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Original Article

A security evaluation of the Rigid-fix crosses pin system used for anterior cruciate ligament reconstruction in tibial fixation site

Huaqiang Fan[1], Jian Wang[1], Yangpan Fu[2], Huixiang Dong[2], Jianxiong Wang[2], Cong Tang[2], Changming Huang[2], Zhanjun Shi[1]

[1]*Department of Orthopedic Surgery, Nanfang Hospital, Southern Medical University, Guangdong 510515, China;* [2]*Department of Orthopedic Surgery, The 174th Hospital of PLA, Xiamen 361003, China*

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Abstract: Our study aims to evaluate the safeness and feasibility that Rigid-fix cross pin system was used for hamstring graft anterior cruciate ligament (ACL) reconstruction in the tibial fixation site. In this study, eleven adult conservative cadaver knees were performed using the Rigid-fix Cross Pin device in the tibial fixation site for modeling the ACL reconstruction. The guide rod top was put through the tibial tunnel at the three horizontal positions: equal pace to articular facet (group A), the plane 5 mm below articular facet (group B), and the plane 10 mm below articular facet (group C). We gave four rotation positions to the cross-pin guide: 0°, 30°, 45°, 60° slope, referring to the parallel line of the posterior border of tibial plateau. We recorded the iatrogenic damages incidence, in the four different slope angle in the three groups, and then compare the incidence using Chi-Square test. Our results suggested that the incidence of chondral injury of tibial plateau in group B and group C was significantly lower compared to group A ($\chi^2_{A\text{-}B}$ = 27.077, $\chi^2_{A\text{-}C}$ 45.517, *P* = 0.000); However, there was no significant difference for the incidence penetrating the medial condyle of tibial plateau among the three groups (χ^2 = 5.733, *P* = 0.057); The highest incidence of injuring ligamentum transversum is in group A with 72.7%, especially at the 60° slope angle. In summary, our study suggested that in order to achieve the satisfactory clinical effect for the Rigid-fix system used in the tibia end fixation of ACL reconstruction surgery, the guide rod top should be put at the 5 mm below articular facet with a slope that parallel to the tibial medial plane at 30°-60° slope angle.

Keywords: Anterior cruciate ligament (ACL), Rigid-fix, tibial, iatrogenic injury

Introduction

Rigid-fix Cross Pin Internal Fixation System can provide an effective internal fixation and provide the fixation point near the anterior cruciate ligament (ACL) physiological end point, it can effectively reduce the incidence rate of relevant complications and is widely used clinically in the femoral end fixation of ACL reconstruction surgery [1, 2]. Especially, the feature that the fixation point is near the ACL physiological end point can reduce the operative procedure dependence on the graft length. This point has been sufficiently demonstrated in the posterior cruciate ligament (PCL) reconstruction [3, 4]. Similarly, the situation that the graft is too short may also appear in the ACL reconstruction surgery, therefore, some scholars used the Rigid-fix Cross Pin System to fix both femoral and tibial ends in the ACL reconstruction surgery, and have achieved satisfactory clinical effects. They have believed that by using this method, graft length requirement in the ACL reconstruction can be reduced accordingly, while good fixation effect can be achieved [5-7].

However, the Rigid-fix system was originally designed for the femoral end fixation of ACL reconstruction surgery, and if apply to the tibial end, is there an iatrogenic injury risk? To solve the problem, Lee et al. performed anatomical study and found that in order to avoid the cross pin fixation system to cause the common peroneal nerve injury during the tibial end operation in PCL reconstruction surgery, it is necessary for the tibial tunnel position to appropriately

Figure 1. The Rigid-fix guide rod was rotated at different angles to drill a cross pin tunnel, and it was found that there was certain distance between the cross pin tunnel inlet position and the knee posterior-lateral structure.

