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 constitutes a major source of potentially preventable deaths. It is very important to establish a model of massive hemorrhage of gunshot wound at junction area which can 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, resulting in an artery rupture. After 30 seconds of uncontrolled hemorrhage, the ballistic wound was filled with combat gauze (QuikClot) to stop bleeding in the BT group ($n = 10$). Combat gauze was used to stop bleeding when the mean arterial pressure (MAP) decreased by 30% in the MD group ($n = 10$). The sham-operated pigs ($n = 10$) underwent the same anesthetic and surgical procedures, but neither shooting nor gauze filling therapy was performed. Blood samples were taken 15 min before injury, and then 10 min, 30 min, and 60 min after the injury.

Results

Histologic anatomy indicated that the right femoral artery and vein were completely ruptured in all 20 swine of MD and BT groups. 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 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-second free bleeding did not meet the criteria for shock. The MAP decrease of 30% emerged as a better predictor of a successful shock model.

Introduction

Exsanguinating hemorrhage is the leading cause of preventable deaths in combat settings, 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 and judicious use of tourniquets for extremity hemorrhage, mortality rates associated with truncal and peripheral-extremity hemorrhage have relatively decreased [2]. Extremity exsanguinating hemorrhage is no longer the prime cause of preventable death on the battlefield because of effective tourniquet application [3]. Junctional hemorrhage, which occurs 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 that are not amenable to treatment with a routine tourniquet have become the focus of research. Novel junctional tourniquets and hemostatic agents have been developed and approved by regulators to control junctional bleeding and prevent deaths [1, 5–6]. Several studies have examined 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 or 45 seconds, with or without involving a splenectomy. However, all these models share the dissection and cutting off the artery as a cause of lethal hemorrhage; artificial wounds make it difficult to approximate real-world conditions.

To improve our understanding of the physiologic response to hemorrhage in combatants and to facilitate the design of future clinical trials, a junctional hemorrhage model that provides consistent and reproducible field simulation conditions is required. The present study aimed to develop a reliable gunshot swine model of junctional femoral artery rupture to accurately simulate field rescue conditions. The secondary aim of this study was to explore the bleeding criteria for a reliable gunshot-hemorrhage shock model.

Materials And Methods

The study protocol was approved by the review committee of the Chinese PLA General Hospital. All experiments were performed in accordance 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 the Institutional Animal Care and Use Committee in China (grant no. SC2019-06-013).

Animal subjects

Thirty landrace pigs (aged approximately 3.5 months, 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 indices were measured to ensure that these values were within the normal range. Animals were deprived of food and water for 12 h and 2 h before anesthesia, respectively.

Animal grouping

Envelope randomization was used 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 mean arterial pressure (MAP) decrease (MD) group, in which the MAP 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

The swine were induced with an injection of zoletil (10 mg/kg, intravenous [i.v.], French Virbac Company, batch number: 76bp) and pumped to maintain anesthesia (0.03 mg/kg/h, i.v.). After anesthetization, the pigs were cut into hair in the operation area. The experimental pigs were then intubated with a combined endotracheal tube without mechanical ventilation.

All operations followed the principle of sterility. Before surgery, all materials and instruments were sterilized, including rubber gloves, venipuncture kit, Picco puncture kit, 5 ml syringe, and 20 ml syringe, among others. While the pigs were placed in the supine position on the experimental console, a Picco catheter was placed in the left femoral artery and a double-lumen catheter was placed in the left internal jugular vein under ultrasound guidance (Fig 1A and B). Bladder puncture was performed in pigs under ultrasound guidance (Fig 1C). After catheterization, the swine were instrumented on 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 that the inner thigh faced the shooter. After 15 min, blood samples were collected and the indices of hemodynamics were recorded as baseline values.

