Research Square

Preprints are preliminary reports that have not undergone peer review. They should not be considered conclusive, used to inform clinical practice, or referenced by the media as validated information.

The alignment alteration of transverse plane in growing rabbits after patella dislocation

Jinghui Niu
Hebei Medical University Third Affiliated Hospital
Qi Qi
Hebei Medical University Third Affiliated Hospital
Kang Piao
Hebei Medical University Third Affiliated Hospital
Kuo Hao
Hebei Medical University Third Affiliated Hospital
Fei Wang (njhxueshu@163.com)
Hebei Medical University Third Affiliated Hospital

Research article

Keywords: Patella, Patella dislocation, Rabbits, Torsional malalignment

Posted Date: April 6th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-20258/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Abstract

Background: Torsional malalignment in transverse plan has been regarded as a risk factor for patella dislocation. But the influence of patella dislocation for torsional alignment development remains unknown. The present study aims to investigate whether the torsion alteration of the hindlimb occur after patella dislocation in growing rabbits.

Methods : Thirty rabbits that were 1 months old were included in the study. The left knees of each rabbit (N = 30 knees/group), were underwent patella lateral dislocation operation and defined as the experimental group. The right knees of each rabbit, defined as the control group (N =30 knees/group), did not undergo any surgical procedures. Computed tomography was performed on each knee immediately post-surgery and 5 months post-surgery to measure femoral version and tibial torsion. The angles was analyzed between the experimental group and control group.

Results : The femoral version and tibia torsion in the experimental and control group were not significantly different immediately after surgery. However, 5 months after surgery, the femoral version of the experimental group (-5.50±6.13°) was significantly different with that of the experimental group (-10.90±4.74°)($P < 0.05$). But the tibia angle in the experimental group (7.17±7.25°) and control group (4.47±6.34°) were not significantly different ($P = 0.144$).

Conclusion : Patella dislocation can lead to significant change in femoral version in growing rabbits. Thus if adolescents suffer from patella dislocation or instability for a long time in growing period, the torsional malalignment in lower limbs may occur.

Background

Anatomic factors, such as patella alta, increased tibial tubercle–trochlear groove (TT-TG) distance, rotational deformities, and trochlear dysplasia, are associated with dislocation of the patella[1, 2, 3, 4, 5]

Of these factors, the lower extremity alignment is very important in pathophysiology and aetiology of patella dislocation. Rotational malalignment may be a risk factor in patellar dislocation and achieved more and more attention. For example, Dejour et al. [2] found that femoral anteversion in controls was 10.8 and 15.6°in patients with patellar instability ($P = 0.013$). In another study, it was found a 1.56-fold higher mean femoral anteversion in patients with a history of patellofemoral instability compared with controls. But no significant differences in tibial torsion were found in patients with patellofemoral instability compared to the control group in the above two studies[3, 4].

Clinically, the torsion of the lower limbs may influence choice of surgical treatment for patients with recurrent patellar dislocation. With high degrees of internal femoral torsion, isolated medial patellofemoral ligament reconstruction for patella instability is insufficient. Femoral internal torsion of more than 15°– 25°is considered as the indication for derotational femoral osteotomy[6].

The influence of patella instability on the morphology of the patellofemoral joint has been investigated. Wang and Li found femoral trochlear dysplasia or flattening after patella instability in growing rabbits[7, 8]. Trochlea flattening after surgery with respect to the patella alta was demonstrated in growing rabbits by Kaymaz[9]. Niu found the sectional shape and articular surface of the patella became more flattened after patella instability in growing rabbits[10]. These studies indicate that patellofemoral joint dysplasia could be caused by patella instability. In the experimental study by Niu[11], tibial tubercle lateralization and an increased tibial tuberosity–trochlear groove (TT-TG) distance were proved after patella dislocation. TT-TG distance reflects the relative location between distal femur and proximal tibia, and affects the lower extremity alignment.

Because two-dimensional (2D) measurements can be affected by the location of the radiation source and/or the limb position, it is possible that the alignment factors have not been assessed correctly. Recently, three-dimensional (3D) evaluation for the lower extremity of alignment has been applied, which was proved to have high intra-observer and inter-observer reliability regardless of femoral neck-shaft angle or postural deformity[5, 12, 13, 14, 15]. Considering the high accuracy of the measurement and the extreme flexion of knee and hip joints in rabbits, the 3D method has been taken account in this study.

