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Analysis of Surgical Parameters in High Tibial Osteotomy: Effects on Resultant Tibiofemoral Force Position

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Abstract

Unintended under- and overcorrections remain a significant challenge in medial open wedge High Tibial Osteotomy (owHTO). Achieving balanced load distribution is a central focus in HTO, yet most studies concentrate on the classical two-dimensional (2D) standing scenario rather than examining the complexities of three-dimensional (3D) load behavior during dynamic motions. This study aimed to investigate the biomechanical effects of key surgical parameters—wedge height, hinge axis, and osteotomy technique—on the position of the resultant force on the tibial plateau during knee flexion. A multibody simulation was conducted on 10 3D computer models of the tibia. The position of the center of pressure (CoP) on the tibial plateau was measured and compared across different surgical scenarios. Results indicate that increasing wedge height causes lateral CoP displacement, with the effect decreasing at higher flexion angles, while anteromedial axial rotation of the hinge axis led to posterior CoP shifts. A comparison of supratuberositary to infratuberositary osteotomies revealed a medial CoP displacement during late flexion (>5°).

1 Introduction

Medial owHTO is a widely used surgical technique for addressing uni-compartmental osteoarthritis of the knee caused by proximal tibial and varus deformities [1] [2]. The procedure aims to shift the knee load from the medial to the lateral compartment to achieve a reduction of medial loading, thereby delaying the need for knee arthroplasty, particularly in young and active patients [2]. However, unintended under- or overcorrections due to surgical errors, planning inaccuracies, or changes in soft tissue balances remain a significant challenge [3] [4] [5]. While many studies investigate load distribution, they predominantly focus on the classical 2D standing scenario [6] [7]. However, incorporating a 3D analysis of the resultant joint force, including flexion and extension motions, is essential. Applying this approach should help ensure a safe distance from the tipping point [8], thereby preventing medial joint opening due to overcorrection and enabling a stable equilibrium. This paper contributes to this understanding by analyzing how key surgical factors—wedge height, hinge axis positioning and osteotomy technique—affect the position of the resultant tibiofemoral force.

2 Materials and Methodes

2.1 Data and Model Preparation

The dataset consists of 10 three-dimensional surface models derived from post-mortem full-leg CT scans, with varus/valgus angles ranging from -0.08° to 4.73° (mean: 2.51°, SD: 1.59°). Following segmentation, the osteotomy plane was defined by an orthopedic surgeon using a Statistical Shape Model (SSM) of the tibia and then applied to the surface models. Detailed descriptions of the segmentation and modeling process are available in prior studies [9] [10] [11] [12]. Two osteotomy techniques, an supratuberositary and an infratuberositary biplanar cut, were simulated with a fixed wedge height of 8°. Additional wedge openings for the ascending biplanar cut were incrementally increased by 1° (ranging from 5° to 11°) to analyze the impact of the wedge height. Implementation details are provided in Schroeder et al. [12]. To investigate the effect of hinge axis orientation, the medial osteotomy cut was rotated incrementally from a medial to an anteromedial incision in 10° steps (0°–30°) with an 8° wedge height for the supratuberositary cut. This approach generated 10 preoperative models and 110 osteotomy models. The position of the CoP, representing the resultant tibiofemoral force, was evaluated across knee flexion angles, with changes assessed per degree of flexion. To compare the displacement, the absolute x- and y-displacement values of the CoP were normalized by the mediolateral width and anteroposterior length of the tibial plateau and expressed as percentages.

2.2 Biomechanical Simulation

The AnyBody Modeling System™ (AnyBody Technology A/S, Aalborg, Denmark) was used for multibody simulations of the knee joint, based on a patient-specific model adapted from a validated total knee arthroplasty (TKA) model [13]. Details of the model are mentioned in previous studies [11] [12]. Osteotomy simulations covered knee flexion angles from 5° to 95°, avoiding full extension and deep flexion to prevent computational instability. This model limitation is attributed to the exclusion of menisci, cartilage, and other soft tissue components, as the model relied only on segmented CT imaging.

2.3 Statistical Methodes

MATLAB (MathWorks, Inc., Natick, MA, USA) was employed for statistical analysis. Data normality was verified through visual inspection of Q-Q plots. The effects of opening angle and hinge axis position on the CoP were evaluated using repeated-measures ANOVA. The influence of the osteotomy technique on CoP was analyzed using an independent-samples t-test. Additionally, standard deviation (SD) was calculated for all surgical parameters.

