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Effect of high tibial osteotomy on hip biomechanics in patients with genu varum: A prospective cohort study

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Abstract: *Background and aims:* The aim of this study is to evaluate the effect of proximal tibia osteotomy on hip biomechanics. *Methods:* This cohort study was conducted on 50 knees of 37 patients divided into two groups of unilateral and bilateral surgeries during 2015–2016. Patients underwent medial open-wedge osteotomy of proximal tibia. Axial alignment of lower limb radiography was carried out for the patients before and after the osteotomy. *Results:* Findings from unilateral and bilateral high tibial osteotomies demonstrated that the average of greater trochanter (GT) angle from femoral head center and also the average angle of knee varus were significantly decreased ($P = 0.001$). Although not statistically significant, the average angle of the mechanical axis of lower limb showed an increase in unilateral osteotomy ($P = 0.889$) and a decrease in bilateral osteotomy ($P = 0.887$). The average angle of pelvic obliquity after unilateral osteotomy increased significantly ($P = 0.001$) but showed no statistically significant difference in bilateral osteotomy ($P = 0.631$). *Conclusion:* High tibial osteotomy significantly affects the GT and causes the downward replacement of GT and consequent shortening of the abductors moment arm, increased hip joint reaction force, and reduction of the shear force on the femoral neck.

Keywords: genu varum, osteotomy, hip, joints, femoral

Introduction

Genu varum is a type of knee deformity in which the mechanical axis of lower limb lies to the medial side of the knee center. This mechanical axis typically projects through the center of the knee joint. In this deformity, patients' knees stand far from each other in a bow shape. In most cases, this deformity caused cartilage damage and degeneration in the medial compartment of the knee joint in long term, because of the imposed imbalanced force on medial and lateral compartments of knees [1]. Osteoarthritis of medial compartment of knee with varus deformity is related to the excessive force imposed on the medial compartment. Genu varum as a prevalent disorder in all age ranges is treated based on severity and location of deformity, with therapies, such as different types of valgus osteotomy [2–4]. Osteotomy of proximal tibia is one of the best treatments for young patients with early osteoarthritis and degenerative changes of knee joint especially in the medial compartment with varus deformities from tibia causing genu varum [5]. Osteotomy is performed for patients who have sufficient muscle strength and motivation to carry out a rehabilitation program. The principle of correcting malalignment is to transfer load to the relatively normal compartment of the knee to relieve signs and suppress the disease progression. The results of high tibial osteotomy vary considerably in the literature, but the procedure generally provides good relief of pain and restoration of function in approximately 80%–90% of patients at 5 years old and 50%–65% at 10 years old [5, 6].

Expression of joint and limbs stabilizing forces in stance and swing conditions have provided a manifest view for diagnosis and treatment of many of orthopedic disorders. Biomechanics science tries to assess such structures and forces, which play roles in different biological parts of body [2, 7]. Knowing the probability and quality of changes in adjacent joints, their biomechanics after the surgery can help the orthopedic surgeons to consider the whole body as a unit and get informed about the pros and cons of this operation, the resulting effects on other joints, their biomechanics, and resulting side effects [8–10]. Comparing with other joints, the hip joint plays an important role in transferring the forces to the ground and keeping the balanced movement force as a connector of trunk and lower limb. This joint has many complexities regarding its osseous structure and multiple ligaments and muscles insertion to the adjacent anatomical structures. Many biomechanics studies tried to express the appropriate patterns to state the normal activity of this system based on the necessity of a balance between function of this joint and the position of the spine and lower limbs. Pauwel was one of the pioneers of stating the theories of forces effecting hip and interactions of these forces. He calculated the total stress on hip joint based on two forces of weight and abductors and also their distance from femoral head. This theory has evolved over time and more components are added to state different conditions. But the changes imposed by knee and ankle joint on hip and their effect on treatment process are less considered [11, 12].