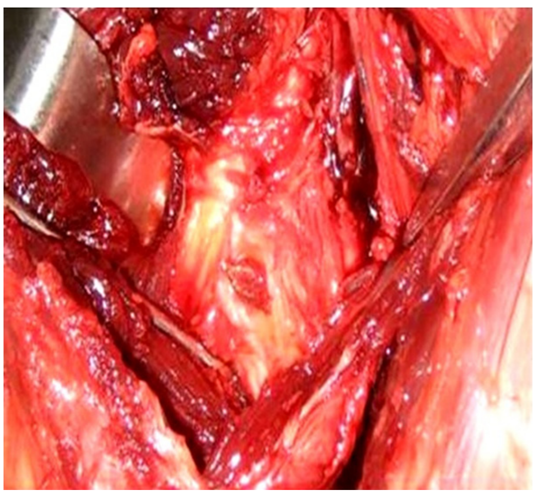

Figure 2. After the cross pin tunnel was drilled, the cross pin set drill was left. The knee posterior-medline incision was performed, the posterior structure was exposed and it was found that the cross pin set drill penetrated the tibial plateau posterior-medial cortex.

shift towards the anterior-superior direction [8]. Then, if the Rigid-fix Cross Pin System was used in the tibial end fixation of ACL reconstruction, will iatrogenic injury occur? Although the clinical effect of this operation is satisfactory, but are there some questions that we have not found? Therefore, by performing the anatomy of 11 adult cadavers, this study discussed the security of the Rigid-fix system used in the tibia end fixation of ACL reconstruction surgery, and provided anatomical basis for clinical applications.

Materials and methods

General information

Eleven knee specimens of adult cadavers were used (the specimens were provided by Anatomy Teaching and Research Office in Southern Medical University). First of all, X-ray examination was performed to determine that these knees had not undergone surgical operations and had no obvious bone organic changes. Among them, there were six men and five women with average death age of 41.4 (41.4 ± 4.6) years old, and before deaths, their average body weight was 60.3 (60.3 ± 8.3) kg and average height was 163.3 (163.3 ± 6.5) cm.

Method

Pre-experiment: After the patient had provided informed consent and had signed, we took a fresh lower limb specimen (2 hours). This adult female (aged 26 years old) had had giant cell tumor of bone on the right tibial plateau and had needed amputation. The specimen was fixed on an operation platform, keeping the knee to bent 90°. The knee medline incision was performed to expose the articular cavity and to cut off the ACL tibial end point. The tibial guide rod angle was adjust to 55°, and the angle between it and the tibial sagittal plane was 25°; the guide rod was located to the posterior part of the ACL tibial physiological end point and 7 mm interior to the posterior cruciate ligament. The diameter of the tibial tunnel was expanded to 7 mm, and the Rigid-fix system guide rod with 7 mm diameter (RIGID-FIX Cross Pin System, DePuy Mitek) was placed under the tibial plateau articular surface. The guide rod angles was rotated; by using the cross pin casing with 3.3 mm diameter, cross pin insertion tunnels were drilled from different directions, and we observed the correlation between the positions of the insertion holes in all directions and the surrounding soft tissue. Through the pre-experiment, we found that the tibial tunnel of ACL reconstruction surgery was relatively near the anterior part compared with the tibial tunnel of PCL reconstruction surgery, and there was certain distance between the cross pin insertion hole position and the knee posterior-lateral structure (the common pero-