Although low extremity malalignment is considered as a predisposing factor for patella dislocation, the effect of patella dislocation on low extremity alignment has remained unclear. Based on the previous studies, we hypothesized that early patella dislocation lead to lower extremity malalignment in the growing rabbits. The objectives of the present study were to elucidate the alignment alteration in transverse plane after patella dislocation in growing rabbits and to discuss the influence of patella dislocation on lower extremity alignment.

Methods

Study design and surgical procedure

This study was approved by the local Animal Ethics Committee (Number:Z2019-006-1). Sixty knees from 30 healthy, 1-month-old New Zealand white rabbits, weighing between 350 and 450 g (provided by the Animal Test Center of the local medical university), were divided into two groups. The experimental group comprised the left knees, which were subjected to patella dislocation surgery. The control group comprised the right knees, and no surgical interventions were performed.

The rabbits were administered anaesthesia of ketamine hydrochloride and xylazine at a dosage of 20 and 5 mg/kg body weight, respectively, into an ear vein. Then, the left knees were shaved and disinfected by standard procedures. A 3-cm incision was performed on the knees, and the soft tissue was dissected to expose the medial retinaculum and medial side of the joint capsule. The medial retinaculum and medial joint capsule were incised while avoiding damage to blood vessels and cartilage. The patella was then pushed laterally, and the lateral joint capsule was sutured with overlapping tissue. Following these procedures, patella dislocation was seen intraoperatively (Fig. 1). The patella dislocated (the femoral trochlear could be seen) when the knee was flexed and extended. After the operation, the incision was sutured, and bandages were applied over the incision. CT scans were performed immediately after surgery to confirm lateral patellar dislocation. Ciprofloxacin (10 mg/kg, po) was administered 3 days after surgery for antibiotic prophylaxis. Because the rabbits achieve skeletal maturation at 28 weeks, both groups were followed for 5 months after dislocation surgery.

Measurements

CT scans of the rabbits were performed immediately post-operatively and 5 months post-operatively using a 16-slice CT scanner (SOMATOM Sensation 16; Siemens Medical Solutions, Erlangen, Germany). The rabbits were anaesthetized and were placed in a supine position. The knee joints were fully extended. The hindlimbs were fixed on a board to prevent any movements during scanning. Contiguous slices (1.0 mm) were obtained from the upper rim of the acetabulum to the most distal part of the lower limbs. Considering the different structure of the hindlimbs in rabbits and the accuracy of the measurements, the measurements were performed in a 3-dimensional strategy. The CT slices were sent to RadiAnt DICOM software (Medixant Ltd., Poznan, Poland) and reconstructed for 3D models. Our measurement methods had an accuracy of 0.01°.

After 3D image construction, horizontal view(femur looking down from top) was acquired by 90°rotation through the program from anteroposterior view for femoral version measurement. The lowest point of the greater trochanter and the lowest point of the medial and lateral condle were moved and rotated. After adjustment, the lowest point of the greater trochanter were located in the middle between medial and lateral condle. The three points were connected by the horizontal line C (Fig. 2). The femoral neck version was the angle formed by the line B (parallel to line C) and the line A connecting the point of centre of the femoral head with the midpoint of the narrowest femoral neck(positive values: femoral neck is anterior to posterior condylar line) [12].

For tibia torsion measurement, the most posterior points of the medial and lateral tibia condyles were connected by Line C. Tibia torsion was measured by the angle between the line B (parallel to line C) and the line A which was drawn through the center of medial and lateral malleoli (positive values: external rotation of the ankle)[5, 16].

Statistical Analysis

Statistical analysis was performed using the SPSS version 21.0 (SPSS, IL, USA). The mean difference of femoral version and tibia torsion between the control group and the experimental group were evaluated by Student's t test. A P value < 0.05 was determined as statistically significant.

The results are expressed as mean ± standard deviation. No a priori power analysis could be performed because of the paucity of research on the topic. To determine the intra-observer variation, the observer A repeated the measurement 2 weeks after first observation. To determine the inter-observer variation, the measurements were performed by observer A, observer B and observer C. Intra-observer consistency and interobserver consistency were analysed using intra-class correlation coefficient (ICC). ICC > 0.75 was regarded as excellent, ICC 0.40–0.75 was fair to good, and ICC < 0.40 was poor.

Result

In this study, the femoral version and tibia torsion in the experimental and control groups before surgery were not significantly different (Table 1). Two rabbits died before the last CT scanning. So 28 rabbits were taken CT scanning 5 months after surgery. The femoral version of the experimental group (-5.50 ± 6.13°) was significantly different with that of the experimental group (-10.90 ± 4.74°). But the tibia torsion in the experimental group (7.17 ± 7.25°) and control group (4.47 ± 6.34°) were not significantly different (Table 2). The intra-observer consistency and interobserver consistency were showed in Table 3.