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). Fifteen minutes after drawing blood, the shooter, who was employed by the No. 208 Research Institute of China Ordnance, fired a common 9-mm bullet along the ultrasonic probe longitudinal axis direction at 3 m apart. The pistols and bullets used were provided by this institute. All shots were performed by the same shooter, blinded to the experimental design and group assignment.

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 the active bleeding wound. Second, five pieces of sterile medical gauze were used to cover the packed wound for 3 min with well-distributed compression. Finally, an emergency bandage was used to dress the wound at an appropriate pressure. All processes were performed by the same person in accordance with 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 h or until they died. Upon reaching the end point, a lethal dose (30 ml) of 10% potassium chloride solution was administered intravenously as a veterinary euthanasia solution.

Data collection

We recorded weight, hemodynamic, coagulation, and arterial blood gas indices at baseline and at 10 min, 30 min, and 60 min post-injury. All dressing 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 death was recorded.

Blood analysis

A laboratory was prepared at the experimental site to test the blood specimens at a constant indoor temperature of 18–24 °C. Venous blood was obtained via internal jugular vein catheterization, placed in heparinized syringes, and centrifuged at 3000 r/min for 10 min. The activated clotting time of whole blood, prothrombin time (PT), international normalized ratio, thrombin time, activated partial thromboplastin time, and fibrinogen were measured using a semi-automatic coagulometer (Rayto, RAC-120) according to the manufacturer's protocols. Arterial blood was obtained through femoral artery catheterization and placed into a syringe for blood gas analysis with an automatic blood gas analyzer (Rayto, ABL-80).

Anatomy

The length of the entrance and exit wounds were recorded (Fig 2A and B). A dissection of approximately 10 cm was performed in the groin area with removal of the adductor muscle overlying the femoral canal; the ruptures of the 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

SPSS software version 26.0 was used for statistical analysis. All measurement data met the normality of distribution assumption. The sex distribution of the animals was evaluated among the groups using the Pearson χ^2 test. Single-factor ANOVA was used to compare all other baseline indices among the groups. Differences in free bleeding time, pre-/pro-tamponade blood loss, total blood loss, and the MAP decline were analyzed by Student's t-test. The overall change to each index over time was examined using repeated measures ANOVA. The Greenhouse-Geisser test was used to correct the data that did not coincide with the sphericity test. Pairwise comparisons were performed using the LSD post-hoc tests, with a significance threshold of $P < 0.0167$. Survival analyses were performed using the Cox proportional hazards regression model. P-values of < 0.05 were considered statistically significant.

Results

Baseline characteristics of experimental groups

Baseline physiological and hematologic characteristics were similar 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 in the MD and BT groups. Histologic anatomy indicated that 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 average entrance and exit diameters of the wounds were 11.4 mm (SD = 0.4) and 26.4 mm (SD = 5.8), respectively.

Free Bleeding Time, Map Decline And Blood Loss

The free bleeding time of the MD group was longer than 30 seconds (83.7 ± 23.3 s vs. 30 s, $P < 0.001$), and the MAP of the BT group decreased significantly to $< 30\%$ 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 kilogram of body weight (mL/kg) was used as the evaluation index. The bleeding volume of the BT group was significantly lower than that of 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 of the MD group (9.54 ± 3.80 mL/kg vs 25.46 ± 3.68 mL/kg, $P < 0.001$) (Fig. 3C).

Body Temperature, Coagulation, And Blood Gas Indices

Physiological indicators, including body temperature, coagulation, and changes in the levels of dissolved gas in the blood stream, were compared between experimental groups. We found that body temperature, PH, and LAC all significantly changed among - 15 min, 10 min, 30 min, and 60 min time points in both experimental groups (all $P < 0.001$). There were differences in PT, PH, and LAC values among the experimental groups ($P = 0.005$, 0.004 , and < 0.001 , respectively) (Table 2). Pairwise comparisons using the LSD test, with a significance threshold of $P < 0.0167$, revealed differences in body temperature, PH, PT, and LAC values of the MD group relative to those of the BT and SHAM groups 60 min after injury (all $P < 0.0167$) (Table 3).