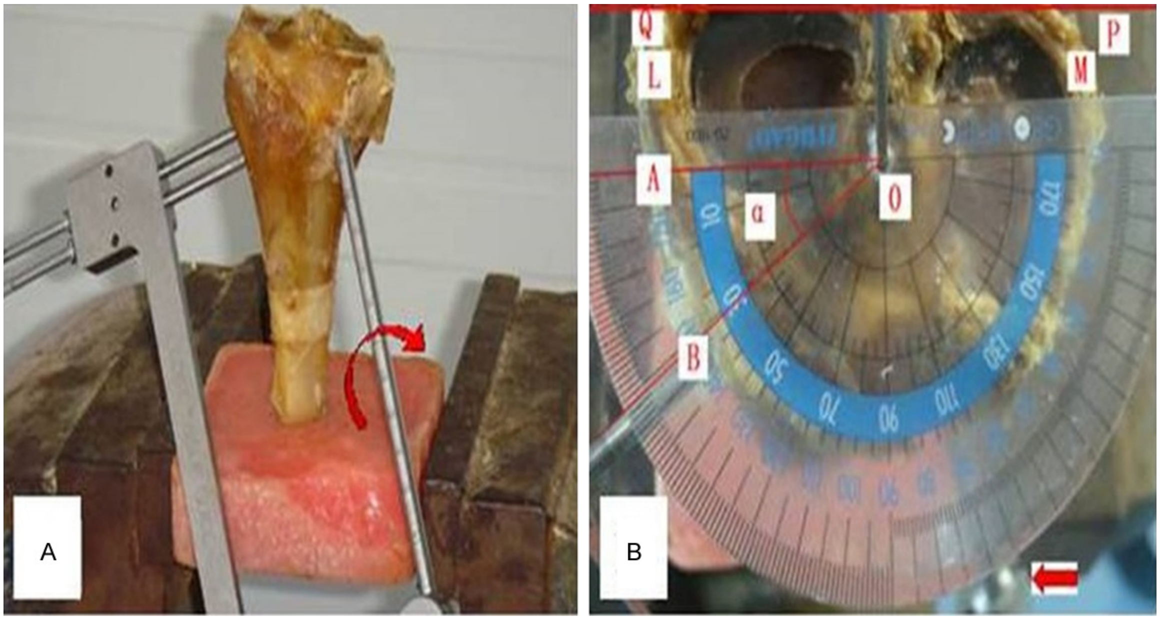

Figure 3. A: The Rigid-fix guide longitudinal rod was placed into the tibial tunnel. A: The longitudinal rod is regarded as the rotation axis (rotation arrow). B: The protractor was placed on the tibial plateau; the tibial plateau posterior edge was used as the reference line (QP line), and from the lateral side, the angle α between the cross pin casing (BO) and line AO parallel to line QP was defined as a rotation angle of the cross pin.

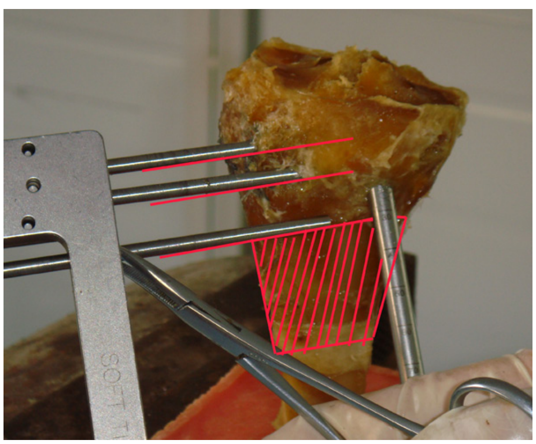

Figure 4. When the Rigid-fix guide rod was placed at 60°, the plane formed by two cross pin casings (the plane formed by the two red lines) was roughly parallel to the medial tibial plane (shown in red shadow).

neal nerve, fibular collateral ligament, etc.) (**Figure 1**). However, we found that the distant end of the cross pin might penetrate osseous cortex, injure posterior-medial structure, protrude into the articular cavity and cause other risks (**Figure 2**). Therefore, the focus in this study was whether the cross pin set drill penetrated the bone cortex.

Specimen preparation: 20 cm up the knee and 20 cm down the knee were intercepted, and the two ends were embedded. The muscles surrounding the knee joint were removed and the retention parts were: the joint capsule, tibial and fibular collateral ligaments, patella, patellar tendon and popliteal tendon. The anterior-medial incision was performed to cut open the joint capsule, to expose the knee joint, to remove ACL tissue and to suture the incision for use.

Knee flexion was 90°, part of the anterior-medial incision suture was cut open, the tibial guide rod angle was adjusted to 55° and the angle between the guide rod and the tibial sagittal plane was 25°. Under direct vision, the tibial tunnel locator was located at the posterior half of the ACL end point and 7 mm anterior to the posterior cruciate ligament. The Kirschner wire was drilled into bone. Via the Kirschner wire, 7 mm hollow drill was used to drill a tibial tunnel, and the length of the tunnel was measured: 32~53 mm (43 ± 3.4 mm). After the tibial tunnel was drilled, in order to perform easy observation, the femur and the soft tissue surrounding it were removed, and only the tibia and the medial meniscus and lateral meniscus were