Table 1
Measurements immediately after operation

Measurement(°)	Experimental group	Control group	P value
Femoral version	11.88 ± 4.89	13.50 ± 5.51	0.205
Tibia torsion	11.56 ± 4.03	12.94 ± 3.48	0.164

Table 2
Measurements five months after operation

Measurement(°)	Experimental group	Control group	P value
Femoral version	−5.50 ± 6.13	−10.90 ± 4.74	0.001
Tibia torsion	7.17 ± 7.25	4.47 ± 6.34	0.144

Table 3
Inter- and Intraobserver Reliability of the Different Measurements

	Intraclass Correlation Coefficient (95% CI)		
Measurements		Immediately after surgery	5 months postoperatively
Femoral version	Intraobserver Reliability	0.931 (0.877–0.961)	0.939 (0.860–0.970)
	Interobserver Reliability	0.912 (0.868–0.944)	0.870 (0.807–0.917)
Tibia torsion	Intraobserver Reliability	0.838 (0.733–0.902)	0.971 (0.953–0.984)
	Interobserver Reliability	0.838 (0.765–0.893)	0.966 (0.947–0.979)

Discussion

The most important finding of this study is that abnormal femoral version was found in growing rabbits after patella dislocation.

Femoral version reflects the relationship of the femoral neck axis to the transcondylar axis or coronal axis of the distal femur. Femoral anteversion is defined as anterior rotation of the femoral head from the coronal plane. While Femoral retroversion refers to the condition where the femoral neck axis is oriented posterior to the transcondylar axis, positioning the femoral neck and head posterior to the coronal plane of the femur [17].

For human beings, there is 30°to 40°of femoral anteversion at birth on average, and it decreases with time to approximately 10°to 15°in skeletally mature individuals. Most of the improvement occurs before the age of 8 years[18, 19]. For rabbits, there were 10°of anteversion in the femur at birth. This had disappeared by the eighth week and by the time the animal was skeletally mature, 10°to 15°degrees of retroversion had developed[20]. The decreasing trends of the femoral version development between human-beings and rabbits are same. For adults, femoral retroversion is not as common as femoral anteversion. In the study by Hartel. A total of 1070 thin-slice CT datasets of left femurs were analyzed and 77 subjects (7.8%) were found with retroverted femur (range − 23.6°–0.2°)[21].

Femoral version relates to the stability and function of the hip and knee joints and is an important clinical factor in many disease, including torsional syndromes, femoral fractures, hip dysplasia, Legg-Calve-Perthes disease, slipped capital femoral epiphysis and anterior cruciate ligament (ACL) rupture[22, 23, 24, 25, 26, 27, 28, 29, 30, 31]. Femoral version also affects patellar stability. The increased femoral anteversion has been regarded as a risk factor for patellar instability, as it produces a lateralizing force on the patella. The lateralizing force exists after MPFL reconstruction, contributes to the inferior clinical outcomes, even reconstruction failure[6, 32, 33, 34].

In this study, the femoral retroversion decreased after patella dislocation in growing rabbits. Patella dislocation may cause the alteration of the strength direction of rectus fomoris muscle. Also, we found knee or ankle lateral rotation in activities of rabbits after patella dislocation. The change of strength direction and position may be the cause for the femoral version difference. The version of the femur changed significantly after patella dislocation, but the tibia torsion did not change significantly. Similar with humans, in the lower extremity, the femur may be markedly abnormal yet the tibia and fifibula well formed or only slightly hypoplastic. And the foot may be normal despite severe proximal anomalies[35].

Just like the previous animal experiments[7, 8, 9, 10, 11], the outcomes of the studies indicates that the aberrant version of the femur may not only be the risk factor for patellar instability, but also be the consequence of patellar instability. This founding may develop pathology and etiology of patella instability. This emphasize the importance of the early effective treatments for patellar instability in children, considering the pathological conditions caused by femur version deformity.

The first limitation of the study is the animal model choice. Although rabbits have been widely used for the orthopedic studies, the structure of the lower limbs are different from human beings'. Therefore, the results of this study may not be directly applicable to humans. Second the knee rotation measurements were not involved in this study because of the extreme flexion in the knee joints in the rabbits. The third limitation is the sample size of the rabbits. And it could give more reliable results if a higher number of experimental animals were used.

