Establishment of a Gunshot Model of Junctional Femoral Artery Hemorrhage in Swine Under Ultrasonic Guidance

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Research

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Abstract

Background: In a combat setting, uncontrolled junctional hemorrhage, which occur at the junction of the torso and appendages, constitutes a major source of potentially preventable deaths. A reliable gunshot swine model of junctional femoral artery rupture was established under ultrasonic guidance to accurately simulate field rescue conditions.

Methods: Picco monitoring was instrumented for the anesthetized Landrace pigs, and the right femoral artery was located by portable ultrasound. The pistol bullet hit the right femoral artery along the direction of ultrasonic probe, resulting in the artery rupture. After 30 seconds of uncontrolled hemorrhage, ballistic was filled with Combat Gauze to stop bleeding in BT group (n=10). Combat Gauze (QuikClot) was used to stop bleeding when the mean arterial pressure (MAP) decreased by 30% in MD group (n=10). The sham-operated pigs (n=10) underwent the same anesthetic and surgical procedures, but neither shooting nor gauze filling therapy were performed. No liquid treatment was performed in the three groups throughout the experiment. Blood samples were taken 15 min before injury, then 10 min, 30 min, and 60 min after injury to determine hemodynamic, coagulation, and arterial blood gas indexes. Animals were then monitored for 180 minutes and surviving animals were killed.

Results: Histologic anatomy indicated that the right femoral artery and vein were completely ruptured in all 20 swine of MD and BT groups. Eighteen pigs had associated proximal femur fractures and the other two had associated midshaft femur fractures. The entrance diameters of wound were 11.4 mm (SD=0.4), and the exits diameters were 26.4 mm (SD=5.8). The blood loss of pre-tamponade (4.97 ± 2.47 mL/kg vs 18.26 ± 3.47 mL/kg, $P < 0.001$), pro-tamponade (4.58 ± 1.49 mL/kg vs 7.20 ± 1.99 mL/kg, $P = 0.004$) and the total amount of bleeding (9.54 ± 3.80 mL/kg vs 25.46 ± 3.68 mL/kg, $P < 0.001$) in MD group were more than those in BT group. There was statistic difference in the PT, PH, LAC of three groups ($P = 0.005$, 0.004 , and < 0.001 , respectively) and in the body temperature, PH, LAC of different time points (all $P < 0.001$). There were differences in body temperature, PH, PT, LAC of MD group compared with BT and SHAM groups 60 minutes after injury (all $P < 0.0167$). The survival time of MD group was shorter than that of BT group ($P = 0.029$).

Conclusion: We established a reliable gunshot model of junctional hemorrhage in swine, which had high accuracy for femoral arterial rupture under ultrasonic guidance and provided consistent and reproducible field-simulation conditions. In this junctional hemorrhage model, blood loss of 30 seconds free bleeding did not meet criteria for shock, and MAP decreased by 30% is a better choice to ensure the success of the shock model.

Trial registration: Authorized by Institutional Animal Care and Use Committee in China (grant no. SC2019-06-013).

Introduction

Exsanguinating hemorrhage is the leading cause of preventable causes of death in the combat setting and over one-third of those cases are due to extremity or junctional injuries [1]. Due to several factors including routine wear of body armor, judicious use of tourniquets for extremity hemorrhage, the mortality from truncal and peripheral-extremity hemorrhage has decreased relatively [2]. Extremity exsanguinating hemorrhage is no longer prime cause of preventable death on the battlefield because of effective tourniquet application [3]. Junctional hemorrhage, which occur at the junction of the torso and appendages, constitutes a major source of potentially preventable deaths in modern warfare [4]. Advanced hemostatic agents or junctional tourniquets applied to wounds not amenable to treatment with a routine tourniquet become the hotspot of the research.

In order to control junctional bleeding and prevent deaths, development led to newly FDA-cleared junctional tourniquets and hemostatic agents [1, 5–6]. To date, there have been lots of literature comparing the hemostatic properties of these devices and materials [2, 7–11]. Different experimental swine models were used in those studies with unrestricted bleeding allowed for 30 seconds or 45 seconds, splenectomy or not. But these models all have one thing in common, which is to dissect and cut off the artery to cause lethal hemorrhage. Because of the artificial wounds, it is difficult to approximate real-world conditions closely.

