skill retention. The study population was firefighters in Oslo and Tromsoe, and the inclusion criterion was any on-duty firefighter. At the time of this study, some fire units were already implementing a tourniquet course as part of their hemorrhage control training. Because the aim was to test the firefighters' skill attainment/retention solely based on the course, these units were excluded from our study. This study did not exclude firefighters with previous tourniquet experience from prior service in The Norwegian Armed Forces because the time between their military service and the study was considered to be substantial enough.

The data sampling occurred in 2 phases. The first phase consisted of baseline precourse testing (T1), a short 45-min tourniquet course based on the national tourniquet recommendation, followed by immediate retesting (T2). The second phase tested skill retention after 3 mo (T3). Primary outcome was successful tourniquet application defined as achieving both absent distal pulse (verified with doppler ultrasound) and correct placement (ie, 5-10 cm proximal to wound), as these are the factors that determine whether hemorrhage is controlled or not. Secondary outcome was application time. A live model was equipped with a simple moulage on the right thigh to simulate a bleeding injury. Each participator was asked to volunteer as moulages for the subsequent test. If a participator did not volunteer, 1 of the authors acted as the moulage. The model was instructed to breathe normally and act unconscious and unresponsive to pain.

The participant was given the following instructions: "In this scenario you will find a patient with a massive arterial bleeding on the right thigh. You are to place a tourniquet as you would in a real scenario. You are only to focus on tourniquet application. Do not examine the patient or perform any other procedures. The scene is safe for you and the patient. There is no need for you to triage the patient or to report to anyone. The tourniquet is located next to the patient. Time starts when you enter the room and stops when you state that you are finished."

The posterior tibial artery was identified and marked before each test to reduce the risk of operator error. To eliminate confounders such as differences in time spent on examining the patient, we excluded everything but the tourniquet application from the test. Descriptive data included age, gender, and previous training/experience with tourniquets. T3 was conducted identically, in addition participants reported the frequency of tourniquet applications during the past 3 mo, either real-life and/or in training. The Combat Application Tourniquet (CAT) GEN7 by C•A•T Resources, Rock Hill, South Carolina, was used in the study. The CAT is designed for 1-time use only; however, our budget did not allow us to purchase the number of tourniquets needed to achieve this. To maintain our budget, we settled to use each tourniquet up to 10 consecutive times. We noted the current round of application for the tourniquet ("tourniquet-round") during each test to see if worse results were associated with increasing number of tourniquet applications.

The participants received a 45-min theoretical and practical course in correct tourniquet application based on the 2019 Norwegian recommendation on civilian prehospital tourniquet use by the National Advisory unit on Trauma based on current evidence and Stop the Bleed Educational Consortium.[13]

The course focused on correct tourniquet indications and technique, and outlined some key concepts on duration, potential complications, and pain management. The firefighters then practiced on each other under supervision. Categorical data are reported as proportions and tested for significance using χ^2 test of independence. Continuous data, that is, application time, is reported as means with 95% confidence intervals, and analyzed using a repeated measure analysis of variance (ANOVA). A multivariate regression was performed to analyze multiple independent variables. A P-value of less than <0.05 was considered statistically significant for all the analyses. The IBM SPSS Statistics 24 software was used to analyze the data. We conducted a power calculation based on available literature on skill retention and estimated a necessary sample size of at least 87 participants, which at a 2-sided 5% significance level would provide at least 90% power to detect a relevant difference between before and after training.

Participation was voluntary and anonymous through study object numbers and the decryption key were stored separately in a locked archive. Every firefighter signed a consent form and received oral and written information on how to withdraw from the study at any time. The project was submitted to the Regional Committee for Medical and Health Research Ethics and was considered not to include elements regulated by the Norwegian Health Research act (2018/2066-2 REK Nord).

