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Experimental study of elastic traction device for assisting reduction of pelvic fracture

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Abstract

The elastic traction theory is proposed, that is, the lower limb elastic traction device is used to balance the resistance of the main muscles around the pelvis, and the elastic deformation generated by the elastic body in the elastic traction device is used to improve the flexibility of the doctor's reduction operation, so as to solve the problem that the existing fracture reduction robot cannot take into account the requirements of large load and operational flexibility. In addition, repeated reduction experiments were carried out on the simulated platform of muscle constraint during the process of pelvic fracture reduction, in order to explore the influence of elastic traction on the reduction force and operational flexibility of pelvic fracture, and to provide experimental basis for the development of surgical robots for pelvic fracture reduction. Based on the simplified conditions of muscle elastomer, an experimental platform was built to simulate muscle constraint during the reduction of pelvic fractures, and the resistance generated by muscles during the reduction under the condition of pelvic injury was simulated. Verification experiments were carried out using the simulation platform. The reduction force curves during the reduction experiment under different conditions of lower limb elastic traction of 0 kg, 5 kg and 10 kg were compared in the test, and the reduction force during the reduction operation was analyzed by single factor error analysis and LSD multiple post-test analysis, so as to analyze the influence of lower limb elastic traction device on the reduction force. Finally, the affected pelvis was translated by 3 cm in the x and y directions, respectively, to analyze the influence of elastic traction on the flexibility of translation operation. Results Elastic traction can significantly reduce the resetting force. During the reduction and maintenance phase, 5kg and 10 kg elastic traction reduced the holding force required to maintain the reduction position by 32.99% and 60.85%(No. 1 control screw) and 31.06% and 62.72% (No. 2 control screw), respectively. In the operating flexibility experiment, the operating force with the aid of elastic traction is reduced by more than 60% on average compared with that with inelastic traction. This study preliminarily verified the effectiveness of elastic traction in assisting the reduction of pelvic fractures. Lower limb elastic traction can effectively reduce the reduction force during the reduction operation, give consideration to the operational flexibility, and help to maintain the correct reduction position.

Keywords

Pelvic fracture; Fracture reduction force; Elastic traction; Pelvic reduction; biomechanics.

1. Introduction

The pelvis is a ring structure, composed of hip bones, sacrum and tailbone and their surrounding ligaments, and is an important organ connecting the trunk and lower limbs of the

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human body. Pelvic fracture is the most complex fracture in traumatic orthopedics, mostly caused by the direct or indirect effect of high energy violence, a variety of displacement methods, often combined with abdominal and pelvic organ damage and massive bleeding, the disability rate is as high as 50% to 60%, and the fatality rate is more than 13%. Whether it is traditional open reduction plate fixation or closed reduction plus minimally invasive screw fixation, the first and most important step is the pelvis

Fracture reduction. Due to the complex situation of pelvic fracture and the rich soft tissues such as muscles and ligaments around the pelvis, muscles and other internal forces determine the shape and stability of pelvic fracture after the occurrence of pelvic fracture. At present, the reduction of pelvic fracture is completely dependent on the manipulation of the physician. During the reduction process, the physician not only needs to carry out a variety of complex operations such as lifting and prying, but also needs to resist the great resistance of the soft tissue. In the internal fixation operation, the physician needs to maintain the reset position for a long time, which is not only easy to lose the reset position, but also a huge physical consumption for the physician. In recent years, with the development of minimally invasive treatment technology, robot-assisted surgery has gradually become the development direction and research focus of fracture reduction surgery in the future. At present, the United States, Germany, Japan and other countries have invested a lot of manpower and material resources in the research and development of fracture reduction robots, and there are many universities and research institutes in China to carry out related work, but these studies are using free bone to simulate fracture, without considering the muscle and other soft tissues on the bone pulling effect. In addition, existing fracture reduction systems, whether series, parallel or series-parallel hybrid robots, are unable to take into account the characteristics of operational flexibility and large loads during pelvic fracture reduction.

Therefore, the concept of elastic traction was innovatively proposed in this study, and a simulation platform for muscle constraint during the reduction of pelvic fractures was built. Reduction experiments were carried out on the platform to verify the effects of elastic traction on the operating force, maintenance force and operational flexibility of pelvic fracture reduction.