Table 2
The physiologic indices 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*
	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 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			
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	30	4.42 ± 1.22	4.45 ± 0.76	4.21 ± 1.17			
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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*
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	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*
	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.												

Survival Rates

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

Discussion

Tourniquet use has dramatically reduced mortality rates associated with massive extremity hemorrhage in modern warfare. A study of the Operation Iraqi Freedom and Operation Enduring Freedom combat casualties from October 2001 to June 2011 showed that junctional sites account for 19.2% of cases of potentially survivable hemorrhage, exceeding the corresponding rate associated with extremity hemorrhage [4]. Recently, several methods have been developed to induce junctional hemorrhage in swine. These models were usually established by cutting off the artery to cause lethal hemorrhage, which is an approach associated with several advantages and limitations. In our model, we aimed to represent the reaction of an animal wounded by a gunshot, and there was no intervention on the wound and ballistics. This approach allows to closely simulate the conditions of the battlefield.

We used a portable ultrasound machine to accurately orient the right femoral artery before shooting. In our study, the femoral artery was hit by the bullet, unlike in other experiments in which bleeding was induced by isolating the femoral arteriovein and cutting the artery. The trajectory of the bullet was 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 ran at a non-vertical angle from the course of the vessel to increase the 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 evaluation revealed that the femoral vein was similarly damaged and the bullet caused entrance and exit wounds of approximately 1.14 cm and 2.64 cm in diameter, respectively, with 100% (20/20) of femur fractures. Of these, 90% (18/20) of cases sustained proximal femoral fractures.

The aim of establishing a junctional site massive hemorrhage model is to evaluate the efficacy of hemostatic materials. Some studies have been conducted on ideal swine femoral artery injury models, which require femoral artery rupture punch and free bleeding for 30 or 45 seconds, with or without involving a splenectomy. Our experiments also explored the choice of intervention timing in our model. In the present study, the hemostatic conditions included a conventional 30-second free bleeding and the MAP of swine decrease by 30%. The MAP drop after 30 seconds of free bleeding was significantly less than 30% in our model, and the amount of blood loss (9.54 ml/kg) was lower than that in previous reports (15–35 ml/kg), in which 30 seconds of 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 the MAP (25.46 ml/kg) was similar to that in previous studies. Compared with 30-second free bleeding, we found that animals with a 30% drop in the MAP developed a drop in body temperature, acidosis, and coagulopathy levels 1 h after the injury, which is known as the triad of death in hemorrhagic shock [15]. Using tamponade as hemostatic gauze without any other treatment, the 3-h survival rate of the BT group could reach 100%. This illustrates that a 30% drop in the MAP is more suitable than 30-second free bleeding for the study of hemostatic materials and techniques.

During the course of the experiment, we also found a problem that may warrant further attention. The bullet tumbles due to bullet eccentricity after it enters the tissue, and the warhead undergoes severe deformation as it strikes the bone. Consequently, 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 may provide suitable simulation conditions for dealing with massive bleeding caused by gunshot wounds. The present model may be used in future studies aimed at exploring the optimization of hemostatic material application methods to improve their efficiency in the field.

Conclusion

The present study established a replicable gunshot model of junctional femoral artery hemorrhage in swine, guided by ultrasound. In this junctional hemorrhage model, blood loss associated with 30-second free bleeding did not meet the criteria for shock. The MAP decrease of 30% emerged as a better indicator of a successful shock model. This model can simulate a lethal massive hemorrhage of potential survivability in a battlefield setting. Our model may help in estimating the effects of blood hemostatic devices and hemostatic materials.

Declarations

Ethics approval and consent to participate

All experiments were performed in accordance 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 the 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 upon 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.

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Figures

Figure 1

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) 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 the 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. ** $P < 0.01$ and *** $P < 0.001$