To improve understanding of the physiologic response to hemorrhage in the combatants, and to facilitate design of future clinical trials, a junctional hemorrhage model which can provide consistent and reproducible field-simulation conditions needs to be established urgently. The objective of this study was to develop a reliable gunshot swine model of junctional femoral artery

rupture to accurately simulate field rescue conditions. A secondary objective was to explore the bleeding criteria to establish the gunshot-hemorrhage shock model.

Materials And Methods

Ethics

The protocol was approved by the review committee of Chinese PLA General Hospital. All experiments were accorded with the principles stated in the guide for the Care and use of Laboratory animals (national institutes of health publication, 1985) and were authorized by Institutional Animal Care and Use Committee in China (grant no. SC2019-06-013).

Animal subjects

Thirty landrace pigs (approximately 3.5 months old, weighing 55 ± 5 kg), purchased from Beijing Shichuangshiji Mini-pig Breeding Base, were utilized for this study. Before the study, all swine were fed a standard diet and were observed for 7 days to adapt to the experimental environment. Before the surgery date, blood samples were collected from pigs and coagulation, and arterial blood gas indexes were measured to ensure these values were in the normal range. Animals were deprived of food 12 hours before anesthesia and water 2 hours before.

Animal grouping

Envelope randomization was utilized to ensure that each group had the same sample capacity. A total of 30 pigs were randomly divided into the following three groups: (1) a sham-operated (SHAM) group that underwent the same anesthetic and surgical procedures but without the conduct of gunshot ($n=10$), (2) a MAP decrease (MD) group in which the mean arterial pressure of the pigs dropped by 30% of the basal value before the application of Combat Gauze ($n=10$), and (3) a bleeding time (BT) group, in which 30 seconds of free bleeding was allowed ($n=10$).

Procedure

Anesthesia preparation—Swine were induced with an injection of Zoletil (10mg/kg, intravenous [i.v.], French virbac company, batch number: 76bp) and pumped to maintain anesthesia (0.03mg/kg/h, i.v.). After anesthetized, pigs were cut the hair in the operation area. Then the experimental pigs were intubated with combined endotracheal tube without mechanical ventilation.

Instrument preparation: All operations followed the principle of sterility. Before operations, all materials and instruments had been sterilized, including rubber gloves, venipuncture kit, Picco puncture kit, 5ml syringe, 20ml syringe, etc. While the pigs were in a supine position on the experimental console, Picco catheter was placed in the left femoral artery and double lumen catheter was placed in the left internal jugular vein under ultrasound guidance (Fig.1A and B). A bladder puncture was performed in pigs under ultrasound guidance (Fig.1C). After catheterization, the swine were instrumented to a Picco monitor (PULSION, PC8500). The pigs were placed on the test bench in a lateral position, with the right hind limb fixed vertically to ensure the inner thigh facing the shooter. After 15 minutes stationary, the blood samples were collected and the indexes of hemodynamics were recorded as the baseline.

Gunshot procedures: In order to improve the accuracy of femoral artery injury, a portable ultrasonic diagnostic instrument (VINNO Q Series-7L) was used to locate the right femoral artery and the midpoint of the descending territory of the artery in the ultrasound images was marked as the shooting point (Fig.1D and E). After 15 min from blood draw, the shooter, who were employed by the No. 208 Research Institute of China Ordnance, fired a common 9 mm along the ultrasonic probe longitudinal axis direction at 3 meters apart. The pistols and bullets used were also provided by this institute. Shootings from the entire experiment were completed by the same shooter, who was blinded to the overall experimental design and grouping.

Hemostatic treatment: After the shooting, the pigs were considered ready for the experiment when spurting bleeding occurred in the wound (Fig.1F). Combat gauze was applied to the bleeding site in accordance with the Tactical Combat Casualty Care Guidelines. First, Combat Gauze was used to fill up the active bleeding wound. Second, five pieces of sterile medical gauze were used to cover the packed wound for 3 minutes with well-distributed compression. Finally, an emergency bandage was used to dress the wound with appropriate pressure. All processes were performed by the same person in accordance with the Tactical Combat Casualty Care, and no fluid resuscitation or drug intervention was administered throughout the experiment. The animals were monitored under general anesthesia for 3 hours or until they died. Upon reaching the end point, a lethal dose (30ml) of 10% potassium chloride solution was administered intravenously as veterinary euthanasia solution.

