Smart Tourniquet System for Military Use

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Abstract

Extremities are the most frequently injured regions of body encountered with the combat casualties. The extremity hemorrhages constitute the leading cause of preventable deaths in the first aid period. Thus, tourniquets are indispensable devices for combat casualty care. There are some military tourniquets, which are produced worldwide and can be manually applied by the wound to prevent blood loss. However, in military applications, there is no tourniquet system comprising these features that can be used with one hand, can be applied quickly and transmits information. We have developed a tourniquet system which applies the required pressure to the extremity of the person by moving a belt connected to the pulley with a motor. When the arm or leg buttons on the device are pressed, the system is activated. Once the belt is fitted to the extremity, the system automatically starts the tourniquet process and is continued until the bleeding is stopped. The information of the blood flow and force applied are acquired via the feedback from the motor encoder and the force sensor. The system starts the tourniquet process and the bluetooth transmits the location and application time of the tourniquet. The receiver informs the headquarters via the military communication standard. In this respect, it is possible to be informed about exact location of the injured soldiers in the hot zone. In order to test the developed tourniquet, we have produced the leg phantoms which consist of femur bones and plastics similar to in actual dimensions of the human leg and artificial veins. Tourniquet operation was applied to the point where the tourniquet operated blood flow stopped. It is thought that the developed system will be used in military applications and internal security.

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Keywords

Extremity injury • Hemorrhage • Preventable death
Tourniquet

1 Introduction

1.1 Tourniquet Structure and Demand of the Tourniquet Systems

The tourniquet is a medical device that has been used for a century and a half ago and that is being used to stop blood flow in amputee operations and to stop bleeding in the limb injuries. The tourniquet is applied to the proximal part of the limb by a tightened belt or a bandage wider than 3 cm [1]. Although the application of tourniquet seems simple, the correct application of tourniquet is critical to prevent mortality. In the terrorist incidents that took place in our country between 2006 and 2014, 677 security force employees were killed, and 1925 personnel were injured [2]. Data from a combat support hospital shows that 70% of casualties inflicted extremity injuries of which 16.4% required tourniquet application due to concomitant vascular injuries [3]. Combat application tourniquet (CAT) is among the most widely used tourniquets in United States Army's with a reported success rate of 79% [4]. Similar tourniquets are being used in Turkish Armed Forces (TAF). However, in two separate prospective randomized trials with 102 and 145 participants, the efficacy in the lower limb was 50–88% and 70%, respectively [5, 6]. It was observed that if the efficacy was not controlled by an objective pressure threshold, the subjective feeling of pressure by the applier leads to 30% application failure [5]. It is therefore possible that military personnel may still to bleed to death in Turkish Armed Forces (TAF) due to extremity injuries.

L. Lhotska et al. (eds.), *World Congress on Medical Physics and Biomedical Engineering 2018*,
IFMBE Proceedings 68/3, https://doi.org/10.1007/978-981-10-9023-3_51

1.2 Tourniquet Systems and Tourniquet Patents in Literature

There are different types of tourniquets developed for military purposes to stop the bleeding in extremity injuries. The Combat Application Tourniquet (CAT) and the Special Operations Forces Tactical Tourniquet (SOFTT) are applied by manually twisting the belt with the windlass. At the Emergency and Military Tourniquet (EMT), the hand pump is manually inflated to create pressure and stop bleeding. Success rates of these tourniquets are 92% in EMT, 76% in CAT and 66% in SOFTT [7]. There are also tourniquets produced for commercial purposes which are Ratcheting Medical Tourniquet (RMT), Mechanical Advantage Tourniquet (MAT) and Combat Ready Clamp (CRoC). There are number of patents such as Tourniquet and Method of Using Same, Tourniquet Timer, Electromechanical Tourniquet for Battlefield Application, Electric Automatic Tourniquet System. Considering tourniquet systems commercially available on the market, there is no system that can be applied with one hand to completely stop the blood flow especially on the lower extremity [8]. It is necessary that tourniquet can reach a constant pressure value and remain at that value for successful application. When the soldier is injured and rapidly loses blood, he tries to wear and squeeze the tourniquet, but it is difficult to adjust the tourniquet with required pressure. Once the tourniquet is applied, it should be loosened for 5 min at intervals of 1 h and let the blood flow of the injured extremity should be ensured. Thus, the risk of possible gangrene is reduced [9]. With this motivation, an intelligent tourniquet system which is named Military Smart Tourniquet (MST) has been produced that can be used for the military field to stop the blood flow on both the lower and upper extremities, can be applied to the arm or leg alone, can show and send the tourniquet's application time, applied position and pressure. Moreover, the MST has been passed the system functionality tests which are tourniquet application between proper time both tightening and loosening, system using in dark environment, stopping blood sample using with a leg phantom and working the MST at least 6 h with a full chargerd battery.