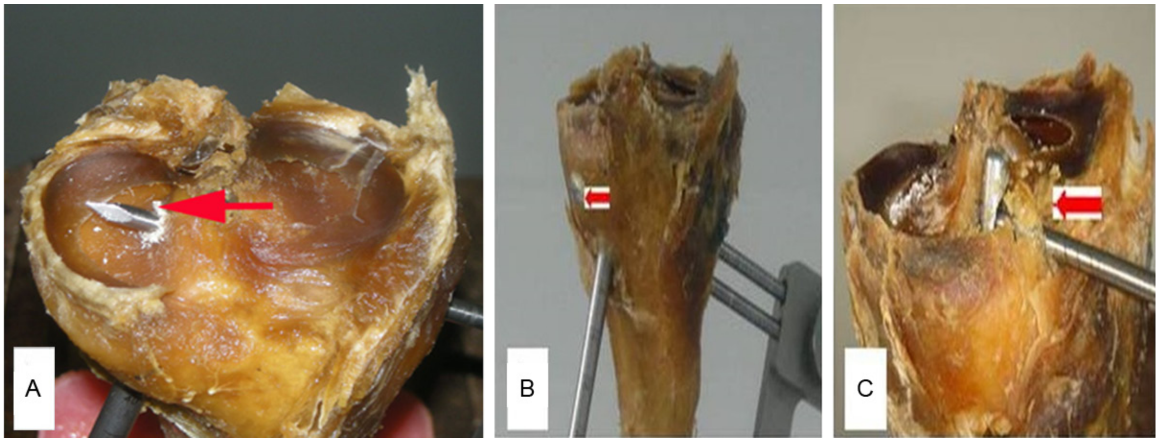

Figure 5. A: A cross pin penetrated the tibial plateau cartilagineus surface (arrow); B: A cross pin penetrated the medial tibial condyle osseous cortex (arrow); C: A cross pin injured the transverse ligament (arrow).

left. The specimen preparation was completed for use.

Determination of measurement angles: originally, we planned that the Rigid-fix guide rod was used as the rotation axis, and a protractor was placed on the plane of the perpendicular guide rod to determine the degree of rotation. However, in the actual operation, we found that as the angle of the tibial tunnel deviated, the position of the plane where the protractor was placed would change accordingly, which might artificially increase experimental error. Therefore, we decided that the relatively constant tibial plateau plane was used as the plane where the protractor was placed, hoping to reduce experimental error.

The Rigid-fix guide longitudinal rod was used as the rotation axis (3a), the protractor was placed on the tibial plateau, and the tibial plateau posterior edge was used as the reference line (line QP); the lateral end (L) was used as 0° (**Figure 3B**), the guide longitudinal rod was use as rotation axis, and then the Rigid-fix guide rod was rotated (the angle α between BOA was shown in **Figure 3B**) and was fixed at 0°, 30°, 45°, 60°, 90°, 120°, 135°, 160°, 180°, respectively. When the cross pin tunnel was drilled, it was found that at 60° the cross pin direction was roughly parallel to the anterior-medial plane of the proximal tibia (**Figure 4**); when the angle became bigger ($\alpha > 60°$), we found that the part of the cross pin which already stayed in the bone became less and the exposed part of the cross pin became more, even the most distant part of the casing could not go into the bone, so that the casing could not be fixed and easily shook or slipped off. If under this condition the cross pin was inserted, it is easy for the cross pin to expose or slip off. Therefore, 4 angles, i.e., 0°, 30°, 45°, 60° were used as the research angles.

Definition of injury: Through the process of the pre-experiment and the experiment, we found that the cartilagineus injury on the tibial plateau articular surface, medial condyle osseous cortex penetration on the tibial plateau, and transverse ligament injury were the relatively common iatrogenic injuries when the Rigid-fix system was operated on the tibial end. Therefore, these three common injuries were used as the subject of this study.

The cartilagineus injury of the tibial plateau articular surface*:* That the cross pin set drill system penetrated the articular surface was defined as injury (**Figure 5A**). The medial condyle osseous cortex penetration on the tibial plateau: That the cross pin set drill system penetrated the medial condyle osseous cortex was defined as injury (**Figure 5B**). Transverse ligament injury: That the cross pin set drill system penetrated the transverse ligament injury was defined as injury (**Figure 5C**).

