Comparison of torsional changes in the tibia following a lateral closed or medial open wedge high tibial osteotomy

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ABSTRACT

Objective: The aim of this study is to evaluate, by computed tomography (CT), whether different torsional changes occur in the tibia following a lateral closed wedge high tibial osteotomy (CWHTO) versus a medial open wedge high tibial osteotomy (OWHTO) procedure. It was hypothesized that the distal fragment of the tibia would show greater internal rotation after CWHTO.

Methods: Thirty knees from 25 patients who underwent HTO were enrolled. Fifteen knees of 14 patients who underwent CWHTO and 15 knees of 11 patients who received OWHTO were match-paired. CT scans were taken before and three weeks after surgery. Rotational changes in the distal fragment of the tibia were assessed by measuring the tibial torsion angle (TTA).

Results: The mean TTA in the CWHTO group pre-operatively and postoperatively was $+23.9° \pm 7.8°$ and $+18.2° \pm 7.0°$, respectively. Internal rotation of the distal fragment of the tibia after CWHTO was $-5.7 \pm 3.3°$ ($P < 0.001$). In the OWHTO group, the mean TTA pre-operatively and postoperatively was $+27.9° \pm 6.9°$ and $+26.8 \pm 7.7°$, respectively, with no significant change in torsion observed ($P > 0.05$).

Conclusions: The distal fragment of the tibia rotated internally after CWHTO but not after OWHTO.

Level of evidence: Level III: case–control study.

1. Introduction

Lateral closed wedge high tibial osteotomy (CWHTO) and medial open wedge high tibial osteotomy (OWHTO) are established surgical treatments for osteoarthritis (OA) in the medial compartment of the knee. There have been several reports of good mid-term and long-term clinical outcomes from both procedures [1,2]. A previous meta-analysis also reported no significant difference between the clinical outcomes of these two procedures over short-term follow-up [3].

There have been some reports of unintended alignment changes in the sagittal plane after either CWHTO or OWHTO, including posterior tibial slope, patellar tilt and patella height [3–7]. Several recent studies have also suggested that unexpected axial tibial

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rotation occurs after OWHTO [8–10]. Jang et al. described an unintended increase in the internal torsion of the tibia after biplanar medial OWHTO [8]. Kendoff et al. evaluated axial torsion of the tibia using cadaver knees, and concluded that axial rotation of the distal tibia occurs following high tibial osteotomy (HTO), with a higher tendency for external rotation following OWHTO [9]. It is known that torsional changes resulting from both HTO procedures can affect the patellofemoral joint [4]. However, few studies to date have evaluated changes in tibial torsion after CWHTO [11]. Furthermore, there have been no studies comparing torsional changes to the tibia following CWHTO and OWHTO.

The current study speculated that postoperative rotation of the distal fragment of the tibia would be different between CWHTO and OWHTO. It therefore evaluated this possibility using the computed tomography (CT) method described by Waidelich et al. [12], and hypothesized that the distal fragment of the tibia would show greater internal rotation after CWHTO.

2. Materials and methods

2.1. Patients and assessment

This cross-sectional cohort study was approved by the institutional Ethics Commission (No. 29-1) and informed consent was obtained from all participants. Forty knees of 31 patients who underwent high tibial osteotomy via either CWHTO or OWHTO between April and July of 2017 at the hospital were prospectively enrolled. All of these patients agreed to undergo a CT scan before and three weeks after surgery to analyze the tibial torsion angle (TTA) in accordance with the method by Waidelich (Figure 1) [12]. The TTA is the angle between the posterior condylar tangent and bisector of the bimalleolar ellipses. To measure the TTA, CT scan slices were taken from the proximal tibial plane just above the fibula head tip and bimalleolar ellipses drawn at the level of the ankle. Subsequently, the CT scan slices were superimposed. The CT scans were performed before and three weeks after surgery (just before discharge) to analyze the unintended influence of the different procedure (CWHTO vs. OWHTO).

Deformity analysis was performed as described by Paley and Tetsworth, both pre-operatively and two weeks after surgery, in the coronal plane by using full weight-bearing long-leg anteroposterior X-rays (Figure 2) [13]. The mechanical tibiofemoral angle (mTFA), defined as the angle between mechanical tibial and mechanical femoral axes, and the correction angle were captured. Planning was performed as described by Miniaci et al., using this radiographic image of the leg as the postoperative weight-bearing line, which passed through 62% laterally from the medial edge of the tibial plateau, and the measured correction angle was captured [14].

The study cohort was divided into two groups in accordance with the surgical procedure. These groups were matched by age, sex, body mass index, and degree of correction using a 1:1 variable ratio. Finally, 15 knees of 14 patients who underwent a hybrid CWHTO operation and 15 knees of 11 patients who received OWHTO were adopted for this study (Table 1).

