The torsional alignment changed significantly in growing rabbits after patella dislocation by a three-dimensional measurement

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Research article

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Abstract

Background: Torsional malalignment has been considered 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: In the present study, 30 one-month old rabbits were included. The experimental group consists of 30 left knees of rabbits and were underwent patella lateral dislocation. And the control group consists of 30 right knees and no surgical procedure was performed. A CT scan was performed on each knee when the surgery was finished and at the time the rabbits were skeletal mature (5 months post-surgery). The angles of femoral version and tibial torsion were measured using a three-dimensional method and analyzed between the experimental group and control group.

Results: The femoral version and tibia torsion in the experimental and control group immediately after surgery were not different significantly. However, 5 months after surgery, the femoral version angle 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 torsion angle in the experimental group (7.17±7.25°) and control group (4.47±6.34°) were not significantly different (P = 0.144).

Conclusion: From this study, patella dislocation can lead to alteration of femoral version in growing rabbits. This may indicate the early treatment for patella dislocation in children is particularly important to avoid torsional malalignment in the future. These findings may develop pathology and etiology of patella dislocation.

Background

Several anatomic factors are associated with patella dislocation, including increased tibial tubercle–trochlear groove (TT-TG) distance, patella alta, rotational deformities, and trochlear dysplasia [1, 2, 3, 4, 5].

Among the factors, the lower extremity alignment is very important in pathophysiology and aetiology of patella dislocation. Rotational malalignment has been regarded as a risk factor for patella dislocation in previous studies. Dejour et al. [2] found that knees in controls have femoral anteversion of 10.8° and in knees of patients with patellar instability was 15.6°(P = 0.013). In another study, the patients with a history of patella instability have a 1.56-fold higher mean femoral anteversion, compared with controls. But no significant differences in tibial torsion were found in patients with patellofemoral instability compared to the control group in the two studies[3, 4]. The increased femoral anteversion, increased knee external rotation and decreased external tibial torsion were found in patients with recurrent patella dislocation [5]. Those parameters also correlate with a higher risk of recurrent patella dislocation.

Clinically, strategical choice of surgical treatment for patients with recurrent patellar dislocation may be influenced by the torsion of the lower limbs. With high degrees of internal femoral torsion, medial
patellofemoral ligament reconstruction for patella instability only may be insufficient. In fact, femoral internal torsion higher than 25° is considered as the indication for derotational femoral osteotomy [6].

Previous animal studies have investigated the influence of patella instability on the morphological development of the patellofemoral joint. Wang, Li and Niu observed femoral trochlear dysplasia and patellar dysplasia could occur after patella dislocation in growing rabbits [7, 8, 9]. Kaymaz reported after surgery for patella alta in growing rabbits, trochlea flattening was found [10]. These studies indicate that patellofemoral joint dysplasia could be caused by patella instability. In the study by Niu [11], tibial tubercle lateralization and tibial tuberosity–trochlear groove distance (TT-TG) increased after patella dislocation. TT-TG reflects the relative location between distal femur and proximal tibia, and affects the lower extremity alignment. It is possible that patella dislocation have influence with lower extremity alignment directly.

It is possible that alignment values have not been measured precisely because two-dimensional (2D) measurements can be affected by the location of the radiation source and the limb position. Recently, three-dimensional (3D) method for measuring the alignment of lower extremity has been widely used, which was proved to have high intra-observer and inter-observer reliability. And the method is not influenced by femoral neck-shaft angle or postural deformity [5, 12, 13, 14, 15]. Considering the high accuracy of the method 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 instability on low extremity alignment development has remained unclear. Based on the previous studies, we hypothesized that early patella dislocation lead to a significant difference of alignment of hindlimbs 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.

**Materials And Method**

**Study Design and Setting**

This study was approved by the local Animal Ethics Committee (Number:Z2019-006-1). Sixty knees from 30 healthy, 1-month-old female New Zealand white rabbits, weighing between 350 and 450g (provided by the Animal Test Center of the local medical university), were divided into two groups. The experimental group consisted of 30 left knees, which were performed patella dislocation surgery. The control group comprised the 30 right knees, and no surgical procedures were conducted. All procedures performed in studies involving animals were in accordance with the ethical standards of the institution or practice at which the studies were conducted. The rabbits were raised under the same conditions with water and food. Every rabbit was housed individually in an stainless steel (310 × 550 × 320 mm) cage. And 30-minute activity out of steel was allowed per day.
**Surgical Procedures**

The one-month old rabbits were administered anaesthesia of ketamine hydrochloride and xylazine at a dosage of 20 and 5 mg/kg body weight by injection though ear vein. Then, the left knees in the experimental group were shaved and disinfected by standard procedures. A 2.5-cm incision was performed on the skin of the knees, and the soft tissue was dissected to expose the medial retinaculum and the joint capsule. The medial retinaculum and medial joint capsule of the knees were incised and the patella was then pushed laterally to expose the femoral trochlea. Then the lateral joint capsule was sutured with overlapping tissue. After these procedures, patella dislocation could be seen intraoperatively (Fig. 1). The patella dislocated (the femoral trochlear could be seen) when the knee was flexed and extended. Then 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 three days postoperatively for prophylaxis. As we all known, the growing rabbits achieve skeletal maturation at 28 weeks, so both groups were followed-up for 5 months after surgery. After that, the rabbits were euthanized by excessive anesthesia of pentobarbital sodium by injection through air vein.