Operative steps: The top of the Rigid-fix guide rod was placed to 3 different positions, i.e., the level of the articular surface, 5 mm under the articular surface, 10 mm under the articular surface, respectively, and according to this, the

Table 1. Statistical analysis of the tibial plateau cartilage surface injury incidence rates of Rigid-fix

Grouping	Angle	Whether the articular surface was penetrated			χ^2			P		
		Yes	No	Incidence rate	A	B	C	A	B	C
A	0	11	0	100%		X_0^2=22.081			P_0=0.000	
	30	10	1	90.9%		X_{30}^2=28.696			P_{30}=0.000	
	45	8	3	72.7%		X_{45}^2=21.120			P_{45}=0.000	
	60	1	10	9.1%		X_{60}^2=2.063			P_{60}=0.357	
	Total	30	14	68.2%		27.077	45.517		0.000	0.000
B	0	6	5	54.5%						
	30	0	11	0						
	45	0	11	0						
	60	0	11	0						
	Total	6	38	13.6%			6.439			0.011
C	0	0	11	0						
	30	0	11	0						
	45	0	11	0						
	60	0	11	0						
	Total	0	44	0						
χ^2 Comparison of total values of three groups						57.750			0.000	

divided 3 groups, i.e., group A, B, C were obtained. The tibial plateau posterior edge was used as the parallel line, and on the lateral and the anterior-lateral tibial plateau, from 4 locations, i.e., 0°, 30°, 45°, 60°, the cross pin insertion tunnels were drilled, respectively; the correlation between the insertion tunnel position and the tibial tunnel articular surface, the tibial plateau medial condyle, the transverse ligament was observed (**Figure 5**). All operations were completed by a senior doctor.

Statistical analysis

SPSS 13.0 statistical software was used to treat data. The incidence rates of the plateau articular surface penetration, the plateau medial condyle osseous cortex, the cross ligament injury in 3 groups were counted and χ^2 test was used to compare incidence rates of 3 iatrogenic injuries in the 3 groups; if the differences were statistically significant ($P < 0.05$), angles were set as a stratified condition to compare incidence rates of iatrogenic injuries in the 3 groups from different angles. $P < 0.05$ was considered statistically different. χ^2 segmentation method was further used to perform multiple comparisons, i.e., $a' = a/[k(k-1)/2 + 1] = 0.0125$ ($k = 3$), and by using a' correction, $P < 0.0125$ was considered statistically significant.

Results

The Rigid-fix system was used for internal fixation of the tibial end in ACL reconstruction surgery, and the Rigid-fix guide rod top was placed in different positions in 3 groups, i.e., group A, B, C. Comprehensively taking into account the four angles, i.e., 0°, 30°, 45°, 60°, there were 44 observation data in each group. The incidence rates of the tibial plateau articular surface penetration were 68.2%, 13.6% and 0%, respectively; the incidence rates of the medial tibial condyle osseous cortex penetration were 0%, 4.5% and 11.4%, respectively; the incidence rates of the tibial plateau transverse ligament injury were 29.5%, 0% and 0%, respectively (**Tables 1-3**).

The incidence rates of the tibial plateau articular surface cartilage large injury were compared among 3 groups, and the difference was statistically significant ($\chi^2 = 57.750$, $P < 0.05$). The angle was set as a stratified condition to further perform χ^2 test of stratified risk degrees, and the obtained result was that the cartilagineus injury incidence rates of 3 groups at 0°, 30°, 45° had statistical significance (χ^2 were 22.081, 28.696, 21.120, respectively, every $P < 0.05$); because the cartilagineus injury inci-

Table 2. Statistical analysis of the medial tibial condyle penetration incidence rate of Rigid-fix

Grouping	Whether it the medial tibial condyle was penetrated			χ^2	P
	Yes	No	Incidence rate		
A	0	44	0	5.733	0.057
B	2	42	4.5%		
C	5	39	11.4%		

Table 3. Comparison analysis of the transverse ligament injury incidence rates of Rigid-fix system

Grouping	Whether the transverse ligament was injured			χ^2	P
	Yes	No	Incidence rate		
A	13	31	29.5%	28.840	0.000
B	0	44	0		
C	0	44	0		

dence rate was low at 60°, for example, only one case in group A occurred, there was no statistically significant difference among 3 groups (χ^2 = 2.063, P = 0.357). Furthermore, χ^2 multiple segmentation method was performed; group C significantly lowered cartilagineus surface injury incidence rate compared with group A, (χ^2 = 45.517, P < 0.0125); compared with group B, the difference also was significant (χ^2 = 6.439, P = 0.011 P < 0.0125); meanwhile, between group B and group A, the difference was statistically significant (χ^2 = 27.077, P = 0.000 P < 0.0125) (**Table 1**).

