The Effect of Sagittal Plane Inclination on Posterior Tibial Slope in Medial Open Wedge HTO – Experimental Study With a Square Column Model-

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Research article

Keywords: Tibia, Osteotomy, High tibial osteotomy, Posterior slope, Simulation

Posted Date: September 21st, 2020

DOI: https://doi.org/10.21203/rs.3.rs-73069/v1

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Version of Record: A version of this preprint was published on January 18th, 2021. See the published version at https://doi.org/10.1186/s12891-021-03951-0.
Abstract

Background:

Medial open-wedge high tibial osteotomy (MOWHTO) is an effective and safe treatment method in medial osteoarthritis of knee. However, it may accompany unintended change of posterior tibial slope (PTS). Several factors are known to cause PTS change after MOWHTO. However, there is a lack of research on the sagittal plane osteotomy inclination (SPOI). The purpose of this study was to evaluate that SPOI affected the change in PTS. The hypothesis was that parallel SPOI causes no PTS change after MOWHTO.

Methods:

A square column model with a 10° posterior slope was produced by two 3D programs and a 3D printer. A series of MOWHTO was performed on a square column model through virtual simulation using two 3D programs and an actual simulation using a 3D printer, a testing machine and a measurement system. The SPOI was divided into 4 types: parallel SPOI plus 10° (SPOI: 20°), parallel SPOI (SPOI: 10°), perpendicular SPOI (SPOI: 0°), and perpendicular SPOI minus 10° (SPOI: -10°). The correction angle was increased by 5° from 0° to 30°. The change of the posterior slope was measured in sagittal plane.

Results:

The posterior slope was increased in the parallel SPOI plus 10° (SPOI: 20°). It was maintained in the parallel SPOI (SPOI: 10°) and decreased in the perpendicular SPOI (SPOI: 0°) and perpendicular SPOI minus 10° (SPOI: -10°).

Conclusion:

SPOI affected the change in PTS. Parallel SPOI causes no PTS change after MOWHTO.

Background

Medial open-wedge high tibial osteotomy (MOWHTO) is an effective and safe treatment method in medial osteoarthritis of knee[1–3]. It is for correction of coronal varus deformity. However, it may accompany unintended sagittal changes. It is already well known that posterior tibial slope (PTS) increases after medial OWHTO[4]. Unintended sagittal changes such as increase of PTS may influence knee kinematics and stability in the sagittal plane[5, 6].

Several studies have been conducted to find the cause of unintended change in PTS after medial OWHTO[2, 7–9]. Known causes are incomplete posterior cut[7], improper gap ratio[8], and inappropriate hinge position[2, 9]. However, there is a lack of study on the effect of sagittal plane osteotomy inclination (SPOI) on increase in PTS. Only one study reported that SPOI is correlated with PTS after medial HTO[10].
The purpose of this study was to evaluate the effect of SPOI on the change in PTS. The hypothesis was that parallel SPOI causes no PTS change after MOWHTO.

**Methods**

1. **Precondition establishment**

To analyze the effect of SPOI on PTS, a square column model with a 10° posterior slope was produced (Fig. 1). The value of the posterior slope 10° was set based on the average value reported[11]. Using this square column model, a virtual surgery was performed and the changes were measured. First, this process was performed with 3D programs. Then a 3D printer was used to make a real square column model and the changes were measured.

The reasons for requiring a square column model are as follows. First, it is difficult to accurately measure the structural changes after MOWHTO due to complexity of proximal tibia. Therefore, it is necessary to accurately measure and analyze even small changes through simple structuring. Second, even simplifying the complex structure of the proximal tibia does not damage its relationship. There may be a difference in the amount of variation between the complex structure of the proximal tibia and the simplified structure, but the relationship does not change.

The reason to be analyzed through experiments rather than through actual surgery is as follow. The actual surgery cannot be performed perfectly at all times, so confounding variables may occur. Therefore, experiments are needed to apply accurately the known cause such as complete posterior cut and true lateral hinge position.

2. **Virtual simulation using two 3D programs**

The Autodesk® Maya® software (Autodesk, San Jose, CA, USA) and the Rhinoceros® software (McNeel, Seattle, WA, USA) were used for virtual simulations. This software's have already been used in many medical papers as tools for 3D modeling and simulation[12–14].