Osteotomy of proximal tibia in genu varum can change the anatomical and mechanical axis of femur and consequently changes the biomechanical parameters of hip joint. Precise evaluation of biomechanical parameters of varus knee and hip joints before and after the osteotomy can result in a factual estimation of the interactions between these joints to apply the best modifications and thus relief from patients' clinical symptoms and pain can be expected [11, 13, 14].

This study aims to evaluate changes in length of the abductors moment arm and its consequent effects on hip joint after relocation of greater trochanter (GT) in high tibial osteotomy. For this purpose, we measured and evaluated knee varus angle, the mechanical axis of lower limb, pelvic obliquity, and GT angle from femoral head center.

Materials and Methods

This prospective cohort study was performed on adult patients with bilateral genu varum who were admitted to Rasoul-e-Akram Hospital for elective high tibial osteotomy during 2015–2016. Study protocol was approved by local ethics committee of the university and was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki.

All patients signed their informed consent forms prior to recruitment in the study. Inclusion criteria were all patients aged between 20 and 60 years with intact ligaments of the knees, intact neurovascular of the lower limbs, and full range of movement of lower extremity joints.

Exclusion criteria were history of fracture, orthopedic surgery, and ligament reconstruction in lower limb, congenital deformities (such as developmental dysplasia of the hip, arthrogryposis, chronic kidney disease, club foot, etc.), systematic diseases (such as Rheumatoid arthritis (*RA*), juvenile rheumatoid arthritis (*JRA*), etc.), metabolic disorder, history of spine problems, and deformities (such as scoliosis, etc.). Based on previous pilot studies, 50 knees (37 patients) were randomly selected and recruited the study. For all patients, standing axial alignment view X-ray from the lower limbs was obtained with direct digital radiography system prior to the surgery.

Patients were randomly divided into two groups of unilateral (24 patients) and bilateral (13 patients) osteotomies. Based on present indication, osteoarthritis and severity of varus knees, all the cases underwent valgus osteotomy of proximal tibia with medial open-wedge technique in a uniform designed procedure. The 4.5-mm Locking T-Plate was used for fixation, and Ceno Bone wedge allograft was used to fill the opened-wedge space. After the surgery, when the patient was able of full weight bearing on the lower limbs (after 3 months on average), the standing axial alignment view of lower limbs X-ray was repeated. With PACS software parameters, such as the knee varus, the mechanical axis of lower limb, the pelvic obliquity, and the GT angle from the femoral head center were measured on radiographs and were recorded before and after the surgery by two other orthopedic surgeons who were blind to the study.

We used varus angle to measure the amount of deviation and calculate the degree of correction. The mechanical axis of lower limb was used to assess whether the correct standing position of the patients was maintained during obtaining the X-rays. Due to increase of limb length in medial open-wedge procedure, we considered pelvic obliquity as well. The GT angle from femoral head center was assessed because after the osteotomy distal to hip region, the location of the GT changes and the femoral head just spins in the acetabulum. The measurement method is shown in *Fig. 1*.

In due course, three patients (five knees) were dismissed because of loss to follow-up, and two patients (three knees) were dismissed because of the recurrence of varus. Pre- and postoperative data from 32 patients (42 knees) in two groups of unilateral (22 knees) and bilateral osteotomies (20 knees) were imported to SPSS software version 19 and reported descriptively.

Data normality was evaluated for all the variables. According to the normality, the appropriate statistical tests were used and the effects of changes on the forces imposed on hip joint were evaluated in accordance with