Results

Study Population

The study population consisted of 109 participants in T1 (Table 1). All were male with a mean age of 40.25 y (range 25-59 y). Of these, 69 firefighters (63.3%) had no previous experience with a tourniquet. All earlier tourniquet experience was related to service in the Norwegian Armed Forces before joining Fire and Rescue. T2 consisted of 105 participants. The remaining were lost because they were dispatched on an emergency mission during the data collection. T3 consisted of 62 participants. Changes in unit schedules made follow-up difficult, which caused the loss of an additional 43 participants.

Successful Tourniquet Applications

The proportion of successful application was 50.5% (55 of 109) at T1, 91.4% (96 of 105) at T2, and 87.1% (54 of 62) at T3 (Table 2). The firefighters achieved a significantly higher proportion of successful tourniquet applications after the course (T2) as well as 3 mo later (T3) ($P = 0.009$). A simple logistic regression was conducted where we adjusted for previous tourniquet experience to see if this affected the baseline skill level. There was no significant difference between firefighters with or without prior tourniquet experience, OR = 0.916 (CI 0.2-2.9; $P = 0.802$), we could, therefore, treat them as equals with equivalent baseline skill level. As each tourniquet was used up to 10 times, an increasing number of consecutive applications («tourniquet-round») could possibly contribute to a worse success-ratio. Also, the testing occurred in 2 parallels, where Dragset and Blix tested separate groups of firefighters. The group selection was random but could introduce observer and confirmation bias due to operator difference in use of doppler ultrasound. We ran a multivariate logistic regression where successful application was adjusted for both tourniquet-round and observer, as well as application time, to

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Table 1. Demographics N (percentage)

Population	Pre-course	109 (100%)
	Immediately after course	105 (96.3%)
	Three-months re-test	62 (56.9%)
Age (y)	Mean	40.25
	Minimum	25
	Maximum	59
Gender	Male	109 (100%)
	Female	0 (0%)
Previous tourniquet experience	None	69 (63.3%)
	>12 mo ago	36 (33%)
	6-12 months ago	2 (1.8%)
	<6 months ago	2 (1.8%)

Note: Baseline demographics for the study population.

Table 2. Tourniquet application

	Pre-course (T1)	Immediately after course (T2)	Three-months re-test (T3)
Successful tourniquet application	55 (50.5%)	96 (91.4%)	54 (87.1%)
Not successful	54 (49.5%)	9 (5.6%)	8 (12.9%)
Total	109	105	62

Note: Proportions of successful tourniquet application in the 3 test rounds.

test for these potential confounders. Neither tourniquet-round (OR, 0.998; confidence interval [CI], 0.876-1.137; $P = 0.979$) or observer (OR, 1.223; CI, 0.594-2.520; $P = 0.584$) was associated with significant differences in successful application. However, application time was statistically significant, OR 0.981 (CI 0.966-0.997; $P = 0.016$) (Table 3). Meaning, faster tourniquet application was associated with a slightly greater odds of achieving a successful application, but the difference was miniscule.

Application Time

Mean application time in the 3 rounds was 59.6 s (55.1-64.2), 34.9 s (33.3-36.6), and 37.7 s (33.9-41.4), respectively (Table 4). A repeated measure ANOVA showed a significant difference between the groups. Mauchly's test of sphericity indicated that the assumption of sphericity was violated ($P < 0.001$), therefore, a Greenhouse-Geisser correction was used ($P < 0.001$). Post-hoc tests using the Bonferroni correction revealed that the firefighters were significantly slower precourse compared with both T2 (mean difference, 24.7 s; $P < 0.000$) and T3 (mean difference 22.0 s; $P < 0.000$), but not between T2 and T3 (mean difference, 2.7 s), $P = 0.983$) (Table 5). The firefighters reduced their mean application time by 41.4% after the course, and the time usage did not increase significantly after 3 mo.

Tourniquet Use Between T2 and T3

The rate of participants who reported tourniquet training or real-life use between T2 and T3 were extremely low 3/62 (4.7%). Based on the low rate, it was considered as a weak confounder and not included in the final analysis.