The simulation was conducted as follows. First, a virtual square column model with a 10° posterior slope was produced. Second, the SPOI was divided into 4 types: parallel SPOI plus 10° (SPOI: 20°), parallel SPOI (SPOI: 10°), perpendicular SPOI (SPOI: 0°), and perpendicular SPOI minus 10° (SPOI: -10°) (Fig. 1). The known elements, complete posterior cut and true lateral hinge position, were applied. The correction angle was increased by 5° from 0° to 30°. The change of posterior slope was measured in sagittal plane.

3. **Actual simulation using a 3D printer, a testing machine and a measurement system**

Using a 3D printer (Objet 24, Stratasys Inc., Israel), four square column models with a 10° posterior slope were produced. The four types of SPOI were produced by different angles of jig attached to four square column models (Fig. 2). A jig is required to attach a square column model to a testing machine. The axis
of coronal correction or rotation is lateral hinge in MOWHTO. In experiments using a testing machine, the axis of coronal correction or rotation is lateral hinge too. The rotation of the square column model occurs around lateral hinge. The central axis of jig is lateral hinge. Therefore, the sagittal plane angle of the jig is SPOI.

The correction angle was increased by 5° from 0° to 30° using a testing machine MTS 858 Bionix (MTS system Corp., MN, USA) (Fig. 2). The change of posterior slope was measured using a MicroScribe™ system (Revware Systems, Inc., USA). The reported accuracy of the device is ± 0.05 mm [14]. To measure the change of posterior slope with a MicroScribe™ system, two holes were made in advance in the square column model. The anterior end point of the posterior slope is point A and posterior end point is point B (Fig. 2). These two points were reconstructed with a slope line using Rhinoceros software. Using this software, the change of posterior slope was determined as the angle (Fig. 2).

Results

1. Virtual simulation using two 3D programs

First, the Autodesk® Maya® software was used for a virtual simulation. The correction angle was increased by 5° from 0° to 30°. In parallel SPOI plus 10° (SPOI: 20°), PTS was changed from 10° to 10.037°, 10.149°, 10.334°, 10.592°, 10.921°, and 11.318°. In parallel SPOI (SPOI: 10°), PTS was changed from 10° to 10°, 10°, 10°, 10°, 10° and 10°. In perpendicular SPOI (SPOI: 0°), PTS was changed from 10° to 9.963°, 9.851°, 9.666°, 9.408°, 9.079°, and 8.682°. In perpendicular SPOI minus 10° (SPOI: -10°), PTS was changed from 10° to 9.930°, 9.720°, 9.370°, 8.882°, 8.256°, and 7.495°(Table 1) (Fig. 3).

Second, the Rhinoceros® software was used for same virtual simulation. The values were same as them of the Autodesk® Maya® software (Table 1).

2. Actual simulation using a 3D printer, a testing machine and a measurement system

The correction angle was increased by 5° from 0° to 30°. In parallel SPOI plus 10° (SPOI: 20°), PTS was changed from 10° to 10°, 10.4°, 10.7°, 11.5°, 11.8°, and 12.6°. In parallel SPOI (SPOI: 10°), PTS was changed from 10° to 10°, 9.9°, 9.9°, 10°, 10° and 9.9°. In perpendicular SPOI (SPOI: 0°), PTS was changed from 10° to 9.9°, 9.8°, 9.5°, 9.2°, 8.6°, and 8.2°. In perpendicular SPOI minus 10° (SPOI: -10°), PTS was changed from 10° to 9.7°, 9.5°, 9°, 8.6°, 7.8°, and 7° (Table 2).

Discussion

The most important finding of the present study was that SPOI affected the change in PTS. PTS was maintained in the parallel SPOI (SPOI: 10°). PTS was increased in the parallel SPOI plus 10° (SPOI: 20°). PTS was decreased in the perpendicular SPOI (SPOI: 0°) and perpendicular SPOI minus 10° (SPOI: -10°).
Previous studies have recommended that the osteotomy line in the sagittal plane be parallel to the PTS in MOWHTO[15–17]. Miller et al.[18] stated that they maintained the osteotomy line parallel to the PTS in MOWHTO to avoid inadvertent alteration of the native PTS. Amendola et al.[19] suggested that parallel osteotomy line is needed because not parallel osteotomy to PTS but perpendicular osteotomy to the tibia sagittal axis would create a very thin bony fragment posteriorly. However, there is still insufficient as a scientific rationale to support parallel osteotomy line.