2 Materials and Methods

2.1 Mechanical Design

MST is a mechanism which has a bandage to surround extremities via a pulley. MST is used to block the bleeding on the limbs and besides it applies certain force on extremities. In order to transfer power and movement a worm gear mechanism is used in MTS. The mechanism design was started first evaluating system needs then it was modeled in computer with 3D solid design software (Fig. 1a). MST is an intelligent system that can apply the required force via tourniquet operation on both upper and lower extremities. In humans, the average arm circumference is 288.4 mm and the average circumference of the leg is 349.7 mm [10]. MTS's tourniquet belt has 47.6 mm wide. Hence, it is possible to calculate the application area of the tourniquet with the extremity known for its width and length. For successful application of the tourniquet, a certain pressure has to apply on extremites which is at least 140 mmHg on the upper limb and at least 229 mmHg on the lower limb [11]. There are no other criteria in the literature about the required pressure (mmHg) to stop the flow of blood in extremity injuries. Using with average leg circumference and tourniquet belt width can be reached the area of tourniquet applying region. Therefore, some cascade equations which are given below between 1 and 4, estimated tourniquet applying force can be derived.

$$A = 47.6 \times 10^{-3}.349.7 \times 10^{-3}\mathrm{m}^2 \tag{1}$$

$$1\,\mathrm{mmHg} = 133.33\,\mathrm{Pa},\ 1\,\mathrm{Pa} = 7.5006 \times 10^{-3}\,\mathrm{mmHg} \tag{2}$$

$$P = 229\ \mathrm{mmHg} \times \frac{1\,\mathrm{Pa}}{7.5006 \times 10^{-3}\mathrm{mmHg}} \tag{3}$$

$$F = \frac{229}{7.5006 \times 10^{-3}} \frac{N}{\mathrm{m}^2} \times 47.6 \times 10^{-3}.349.7 \times 10^{-3}\mathrm{m}^2 \tag{4}$$

According to calculations, the desired force must be applied on the average leg circumference has determined as 508 N in the tourniquet application. Moreover, to tourniquet application a motor is specified which can be applied 2288.28 N in MTS. In this case, the selected motor can be able to apply a force of 1.96 times the targetted force to the muscle with the MST [8]. The mechanical design of the MST (Fig. 1b) is completed by the addition of the MST's electronic control card, user information display, system user buttons, tourniquet belt, tourniquet belt lock mechanism.

2.2 Electronics Design

While the MST electronic design was being made, the requirements of the system were determined first, then the electronic materials needed for the system design were procured and the PCB of the system control board was produced. Simultaneously with the hardware design, the software development process was completed by embedding