Data collection

We recorded weight, hemodynamic, coagulation, and arterial blood gas indexes at baseline and 10min, 30min, 60min postinjury. All dressings and gauze used during the operation were weighed before use and afterward to determine the volume of blood loss. The pigs were observed until they died, and the time of deaths was recorded.

Blood analysis

A laboratory was prepared in the experimental site to test the blood specimens at a constant indoor temperature of 18°C-24°C. Venous blood was obtained via internal jugular vein catheterization, placed in heparinized syringes, and centrifuged at 3000r/min for 10 minutes. Activated clotting time of whole blood (ACT), Prothrombin time (PT), International normalized ratio (INR), Thrombin time (TT), Activated partial thromboplastin time (APTT), Fibrinogen (FIB) were measured using a semi-automatic coagulometer (Rayto, RAC-120) according to the manufacturer's protocols. The arterial blood was obtained through femoral artery catheterization and put into syringe for blood gas analysis with automatic blood gas analyzer (Rayto, ABL-80).

Anatomy

The length of the entrance and exit of the wound were recorded (Fig.2A and B). A approximately 10 cm dissection in the groin area was then conducted with removal of the adductor muscle overlying the femoral canal, and the ruptures of femoral artery and vein were found and recorded (Fig.2C). The femoral fracture site was also recorded if there was a fracture of the femur (Fig.2C and D).

Statistical analyses

The statistical analysis in this study was based on the SPSS 26.0 software. All measurement data were in accordance with or approximated normal distribution after normality test. Sex of animals was evaluated using Pearson's χ^2 test. Single factor ANOVA was used for other indexes of animal baseline characteristics. Differences of free bleeding time, pre-/pro-tamponade blood loss, total blood loss and MAP decline were analyzed by Student's t test. The overall effect of each index over time was compared using repeated measures ANOVA and Greenhouse-Geisser test was used to correct the data that did not coincide with the sphericity test. Pairwise comparisons were performed using LSD-t post hoc tests, with a significance threshold of $P < 0.0167$. Survival analyses were made by using Cox proportional hazards regression model. Significance for results was established when p-values were less than 0.05.

Results

Baseline characteristics of experimental groups

No difference was found in baseline physiologic and hematologic measurements among the groups (Table 1).

Table 1
Animal Baseline Characteristics

Index	SHAM group (n = 10)	MD group (n = 10)	BT group (n = 10)	P
Sex(male/female)	5/5	4/6	4/6	0.873 [#]
Length of pig(cm)	93.2 ± 4.8	93.7 ± 3.2	94.4 ± 4.1	0.806
Weight (kg)	54.2 ± 3.6	55.8 ± 3.0	55.6 ± 3.1	0.472
Body temperature (°C)	38.72 ± 0.69	38.84 ± 0.60	38.35 ± 0.53	0.191
MAP(mmHg)	121.0 ± 10.4	129.2 ± 25.0	121.2 ± 15.5	0.518
LAC (mmol/L)	0.91 ± 0.25	1.78 ± 1.10	1.49 ± 0.97	0.088
PH	7.468 ± 0.461	7.457 ± 0.786	7.404 ± 0.766	0.103
HCT (%)	33.0 ± 3.6	30.2 ± 4.7	32.4 ± 2.9	0.240
PT (s)	14.74 ± 1.19	13.95 ± 1.03	13.33 ± 1.68	0.077
APTT (s)	26.64 ± 2.94	26.74 ± 2.41	26.21 ± 2.62	0.895
FIB (g/L)	4.68 ± 1.37	4.79 ± 0.62	4.68 ± 0.94	0.962
[#] : Data of Sex analyzed by Pearson's χ^2 test. Other data expressed as mean ± SD and analyzed by one-way analysis of variance test. No difference was found among groups.				

Characteristics of the gunshot model of junctional femoral artery hemorrhage

Hemorrhages were generated in all 20 pigs of MD and BT groups. Histologic anatomy indicated the right femoral artery and vein were completely ruptured in all swine, ultimately resulting in pulsatile bleeding. Eighteen pigs had associated proximal femur fractures (Fig. 2D) and the other two had associated midshaft femur fractures (Fig. 2C). The entrance diameters of wound were 11.4 mm (SD = 0.4), and the exits diameters were 26.4 mm (SD = 5.8).