To provide adequate scientific evidence, we attempted to interpret the results of this study mathematically (Fig. 4). The results were analyzed by applying the perpendicular SPOI (SPOI: 0°) to a square column model with a 10° posterior slope. In the sagittal view of a square column model, the anterior end point of 10° posterior slope is called P1, and the posterior end point is called P2. In the transverse view of a square column model, the anterior end point of the lateral hinge line is called H1, and the posterior end point is called H2. The Perpendicular SPOI (SPOI: 0°) and the lateral hinge line are the same line in the sagittal view of a square column model and this line is the osteotomy plane. In the anterior view of a square column model, a triangle consisting of P1, H1, and the osteotomy plane line (OP line) can be created. At this time, P1 has a distance of r1 from H1, a distance of x1 from OP line, and an angle of θ1. In the posterior view, similar to the anterior view, P2 has a distance of r2 from H2, a distance of x2 from OP line, and an angle of θ2. A virtual simulation of MOWHTO was performed to correct the angle of θ. After correction, the position of P1 in the anterior view changed to P1’. The value of r1 is same. However, the distance from OP line changed from x1 to x1’ and the angle changed from θ1 to θ1 + θ. After correction, the position of P2 in the posterior view changed to P2’. The value of r2 is the same. However, the distance from the OP line changed from x2 to x2’ and the angle changed from θ2 to θ2 + θ. The 10° posterior slope of the square column model can be described by the height of P1 and P2 in the sagittal view. As described above, the height of P1 is x1 and the height of P2 is x2 for the OP line. After correction with θ angle, the height of P1’ is x1’ and the height of P2’ is x2’. Then, x1, x2, x1’, x2’ can be formulated as follows.

\[ X1 = r1 \times \sin (\theta1) \]
\[ X2 = r2 \times \sin (\theta2) \]
\[ X1' = r1 \times \sin (\theta1 + \theta) \]
\[ X2' = r2 \times \sin (\theta2 + \theta) \]

If θ1 and θ2 are the same value, the changing values from x1 and x2 to x1’ and x2’ are the same. Therefore, posterior slope is the same. If θ1 and θ2 are different values, the changing values are different. Therefore, posterior slope is changed. After all, in order for θ1 and θ2 to be the same value, it should be a parallel SPOI.

Lee et al.[10] reported that only 12.9% of patients were parallel and 87.1% of patients had anterior-inclined osteotomy (AIO) despite trying to do parallel osteotomy. In this paper, the changes in PTS after
surgery were significantly correlated with sagittal osteotomy inclination. Therefore, they concluded that surgeons should make all efforts to perform parallel osteotomy. Although the result is similar with our result in that PTS was maintained in the parallel SPOI, there is a difference in the direction of the PTS change. Our results showed a decrease in PTS in perpendicular SPOI similar to the AIO group while Lee et al.[10] reported that PTS was increased in the AIO group. This difference may come from the hinge position. The AIO group may have the increased PTS by posterolateral hinge position.

Akamatsu et al.[20] reported that there was no significant difference between the sagittal osteotomy plane angle and the change in PTS while the AP hinge position ratio were significantly correlated with the change in PTS. This result is inconsistent with our results. However, they could not control the effect of hinge position in the analysis of the association between the sagittal osteotomy plane angle and the change in PTS. This may obscure the relationship. It is thought that consideration for the effect of hinge position is needed to evaluate the effect of SPOI on the change in PTS.

This study had some limitations that be considered. First, it was an experimental study using a square column model with two 3D programs and a 3D printer. Therefore, it is different from the proximal tibia. However, as described above, even though the complex structure of the proximal tibia is simplified to a square column model, the relationship between the variables we want to observe is not compromised. Rather, it is possible to analyze accurately the relationship between SPOI and PTS. However, due to the difference in structure, the difference in the amount of change may occur. Therefore, in the proximal tibia, the amount of change in PTS may be greater than the result of this experiment. Second, this study has no consideration for soft tissue around the knee. Therefore, the results may vary due to the effect of soft tissue in MOWHTO. Third, although our results show the changes in PTS by SPOI, the differences of PTS may not seem to be clinically significant. However, the change in PTS was evaluated only in lateral hinge position. If SPOI is increased in the posterolateral hinge position, the change in PTS can be greatly increased. Therefore, further model study is need to demonstrate the effect of SPOI on the change of PTS by hinge positions.