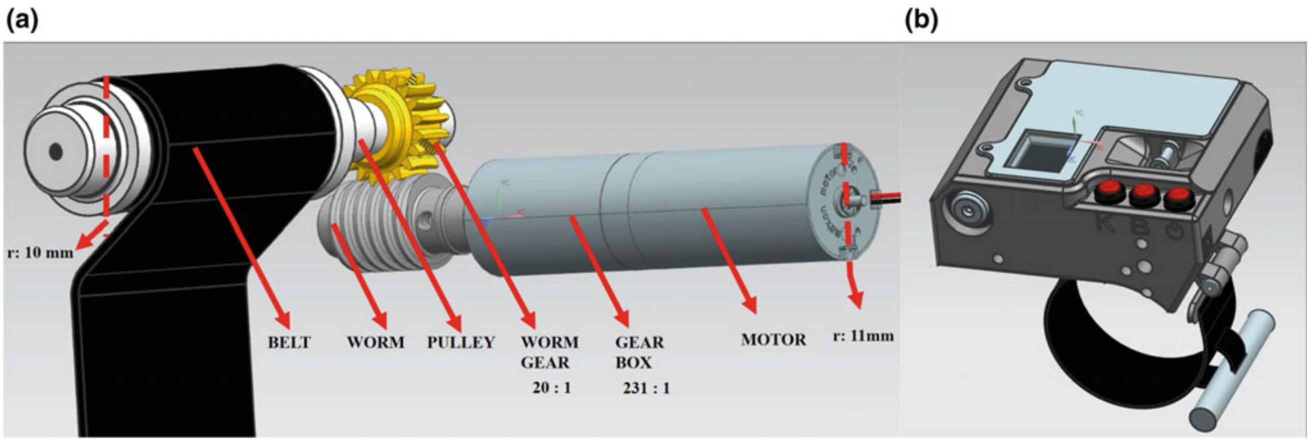

Fig. 1 **a** MST's worm gear mechanism 3D design, **b** MST's 3D design

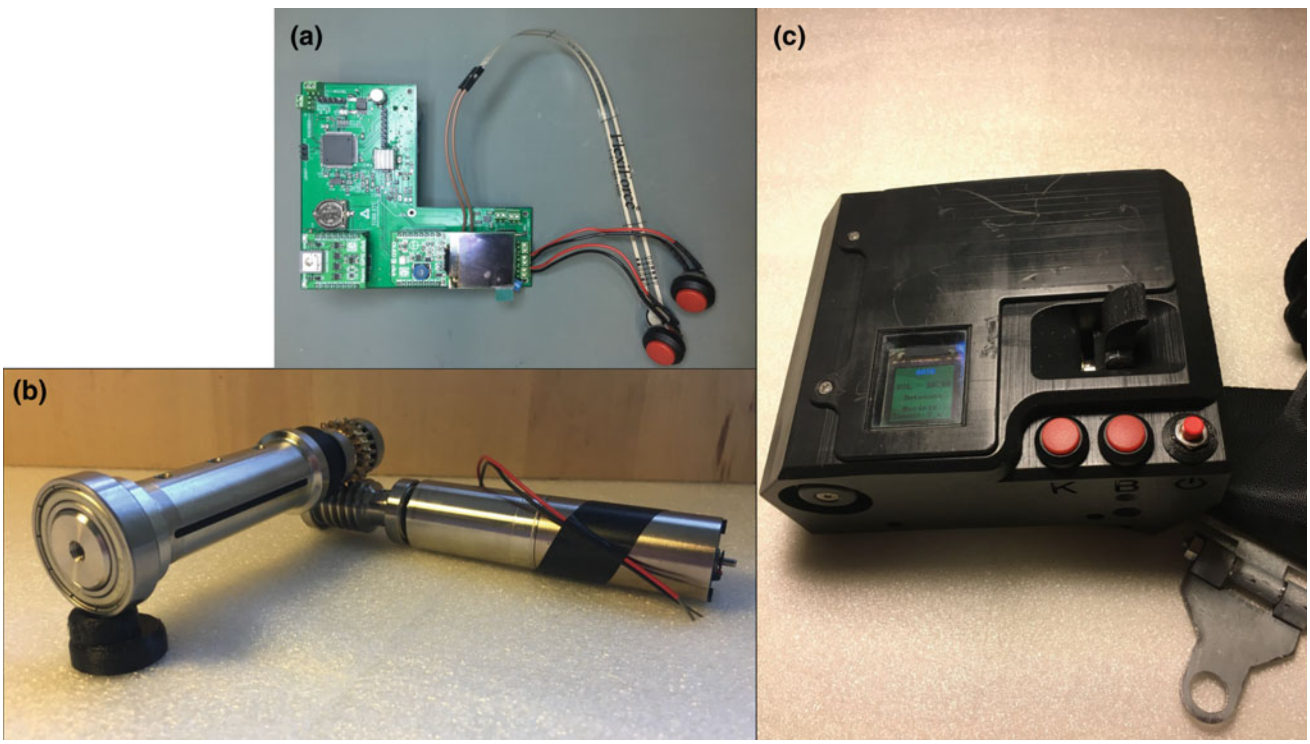

Fig. 2 **a** MST's control card, **b** MST's worm gear mechanism assembly, **c** MST