Discussion

The firefighters achieved 91.4% successful applications and reduced their time use by 41.4% after the course. Skill retention was satisfactory after 3 mo by achieving 87.1% successful applications, without significantly increasing the time usage. This validates the quality of the course based on the new tourniquet recommendation. We believe that a short 45-min tourniquet course including indications, technique, possible complications and practical training is both necessary and highly cost-beneficial. The rate of 50.5% successful tourniquet applications pre-course confirms that a course is necessary to be able to correctly apply a tourniquet. Placement of the tourniquet directly over the wound among some of the firefighters illustrated a basic knowledge gap, but the subsequently excellent results in T2 and T3 demonstrated that tourniquets are simple devices which can be mastered by people with limited medical qualifications. This observation is substantiated by the 2019 study by Smith and colleagues where law enforcement officers and/or firefighters constituted 27.3% (65 of 238) of all tourniquet application.[15] Contrary to this, Goralnick et al. assessed tourniquet skill attainment and retention among laypersons after a 1-h in-person course and found similar 87.7% successful applications immediately after the course, but only 54.5% when retested 3-9 mo later. Of interest though, they did not discover further skill decay between 3 and 9 mo.[16] A 2019 study by McCarty et al. compared self-reported prior first aid (FA) and hemorrhage control (HC) training with no prior training in laypersons' ability to apply a tourniquet.[17] The proportion of successful applications for those who reported no prior training, FA training only, and FA+HC training was 14.4% (16 of 111), 25.2% (35 of 139), and 35.8% (24 of 67), respectively. The control group from the study by Goralnick et al. achieved similar numbers (16.3%).[16] The comparatively greater precourse success-ratio among the firefighters in our study (50.5%) indicate that the firefighters were dexterous and quick learners. As firefighters with prior tourniquet experience preceding more than 12 mo before the study did not achieve better T1 success-ratio, skill decay occurs presumably between 3 and 12 mo. Martinez et al. evaluated the effect of a tourniquet refresher training session among French soldiers and concluded that a tourniquet refresher session was especially effective 6 mo since the previous training.[18] Norwegian firefighters re-certify their first aid and cardiopulmonary resuscitation (CPR) qualifications every 12 mo. We view CPR as more essential and challenging than tourniquets, and do not believe they should require re-certification more frequently than CPR. We suggest tourniquet re-certification every 12 mo as part of firefighters' hemorrhage control training. Twenty-five people were murdered in 2018 in Norway, 13 of which were killed by firearms or stab-weapons.[19,20] In the same year, 108 people were killed in motor vehicle accidents The estimated number of murders in the United States in 2017 was 17 284 and 37,461 people were killed in motor vehicle accidents in 2016.[21] These numbers illustrate that the rate of incidents with potentially exsanguinating extremity hemorrhage is very low in Norway. Also, the number of emergency providers generally exceeds the number of patients, which permits the use of traditional hemorrhage control such as direct pressure and wound packing. This might not be the case for rural Norway, where firefighters, especially, could arrive on-scene several minutes before emergency medical services and law enforcement. Regardless of emergency services' mobility, one can never foresee a pending mass casualty event with multitudes of exsanguinating extremity hemorrhage where tourniquets could be lifesaving.

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Table 3. Adjusted odds ratio for time, observer, and tourniquet round (T1-T3)

	B	S.E.	df	Sig.	OR	95% CI
Tourniquet-round	−0.002	0.066	1	0.979	0.998	0.876 – 1.137
Tourniquet-round	−0.002	0.066	1	0.979	0.998	0.876 – 1.137
Application time	−0.019	0.008	1	0.016	0.981	0.966 – 0.997
Observer	0.202	0.369	1	0.584	1.223	0.594 – 2.520

Table 4. Application time

			95% CI for mean	
	N	Mean ± SD (s)	Lower bound	Upper bound
Pre-course	109	59.64 ± 23.7	55.14	64.15
Immediately after	105	34.94 ± 8.5	33.30	36.59
Three-months re-test	62	37.66 ± 14.8	33.90	41.43
Total	276	45.31 ± 20.8	42.84	47.77

Note: Mean time used on tourniquet application in the 3 rounds.