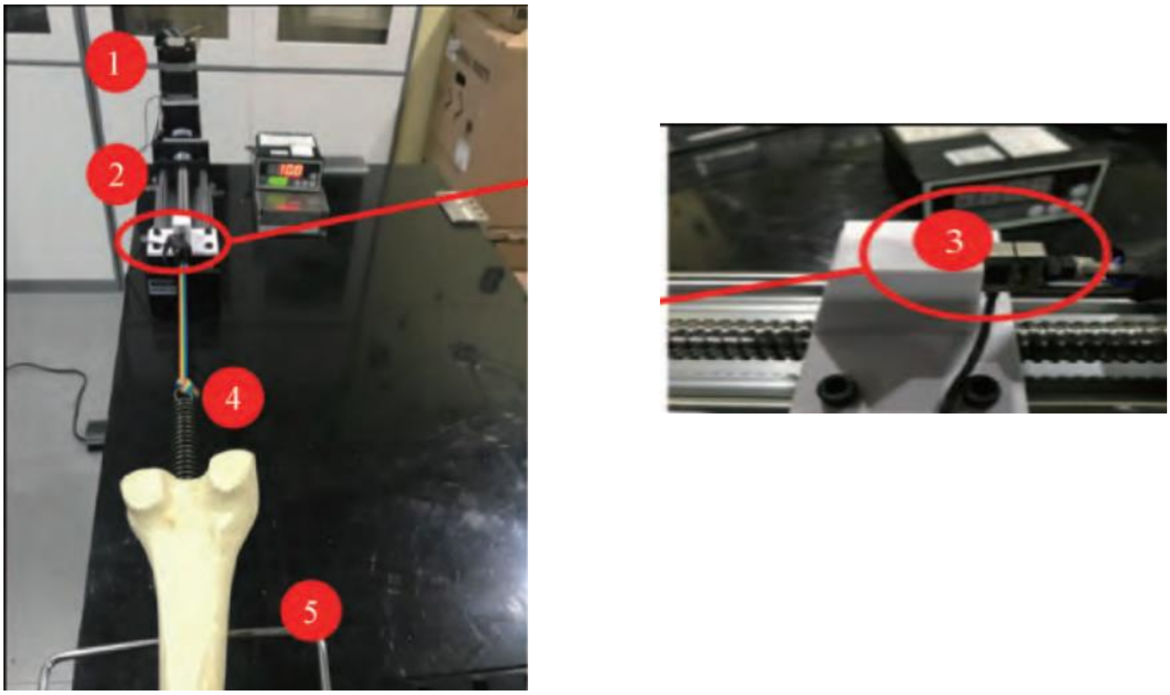
2. Research method

2.1. Lower limb elastic traction concept

Lower limb traction concept, that is, elastic elastomers such as springs are added to the traditional rigid traction mode, and the elastic force of elastomers is used to balance the binding force of major muscles near the pelvis, such as gluteus maximus and adductor maximus, as well as soft tissues such as ligaments, so as to effectively reduce the reduction operation force in the process of reduction by physicians. At the same time, the elastic deformation produced by the elastomer during the traction process can improve the flexibility of the physician during the reduction operation, and does not affect the physician to carry out complex reduction operation.

2.2. Lower limb elastic traction platform

The electric lower limb elastic traction platform is composed of 57 stepper motor and its supporting reducer (reduction ratio 1:16), ball linear guide rail (effective stroke 200mm, screw specification 1605), one-dimensional force sensor and elastic traction device (Figure 1). Among them, the motor and the reducer provide traction driving force, the linear guide rail is used to transfer traction, while ensuring the direction of traction, the elastic traction device in the transfer of traction while ensuring the flexibility of reset operation, one-dimensional force sensor is used to record the size of traction, while ensuring that the traction does not exceed the safe value. The motor, the reducer and the linear traction unit are fixed at the end of the bed through screw connection. The traction bow is flexibly connected with the linear traction device through spring and rope. The one-dimensional force sensor is used to measure the traction force on the elastic traction device.