2.2. Surgical technique

The indication for an HTO intervention included either medial compartment osteoarthritis (OA) or osteonecrosis of the medial femoral condyle combined with a varus deformity. The decision to use an OWHTO procedure was made if the flexion contracture was <10°, there was no clinical evidence of patellofemoral OA, and no remarkable cartilage degeneration in the patellofemoral joint was evident on magnetic resonance imaging (MRI). In contrast, CWHTO was used if the flexion contracture was >10°, there was clinical evidence of patellofemoral OA combined with radiological patellofemoral OA in a 30° flexion skyline view, and if a knee MRI indicated cartilage degeneration in the patellofemoral joint. The exclusion criteria for HTO included: (1) both medial and lateral compartment OA of the knee; (2) infection of the knee; (3) acute or chronic osteomyelitis of the tibia; and
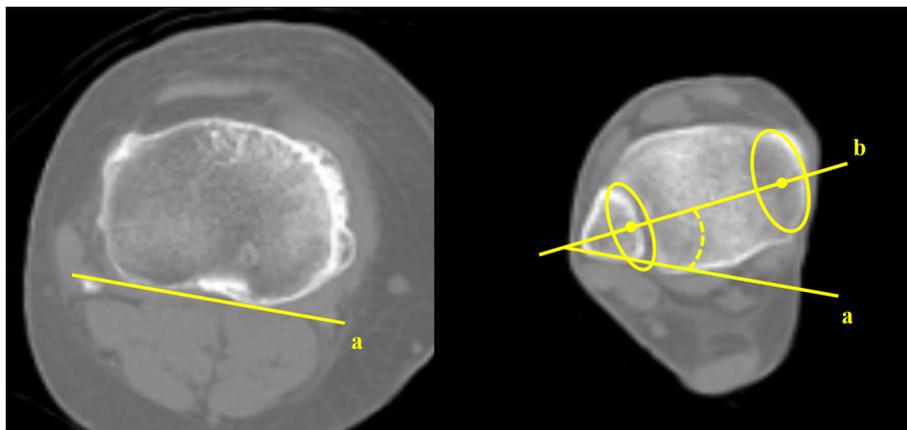

Figure 1. Tibial torsion angle. a: Posterior tangent of the proximal tibial condyles. b: The distal tibial axis is drawn between the centers of an ellipse from the surface of the medial malleolus and another ellipse formed by the incisura fibularis.
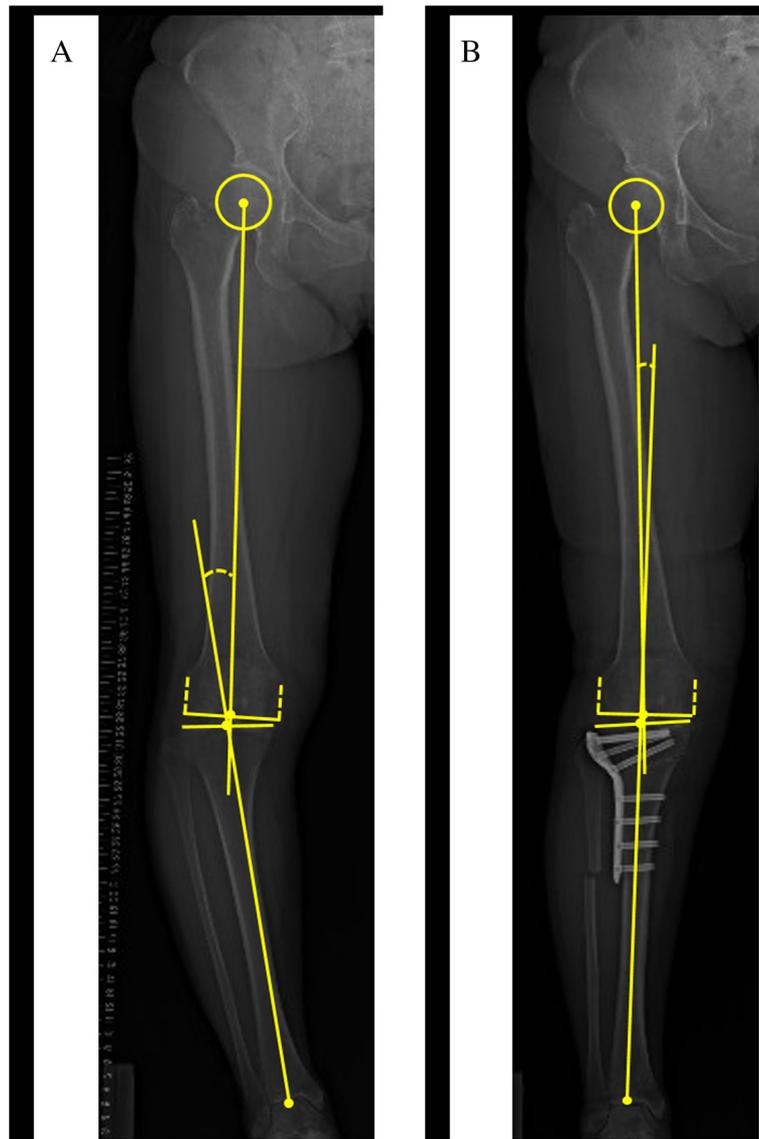
Figure 2. Mechanical tibiofemoral angle (mTFA) in a patient who underwent hybrid CWHTO. a: Pre-operative mTFA. b: Postoperative mTFA.