**CT assessment**

CT scans of the rabbits were performed immediately post-operatively, one month post-operatively and 6 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 limbs 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 hindlimbs. 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 measuring methods had an accuracy of 0.01°.

After 3D image construction, for measuring femoral version, the femur was rotated 90° from anteroposterior view to horizontal view (femur looking down from top). The lowest point of the greater trochanter, the femoral medial condyle and femoral lateral condyle were moved and rotated for adjustment until the lowest point of the greater trochanter were positioned in the middle between medial and lateral femoral condyle. 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 which connecting the point of the femoral head center with the midpoint of the narrowest femoral neck part. The condition that femoral neck is anterior to posterior condylar line is defined positive [12].

For tibia torsion measurement, the most posterior points of the medial and lateral tibia condyle 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 lateral and medial malleoli. The condition that the ankle laterally rotated to the posterior tibial plateau is defined positive [5, 16].
Statistics

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 no research on the topic of torsional alignment of rabbits was found. For determining the intra-observer variation, the observer One repeated the observations 2 weeks after first measurement. To determine the inter-observer variation, the observations were performed by observer One, observer Two and observer Three. Intra-observer consistency and inter-observer consistency were analysed using intra-class correlation coefficient (ICC). ICC higher than 0.75 was regarded as excellent, and ICC lower than 0.40 was poor, ICC among 0.40 to 0.75 was fair to good.

Results

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.

| 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   |

| 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

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

### Discussion

The most important finding of this study is that femoral version is significantly different between study group and control group in growing rabbits after patella dislocation.

Femoral version shows the relative position of the femoral neck axis and the transcondylar axis or coronal plane of the distal femur. Femoral anteversion refers to anterior rotation of the femoral head from the coronal plane. While Femoral retroversion is defined as the condition that the femoral neck axis locates posterior to the transcondylar axis or the coronal plane of the femur [17].

For human beings, there is 30° to 40° of femoral anteversion at birth, then it decreases to 10° to 15° when skeletally mature. Most of the alteration occurs before the age of 8[18, 19]. For rabbits, there were 10° of anteversion in the femur at first. The anteversion disappeared by the eighth week and by the time the rabbits was skeletally mature, 10° to 15° degrees of femoral retroversion has been observed[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 scans 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 for 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 even after medial patellofemoral ligament 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 alteration of strength
direction and bone position may be the reason for the femoral version difference during growth. The version of the femur changed significantly after patella dislocation, but the tibia torsion did not change significantly in the growing rabbits after patella dislocation. Similar with humans, in the lower extremity, the femur may be abnormal obviously but the tibia and fibula are well formed or only slightly hypoplastic. And the foot may be normal despite the severe anomalies in the proximal part of the lower extremity[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 patella dislocation, but also be the consequence of patella dislocation. After patella dislocation in growing rabbits, the morphology of patella, femoral trochlea and the version of the femur were found changed significantly. These findings may develop pathology and etiology of patella instability. This emphasize the importance of the early effective treatments for patella instability in children, considering the possibility of pathological conditions caused by femur version deformity.

The first limitation of the study is the different structure of animal model. Although rabbits have been widely used for the orthopedic studies, the structure of the hind limbs are different from human beings’. So the conclusion of this study may not be right for 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 be more reliable if a higher number of experimental animals were used. Also, the reason for the alteration of femoral version in biomechanical and molecular biological level should be researched.

**Conclusion**

Based on the outcomes of this study, we conclude that early patella dislocation can lead to abnormal femur version in growing rabbits. So patella dislocation may have an effect on lower extremity alignment. Clinically, early intervention for adolescent patients with patella dislocation will be particularly important to avoid the deformities of patellofemoral joint and lower extremity alignment.

**Declarations**

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**Authors’ contributions**

FW designed the study. JHN, QQ, and KH performed the experimental work.

JHN, QQ, and KP evaluated the data. JHN wrote the manuscript. All authors read and approved the final manuscript.
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Availability of data and materials

The detailed data and materials of this study are available from the corresponding author via e-mail on reasonable request.

Ethics approval and consent to participate

Institutional review board approval of the Animal Ethics Committee of the third hospital of Hebei Medical University (Number:Z2019-006-1)) was obtained.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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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 condyle. 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.

Supplementary Files

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