Conclusion

Based on the outcomes of this study, we conclude that early patellar dislocation can lead to abnormal femur version in growing rabbits. Thus if adolescents suffer from patella dislocation or instability for a long time in growing period, the torsional malalignment in lower limbs may occur. Clinically, early intervention for adolescent patients with patellar dislocation will be particularly important.

Abbreviations

CT: Computerized tomography; 2D: Two dimensional; 3D: Three-dimensional

Declarations

Ethics approval and consent for participate

All animals were treated humanely according to the guidelines of the Guidebook for the Care and Use of Laboratory Animals. The investigation process was approved by the ethics committee of the Third Hospital of Hebei Medical University. The number is Z2019-006-1. The study is an animal experiment, so no consent was needed.

Consent for publication

Not Applicable.

Availability of data and materials

The supporting data for the conclusions of the study are included within the article and are available upon request from the corresponding author.

Competing interests

None

Funding

This study has been supported by the Fund for Graduates’ Innovative Projects of Hebei Provincial Department of Education (No. CXZZBS2020121).

Authors’ contributions

JHN carried out the research design and drafting of this manuscript. QQ completed the acquisition and interpretation of the data. JHN and KH raised the rabbits and performed the surgeries. KH, KP, and WL carried out measurements. FW critically revised the manuscript and provided final approval of the version to be published. All authors read and approved the final manuscript.

Acknowledgements

None.

References

1. Robert N. Steensen, Jared C. Bentley, Thai Q. Trinh, et al. The Prevalence and Combined Prevalences of Anatomic Factors Associated With Recurrent Patellar Dislocation. The American Journal of Sports Medicine. 2015; 43(4):921-927.doi: 10.1177/0363546514563904.
2. DejourH, WalchG, Nove-JosserandL, GuierCH. Factors of patellar instability: an anatomic radiographic study. Knee Surg Sports Traumatol Arthrosc. 1994; 2:19–26.
3. Erkocak OF, Altan E, Altintas M, Turkmen F, Aydin BK, Bayar A. Lower extremity rotational deformities and patellofemoral alignment parameters in patients with anterior knee pain. Knee Surg Sports Traumatol Arthrosc. 2016; 24:3011–3020.doi: 10.1007/s00167-015-3611-y.
4. Diederichs G, Köhlitz T, Kornaropoulos E, Heller MO, Vollnberg B, Scheffler S. Magnetic resonance imaging analysis of rotational alignment in patients with patellar dislocations. Am J Sports Med. 2013; 41:51–57.doi: 10.1177/0363546512464691.
5. Takagi. Shigeru; Sato. Takashi; Watanabe. Satoshi. Alignment in the transverse plane, but not sagittal or coronal plane, affects the risk of recurrent patella dislocation. Knee Surgery, Sports Traumatology, Arthroscopy. 2018; 26(10): 2891-2898.doi: 10.1007/s00167-017-4806-1.
6. P. Kaiser , W. Schmoelz, P. B. Schöttle, Ch. Heinrichs, M. Zwierzina, R. Attal. Isolated medial patellofemoral ligament reconstruction for patella instability is insufficient for higher degrees of internal femoral torsion. Knee Surgery, Sports Traumatology, Arthroscopy. 2019; 27:758–765.doi: 10.1007/s00167-018-5065-5.
7. Li W, Wang Q, Wang F, Zhang Y, Ma L, Dong J. Femoral trochlear dysplasia after patellar dislocation in rabbits. Knee. 2013;20:485–9. doi: 10.1007/s00167-018-5065-5.
8. Wang S, Ji G, Yang X, Wang X, Wang R, Li M, et al. Femoral trochlear groove development after patellar subluxation and early reduction in growing rabbits. Knee Surg Sports Traumatol Arthrosc. 2016;24:247–53.doi: 10.1007/s00167-014-3372-z.
9. Kaymaz B, Atay OA, Ergen FB, Mermerkaya MU, Olgun ZD, Atesok K, et al. Development of the femoral trochlear groove in rabbits with patellar malposition. Knee Surg Sports Traumatol Arthrosc. 2013;21:1841–8.doi: 10.1007/s00167-012-2163-7.
10. Jinghui Niu, Qi Qi, Yingzhen Niu, Conglei Dong, Zhenyue Dong, Peng Cui and Fei Wang. Patella morphological alteration after patella instability in growing rabbits. Journal of Orthopaedic Surgery

and Research. 2017; 12:106.doi: 10.1186/s13018-017-0615-y.