Comparison of free bleeding time, MAP decline and blood loss

The free bleeding time of MD group was longer than 30 seconds (83.7 ± 23.3 s vs 30 s, $P < 0.001$), and the MAP of BT group decreased significantly less than 30% after 30 seconds of uncontrolled bleeding ($4.3\% \pm 2.8\%$ vs 30%, $P < 0.001$). The volume of blood loss before and after filling was calculated and recorded. The bleeding volume per kg of body weight (mL/kg) was used as the evaluation index. We found that the bleeding volume of the BT group was significantly lower than that in the MD group (4.97 ± 2.47 mL/kg vs 18.26 ± 3.47 mL/kg, $P < 0.001$) before packing (Fig. 3A). The bleeding volume after tamponade in the BT group remained significantly lower than that in the MD group (4.58 ± 1.49 mL/kg vs 7.20 ± 1.99 mL/kg, $P = 0.004$) (Fig. 3B). The total bleeding volume of the BT group was significantly lower than that in the MD group (9.54 ± 3.80 mL/kg vs 25.46 ± 3.68 mL/kg, $P < 0.001$) (Fig. 3C).

Comparison of indexes for body temperature, coagulation, and blood gas

We then compared physiological indicators between experimental groups on body temperature, coagulation, and changes in dissolved gas in the blood stream. We found that body temperature, PH, LAC all significantly changed over – 15 min, 10 min, 30 min, and 60 min time points within each of the experimental groups (all $P < 0.001$), and there were differences in PT, PH and LAC among the experimental groups ($P = 0.005$, 0.004 and < 0.001 , respectively) (Table 2). Each index among the experimental groups was tested by pairwise comparison using the LSD test, with a significance threshold of $P < 0.0167$, and there were differences in body temperature, PH, PT, LAC of MD group compared with BT and SHAM groups 60 minutes after injury (all $P < 0.0167$) (Table 3).

Table 2
The physiologic indexes of body temperature, coagulation, and blood gas

Index	Time (min)	SHAM group (n = 10)	MD group (n = 10)	BT group (n = 10)	Inter group	Time	Interaction
					F, P	F, P	F, P
Body temperature (°C)	-15	38.72 ± 0.69	38.84 ± 0.60	38.35 ± 0.53	3.467,0.053	15.511, < 0.001*	16.539, < 0.001*
	10	38.80 ± 0.70	38.24 ± 0.50	38.32 ± 0.76			
	30	38.33 ± 0.45	37.68 ± 0.38	38.04 ± 0.60			
	60	38.82 ± 0.47	37.43 ± 0.87	38.28 ± 0.77			
PT (s)	-15	14.74 ± 1.19	13.95 ± 1.03	13.33 ± 1.68	7.937,0.005*	1.077,0.364	8.351, < 0.001*
	10	15.04 ± 2.01	12.40 ± 0.85	13.71 ± 1.68			
	30	15.23 ± 2.34	12.48 ± 0.91	13.47 ± 1.23			
	60	15.10 ± 2.03	12.30 ± 1.05	14.38 ± 1.04			
APTT (s)	-15	26.64 ± 2.94	26.74 ± 2.41	26.21 ± 2.62	2.749,0.099	2.139,0.144	2.001,0.140
	10	27.21 ± 2.87	24.48 ± 2.70	26.27 ± 2.37			
	30	26.80 ± 3.45	24.09 ± 2.70	26.21 ± 3.08			
	60	27.04 ± 1.49	23.65 ± 3.60	25.06 ± 1.28			
FIB (g/L)	-15	4.68 ± 1.37	4.79 ± 0.62	4.68 ± 0.94	0.216,0.778	2.689,0.078	1.664,0.189
	10	4.40 ± 0.98	4.58 ± 0.97	5.02 ± 1.04			
	30	4.42 ± 1.22	4.45 ± 0.76	4.21 ± 1.17			
	60	4.33 ± 1.28	4.78 ± 0.79	4.88 ± 0.77			
PH	-15	7.468 ± 0.046	7.457 ± 0.079	7.404 ± 0.077	7.666,0.004*	10.389, < 0.001*	11.083, < 0.001*
	10	7.461 ± 0.040	7.441 ± 0.079	7.409 ± 0.052			
	30	7.467 ± 0.048	7.375 ± 0.091	7.420 ± 0.071			
	60	7.479 ± 0.042	7.264 ± 0.130	7.394 ± 0.070			
LAC (mmol/L)	-15	0.91 ± 0.25	1.78 ± 1.10	1.49 ± 0.97	24.613, < 0.001*	98.047, < 0.001*	41.060, < 0.001*

The Two-way Repeated Measures ANOVA was used to analyze the physiologic indexes among different time points and groups. Body temperature, PH, LAC were statistically different over time after the spherical test or greenhouse-Geisser test. PT, PH, LAC were statistically different among groups after the spherical test or greenhouse-Geisser test. *: P < 0.05.