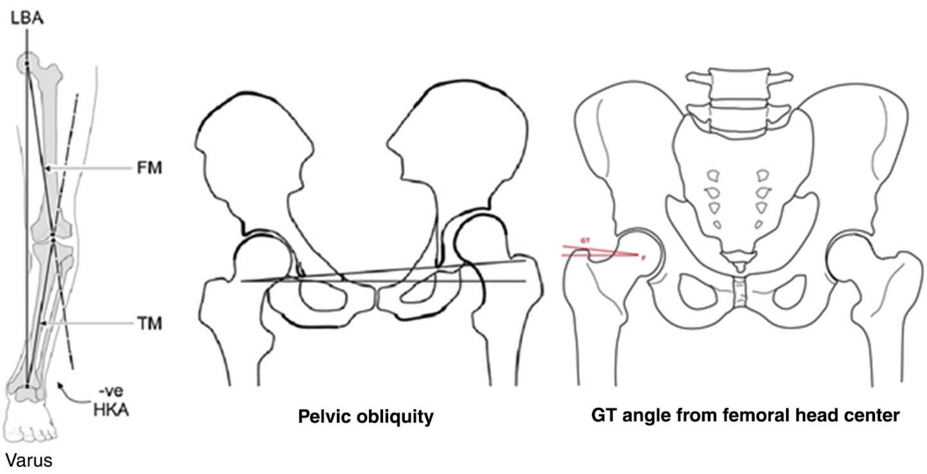

Fig. 1. The measurement method of the angle of varus knee, mechanical axis of lower limb, pelvic obliquity, and GT angle from femoral head center. *LBA*: load-bearing axis, *FM*: femoral mechanical axis; *TM*: tibial mechanical axis

present mathematical patterns. The paired-samples *t*-test was used to analyze the data. *P* value < 0.05 was considered to be statistically significant.

Results

This study was performed on 32 patients (42 knees) who were admitted to Rasoul-e-Akram Hospital during 2015–2016. Demographic data and clinical profile of the patients are presented in *Table I*.

Unilateral osteotomy group

Among the 22 patients who underwent the high tibial osteotomy on one leg, 16 patients (72.7%) were males and 6 patients (27.3%) were females. Patients aged between 21 and 54 years old with the average of 31.45 ± 9.038 years old.

This study revealed that the amount of varus average after the surgery (1.00 ± 2.9) has significantly decreased comparing with the varus average before the surgery (10.18 ± 4.12) ($P = 0.001$). The average of mechanical axis of lower limb after the surgery was 3.43 ± 0.80, which had a slight increase comparing with the previous amount (3.40 ± 1.22); however, this increase was not significant in statistical analysis ($P = 0.889$).

Also statistical analysis shows a statistically significant increase in pelvic obliquity after the surgery (1.52 ± 2.10) comparing with the preoperative conditions (0.07 ± 2.21) ($P = 0.001$). The average GT angle from femoral head center before the surgery was 3.00 ± 2.86 and after the surgery, it was −1.81 ± 2.92. The analysis demonstrated that the average of this angle after the surgery had reduced significantly comparing with the conditions before the surgery ($P = 0.001$) *(Table II)*.

Table I Demographic information for patients undergoing high tibial osteotomy

Demographics	Number	Percentage
Gender		
Male	23	71.9
Female	9	28.1
Mean BMI (kg/m^2)	27.2 ± 3.1	–
Laterality		
Right	12	54.5
Left	10	45.5
Unilateral osteotomy	22	–
Bilateral osteotomy	10	–
Mean age (years)	33 ± 9	–
Mean follow-up time (days)	92	–

Bilateral osteotomy group

Among the 10 patients who underwent the high tibial osteotomy on both legs, 70% of them were males and 30% were females. Patients were in an age range of 23–52 years old. The age average was 35.10 ± 9.67. The results demonstrate that the knee varus average after the surgery (1.70 ± 2.73) has significantly decreased comparing with the varus average before the surgery (10.35 ± 2.39) ($P = 0.001$).

