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ORIGINAL SCIENTIFIC REPORT

Extremity Tourniquet Training at High Seas

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Abstract

Background Future navy officers require unique training for emergency medical response in the isolated maritime environment. The authors issued a workshop on extremity bleeding control, using four different commercial extremity tourniquets onboard a training sail ship. The purposes were to assess participants' perceptions of this educational experience and evaluate self-application simplicity while navigating on high seas.

Methods A descriptive observational study was conducted as part of a workshop issued to volunteer training officers. A post-workshop survey collected their perceptions about the workshops' content usefulness and adequacy, tourniquet safety, self-application simplicity, and device preference. Tourniquet preference was measured by frequency count while the rest of the studied variables on a one-to-ten Likert scale. Frequencies and percentages were calculated for the studied variables, and application simplicity means compared using the ANOVA test ($p < 0.05$).

Results Fifty-one Spanish training naval officers, aged 20 or 21, perceived high sea workshop content's usefulness, adequacy, and safety level at 8.6/10, 8.7/10, and 7.5/10, respectively. As for application simplicity, CAT and SAM-XT were rated equally with a mean of 8.5, followed by SWAT (7.9) and RATS (6.9), this one statistically different from the rest ($p < 0.01$). Windlass types were preferred by 94%.

Conclusions The training sail ship's extremity bleeding control workshop was perceived as useful and its content adequate by the participating midshipmen. Windlass types were regarded as easier to apply than elastic counterparts. They were also preferred by nine out of every ten participants.

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Abbreviations

JSE	Juan Sebastian de Elcano
ET	Extremity tourniquet
PHEC	Pre-Hospital Emergency Care
M-PHEC	Military Pre-Hospital Emergency Care
MERT	Medical Emergency Response Teams
PRT	Primary Retrieval Teams
CAT	Combat Application Tourniquet Gen 7
SAM-XT	SAM-Extremity Tourniquet
SWAT	Stretch Wrap and Tuck Tourniquet Gen 1
RATS	Rapid Application Tourniquet System
SOFTT	Special Operations Force Tactical Tourniquet

Introduction

Training sail ships are employed by several navies worldwide as navigating classrooms where future officers receive training. The Spanish Navy has the Juan Sebastian de Elcano (JSE), a four-masted sail ship that has sailed over two million nautical miles [1]. The ship is the campus for the semester at sea, within the Naval Academy's fourth academic year program syllabus. The studies onboard typically include navigation, meteorology, geography, naval maneuvers, electronic warfare, and naval weaponry. In 2019 the XCI voyage of the JSE included an innovative extracurricular workshop during high sea navigation. For the first time, extremity bleeding control and tourniquet self-application training were scheduled as part of the onboard educational program.

Hemorrhage is the leading cause of preventable death in both military and civilian trauma. Early application of extremity tourniquets (ETs) is currently accepted as the standard treatment for life-threatening extremity hemorrhage [2–4]. The classic Pre-Hospital Emergency Care (PHEM) paradigm has changed from airway-breathing-circulation (ABC) to Military-PHEM (M-PHEC), addressing catastrophic hemorrhage before airway, breathing, or circulation (< C > ABC) [5]. These changes and ET application at the site of injury before the onset of shock are associated with improved survival [6]. This innovative approach introduced by the military is currently advocated for civilian practice [7]. Most of the tourniquet reports published focus on military experience gained from its application by ground troops and field hospitals [8–10]. However, this lifesaving technique employed by Medical Emergency Response Teams (MERT) is useful not only for ground troops but also in austere environments and during transoceanic navigation. [11] Naval operations require unique emergency medical response training due to the accompanying circumstances, such as isolated setting, distance from medical facilities, restricted storage capacity, limited onboard resources, and seasickness caused by constant and irregular movement that can influence medical response and ET self-application.

Specialized units of the Royal Navy have developed specifically trained teams for M-PHEC in the maritime environment [11–14]. These Primary Retrieval Teams (PRT) provide emergency care with limited equipment during hostile maritime activities. Hemorrhage control employing ETs and hemostatic agents is one of the PRT teams' crucial skills, but not yet part of the Spanish midshipmen's current syllabus. Training gaps for military naval surgeons isolated at sea have been identified before. [15] Those gaps are also present for Spanish midshipmen.

Nevertheless, currently, all future navy officers should be instructed in PHMC, including updated tourniquet application and limb pressure dynamics concepts. Current understanding of how extremity tourniquets work has changed. Because tourniquet occlusive pressure decreases over time [6], even if effectively applied, its performance has to be monitored until hospital arrival. [16] Today, the tetrad concept of use, patient, intervention, and situation, explain why that happens, and those innovative concepts should be a part of the training provided onboard training sail ships.