11. Yingzhen Niu, Pengkai Cao, Chang Liu, Jinghui Niu, Xu Yang, Fei Wang. Early patellar dislocation can lead to tibial tubercle lateralization in rabbits. Knee Surg Sports Traumatol Arthrosc .2018; 26:2602–2606. doi: 10.1007/s00167-017-4541-7.
12. JingYu Jia, LianYong Li, LiJun Zhang, Qun Zhao, XiJuan Liu. Three dimensional-CT evaluation of femoral neck anteversion, acetabular anteversion and combined anteversion in unilateral DDH in an early walking age group. International Orthopaedics (SICOT).2012; 36:119–124.doi: 10.1007/s00264-011-1337-0.
13. Riccio AI, Carney CD, Hammel LC, Stanley M, Cassidy J, Davids JR. Three-dimensional computed tomography for determination of femoral anteversion in a cerebral palsy model. J Pediatr Orthop 2015;35:167-71.doi: 10.1097/BPO.0000000000000209.
14. Ki Hyuk Sung; Kibeom Youn; Chin Youb Chung; Muhammad I Kitta; Hendra C Kumara; Jae Jung Min; Jehee Lee; Moon Seok Park. Development and Validation of a Mobile Application for Measuring Femoral Anteversion in Patients With Cerebral Palsy. J Pediatr Orthop. 2019;00:000–000.doi: 10.1097/BPO.0000000000001468.
15. Soodmand E; Zheng G; Steens W; Bader R; Nolte L; Kluess D. Surgically Relevant Morphological Parameters of Proximal Human Femur: A Statistical Analysis Based on 3D Reconstruction of CT Data. Orthopaedic Surgery. 2019: 11(1):135-142. doi: 10.1111/os.12416.
16. Liodakis E, Doxastaki I, Chu K, et al. Reliability of the assessment of lower limb torsion using computed tomography: analysis of five different techniques. Skeletal Radiol. 2012; 41: 305–311.
17. Chia-Ling Chiang, Meng-Yuan Tsai, Wei-Ning Chang, Clement Kuen-Huang Chen. Aberrant Femoral Torsion Presenting with Frog-leg Squatting Mimicking Gluteal Muscle Contracture. Clin Orthop Relat Res. 2012; 470:1165–1170.doi: 10.1007/s00256-011-1185-4.
18. Fabry G, Cheng LX, Molenaers G. Normal and abnormal torsional development in children. Clin Orthop Relat Res. 1994;302:22-6.
19. Folinais D, Thelen P, Delin C, Radier C, Catonne Y, Lazennec JY. Measuring femoral and rotational alignment: EOS system versus computed tomography. Orthop Traumatol Surg Res: OTSR.2013;99(5):509–16.doi: 10.1016/j.otsr.2012.12.023.
20. John A. Wilkinson. FEMORAL ANTEVERSION IN THE RABBIT. Journal of Bone and Joint Surgery - British Volume.1962; 44B(2): 386-397.
21. Maximilian J. Hartel, Andreas Petersik, Anne Schmidt, Daniel Kendoff, Jakob Nüchtern, Johannes M. Rueger, Wolfgang Lehmann, Lars G. Grossterlinden. Determination of Femoral Neck Angle and Torsion Angle Utilizing a Novel Three-Dimensional Modeling and Analytical Technology Based on CT Datasets. PLoS ONE. 2016;11(3):1-10.doi: 10.1371/journal.pone.0149480. eCollection 2016.
22. Leonardi F, Rivera F, Zorzan A, Ali SM. Bilateral double osteotomy in severe torsional malalignment syndrome: 16 years follow-up. J Orthop Traumatol. 2013;15:131–6.doi: 10.1007/s10195-013-0260-0.
23. Brouwer KJ, Molenaar JC, van Linge B. Rotational deformities after femoral shaft fractures in childhood. A retrospective study 27–32 years after the accident. Acta Orthop Scand. 1981;52(1):81–

9.