Although there were several limitations, this square column model study has an advantage in that other factors affecting the PTS can be completely controlled in measuring the change of PTS. Thus, our study shows the relationship between the change in PTS and SPOI excluding other related factors of PTS.

**Conclusion**

In this study, SPOI affected the change in PTS and PTS was maintained in the parallel SOPI. It seems that parallel SOPI in MOWHTO is necessary to prevent the change in PTS. In the further study, it is need to demonstrate the effect of SPOI on the change of PTS by hinge positions.

**Abbreviations**

MOWHTO
Medial open-wedge high tibial osteotomy
PTS
Posterior tibial slope
SPOI
Sagittal plane osteotomy inclination
HTO
High tibial osteotomy

**Declarations**

Ethics approval and consent to participate: None

Consent for Publication: Not Applicable

Availability of data and material: All data is contained within the manuscript and additional files

Competing interests: The authors declare that they have no competing interests.

Funding:

This project (Ref: AOTAP17-08) was supported by AO Trauma Asia Pacific.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2017R1C1B5077039).

Authors’ contributions:

SWM and YC conceived and planned the experiments. SJL and SWW carried out the experiments. SWM, SWW and SHP contributed to the interpretation of the results. SWM and JYR took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript.

Acknowledgements:

The authors wish to thank Young Woo Kwon for their technical support.

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Tables

| Correction Angle | SPOI 20° | SPOI 10° | SPOI 0° | SPOI -10° |
|-----------------|----------|----------|---------|-----------|
| 5°              | 10.037°  | 10°      | 9.963°  | 9.930°    |
| 10°             | 10.149°  | 10°      | 9.851°  | 9.720°    |
| 15°             | 10.334°  | 10°      | 9.666°  | 9.370°    |
| 20°             | 10.592°  | 10°      | 9.408°  | 8.882°    |
| 25°             | 10.921°  | 10°      | 9.079°  | 8.256°    |
| 30°             | 11.318°  | 10°      | 8.682°  | 7.495°    |
Table 2. Changes of posterior slope in actual simulation.

| Correction Angle | SPOI 20° | SPOI 10° | SPOI 0° | SPOI -10° |
|------------------|----------|----------|---------|------------|
| 5°               | 10°      | 10°      | 9.9°    | 9.7°       |
| 10°              | 10.4°    | 9.9°     | 9.8°    | 9.5°       |
| 15°              | 10.7°    | 9.9°     | 9.5°    | 9°         |
| 20°              | 11.5°    | 10°      | 9.2°    | 8.6°       |
| 25°              | 11.8°    | 10°      | 8.6°    | 7.8°       |
| 30°              | 12.6°    | 9.9°     | 8.2°    | 7.0°       |

Figures
Figure 1

(A) A square column model with 10° posterior slope. (B) Medial view of a square column model.
Figure 2

(A) The four square column models with different angles of jig attached. (B) After correction with a MTS 858 Bionix, measuring the end point of posterior slope using a MicroScribeTM system. (C) The change of posterior slope was determined with Rhinoceros® software.
Figure 3

Changes of posterior slope in virtual simulation with SPOI 20°(A), SPOI 10°(B), SPOI 0°(C), and SPOI -10° (D).
Figure 4

Mathematic formula: A before correction; B after correction; P1: anterior end point; P2: posterior end point; H1: anterior end point of the lateral hinge; H2: posterior end point of the lateral hinge; r1: distance from H1 to P1; r2: distance from H2 to P2; \( \theta_1 \): angle of P1 with the OP line; \( \theta_2 \): angle of P2 with the OP line;
\[ x_1 = r_1 \times \sin(\theta_1); \quad x_2 = r_1 \times \sin(\theta + \theta_1); \quad x_3 = r_2 \times \sin(\theta_2); \quad x_4 = r_2 \times \sin(\theta + \theta_2) \]