Training future navy officers during the semester at sea voyage offers unique opportunities for teaching M-PHEC while navigating high-sea conditions. These conditions have been simulated before to train surgical teams afloat [17]. However, no previous studies have reported ET application workshops aboard naval training sail ships on high seas to our knowledge. Navy training sail ships offer a unique scenario for practicing tourniquet application. To enhance future officers' education aboard the JSE and assess the acceptance of such training, the researchers conceived a novel extremity bleeding control workshop. It was designed to be delivered during a transoceanic voyage, considering that the sailing conditions are challenging to reproduce.

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This study's main objective was to assess the midshipmen's perception of the workshop's usefulness, content adequacy, onboard tourniquet application safety, and overall satisfaction with the activity. Additionally, the study attempted to evaluate which type of tourniquet mechanism, windlass or elastic, would be easier to apply while navigating in high sea conditions and which of the tested types would be preferred. We hypothesized that the activity's innovativeness would be well received by the young midshipmen onboard the JSE and serve as a unique training experience for future naval officers.

Methods

A descriptive observational study was conducted during the 2019 voyage aboard the Spanish Armada's JSE training sail ship. (Fig. 1) The study was conducted with the Educational Committee's approval and authorized by the JSE's commanding officer. It exempted ethical approval since all the study activities were part of the sailors' onboard training program and did not involve any human or animal experimental activities. The authors conceived a one-day workshop issued in a high sea state in the middle of the South Atlantic Ocean after 30 days of navigation. The workshop was composed of two activities, theoretical content, and hands-on practice. The theory included two 1-h sessions, the first of which was addressing the physiology of trauma hemorrhage, extremity bleeding control techniques, updated principles of tourniquet dynamics, and indications for ET use. The second session was about prepositioning on upper or lower extremity, actual positioning, and securing technique for each device. The two-hour hands-on experience was performed in a fully equipped sailing uniform with offshore waterproof gear. All the participants had the opportunity to perform self-application and buddy-application techniques on the upper and lower extremities using four different commercial ETs, two windlass and two elastic types. The tourniquets selected were the windlass models, C•A•T Resources, LLC, Combat Application Tourniquet® Gen-7 (CAT), and the SAM Medical®, SAM-Extremity Tourniquet (SAM-XT). The elastic models employed were the HH Med-Corp, Stretch, Wrap, and Tuck Tourniquet (SWAT™), and the RATS- Rapid Medical, Rapid Application Tourniquet System Gen 1 (RATS®). The ship's physician, a seasoned surgeon with tourniquet use experience, delivered all the lectures and briefings. Two senior officers assisted him during the hands-on activities, supervising tourniquet application technique and assessing application effectiveness by palpating radial pulse on the upper extremity and by inspection when used in the lower extremity.

Fig. 1 Spanish Armada Juan Sebastian de Elcano training sail ship that hosted the tourniquet application and assessment workshop during the 2019 semester at sea voyage

Two hundred sixty sailors, including eighty midshipmen, formed the JSE's complete crew; fifty-one of them volunteered to participate in the study. All the workshop participants were healthy midshipmen studying the semester at sea within the fourth year of the Spanish naval academy curricular program. None of the participants had prior experience with tourniquet application and had not participated in previous tourniquet workshops during navigation. Participation in the study was voluntary and excluded those performing essential navigation tasks. A post-workshop anonymous structured survey collected data in four categories. The first obtained participants' demographic data, the second queried attendees' perceptions regarding the workshop's usefulness, content adequacy, perception of onboard tourniquet application safety, and overall satisfaction with the activity. The third category assessed participants' opinions concerning the simplicity of application for each of the models tested, and the last asked for device preference. Descriptive statistics were applied to the demographical data, and the rest of the assessed variables were measured on a Likert one-to-ten linear scale. Ten represented highly adequate or useful, simplest or safest, and one, less adequate or useful, the least simple or least safe, depending on the variable queried. Tourniquet preference was measured by frequency count, with only one device to select as the preferred. Likert scale mean values for the perception of application simplicity during navigation for the different tourniquets were compared using the ANOVA test with repeated measure; $p < 0.05$ was considered statistically significant.