24. Folinais D, Thelen P, Delin C, Radier C, Catonne Y, Lazennec JY. Measuring femoral and rotational alignment: EOS system versus computed tomography. Orthop Traumatol Surg Res: OTSR. 2013;99(5):509–16. doi: 10.1016/j.otsr.2012.12.023.
25. Sankar WN, Neubuerger CO, Moseley CF. Femoral anteversion in developmental dysplasia of the hip. J Pediatr Orthop. 2009;29(8):885–8.
26. Wines AP, McNicol D. Computed tomography measurement of the accuracy of component version in total hip arthroplasty. J Arthroplasty. 2006;21(5):696–701.
27. Daly PJ, Morrey BF. Operative correction of an unstable total hip arthroplasty. J Bone Joint Surg Am. 1992;74(9):1334–43.
28. Kim HT, Wenger DR. "Functional retroversion" of the femoral head in Legg-Calve-Perthes disease and epiphyseal dysplasia: analysis of head-neck deformity and its effect on limb position using three-dimensional computed tomography. J Pediatr Orthop. 1997;17(2): 240–6.
29. GelbermanRH, CohenMS, ShawBA, KasserJR, GriffinPP, Wilkinson RH. The association of femoral retroversion with slipped capital femoral epiphysis. J Bone Joint Surg Am. 1986;68(7):1000–7.
30. Stanitski CL, Woo R, Stanitski DF. Femoral version in acute slipped capital femoral epiphysis. J Pediatr Orthop B. 1996;5(2):74–6.
31. Yakup Alpay, Atakan Ezici, Muhammed Bilal Kurk, Osman Nuri Ozyalvac, Evren Akpinar, Avni Ilhan Bayhan. Increased femoral anteversion related to infratrochanteric femoral torsion is associated with ACL rupture. Knee Surgery, Sports Traumatology, Arthroscopy 2020. doi: 10.1007/s00167-020-05874-0.
32. Kaiser P, Schmoelz W, Schoettle P, Zwierzina M, Heinrichs C, Attal R. Increased internal femoral torsion can be regarded as a risk factor for patellar instability—a biomechanical study. Clin Biomech (Bristol, Avon).2017; 47(4):103–109.doi: 10.1016/j.clinbiomech.2017.06.007.
33. ZhiJun Zhang, Hui Zhang, GuanYang Song, Tong Zheng, QianKun Ni, Hua Feng. Increased femoral anteversion is associated with inferior clinical outcomes after MPFL reconstruction and combined tibial tubercle osteotomy for the treatment of recurrent patellar instability. Knee Surgery, Sports Traumatology, Arthroscopy. 2019.doi: 10.1007/s00167-019-05818-3.
34. Nelitz M, Williams RS, Lippacher S, Reichel H, Dornacher D. Analysis of failure and clinical outcome after unsuccessful medial patellofemoral ligament reconstruction in young patients. Int Orthop. 2014; 38(11):2265–2272.doi: 10.1007/s00264-014-2437-4.
35. Henkel L, Willert HG. Dysmelia. A classifification and a pattern of malformation in a group of congenital defects of the limbs. J Bone Joint Surg. 1969; 51(3):399–414. PubMed PMID: 5820783. Epub 1969/08/01. eng.