Index	Time (min)	SHAM group (n = 10)	MD group (n = 10)	BT group (n = 10)	Inter group	Time	Interaction
					F, P	F, P	F, P
	10	1.75 ± 0.55	4.90 ± 2.53	1.67 ± 0.93			
	30	1.91 ± 0.66	7.39 ± 3.64	2.53 ± 1.46			
	60	2.06 ± 0.84	12.01 ± 2.99	2.83 ± 1.78			
HCT (%)	-15	33.0 ± 3.6	30.2 ± 4.7	32.4 ± 2.9	2.978,0.083	2.352,0.130	2.355,0.085
	10	31.5 ± 5.8	27.9 ± 3.4	34.1 ± 2.6			
	30	31.7 ± 5.4	27.3 ± 3.0	30.3 ± 4.6			
	60	31.7 ± 5.9	29.5 ± 3.6	32.8 ± 5.6			
The Two-way Repeated Measures ANOVA was used to analyze the physiologic indexes among different time points and groups. Body temperature, PH, LAC were statistically different over time after the spherical test or greenhouse-Geisser test. PT, PH, LAC were statistically different among groups after the spherical test or greenhouse-Geisser test. *: P < 0.05.							

Table 3
P-value of Pairwise comparisons/LSD-t post hoc tests in three groups

Time (min)	Body temperature			PT			PH			LAC		
	SHAM vs MD	SHAM vs BT	MD vs BT	SHAM vs MD	SHAM vs BT	MD vs BT	SHAM vs MD	SHAM vs BT	MD vs BT	SHAM vs MD	SHAM vs BT	MD vs BT
-15	0.155	0.783	0.247	0.195	0.025	0.306	0.723	0.047	0.096	0.032	0.142	0.456
10	0.069	0.117	0.789	0.001*	0.073	0.077	0.455	0.059	0.236	< 0.001*	0.911	< 0.001*
30	0.006*	0.194	0.110	0.001*	0.022	0.181	0.008*	0.157	0.175	< 0.001*	0.551	< 0.001*
60	0.002*	0.466	0.014*	< 0.001*	0.278	0.003*	< 0.001*	0.041	0.003*	< 0.001*	0.412	< 0.001*
Pairwise comparisons were performed using LSD-t post hoc tests on the abovementioned indexes. *: P < 0.0167.												

Comparison of survival rates

We then compared survival time between MD and BT group. We found that all swine from MD and BT groups survived for greater than 1 h. No swine in the BT group died before 3 h. In contrast, four swine in the MD group died before 3 h resulting in a 3-h survival rate of 60% for the MD group. Survival analysis showed that the survival time of BT group was longer than that of MD group (P = 0.029) (Fig. 3D).

Discussion

Tourniquet use has dramatically reduced mortality from massive extremity hemorrhage in modern warfare. A statistical study of Operation Iraqi Freedom and Operation Enduring Freedom combat casualties from October 2001 to June 2011 showed that junctional site accounts 19.2% potentially survivable hemorrhage, exceeding extremity hemorrhage [4]. In recent years, there are numerous methods to induce junctional hemorrhage in swine. These models were usually established with cutting off the artery to cause lethal hemorrhage, and there are advantages and limitations associated with these methods. In our model, we aim to

represent the reaction of the animal wounded after gunshot, and there was no intervention on the wound and ballistics. With this method, the injury is as close to the battlefield situation as possible.

It is important to note that we used a portable ultrasound machine to accurately orientate the right femoral artery before shooting. In our study the femoral artery was hit by the bullet, unlike other experiments in which bleeding was induced by isolating the femoral arteriovein and cutting the artery. The trajectory of the bullet should be consistent with the long axis direction of the ultrasonic probe. The midpoint of the descending territory of the artery in the ultrasound images was marked as the shooting point so that the bullet runs at a non-vertical angle from the course of the vessel to increase hit rate. In our experiment, the gunshot model of junctional femoral artery hemorrhage was established under ultrasonic guidance with a high success rate (100%, 20/20). Post-experimental anatomy revealed that the femoral vein is similarly damaged and the bullet caused about 1.14-centimeter diameter entrance wounds and 2.64-centimeter diameter exit wounds, with 100% (20/20) of femur fractures. Of these, 90% (18/20) sustained proximal femoral fractures.