The incidence rates of the tibial plateau medial condyle osseous cortex penetration were compared among 3 groups, and the difference was not significant (χ^2 = 5.733, P = 0.057) (**Table 2**).

Comparing the incidence rates of the transverse ligament injury among the three groups, the difference was statistically significant (χ^2 = 28.840, P < 0.05) (see **Table 3**). The transverse ligament injury was found only in group A, therefore, χ^2 test with RXC table data was used to analyze the incidence rates of group A at different angles, and the conclusion was that the incidence rates of the transverse ligament injury at different angles had statistical significance (χ^2 = 13.226, P = 0.004) (see **Table 4**).

Discussion

After ACL injury, knee joint instability and cartilagineus injury secondary to it eventually cause knee joint function limitation, thus reconstruction of ACL is required to restore joint stability as far as possible so that the further injury of the joint can be avoided and the joint function can be restored. The selection of the graft is one of the key steps of the ACL reconstruction. Hamstring tendon is used for ACL reconstruction, can significantly reduce pre-patellar pain, limitations of flexion and extension, and other donor site complications; furthermore, the elastic modulus of hamstring tendon is similar to that of ACL, but its strength is much larger than that of ACL, thus it can restore stability of the knee joint after reconstruction [9-11]. After Tohyama et al. [12] measured 16 fresh adult specimens, concluded that semitendinosus average length was 235 mm ± 20 mm, and gracilis average length was 200 mm ± 17 mm among which the shortest one was 180 mm. If dual-beam and four-share reconstruction were performed and the length could reach up to 90 mm, the length requirement of reconstruction could be met. Therefore, in recent years, the application of hamstring tendon has become wider and wider, accounting for nearly half of ACL reconstruction [13, 14]. However, in actual clinical work, probably due to individual reasons, the length of the hamstring tendon cannot be taken enough and we can only screw the interface screw into the tunnel for squeezing fixation or use the interference screw etc. to fix the braided suture of the grafted tendon distal end to cortical bone at the tunnel outlet and use other remedy ways, which may affect the fixation strength. Also, the use of interface screws is prone to tendon graft cutting, tunnel wall microscopic fracture, rejection reaction, induction of periosteum inflammatory reaction as well as increase of postoperative bone tunnel enlargement incidence rate [15-17], which affect the outcome of the operation and to some extent restrict hamstring tendon applications. About how to solve the problem of ACL

Table 4. Comparison analysis of the transverse ligament injury incidence rates of Rigid-fix system at all individual angles in group A

Grouping	Angle	Whether the transverse ligament was injured			χ^2	P
		Yes	No	Incidence rate		
A	0	0	11	0	13.226	0.004
	30	1	10	9.1%		
	45	4	7	36.4%		
	60	8	3	72.7%		
	Total	13	31	29.5%		

reconstruction surgery dependence on the length of the graft, the choice of internal fixations is crucial.

The internal fixation choice of the graft commonly includes the Endobutton miniature plate, the interference screw and the cross pin internal fixation system. The cross pin internal fixation system possesses several following advantages: (1) The fixaton point is near the ACL anatomical end point; according to the design, the distal cross pin is 13 mm from the articular surface, which can reduce "rubber band and rain wiper" effect and reduce incidence rates of postoperative tunnel enlargement and other complications [17]. (2) The graft contacts with the bone tunnel at the whole 360° to facilitate bone tendon healing. (3) The system has firm and stable fixation and other advantages, has been recognized by many scholars and is used in clinical practice [1, 2, 14]. Among cross pin internal fixation devices, the Rigid-fix system is the most common one [14].