The average of mechanical axis of lower limb after the surgery (3.20 ± 1.19) had a decrease comparing with the previous amount (3.25 ± 1.24); however, this decrease was not statistically important ($P = 0.887$). Statistical analysis shows an increase in pelvic obliquity after the

Table II | Distribution and evaluation of study parameters before and after the surgery in unilateral osteotomy group

	Mean ± SD	Mean differences ± SD	*t*	*df*	*P* value
Angle of varus knee		9.18 ± 2.66	16.153	21	0.001
Before surgery	10.18 ± 4.12				
After surgery	1.00 ± 2.9				
Mechanical axis of lower limb		−0.031 ± 1.054	−0.141	21	0.889
Before surgery	3.4 ± 1.22				
After surgery	3.43 ± 0.80				
Pelvic obliquity		−1.590 ± 1.508	−4.945	21	0.001
Before surgery	−0.07 ± 2.21				
After surgery	1.52 ± 2.10				
GT angle from femoral head center		4.8 ± 2.8	8.00	21	0.001
Before surgery	3.00 ± 2.86				
After surgery	−1.81 ± 2.92				

surgery (0.45 ± 3.33) comparing with preoperative conditions (0.02 ± 3.27), but this increase was not statistically significant ($P = 0.631$).

The average GT angle from femoral head center before the surgery was 3.90 ± 3.46 and after the surgery, it was −1.10 ± 3.29. The assessments showed that the average of this angle after the surgery had decreased significantly comparing with preoperative conditions ($P = 0.001$) *(Table III)*.

Discussion

High tibial osteotomy is commonly used for genu varum deformity in young and active patients. Correct understanding of the effects of high tibial osteotomy on adjacent joints is crucial because any alterations in limb alignment can lead to abnormal stress, non-standard stress distribution on the adjacent joints, and biomechanical changes [2, 12, 14, 15]. This study showed an increased stress imposed on the hip joint after high tibial osteotomy. The first and leading hypothesis in this field was Pauwels' theory of hip biomechanics assuming bending stresses of the proximal femur [12, 13].

The hip–knee–ankle (HKA) angle is an important measurement to assess the varus deformity of the knee and good results are directly related to achieve optimal alignment. The HKA angle was measured preoperatively as a part of the indication for surgery and postoperatively during the correction period to determine the progress of the correction and to determine that the desired alignment was obtained [14]. Our findings from unilateral and

Table III | Distribution and evaluation of study parameters before and after the surgery in bilateral osteotomy group

	Mean ± SD	Mean differences ± SD	*t*	*df*	*P* value
Angle of varus knee		8.650 ± 2.852	13.564	19	0.001
Before surgery	10.35 ± 2.39				
After surgery	1.70 ± 2.73				
Mechanical axis of lower limb		0.050 ± 1.546	0.145	19	0.887
Before surgery	3.25 ± 1.19				
After surgery	3.20 ± 1.24				
Pelvic obliquity		−0.425 ± 3.897	−0.488	19	0.631
Before surgery	0.02 ± 3.27				
After surgery	0.45 ± 3.33				
GT angle from femoral head center		5.00 ± 1.3	16.71	19	0.001
Before surgery	3.90 ± 3.46				
After surgery	−1.10 ± 3.29				

bilateral osteotomy groups demonstrated that the average angle of knee varus and the GT angle from femoral head center after the surgery reduce significantly in comparison with preoperative condition.

In the preoperative planning for high tibial osteotomy, angle of mechanical axis of lower limb (line from femoral head center to talus dome) toward vertical line has to be measured before proceeding to the surgery. The lower limb alignment is generally assessed two-dimensionally using gray-scale radiographic images of the whole lower limb. Postoperative alignment in open-wedge high tibial osteotomy highly depends on an accurate preoperative plan [16–19]. In this study, the average angle of mechanical axis of lower limb after the surgery showed no statistically significant changes, and this means that the correct standing position of the patients was maintained while obtaining the X-rays.

The pelvic obliquity average increased significantly in the unilateral group but not significant in bilateral group, which was expected due to increased length of tibia in the medial open-wedge way. By unilateral osteotomies, limb length discrepancy occurs and causes increased pelvic obliquity. This caused no statistically significant difference in mechanical axis of lower limb and therefore its effect on the changes of GT angle from femoral head center is ignorable. Our findings are consistent with the results, which were carried out by Benedetti et al. [20] and Fraser et al. [21].