Figures

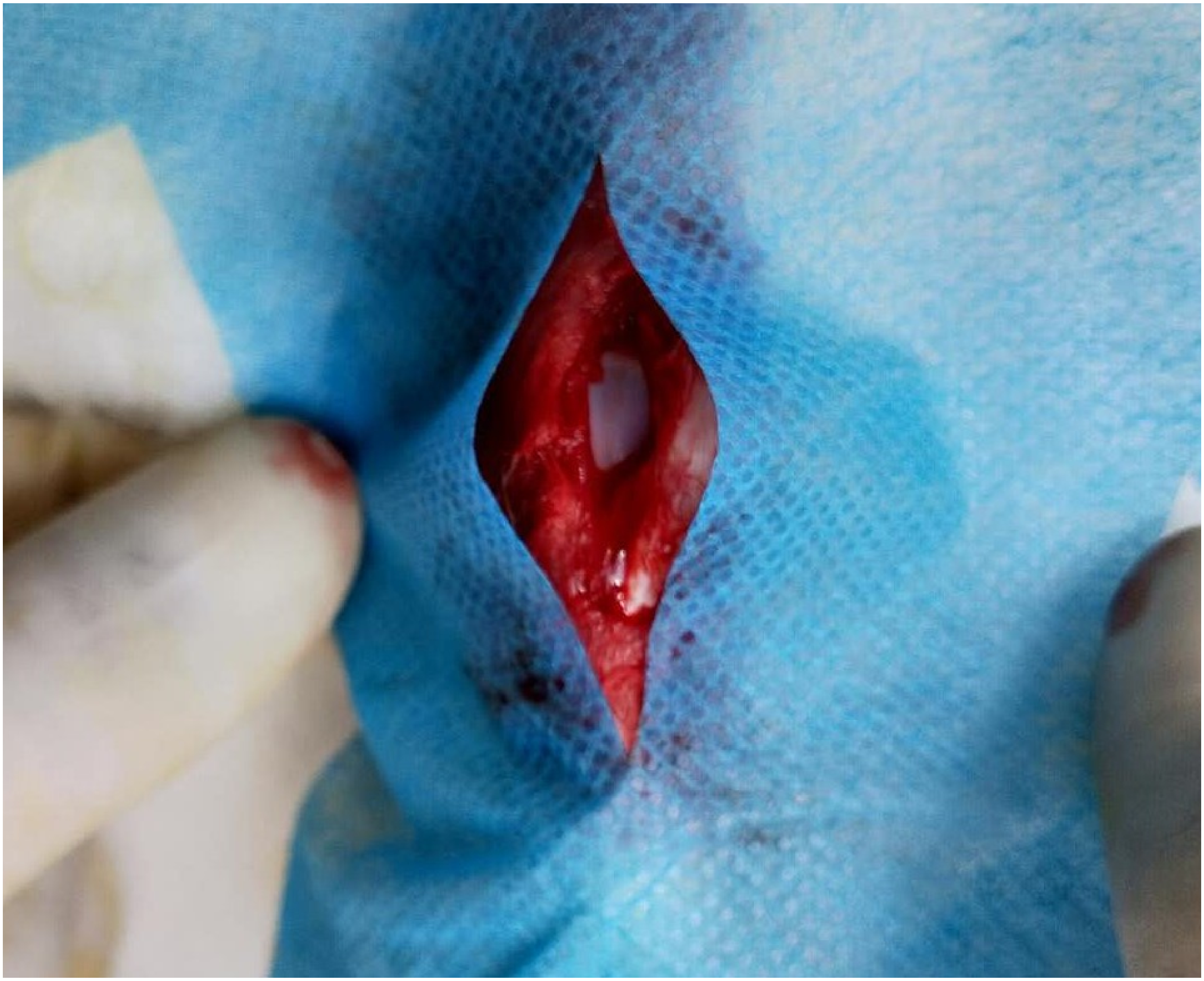

Figure 1

The picture during surgery. Medial retinaculum and joint capsule were incised. Patella was moved laterally and femoral trochlear could be seen.