3 Results

Figure 1 illustrates the normalized CoP displacement for the three surgical parameters, while **Table 1** summarizes the mean relative x-/y-displacement values, including SD and p-values. For the wedge height, the preoperative model was compared to postoperative models of a supratuberositary osteotomy with a medial hinge axis. As shown in **Figure 1A**, lateral CoP displacement increased with larger wedge heights but progressively decreased at higher knee flexion angles. The impact of the hinge axis is depicted in **Figure 1C** and **Figure 1D**. In an supratuberositary biplanar osteotomy with an 8° wedge height, greater hinge axis angles caused a posterior displacement of the CoP. Comparing the infratuberositary to the supratuberositary osteotomy with a medial hinge axis and an 8° wedge height revealed a medial CoP displacement (**Figure 1E**) during late flexion (>5°).

Degree of Flexion		**x - direction [medial(-)/lateral(+)]**						**y - direction [posterior(-)/anterior(+)]**					
		5 deg [%]	SD [%]	p	90 deg [%]	SD [%]	p	5 deg [%]	SD [%]	p	90 deg [%]	SD [%]	p
Wedge Opening													
(ascending cut,	5 deg	7,51	0,81	< 0,01	1,79	0,36	< 0,01	-1,11	0,73	< 0,01	1,05	0,89	< 0,01
0 deg Hinge Axis)	6 deg	9,03	0,92	< 0,01	2,10	0,42	< 0,01	-1,29	0,82	< 0,01	1,16	1,04	< 0,01
	7 deg	10,46	1,08	< 0,01	2,40	0,48	< 0,01	-1,45	0,93	< 0,01	1,25	1,17	< 0,01
	8 deg	11,95	1,23	< 0,01	2,70	0,53	< 0,01	-1,59	0,99	< 0,01	1,30	1,29	< 0,01
	9 deg	13,39	1,35	< 0,01	2,98	0,58	< 0,01	-1,72	1,04	< 0,01	1,33	1,40	< 0,01
	10 deg	14,83	1,48	< 0,01	3,27	0,63	< 0,01	-1,82	1,10	< 0,01	1,33	1,49	< 0,01
	11 deg	16,27	1,66	< 0,01	3,56	0,69	< 0,01	-1,88	1,16	< 0,01	1,33	1,57	< 0,01
Hinge Axis													
(ascending cut,	10 deg	-0,66	0,49	< 0,01	-0,16	0,08	< 0,01	-0,98	< 0,01	0,83	-1,71	0,57	< 0,01
8 deg Wedge Opening)	20 deg	-1,04	1,52	0,08	-0,36	0,21	< 0,01	-1,76	< 0,01	0,98	-2,92	0,86	< 0,01
	30 deg	-2,56	1,58	0,03	-0,95	0,41	0,02	-2,41	< 0,01	0,98	-4,22	1,06	< 0,01
Cut Variant													
(0 deg Hinge Axis, 8 deg Wedge Opening)	descending	0,02	0,46	0,62	-1,33	0,19	< 0,01	-0,35	0,34	< 0,01	0,42	1,16	0,64

Table 1: Mean relative values for x-/y-displacements with SD and p-values

4 Discussion and Outlook

This study analyzed the effects of surgical parameters—wedge height, hinge axis, and osteotomy technique —on the CoP position on the tibial plateau using a multibody simulation model.

The findings confirm a lateral displacement of the tibiofemoral force with increasing wedge height, consistent with the results reported by Agneskirchner [14], who demonstrated that lateralizing the leg axis reduces medial compartment pressure. The magnitude of this displacement varied with knee flexion angles, emphasizing the importance of dynamic analysis. Increasing hinge axis angles were associated with posterior CoP displacement. Kuriyama [15] and Jörgens [10] reported that shifting the hinge axis increases the posterior tibial slope (PTS), while Giffin et al. [16] observed that greater PTS causes an anterior shift of the tibial plateau. These biomechanical changes could explain the observed posterior CoP displacement during flexion. When comparing the infratuberositary to the supratuberositary osteotomy, a medial CoP displacement was observed during flexion (>5°). While this study focused on infratuberositary versus supratuberositary osteotomy, Schroeder et al. [12] analyzed the reverse comparison in owHTO and reported an increase in the TT-TG distance with supratuberositary osteotomy. They suggested that this increase raises the Q-angle and alters muscle force vectors, which may also explain the medial shift observed in this study.

Several methodological limitations of this study should be noted. The model lacked detailed representation of soft tissues, as it relied solely on CT data. Additionally, CoP calculations averaged forces across the entire tibial plateau rather than differentiating between compartments. The use of cadaveric models, which exhibited a mean valgus angle of 2.51°, may have contributed to the potential overcorrection of alignment. Lastly, the small sample size limits the generalizability of the findings. Future studies should focus on addressing the small sample size and exploring additional surgical and patient-specific factors. Investigating these aspects will contribute to a better understanding of overcorrection mechanisms and advance patient-specific optimization of 3D planning in HTO.