1: Motor and reducer; 2: Linear traction device; 3: Dimensional force sensor; 4: Elastic traction device; 5: Traction bow

Figure 1： Platform for elastic traction

2.3. Establishment of muscle binding simulation platform during pelvic fracture reduction

Although it has been proved that biological soft tissues have viscoelastic or hyperelastic properties, for the complex musculoskeletal system such as the pelvis, the current researchers mostly assume the muscle as an elastic body for analysis. Based on the simplified elastomer conditions, springs with different elastic parameters were used to simulate the main muscle binding force near the pelvis. According to the study of Elabjer et al., 10 groups of muscles that have a greater impact on pelvic displacement were selected in this study, and springs of different specifications were selected according to the muscle properties reported in the literature (muscle K value, muscle resting length, etc.). Screws were used to fix springs of different specifications on the left half of the pelvis (affected side). Simulate the restraint of the surrounding muscles during pelvic reduction. Radiating muscles such as gluteus medius and gluteus minimus are modeled by applying multiple springs uniformly in a certain area, as shown in Figure 2. The model consists of 10 groups of 22 springs. The sacroiliac joint on the affected side was separated to simulate the fracture of sacroiliac joint dislocation commonly seen in clinic. After the fracture was caused, the pelvis of the affected side was significantly shifted upward and rotated in the open direction under the force of the spring, which was consistent with the common clinical situation.

According to the study of Bishop et al., the commonly used holding channels for the reduction experiment were selected in this paper, which were entering the iliac alar along the iliac spine (channel 1) and entering the anterior inferior iliac spine to the greater ischiatic notch (channel 2). Screw 1 and screw 2 with a diameter of 5 mm are respectively driven into the affected side for holding during the reset operation (Figure 4). Two holding screws were inserted into the anatomically symmetric position of the healthy side for fixation of the pelvis. The stable holding of the pelvis was achieved by the multi-degree of freedom passive arm, and the pelvis was kept in the supine position commonly used in surgery.

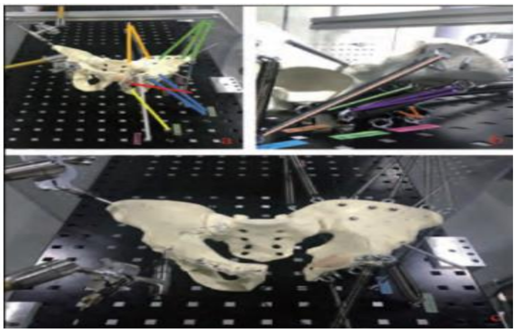


Figure 3: Experimental platform for simulated reduction of pelvic fractures including muscles

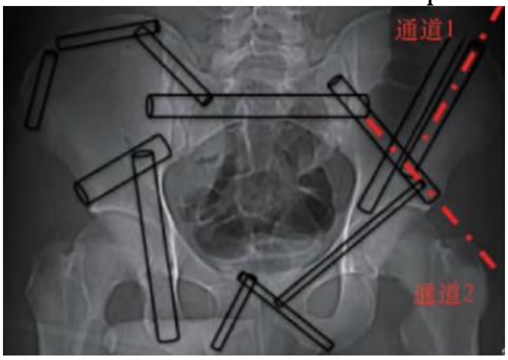


Figure 3: The position of reduction handle screw

In order to measure and record the resetting force during the resetting process, the measuring device of the resetting force was installed on the holding screw. It is directly fixed to the holding screw through a quick connection device, and does not change the physician's reset operation habit. The reset force measuring device mainly includes a quick connection device, ATI six-dimensional force sensor and an operating handle. The ATI six-dimensional force sensor and its supporting acquisition software are used to measure and collect the reset force and record the force in all directions during the reset process in real time.

Repeated experiments were carried out on the established muscle-binding simulation platform for the process of pelvic fracture reduction. Subjects held two fixed holding screws with both hands at the same time for the reduction operation. When the pelvis returned to the anatomical position, the reduction was considered to be complete, and the correct reduction position was maintained for 10 s after the reduction. The experiment was carried out under the lower limb traction force of 0kg, 5kg and 10kg respectively, and the experiment was repeated five times in each group. The reduction force data of 2 holding screws were measured respectively, and the reduction mechanical data under different lower limb traction forces were compared. The influence of lower limb elastic traction force on the reduction force was analyzed by multiple post-LSD tests.

2.4. Operation flexibility experiment with the aid of elastic traction

The common pelvic displacement in clinical practice is upward and outward displacement, so the two directions with greater reduction force in the reduction are usually traction along the lower limb direction and the inner apex along the coronal axis. The parallel bed surface is defined as y direction down the thigh direction, and the vertical thigh direction towards the pelvic healthy side is defined as x direction. In ordinary traction, there is a rigid connection between the traction bow and the linear traction device. In elastic traction, a spring with a size of 2 mm×20 mm×100 mm is added between the traction bow and the linear traction device. The pelvis was translated 3 cm along the positive direction of x axis and y axis respectively during 10 kg ordinary traction and 10 kg elastic traction, and the operating force curve and its peak value were recorded. The difference between the operating force and the initial operating force at the completion of translation was calculated, and the influence of elastic traction on operational flexibility was analyzed.