the software in the designed PCB and ensuring the optimum operation with the peripheral elements. MST comprises of; electronic control card (Fig. 2a), tourniquet mechanism, tourniquet belt's lock mechanism, system battery, user information display and user system control buttons. The ARM Cortex-M4 based STM32F407VGT microcontroller is used in the controller of the MST. The controller takes input from the output of the encoder which calculates the number of rotations of the motor, digital signals are produced by user buttons, the output of the force sensor, which provides feedback for the user to make the tourniquet process happen. The controller uses different communication protocols during tourniquet operation. It controls the user information display via SPI, the Bluetooh module via USART, the motor driver using with TIMER and GPIO peripherals. The controller, which uses its own FLASH memory to keep the data from the encoder in memory, uses the TIMER interrupt so that the system algorithm can take place at a certain time. The tourniquet time information applied by the injury, the force information applied by the tourniquet taken from the force sensor are sent as a text message to the CENKER system with the Bluetooth module. CENKER is a system designed by ASELSAN, which is integrated with MTS. The CENKER system, which is equipped with hightech products, designed for military personal in the hot zone. With the GPS module mounted on the CENKER system, latitude and longitude information of the injured person, who applies the tourniquet system, is sent to the headquarters with other vital data of the injured via the special military communication standart by means of CENKER. The MST also has safety protocole to prevent applying over force on the extremity. When the MST is started, running algorithm checks the increasing force sensor's data. If algorithm doesn't catch any slope, motor will disable, and system will give an error which indicates the tourniquet doesn't apply properly.

2.3 System Manufacturing

According to the production speed, precision and durability, additive manufacturing the best solution of to produce MST main body. 3D design of MST main body generates vectors based on the spatial proximity of all points which are modeled as rigid bodies. The merging of vectors exists a data cloud file. Slicer software divides the model, which is.stl format, into layers according to the printing quality of the 3D printing device. Coordinates of the points to which the laser beam is transmitted for each layer separated by the stereolithography (SLA) layered manufacturing tech-nique are also created by the resolving functions that works in the background of the Slicer software. All 3D parts of the MST were produced by selecting a layer thickness of 50 µm with downward SLA technique. MST's some parts, which should have high mechanical resistance, has been produced with machining (Fig. 2b). The pulley and worm parts manufactured from stainless stell 304 and worm gear manufactured from CuAl11Ni materials. As a final step, all subcomponents of the MST were combined according to fit the 3D dimensional assembly file. The system integration is completed in Fig. 2c. The whole tourniquet system weight is 1606 gr and it has 75 × 125 × 155 mm dimensions. The MST works with 8.4 V 2S Li-ion battery to drive 6 V DC motor and other electronic components. Aid of internal charging circuit, the MST can be charged only a 8.4 V switching power supply from outside of the cage.

3 Conclusion

In this study, military purpose MST system has been developed. The developed system was electronically tested in computer environment and the system passed all the hardware and software tests. The most important test of tourniquet systems is stopping bleeding. For this, we have developed a limb phantom which is nearly the same with human tissue in terms of mechanical characteristicsm that can be used in flow and pressure tests [12]. With the developed leg phantom, the tourniquet system was tested and the blood flow was stopped with MST. In order to test the MST on humans, a medical device ethics committee permission must be obtained. If necessary permissions are obtained, the system will be tested on human and the accuracy of operation of the system will be determined statistically. Moreover, the MST has been tested in both cold and hot condition according to MIL-STD-810G Method 502.5 and the system has been accopmlished the test in −33 °C and 43 °C stabilize temperature. Thanks to the improved tourniquet system, severe extremity injuries and blood loss can be prevented on the battlefield, resulting in gun injuries and explosions. Accordingly, even if the wounded does not know how to apply the tourniquet, he will be able to easily and correctly apply the tourniquet by putting on the MTS and pressing a button on its wounded extremity. In addition, since the location information of the injury will be reported to the headquarter, the medics will be able to intervene as soon as possible. The smart tourniquet system is not only use in the military field but also it can use in civilian area to prevent emergency injuries. Some researches, which are about on emergency smart tourniquet system, still continue in the Medical Device Design Laboratory where it is in the TOBB University of Economics and Technology Biomedical Engineering Department.

Acknowledgements The developed tourniquet system has been funded by The Scientific and Technological Research Council of Turkey as a science—industry project which has "Military and Emergency Field Smart Tourniquet (Harp ve Acil Yardım Akıllı Turnikesi—HAYAT)" name and "0932.STZ.2015" project no. Besides, we thanks to project industry partner of ASELSAN A.Ş. which is a Turkish Armed Forces Foundation company.

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