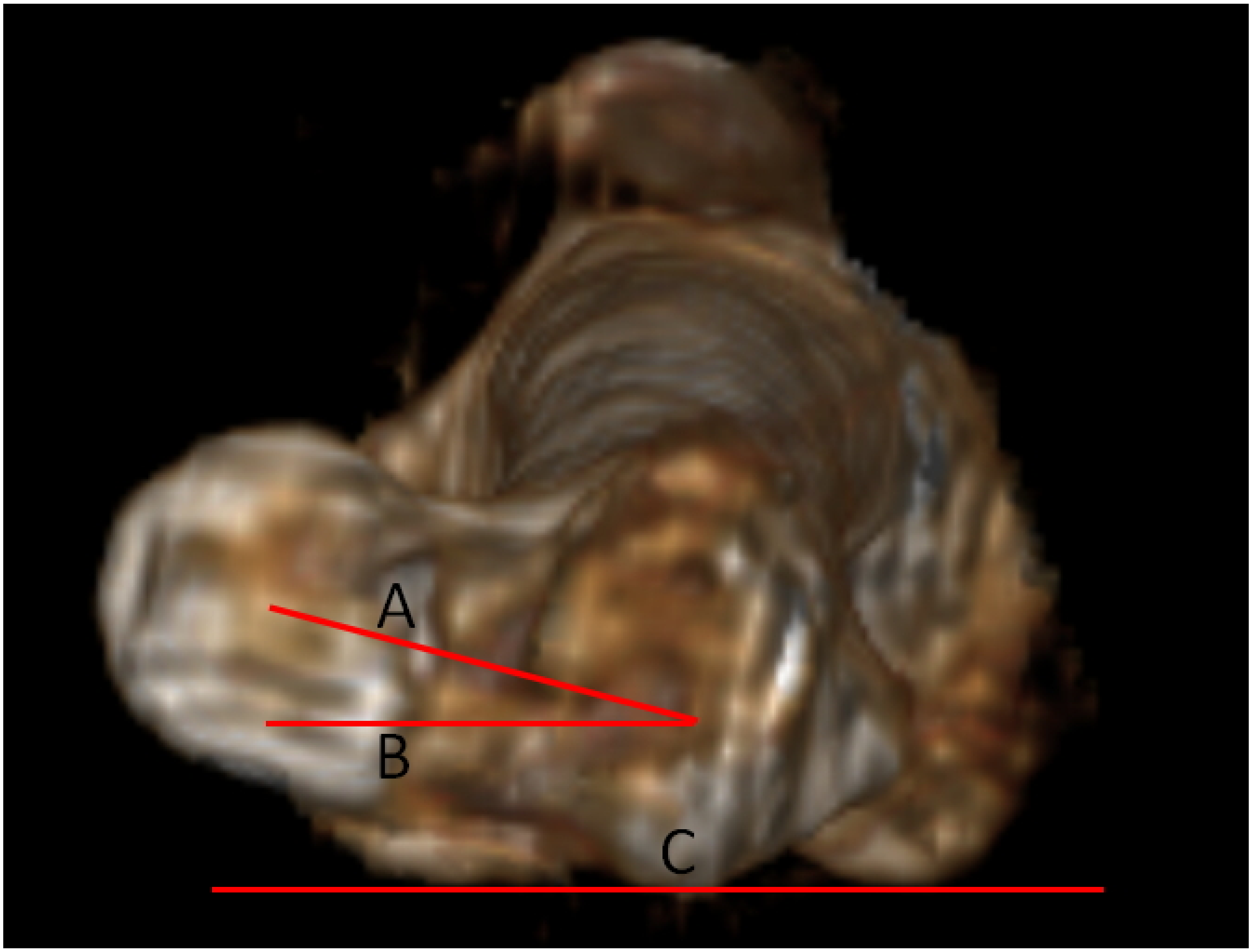

Figure 2

The schematic diagram of femoral version angle measurement. Line C connects the lowest point of the greater trochanter and femoral medial and lateral condle. Line B parallels to line C. Line A connects the point of centre of the femoral head with the midpoint of the narrowest femoral neck.

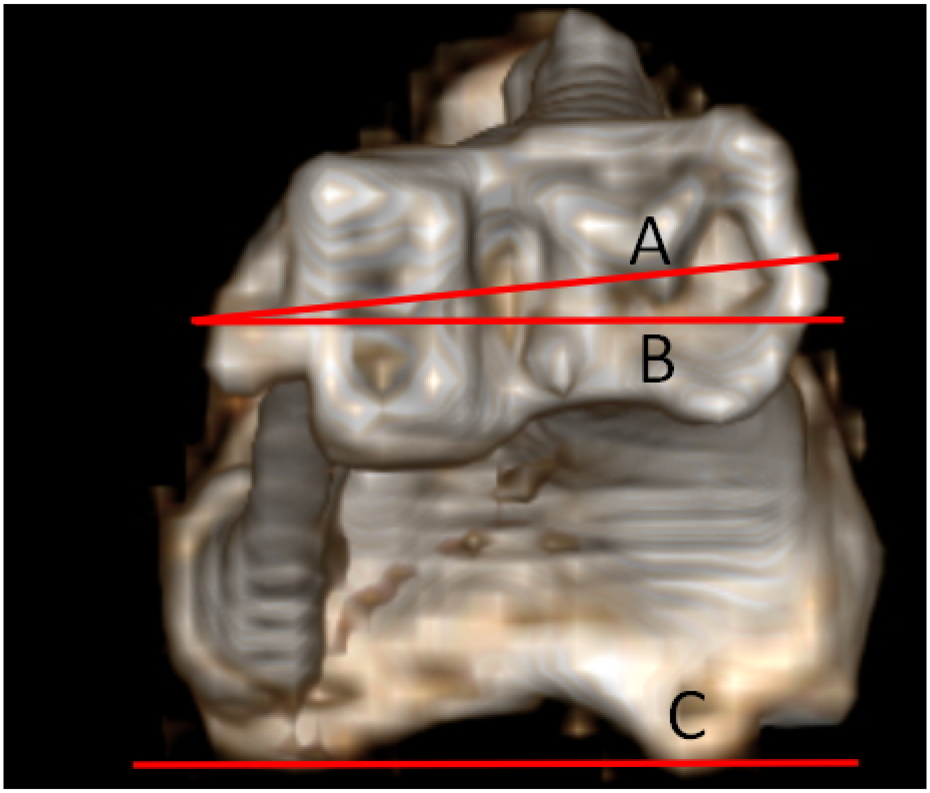

Figure 3

The schematic diagram of tibia torsion angle measurement. Line C connects the medial and lateral tibia condyles. Line B parallels to line C. Line A is drawn through the center of medial and lateral malleoli.