3. The influence of different elastic traction forces of lower limbs on the operating force of reduction

In this paper, all pelvic reduction experiments were performed by a senior attending physician in the Trauma Department of Jishuitan Hospital. As shown in Figure 4, the reset forces of the two holding screws in 5 groups of reset operations under no traction, 5 kg elastic traction, and 10 kg elastic traction were recorded respectively. When the operator performed downward traction, the force and time had a good linear relationship, but when performing the reduction operation, the curve of each group was significantly different, indicating that the force during the reduction operation largely depended on the physician's manipulation.

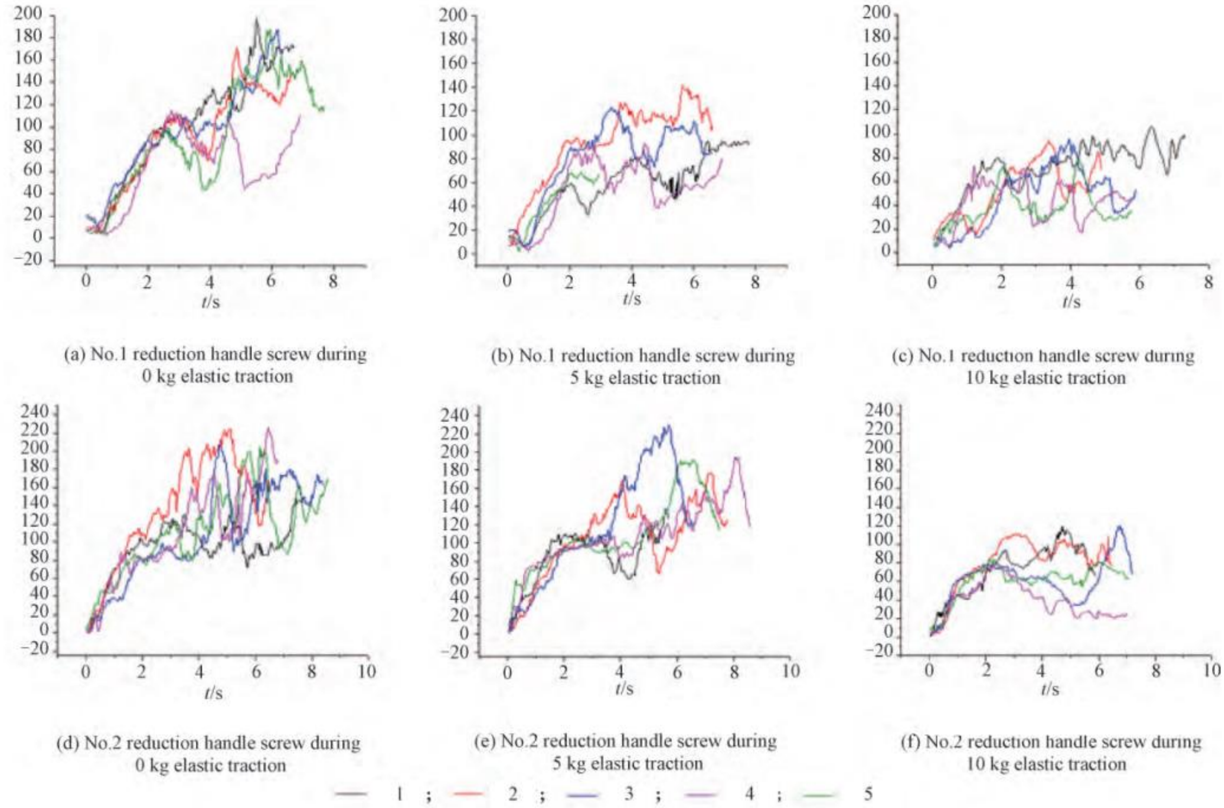


Figure 4: Reduction forces of holding screws under different traction conditions

3.1. Analysis of reset force during reset

The elastic traction device can effectively reduce the size of the reset force during the reset operation, and with the increase of the elastic traction force, the reset force required in the reset operation will also decrease. In the absence of lower limb traction, the peak reduction force of the No. 1 holding screw reached 198.1 N, and that of the No. 2 holding screw reached 224.2 N. When the lower extremity traction force was 10 kg, the peak value of the resetting force of the No. 1 and No. 2 holding screws decreased to 106.3 N and 120. 4 N, respectively. Compared with the reduction process with inelastic traction, the mean peak reduction operating force decreased by 35.43% at 5 kg lower limb traction compared with inelastic traction, and by 57.81% at 10 kg lower limb traction compared with no traction. One-way ANOVA was performed on the reduction force in the three groups of no traction, 5 kg traction and 10 kg traction, and the results showed significant difference (P < 0. 001). The results of multiple post-LSD tests (Table 1) showed that there were significant differences in the reduction force between the no-traction group, the 5 kg traction group and the 10 kg traction group.