However, for the fixation of the tibia end, the selected surface is relatively small, and the interface screw, the door-shaped pin or the Intrafix system is all far from the ACL physiological end point. Therefore, certain requirement of graft length is proposed. Ahn et al. [3] used the Rigid-fix system for tibial end fixation in posterior cruciate ligament (PCL) reconstruction, and have thought that this will reduce PCL reconstruction dependence on graft length. Furthermore, various bio-mechanics results show that the cross pin internal fixation system, which is used in tibial end fixation of PCL reconstruction, can meet firm fixation requirement [9, 18]. Therefore, people have gradually accepted the application of Rigid-fix and other cross pin internal fixation systems in tibial end fixation of PCL reconstruction [3, 4, 19-21]. Then, can the Rigid-fix system be applied in tibial end fixation of ACL reconstruction? Antonogiannakis [5] had a try in this regard. He used the Rigid-fix system to fix both the tibial end and the femoral end and has thought that 8-9 cm length of quadriceps tendon can meet the requirement of the reconstruction. Volpi et al. [6] performed comparison of postoperative functional scores of the absorbable interference screw and the Rigid-fix system used in tibial end fixation of reconstruction surgery; the authors performed 5-year followed-up and found that there was no statistically significant difference between the two methods, therefore, they have thought that the Rigid-fix system can meet the requirement of ACL reconstruction surgery in the aspect of biological mechanical strength. Yujie Liu et al. [7] used the femoral end the Rigid-fix system to fix the tibial end, and they placed the top of the Rigid-fix guide rod under the cartilage and performed follow-up for 32 patients, so that they have thought that the method can compensate the disadvantage of the interface fixation screw and the bolt pile and other methods, because the tendon can fully contact with the bone tunnel to facilitate the tendon healing and the postoperative MRI examination revealed that the fixation point was near the joint line and no case had the widened bone tunnel.

In the application, we have found that because the internal fixations of the femoral end and the tibial end are all close to the articular surface end point, the cross pin on the femoral end is 20 mm from the articular surface as the farthest distance; if on the tibial end the top of the Rigid-fix guide rod is placed under articular cartilagineus surface, the furthest end is fixed 17 mm from the articular surface; a tendon with thickness of about 3 mm is added to both ends, therefore, only 43 mm length of the tendon in the tunnel is needed; plus 26.9 mm intra-articular tendon length [22], only 69.9 mm transplanted tendon length is needed to meet the graft requirement of ACL reconstruction, greatly reducing graft length requirement of ACL reconstruction surgery. The traditional method is that the femoral end was fixed with Rigid-fix, and at least 23 mm length is needed in the femoral tunnel, plus 43 mm tibial tunnel length and 26.9 mm intra-articular length, thus about 93 mm graft length is needed.

We believe, if the Rigid-fix system is applied for the ACL tibial end, there also are firm fixation, tendon-bone 360° contact and other advantages, while if the system is used on both femoral end and tibial end, the fixation point is near the ACL anatomical end point, which meets the physiological reconstruction requirement and reduces the requirement of the graft length. However, the Rigid-fix system was originally designed to fix the femoral end in the ACL reconstruction surgery; if applied to the tibial end, is there risk of iatrogenic injury? By autopsy, Lee et al. have found that when the cross pin internal fixation system is used for the tibial end fixation in the PCL reconstruction surgery, the operation needs to pay attention to not damaging the common peroneal nerve and other posterior-lateral structures [8]. Through the pre-experiment, this study has found that because in the ACL reconstruction surgery, the tibial tunnel position is relatively near the anterior part, the risk of posterior-lateral structure injury of the knee joint is greatly reduced. However, we have found that the cartilagineus injury on the tibial plateau articular surface, the medial condyle osseous cortex penetration on the tibial plateau, and the transverse ligament injury are the more common iatrogenic injuries when the Rigid-fix system was operated on the tibial end during ACL reconstruction surgery.

The study found that group B and group C could significantly reduced the incidence rates of tibial plateau cartilagineus injury compared with group A ($P < 0.0125$). When placement angles were different, the incidence rates were also somewhat different: When the angles were 30°, 45°, 60°, the incidence rates in Groups B, C are 0, and comparing the 3 groups the result had statistically significant difference ($P < 0.05$). That is, we believe that if the guide rod is placed at the level 0.5 cm under the articular surface (groups B, C), the incidence rates of tibial plateau cartilagineus injury will be significantly lowered, and meanwhile if the guide rod is placed at more than 30°, the incidence rate of tibial plateau cartilagineus injury can be effectively reduced.