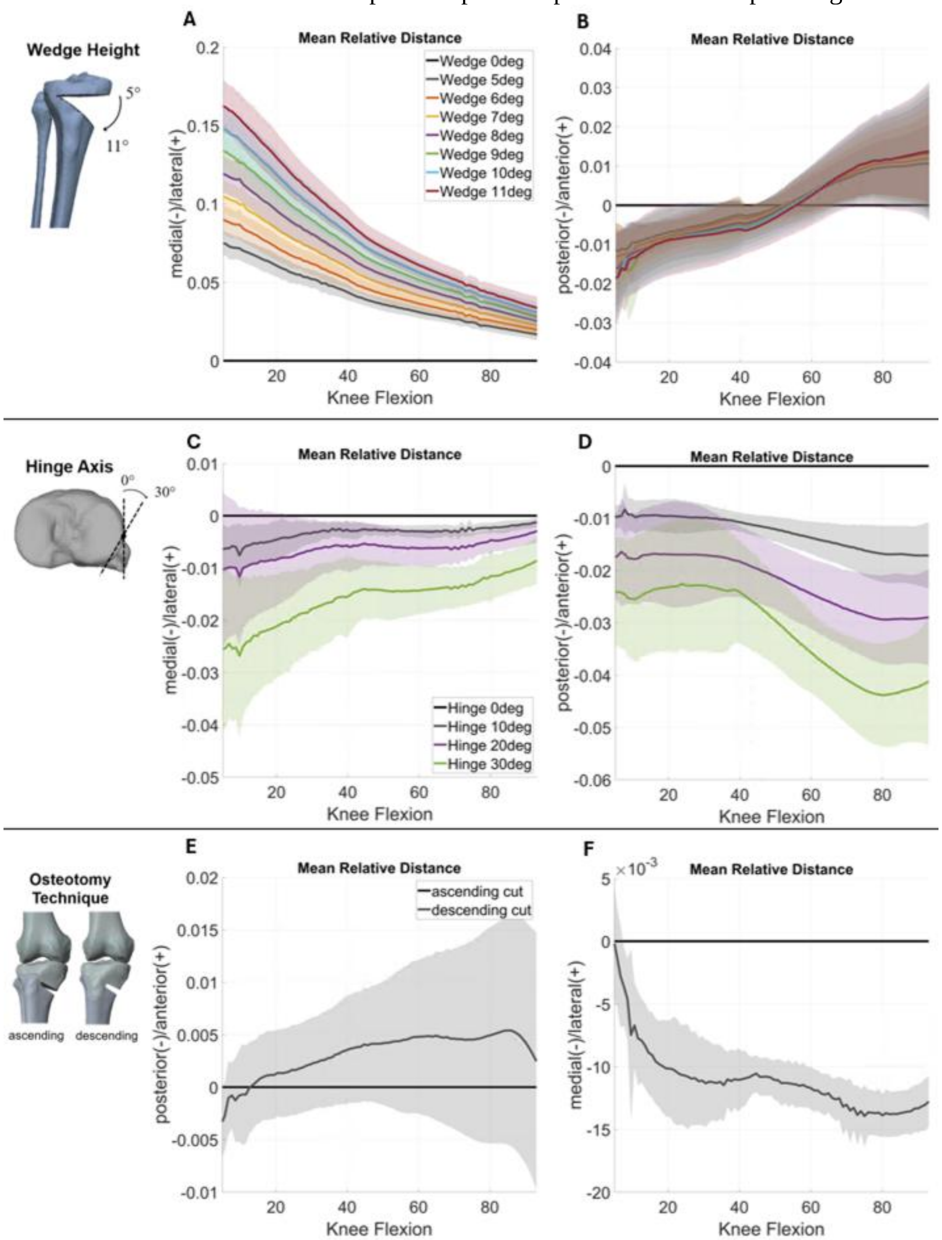

Figure 1: Normalized CoP Displacement in the Medial/Lateral (x-direction) and Anterior/Posterior (y-direction) Axes Across Knee Flexion Angles for Different Wedge Heights, Hinge Axes and Osteotomy Techniques [12]

5 References

[1] A. A. Amis, "Biomechanics of high tibial osteotomy," *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA*, vol. 21, no. 1, pp. 197–205, 2013, doi: 10.1007/s00167-012-2122-3.