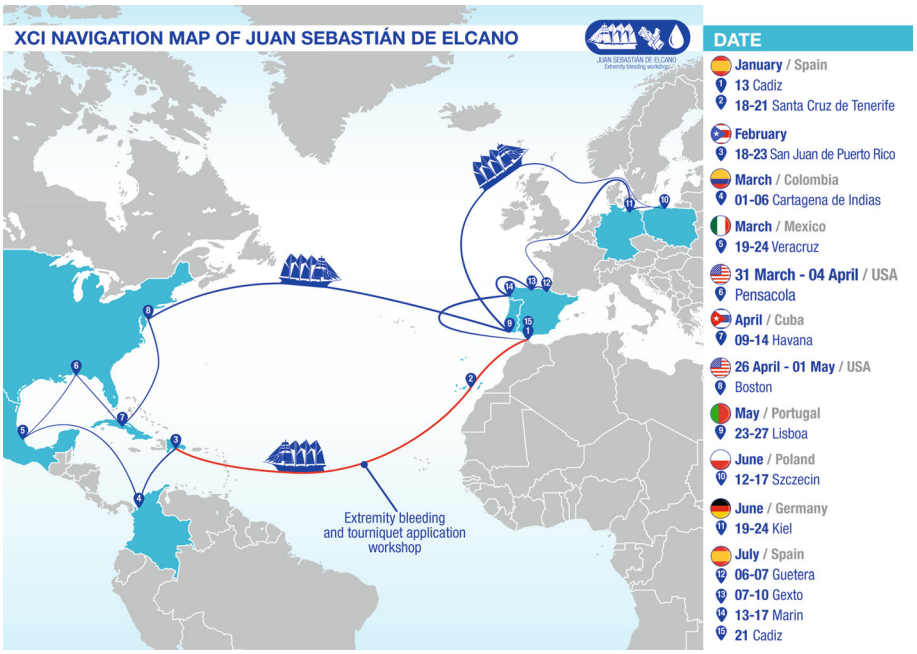

Fig. 2 Navigation map of the Juan Sebastian de Elcano 2019 six-month voyage. The extremity tourniquet workshop was performed on high seas during the trip from Santa Cruz, Tenerife, to San Juan, Puerto Rico, in the middle of the South Atlantic Ocean

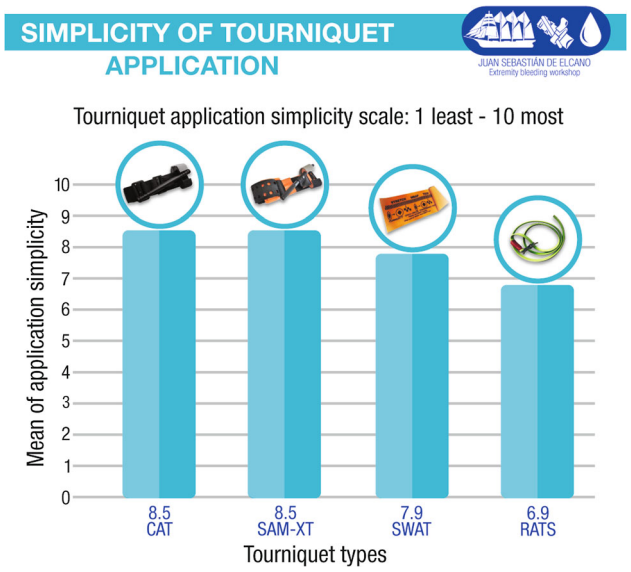

Fig. 3 Application simplicity mean values for the tourniquets employed during the JSE workshop during high sea navigation. (CAT 7- Combat application Tourniquet® Gen-7, SAM-XT Sam Application Tourniquet®, SWAT™ Stretch Wrap and Tuck Tourniquet, RATS® Rapid Application Tourniquet System)

Results

The study population (n = 51) was composed of 8 (16%) females, and 43 (84%) males, aged 20 or 21.

The study was conducted during the six-month XCI voyage of the JSE that departed from Cadiz, Spain, on the 13th of January of 2019. The workshop was issued in the middle of the South Atlantic Ocean. (Fig. 2).

The reported mean value for workshop usefulness among participants was 8.6 and 8.7 for content adequacy, while overall satisfaction was given a mean rating of 9.3. The opinion regarding onboard tourniquet use safety was rated with a mean of 7.5. Assessment of the four devices' application simplicity showed that both with a windlass mechanism (CAT and SAM-XT) were considered simpler to use, with a mean value of 8.5. The elastic types were ranked lower (SWAT, 7.9; RATS, 6.9). (Fig. 3).