Table 1: LSD multiple test of reset force in the process of reset

(I) Groups	(J) Groups	Difference of mean (I-J)	Standard error	Significance	95% confidence interval	
					Lower linit	Upper limit
0kg	5kg	91.18	14.50	0.00	59.59	122.77
	10kg	112.68	14.50	0.00	81.09	144.27
5kg	0kg	-91.18	14.50	0.00	-122.77	-59.59
	10kg	21.5	14.50	0.00	-10.09	53.09
10kg	0kg	-112.68	14.50	0.00	-144.27	-81.09
	5kg	-21.5	14.50	0.00	-53.09	10.0

3.2. Resetting force analysis in resetting maintenance stage

As can be seen from Figure 5, elastic traction not only effectively reduces the reset force, but also facilitates the maintenance of the correct reset position. The reduction and maintenance forces on No. 1 and No. 2 holding screws in the maintenance stage were counted and analyzed statistically, as shown in Table 2 and Table 3. It can be seen that during the reduction and maintenance stage, The average reduction sustaining force of No. 1 holding screw under traction, 5 kg traction and 10 kg traction were 142.18 N, 95.28 N and 55.66 N, respectively, and the reduction sustaining force was 32.99% and 60.85%, respectively, compared with that without traction. The holding force of No. 2 holding screw was reduced by 31.06% and 62.72% respectively. At the same time, the variance in the maintenance process is also significantly reduced, which proves that the maintenance force in the elastic traction is more stable, and the elastic traction is conducive to the maintenance of the correct reset position.

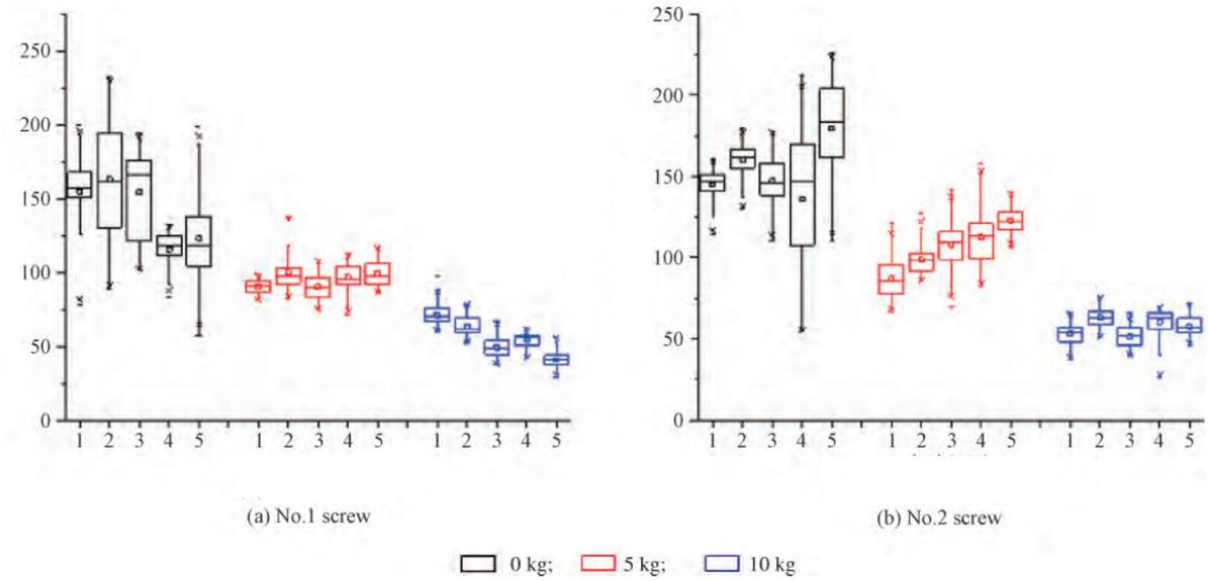


Figure 5: The maintenance force under different tractions

Table 2： Statistical analysis for the maintenance force of the No. 1 reduction handle screw