[2] Y. Akamatsu, H. Kobayashi, Y. Kusayama, K. Kumagai, and T. Saito, "Comparative Study of Opening-Wedge High Tibial Osteotomy With and Without a Combined Computed Tomography-Based and Image-Free Navigation System," *Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association*, vol. 32, no. 10, pp. 2072–2081, 2016, doi: 10.1016/j.arthro.2016.02.018.

[3] P. Behrendt *et al.*, "Preoperative joint line convergence angle correction is a key factor in optimising accuracy in varus knee correction osteotomy," *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA*, vol. 31, no. 4, pp. 1583–1592, 2023, doi: 10.1007/s00167-022-07092-2.

[4] K. Kumagai *et al.*, "Adjusted planning based on the joint line convergence angle improves correction accuracy in the standing position after opening wedge high tibial osteotomy," *J Orthop Surg Res*, vol. 19, no. 1, 2024, doi: 10.1186/s13018-024-05096-x.

[5] J. D. Agneskirchner, C. Hurschler, C. Stukenborg-Colsman, A. B. Imhoff, and P. Lobenhoffer, "Effect of high tibial flexion osteotomy on cartilage pressure and joint kinematics: a biomechanical study in human cadaveric knees.," *Archives of orthopaedic and trauma surgery*, vol. 124, no. 9, pp. 575–584, 2004, doi: 10.1007/s00402-004-0728-8.

[6] Y. Fujisawa, K. Masuhara, and S. Shiomi, "The effect of high tibial osteotomy on osteoarthritis of the knee. An arthroscopic study of 54 knee joints," *The Orthopedic clinics of North America*, vol. 10, no. 3, pp. 585–608, 1979.

[7] S.-S. Lee *et al.*, "Avoiding Overcorrection to Increase Patient Satisfaction After Open Wedge High Tibial Osteotomy," *The American journal of sports medicine*, vol. 50, no. 9, pp. 2453–2461, 2022, doi: 10.1177/03635465221102144.

[8] E. Heijens, P. Kornherr, C. Meister, "The coronal hypomochlion: A Tipping Point of Clinical Revelance When Planning Valgus Producing High Tibial Osteotomies," *The Bone & Joint Journal*, vol. 2016, no. 5, pp. 628–633, doi: 10.1302/0301-620X.98B5.

[9] J. Fürmetz *et al.*, "Three-dimensional assessment of lower limb alignment: Accuracy and reliability," *The Knee*, vol. 26, no. 1, pp. 185–193, 2019, doi: 10.1016/j.knee.2018.10.011.

[10] M. Jörgens *et al.*, "Reliability of 3D planning and simulations of medial open wedge high tibial osteotomies," *Journal of orthopaedic surgery (Hong Kong)*, vol. 30, no. 2, 10225536221101699, 2022, doi: 10.1177/10225536221101699.

[11] M. Jörgens *et al.*, "Increased kinematic changes in ascending compared with descending biplanar cut in open wedge high tibial osteotomy-a multibody simulation," *Knee surgery & related research*, vol. 36, no. 1, p. 35, 2024, doi: 10.1186/s43019-024-00244-3.

[12] L. Schroeder *et al.*, "Open wedge high tibial osteotomy alters patellofemoral joint kinematics: A multibody simulation study," *Journal of orthopaedic research : official publication of the Orthopaedic Research Society*, vol. 42, no. 12, pp. 2705–2713, 2024, doi: 10.1002/jor.25945.

[13] M. Asseln, "Morphological and functional analysis of the knee joint for implant design optimization," Dissertation, Shaker Verlag.

[14] J. D. Agneskirchner, C. Hurschler, C. D. Wrann, and P. Lobenhoffer, "The effects of valgus medial opening wedge high tibial osteotomy on articular cartilage pressure of the knee: a

biomechanical study," *Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association*, vol. 23, no. 8, pp. 852–861, 2007, doi: 10.1016/j.arthro.2007.05.018.

[15] S. Kuriyama *et al.*, "Clinical efficacy of preoperative 3D planning for reducing surgical errors during open-wedge high tibial osteotomy," *Journal of orthopaedic research : official publication of the Orthopaedic Research Society*, vol. 37, no. 4, pp. 898–907, 2019, doi: 10.1002/jor.24263.

[16] J. R. Giffin, T. M. Vogrin, T. Zantop, S. L. Y. Woo, and C. D. Harner, "Effects of increasing tibial slope on the biomechanics of the knee," *The American journal of sports medicine*, vol. 32, no. 2, pp. 376–382, 2004, doi: 10.1177/0363546503258880.