The reason for selecting the GT angle from the femoral head center is that after the osteotomy distal to hip region, no changes happen in acetabulum and the pelvis except the pelvic obliquity in unilateral osteotomy group. Moreover, the femoral head does not displace, just spins in the acetabulum and the distance of GT from center of femoral head remains intact [22]. As previously mentioned, the mechanical axis of lower limb also did not change importance after surgery. Therefore, the only change is the location of GT toward the center of femoral head, which causes the changes on the forces imposed on the hip joint [23]. Therefore, we introduce the location of the GT toward the center of femoral head and the horizontal line by measured angle and also its changes after the surgery. The results of reduction in GT angle from femoral head center demonstrate the lower location of the GT after the surgery. According to the geometrical and mechanical analyses, the changing rate of this angle is equal to the angular changes of femur mechanical angle, femur anatomical angle, and femoral neck angle toward horizontal line. Therefore, the GT moves downward as the same angle as femur adduction caused by the high tibial osteotomy. The distance from the center of femoral head to the GT is fixed and GT turns around it. According to biomechanics of the hip in the stance phase gait, the joint reaction force is one third of the body weight. In this case, the abductors are in the rest condition and do not impose any forces [13].

In the swing phase gait, the weight of the swing limb adds up to the 2/3 of the body weight and increases it to 5/6. In this case, the center of gravity of the body moves even further from the hip, which is tolerating the weight. The mechanism of maintaining the balance is like lever in which one arm is the distance of femoral head center from the center of gravity and the other arm is the distance of femoral head center from the abductor muscles insertion. Thus, the imposed weight force in addition to the compensative abductors force equals to hip joint reaction force [12, 13]. Therefore, the hip joint reaction force depends on items, such as the location of the center of gravity, the length of abductors moment arm, the femoral neck angle, and the body weight. The longer abductors moment arm, the less force imposed on the hip joint and vice versa [13, 14]. In the normal conditions, the femoral head center and the tip of the GT are at the same level. The longer abductors moment arm was found in superolateral region, means a location of the GT in which the angle of abductors vector force is equal to the GT angle from femoral head center and they make a perpendicular angle together. The more the GT comes down from this location, the shorter abductors moment arm [24, 25].

After the high tibial osteotomy in this study, the GT has moved downward and generally the femur is adducted; therefore, the abductors moment arm in this study has decreased which causes increased hip joint reaction force. Also, after the GT is positioned more downward, the neck of the femur stays more vertically toward the pelvis, which is the same changed degree of the GT angle from femoral head center. However, the effect of this change on the clinical function of the patient is unknown, but theoretically, the high tibial osteotomy of genu varum increases the hip joint reaction force and more energy consumption by abductors, but it reduces the shear force on the femoral neck.

Investigating articles and references, no study has been showed in which hip biomechanics after high tibial osteotomy in genu varum patients is evaluated. Therefore, comparison and confirming of our findings with other studies was not possible. Since this study is one of the first studies, which uniquely compare hip biomechanical variables before and after high tibial osteotomy for varus knee deformity correction, further development of this process, a long-term study with larger sample size and use of more precise radiological devices (i.e., CT scan) for evaluation of angles and intervals is suggested. In this study, clinical significance of the findings is not discussed which can also be recommended for further studies.

Based on the findings of this study, it can be concluded that high tibial osteotomy in the patients with genu varum has a significant effect on the location of the GT and displace it downward. By considering the biomechanics of the hip and geometrical calculations, on the one hand, this downward replacement of GT causes shortening of the abductors moment arm and consequently increased force on hip joint (hip joint reaction force). Therefore, more energy consumption by abductors is expected. But on the other hand, it reduces the shear force imposed on the femoral neck.

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Authors' contribution: All authors had full access to all data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Their roles on all works of study were equal. All authors read and approved the final form of this manuscript.

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