(Fig. 3) However, a statistical difference was only found for the RATS ($p < 0.01$), which ranked the lowest. (Fig. 4) The CAT was selected as the preferred by 38 participants (74%), followed by the SAM-XT 10 (20%), SWAT 2 (4%), and RATS 1 (2%). When comparing device choice based on their mechanism, the windlass types were chosen by 94%, and only 6% favored the elastic ones (SWAT and RATS). (Fig. 5).

Discussion

This descriptive observational study of the implementation of an extremity bleeding control and tourniquet application workshop, among inexperienced midshipmen of the JSE, during navigation demonstrates the high level of acceptance among participants of performing PHMC training. The ranked perception of usefulness (8.6) and content adequacy (8.7) of the ET training workshop during high sea navigation suggest the convenience of including these

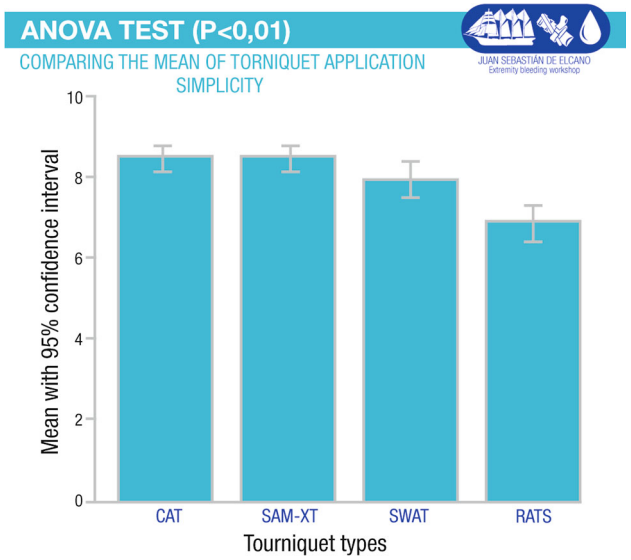

Fig. 4 ANOVA test comparing the mean of tourniquet application simplicity. Although the tourniquets with a windlass mechanism (CAT-7 and SAM-XT) were considered simpler to use, statistical difference was only found for the RATS ($p < 0.01$), which ranked the lowest among all four. (CAT- Combat application Tourniquet® Gen-7, SAM-XT Sam Application Tourniquet®, SWAT™ Stretch Wrap and Tuck Tourniquet, RATS® Rapid Application Tourniquet System)

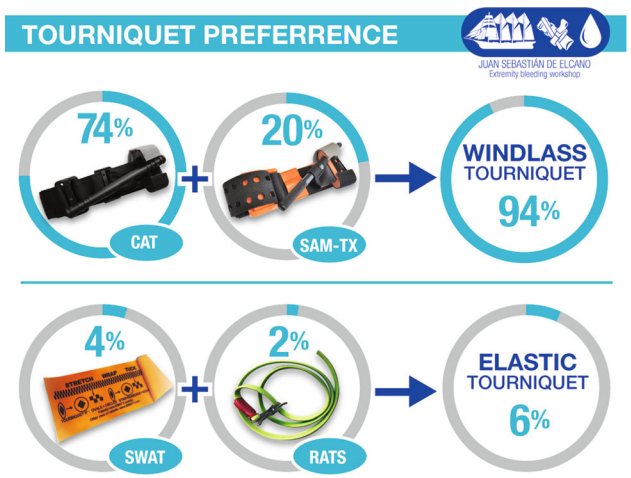

Fig. 5 The percentages of tourniquet preference among the four devices tested are depicted individually and by the mechanism of vascular occlusion (windlass vs. elastic types). (CAT- Combat application Tourniquet® Gen-7, SAM-XT Sam Application Tourniquet®, SWAT™ Stretch Wrap and Tuck Tourniquet, RATS® Rapid Application Tourniquet System)

activities into the academic program aboard training sail ships. The unique conditions in which we conducted the workshop are not reproducible in conventional training scenarios. Additionally, the high level of overall satisfaction (9.3) declared during the activity stimulated teamwork and partnership. It is worth commenting that during PHM in isolated scenarios, tourniquet application is a temporary bleeding control measure that should only be employed in severe life-threatening extremity hemorrhage when other bleeding control methods fail. When applied, they should be re-evaluated and replaced with a hemostatic dressing or other definitive bleeding control methods as soon as possible. Even though there was no direct measure about teaching activity success onboard the sailing ship, the authors consider that the hands-on supervised training with four commercial TQs had a tremendous educational value. This introductory study performed for the first time afloat the JSE served as a pilot study for the organizers and as a foundation to ET use for midshipmen.