Item	Traction 0 kg	Traction 5 kg	Traction 10 kg
Mean/ N	142.17	95.28	55.66
Standard deviation/N	32.97	9.44	12.06
Minimum /N	57.11	71.76	29.06
Maximum/N	232.28	137.85	97.10

Table 3 Statistical analysis for the maintenance force of the No. 2 reduction handle screw

Item	Traction 0 kg	Traction 5 kg	Traction 10 kg
Mean/ N	153.6	105.88	57.26
Standard deviation/N	28.65	17.01	7.9
Minimum /N	54.89	66.76	25.91
Maximum/N	226.4	157.95	76.14

Table 4 Analysis of the force during translation actions along the x-axis and the y-axis

Direction	Control screw number	Elastic traction		Ordinary traction	
		Fmax /N	ΔF /N	Fmax /N Δ	ΔF /N
x	1	37.02	10.64	226.64	150.11
	2	90.80	57.72	124.69	90.58
y	1	78.59	43.92	226.64	143.05
	2	80.8	51.19	135.82	110.28

3.3. Analysis of operating flexibility under elastic traction

As can be seen from FIG. 9 and FIG. 10, during the translation operation process, the mechanical curves of No. 1 and No. 2 holding screws are relatively linear regardless of whether elastic traction is carried out. The peak forces Fmax and ΔF in each group during the experiment were calculated, and the average values of each group were calculated as shown in Table 4. After the introduction of elastic traction, the operation force required for the 1 and 2 holding screws to translate 3 cm along the x axis is reduced by 92.91% and 36.28%, respectively, and the operation force for translating along the y axis is also reduced by 69.30% and 53.58%, respectively. It can be seen that compared with the traditional rigid traction, the introduction of elastic traction can significantly reduce the operating force required in the reset operation, and effectively improve the operating flexibility.

4. Conclusion

In the process of reduction of sacroiliac joint dislocation, the physician performs lifting, internal rotation, traction and other actions with instruments such as holding screws to close the sacroiliac joint and achieve the reduction of the posterior pelvic ring. This process not only needs to rely on the doctor's experience, but also requires a great reduction force during the reduction process, which consumes a lot of physical energy for the doctor. Robot-assisted surgery has become the future development direction of pelvic fracture reduction surgery, but the existing robots can not take into account the large load and operational flexibility required for pelvic fracture reduction, and can not meet the clinical needs. In this paper, a new idea is proposed to balance the muscle constraint in the process of reduction by means of lower limb elastic traction. The experimental results show that the introduction of elastic traction can effectively reduce the reduction force during the reduction operation, and does not affect the complicated operation of the physician during the reduction process, so that the fracture reduction auxiliary system has both large load and operational flexibility.

By building a bionic model based on the hypothesis of muscle elastic body, this study simulated the effect of muscle binding force in the reduction process of sacroiliac joint dislocation. Through experimental research, the reduction force in the reduction process was preliminarily obtained, and it was verified that elastic traction can effectively reduce the reduction force and maintenance force, and ensure sufficient flexibility of reduction operation. The validity of elastic traction concept is preliminarily proved. However, there are still some shortcomings in this study: (1) The selection of K value and length of spring is based on the research data of cadaver in previous literature, but the cadaver and living muscle are different in meat characteristics and anatomical morphology, so it may not accurately reflect the muscle binding conditions during real reduction. (2) Due to the complex conditions of muscles and other soft tissues during pelvic fracture, this model has been simplified to some extent, for example, the influence of ligaments has not been considered, and the viscoelasticity of muscles has been ignored, so it cannot completely simulate the real situation. (3) Only the influence of elastic traction on translation operation is analyzed, and the influence on rotation operation is not yet analyzed. (4) The influence of elastic traction with different K values on the resetting force has not been analyzed. The above problems will be improved and perfected in the future research.

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