The aim of establishing such a junctional site massive hemorrhage model is to evaluate the hemostatic efficacy of hemostatic materials. Some studies were conducted on ideal swine femoral artery injury models, which required femoral artery rupture punch and free bleeding for 30 s or 45 s, with splenectomy or not. Our experiments also explored the choice of timing of intervention in our model. In our study, we chose the conventional “30 s free bleeding” and “MAP of swine decreased by 30%” as the hemostasis intervention time. By comparison, we found that the MAP drop after 30 s of free bleeding was significantly less than 30% in our model, and the amount of blood loss (9.54 ml/kg) was lower than previous reports (15–35 ml/kg) in which 30 s free bleeding was allowed [9, 12–14]. This difference may be caused by the contraction and compression of the muscles around the femoral artery. Conversely, the amount of blood loss at a 30% decrease in MAP (25.46ml/kg) was resemble to previous studies. Compared with 30-s free bleeding, we found that animals with a 30% drop in mean arterial pressure developed a drop in body temperature, acidosis, and coagulopathy one hour after injury, which is known as the triad of death in hemorrhagic shock [15]. With merely tamponade by hemostatic gauze without any other treatment, the 3-h survival rate of BT group could reach 100%. This illustrates that a 30% drop in MAP is more suitable for the study of hemostatic materials and techniques than 30-s free bleeding.

In course of the experiment, we also found a problem worthy of attention. The bullet tumbles as a result of bullet eccentricity after it enters the tissue and the warhead undergoes severe deformation as it strikes the bone. For this reason, the perforating gunshot wound has the characteristics of “small entry and big damage”. Because the entrance of the wound is very small and the cavity is very large, it is very difficult to pack the gauze. Therefore, our model can provide a perfect simulation in dealing with massive bleeding caused by gunshot wounds. With our model, future studies can explore the optimization of hemostatic materials application methods to improve their efficiency in the field.

Conclusion

In our study, we established a replicable gunshot model of junctional femoral artery hemorrhage in swine guided by ultrasound. In this junctional hemorrhage model, blood loss of 30-s free bleeding did not meet criteria for shock, and MAP decreased by 30% is a better choice to ensure the success of the shock model. This model can simulate lethal massive hemorrhage of potentially survivable in a battlefield setting. Our model may do some help in estimating the effect of blood hemostatic devices and hemostatic materials.

Declarations

Ethical Approval and Consent to participate

All experiments were accorded with the principles stated in the guide for the Care and use of Laboratory animals (national institutes of health publication, 1985) and were authorized by Institutional Animal Care and Use Committee in China (grant no. SC2019-06-013).

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during this study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Hongliang Zhang and Tanshi Li contributed to conception and design. Hongliang Zhang and Chengyu Guo contributed to analysis and interpretation. Hongliang Zhang, Chengyu Guo, Junkang Wang, Jing Wang, and Cong Feng contributed to data collection. Hongliang Zhang contributed to writing the article. Hongliang Zhang and Chengyu Guo contributed to critical revision of the article. Tanshi Li contributed to final approval of the article. Hongliang Zhang and Cong Feng contributed to statistical analysis. Tanshi Li obtained funding. Hongliang Zhang and Tanshi Li took overall responsibility.

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Disclosure Statement

No competing financial interests exist.