Table 5. Post hoc analysis Bonferroni correction

Test (A)	Comparator (B)	Mean difference (A-B)	Std. error	Sig.	95% CI
Pre-course (T1)	T2	24,699*	2,366	,000	19,00 – 30,40
	T3	21,981*	2,753	,000	15,35 – 28,61
Immediately after course (T2)	T1	−24,699*	2,366	,000	−30,40 – −19,00
	T3	−2,718	2,772	,983	−9,39 – 3,96
Three-months re-test (T3)	T1	−21,981*	2,753	,000	−28,61 – -15,35
	T2	2,718	2,772	,983	−3,96 – 9,39

Note: Bonferroni post hoc multiple pairwise comparison of time used on tourniquet application between T1-T3.

To prepare for such an unforeseeable event, we strongly recommend that firefighters and emergency medical services implement tourniquets in their hemorrhage control protocol. Emergency medical personnel are obviously qualified to use tourniquets, and we do not know whether they would succeed without the course. Regardless of expertise, we would not recommend implementing new equipment without proper training.

Limitations

Oslo Fire- and Rescue Department was selected because it is the largest fire department in the country, and Tromsoe Fire- and Rescue Department was selected because of its close vicinity to UiT – The Arctic University of Norway. Every on-duty firefighter was invited to participate, and none declined. Every participant was male, but as only 2.3% of firefighters in Norway are female, we believe that the study population is representative for Norwegian firefighters. The initial population size of 109 participants was positive. The loss to follow-up was 3.7% at T2 and 43.1% at T3. The follow-up rate was lower than desirable at 3-mo, but the loss was out of our control and caused by changes in the unit schedules. The execution of the testing has some limits. First, confirmation bias and observer bias cannot be ruled out as we conducted our own testing. Second, we would have preferred to use the tourniquets only 1 time each, as recommended by the manufacturer. We did not have the budget to accomplish this; however, an increased number of "tourniquet-rounds" was not associated with a lower odds-ratio of achieving a successful tourniquet application (Table 3). Third, the moulage/model during the testing was the firefighter that had just finished the test. They were instructed to act unconscious and unresponsive to pain, but tourniquets will elicit considerable pain when applied correctly. The fear of hurting a colleague was partly a cause of unsuccessful applications among the firefighters. This was observed in all 3 test rounds, but predominantly in the pre-course testing. An inert model could eliminate this source of error but would not prepare the firefighters for a real-life response. A patient's likely intense pain as a response to tourniquet application was discussed in the course. Last, to evaluate the full benefit and quality of the course, we should have tested their knowledge and skill concerning indications for tourniquet use. Tourniquets are recommended in exsanguinating extremity hemorrhage which cannot be controlled by direct pressure and wound packing. Tourniquet use in hemorrhage where direct pressure and wound packing is enough, increases the risk of possible complications without increasing survival benefit. We did not have the time or resources to conduct a theoretical or practical test to evaluate indications for tourniquet use.

Conclusions

A sample of firefighters can successfully apply a tourniquet after a 45-min course based on the Norwegian recommendation for

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civilian prehospital tourniquet use. The firefighters achieved 91.4% successful applications and reduced their time usage by 41.4% after the course. Skill retention was satisfactory after 3 mo by achieving 87.1% successful applications, without significantly increasing the time usage. We strongly recommend that tourniquets should be a part of firefighters' hemorrhage control kit, but they should not be implemented without proper training. We recommend that tourniquet use, and validated training is standardized through all prehospital first aid providers across the country, including both the fire and rescue service, law enforcement, and emergency medical service. Further studies should investigate the potential survival benefit after structured implementation of tourniquets in the prehospital emergency care across all emergency response services.

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