Since the participants had no prior experience using ETs, the study served as a formative experience that other prospective studies of objective nature should follow. For the upcoming studies, the authors consider applying objectives methods of training quality assessment. Martinez et al. describe a useful performance score for ET training programs that includes a scale with four categories: effectiveness, total placement time, tourniquet prepositioning, and tourniquet preparation [18]. The conditions in which our study was developed made its application impracticable. Nonetheless, it does highlight the benefit of progressive refreshing training sessions, and a modified version could be employed in future studies on the JSE. Kragh et al. report similar findings, advocating for basic training early during the soldiers' formation, followed by retraining with refresher drills before deployment [6]. Our workshop attempted to issue basic training in extraordinary conditions, creating a foundation for future and progressive skill acquirement.

Several countries have training sail ships: U.S Coast Guard the "USCG Eagle," German Navy the "Gorch Fock," Royal Australian Navy the "Young Endeavour," Italian Navy the "Americo Vespucci," Indian Navy the "INS Tarangini," Bolivarian Navy of Venezuela the "Simon Bolivar," Japanese Navy the "Kaiwo Maru," Peruvian Navy the "BAP Union," and Polish Navy the "Dar Młodzieży," Chilean Navy "Esmeralda." However, to our knowledge, ET workshops have not been previously reported in any of them. Naval training sail ships offer the ideal scenario for training maritime PHEC. ET application is a life-saving skill that may be required in future missions. Specific bleeding control training better prepares future naval officers for potential injuries during high sea navigation in isolated maritime environments. Even during non-hostile training voyages, sailing in adverse weather can cause injuries from broken sail lines under tension, causing lacerations and extremity hemorrhage [19]. Future

naval officers must also prepare themselves for hostilities related to sea battles and piracy encounters that might expose them to penetrating trauma and or blast injuries.

Training PHEC and ET applications while navigating high seas vary considerably from those for land troops, primarily due to wet conditions and constant and irregular vessel motion, which can cause seasickness, making tourniquet self-application challenging. Our study reported higher application ease for the windlass over the elastic models. There are few reports of ET application by naval units to compare our results. Heldenberg et al. evaluated three tourniquet types (CAT, Special Operations Force Tactical Tourniquet "SOFTT" and an improvised device) among 23 operators of the Israeli Naval Defense Forces [20]. Their findings regarding application simplicity were similar to ours, with windlass tourniquet types graded higher for application simplicity. Our results show that even without prior training, the JSE midshipmen considered that the two windlass types were easier to apply than the two elastic types, and concerning device preference, the participants favored those with the windlass mechanism over the elastic counterpart, the choice that might have resulted from the simplicity of the tourniquet securing system. Compared with the elastic models, the windlass type devices required less effort to place around the extremity, and the locking system was easier to secure. We consider that these elements influenced participants' preference between the types tested.

Limitations of this study include the lack of participation of all the midshipmen aboard.

The study's descriptive nature, the limited time dedicated to the hands-on practice, and the attendees' responses and preferences were based on personal perceptions. Furthermore, due to the study conditions, there was no objective measure of the teaching success; this should be introduced in future training activities. However, our workshop's participants' perceptions about its usefulness, content adequacy, and overall satisfaction suggest the high educational benefit of such activities onboard. The workshop added valuable ET application training in high sea conditions to future navy officers. Further research should be directed at developing maritime M-PHEC educational programs on other training sail ships and designing methods to evaluate the effectiveness level of such endeavors.

Conclusion

Participating future Spanish navy officers were exposed to self- and buddy tourniquet application while on high seas aboard a sail training ship, after receiving theoretical information on when and how to use them. The workshop was perceived as valuable and its content adequate. The two windlass tourniquet models (CAT and SAM-XT) were regarded equally, as simpler and easier to apply than the two elastic ones tested (SWAT and RATS). Those with windlass mechanism were preferred over the elastic by nine out of every ten participants.

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Declarations

Conflict of interest Carlos Yánez Benítez, Marcelo A. F. Ribeiro Jr., Mansoor Khan, Teófilo Lorente, Esther Asensio, José Antonio López, Isabel Martínez, Marcelo A. F. Ribeiro Jr., Juan L Blas, Antonio Güemes have no conflict of interest.

Ethical approval The study was conducted with the approval of the Spanish Navy Educational Committee and of the Juan Sebastian de Elcano's commanding officer. Ethical approval was exempted due to the lack of because experimentation on humans or animals. All the activities related to the study were part of the sailors' onboard training program and did not involve experimental activities.

Consent for publication The submission does not include images that may identify any person. Informed consent was obtained from all the participants included in the study.

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