References

1. Stuart SM,Zarow G,Walchak A,McLean J,Roszk P.Pilot study of a novel swine model for controlling junctional hemorrhage using the itclamp in conjunction with hemostatic agents.Mil Med,2019;184: 367-373.
2. Clay JG,Grayson JK,Zierold D.Comparative testing of new hemostatic agents in a swine model of extremity arterial and venous hemorrhage.Military medicine,2010;175: 280-284.
3. Tjardes T,Luecking M.The platinum 5 min in tccc: Analysis of junctional and extremity hemorrhage scenarios with a mathematical model.Mil Med,2018;183: e207-e215.
4. Eastridge BJ,Mabry RL,Seguin P,Cantrell J,Blackbourne LH.Death on the battlefield (2001-2011): Implications for the future of combat casualty care.Journal of Trauma & Acute Care Surgery,2012;73: S431.
5. Kragh JF,Kotwal RS,Cap AP,Aden JK,Walters TJ,Kheirabadi BS, et al.Performance of junctional tourniquets in normal human volunteers.Prehosp Emerg Care,2015;19: 391-398.
6. Kheirabadi BS,Edens JW,Terrazas IB,Estep JS,Klemcke HG,Dubick MA, et al.Comparison of new hemostatic granules/powders with currently deployed hemostatic products in a lethal model of extremity arterial hemorrhage in swine.J Trauma,2009;66: 316-326; discussion 327-318.

7. Alam HB,Uy GB,Miller D,Koustova E,Hancock T,Inocencio R, et al.Comparative analysis of hemostatic agents in a swine model of lethal groin injury.J Trauma,2003;54: 1077-1082.
8. Kheirabadi BS,Scherer MR,Estep JS,Dubick MA,Holcomb JB.Determination of efficacy of new hemostatic dressings in a model of extremity arterial hemorrhage in swine.J Trauma,2009;67: 450-459; discussion 459-460.
9. De Castro GP,Dowling MB,Kilbourne M,Keledjian K,Driscoll IR,Raghavan SR, et al.Determination of efficacy of novel modified chitosan sponge dressing in a lethal arterial injury model in swine.J Trauma Acute Care Surg,2012;72: 899-907.
10. Kragh JF,Dubick MA,Aden JK,McKeague AL,Blackbourne LH.U.S. Military experience with junctional wounds in war from 2001 to 2010.Journal of Special Operations Medicine A Peer Reviewed Journal for Sof Medical Professionals,2013;13: 76.
11. Dj A,Sb A,Sn A,As A,Ah A,Tl A, et al.The effects of quikclot combat gauze on hemorrhage control in the presence of hemodilution and hypothermia.Annals of Medicine and Surgery,2014;3: 21-25.
12. St John AE,Wang X,Lim EB,Chien D,Stern SA,White NJ.Effects of rapid wound sealing on survival and blood loss in a swine model of lethal junctional arterial hemorrhage.J Trauma Acute Care Surg,2015;79: 256-262.
13. Baylis JR,John AS,Wang X,Lim EB,Statz ML,Chien D, et al.Self-propelled dressings containing thrombin and tranexamic acid improve short-term survival in a swine model of lethal junctional hemorrhage.Shock,2016;1.
14. Rall JM,Cox JM.Evaluation of xstat and quickclot combat gauze in a swine model of lethal junctional hemorrhage in coagulopathic swine.Journal of special operations medicine : a peer reviewed journal for SOF medical professionals,2017;17: 64-67.
15. Chipman AM,Jenne C,Wu F,Kozar RA.Contemporary resuscitation of hemorrhagic shock: What will the future hold?Am J Surg,2020;220: 580-588.

Figures

Figure 1

Establishment of the Gunshot Model of Junctional Femoral Artery Hemorrhage. A, Picco catheter was placed in the left femoral artery (arrow). B, Double lumen catheter was placed in the left internal jugular vein (arrow). C, Bladder (arrow) puncture was performed in pigs. D, The midpoint of the descending territory of the right femoral artery was marked as the shooting point (arrow). E, Portable ultrasonic diagnostic instrument (VINNO Q Series-7L) was used to locate the right femoral artery. F, Spurting bleeding occurred in the wound.

Figure 2

Anatomy. A, The entrance of the wound. B, The exit of the wound. C, The ruptures of femoral vessels and the fracture of midshaft femur. D, The proximal femur fractures.

Figure 3

Comparison of blood loss and survival rates in MD and BT groups. A, Differences in pre-tamponade blood loss. Data represent mean $\pm$ SD. B, Differences in post-tamponade blood loss. Data represent mean $\pm$ SD. C, Differences in total blood loss. Data represent mean $\pm$ SD. D, Differences in survival times. ** and ***: P<0.01 and P<0.001, respectively.

Figure 4

Comparison of indexes for body temperature, coagulation, and blood gas. A, Differences in body temperature. Temperature is measured in degrees Celsius (°C). B, Differences in PT. C, Differences in PH. D, Differences in LAC.