The incidence rates of medial tibial condyle osseous cortex penetration in groups A, B, C were 0, 4.5 %, 11.4%, respectively; because of their low incidence rates, there was no statistically significant difference ($P > 0.05$). However, it is not difficult to observe that the incidence rate in group C (the group: 10 mm under the articular surface) was the highest. The incidence rate of the injury was relatively low, however, little soft tissue covered the medial tibial wall and once a cross pin penetrated the cortex, it easily caused local eminence and pain to affect the efficacy of the operation; furthermore, taking into account an inverted cone shape of the tibial plateau, as the plane where the guide rod was placed became low, the incidence rate that the cross pin penetrated medial osseous cortex should gradually increase, and if the number of samples appropriately increased, this trend would be more obvious. During operation, we found that the incidence rate of the injury was closely related to the tibia volume and the tunnel length; all samples in which the cross pins penetrated medial osseous cortex had tibial tunnel length ≤ 4 cm, among which the length of a tunnel was 3.2 cm. In group B and group C, we found that the set drill system all penetrated osseous cortex at 0°, 30°, 45°; however, interestingly, when the guide rod was position at 60° position, in no case did the set of drill system penetrate. We considered that it might be related to the fact that at 60° the set of drill system was parallel to anterior-medial surface of the proximal tibia (**Figure 4**) and the bone was relatively thick at anterior-posterior diameter. However, because statistical analysis cannot be performed duo to the small samples and the low incidence rates, the phenomenon will be further investigated in the next study.

When the top of the Rigid-fix guide rod was placed on the level of the articular surface, the transverse ligament injury risk existed, especially when it located at 60° and the cross pin casing was perpendicular to the transverse ligament so that its injury incidence rate was the highest, up 72.7%. Integrating the statistical results of the incidence rates of 3 kinds of iatrogenic injuries, we believe: When the Rigid-fix system was used in ACL tibial end fixation, the guide rod should be placed 5 mm under the articular surface, and meanwhile the rotation angle of the guide rod should be adjusted to

30°-60° to reduce risks of the cross pin exposure (penetrating cartilagineus surface or medial osseous cortex) and the transverse ligament injury. Especially when the cross pin insertion angle is roughly parallel to the anterior-medial surface of the proximal tibia (about 60°), this advantage is more obvious. That is, as for the insertion angle, the cross pin should be inserted from superior-lateral direction to inferior-medial direction and should avoid be inserted from the bottom to the top, or from the medial surface.

It is different to obtain fresh cadavers, therefore, in this experiment the prep-experiment only used a fresh specimen and whether it can represent iatrogenic conditions appearing in large samples needs to be further studied. Because the number of the specimens in this study was relatively small, statistical analysis for correlation between iatrogenic injury incidence rate and body size could not be performed despite repeated measurements for increasing the statistical number of cases. In order to reduce experimental error in this study, the plane where the tibial plateau occupied was chosen as the plane where a protractor was placed, but this choice might cause difficulty of angle conversion in actual operation; however, this study converted the angles to anatomical insertion directions, and might partially compensate for this deficiency.

In summary, when the Rigid-fix system is used on the tibial end, the fixation point is near ACL physiological end point and the graft can sufficiently contact with the bone tunnel, so that the bone and tendon healing is facilitated. For example, when the Rigid-fix system is used on both femoral and tibial ends, the required length of the graft can be reduced while the firm internal fixation is obtained.

According to the conclusion in this study, it is suggested that the top of the guide rod be placed 5 mm under the articular surface. This method can effectively prevent the cross pin set drill from penetrating the articular surface and for damaging the transverse ligament. The set drill should drill into the bone from anterior-lateral-superior direction to posterior-medial-inferior direction (30°-60°), and they have better drill at the direction parallel to the anterior-medial surface of the proximal tibia (about 60°), so that the tibial tunnel is centered and the across pin can be embedded in the bone to avoid the cross pin from exposing or unstably sliding off.

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Disclosure of conflict of interest

None.

Address correspondence to: Dr. Changming Huang, Department of Orthopedic Surgery, The 174th Hospital of PLA, Xiamen 361003, China. E-mail: hangchm123@163.com; Dr. Zhanjun Shi, Department of Orthopedic Surgery, Nanfang Hospital, Southern Medical University, Guangdong 510515, China. E-mail: zhanjunshi@sohu.com; yuan.wang@health.nsw.gov.au

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