(4) a flexion contracture >20° and a maximum flexion <100°. A randomized study was not used to compare the two surgical procedures because of the different indications.

Table 1
Demographic data for the study patients.

	CWHTO	OWHTO	P
Number of knees	15	15	
Diagnosis, OA/SONK	15/0	13/2	
K–L grade, II/III/IV	6/6/3	6/6/1	
Pre-operative age, years	64.9 ± 6.6	65.5 ± 8.2	0.826
Gender, male/female	5/10	3/12	0.407
Body mass index, kg/m^2	25.6 ± 3.6	24.3 ± 3.0	0.312
Correction angle, °	9.4 ± 2.4	8.7 ± 2.9	0.510

CWHTO, closed wedge high tibial osteotomy; OWHTO, open wedge high tibial osteotomy; OA, osteoarthritis; SONK, spontaneous osteonecrosis of the knee; K–L grade, Kellgren–Lawrence grade [24]; mTFA, mechanical tibiofemoral angle (negative value means varus).
Statistical significance was set at $P < 0.05$.

Figure 3. Open wedge high tibial osteotomy.

All of the knees in the OWHTO cohort underwent medial OWHTO using a biplanar minimally invasive technique described previously (Figure 3) [15]. The OWHTO consisted of a biplanar 110° L-shaped osteotomy. From medial to lateral, two Kirschner wires (K-wires) were positioned parallel to the lateral tibial slope above the pes anserinus and aiming for the upper third or fibula head. A transverse osteotomy was made up to five millimeters to the lateral cortical bone. The second bone cut, the ascending osteotomy, was performed at an angle of 110° to the first one. The ascending osteotomy started ≥10 mm proximal to the insertion of the patellar tendon. The osteotomy was opened slowly to achieve the opening, according to pre-operative planning. Briefly, bone substitute (Osferion 60; Olympus Termo Biomaterials, Tokyo, Japan) was inserted into the osteotomy site, and TomoFix MHT small or TomoFix MHT anatomical (DePuySynthes, Bettlach, Switzerland) was used for fixation of the osteotomy.

A hybrid CWHTO was performed on all knees in the CWHTO group, as described in a previous study (Figure 4) [16,17]. The first K-wire was inserted at a position 35 mm distal to the lateral proximal tibial joint surface and to the medial target position on the coronal plane (about 15 mm distal to the medial proximal tibial joint surface) under fluoroscopy. The proximal second K-wire insertion point was posterior to the first K-wire, perpendicular to the operating table, and parallel to the first wire. The hinge point, which divides the proximal tibial osteotomy line by about 2:1, was then determined. A K-wire was percutaneously inserted at this hinge point from anterior to posterior. After the second K-wire was inserted, the distal osteotomy line was determined with a goniometer, and a third K-wire was inserted from this point to the hinge point. Osteotomy was performed with biplanar technique. The ascending osteotomy was performed at an angle of 100° to the first one, and the lateral wedge block was removed.

The proximal and distal fragments were then approximated to correct any deformity. The proximal and distal fragments rotated about the hinge point so that both lateral cortexes met, and the medial side was opened, while the lateral side was closed. In this way, the distal fragment was advanced proximally and anteriorly by the thickness of the flange (thickness of the tibial tuberosity). The lateral HTO plate (Olympus Terumo Biomaterials, Tokyo, Japan) was used for fixation. In most cases, the distal tibial shaft tended to dislocate medially compared with the proximal fragment. After the plate head was fixed to the proximal fragment, the distal fragment was pulled up to the plate shaft using a compression screw technique until both the proximal and distal lateral cortices were in firm contact. A compression screw technique was used to attach the distal fragment of the tibia to the plate shaft, and also to acquire a rigid contact force at the lateral proximal and distal cortex. The medial cortical hinge was cut completely in hybrid CWHTO, whereas, the lateral hinge was preserved in OWHTO.

One of the most different points of hybrid CWHTO from classical CWHTO is no step-off at the lateral osteotomy site. In classical CWHTO, the osteotomy is performed parallel to the tibial plateau; however, this results in a step-off of the proximal tibia shape. In addition, an increased lateral step-off could cause a difference in contact area between the proximal and distal osteotomy sites [16].

Figure 4. Hybrid closed wedge high tibial osteotomy.

The oblique osteotomy used in the current hybrid CWHTO procedure had a larger contact area of the osteotomy site than in conventional osteotomy. Early full weight-bearing walking can be realized after surgery because the lateral cortices of the proximal and distal fragments are firmly attached. Furthermore, a smaller bone wedge is removed from the lateral site of the osteotomy in hybrid CWHTO, which can reduce leg length shortening compared with classical CWHTO. A fibula osteotomy was performed at its mid portion, and segmental resection was performed to remove a sufficient length of bone to enable tibial correction through a separate incision in hybrid CWHTO. The mid-portion osteotomy of the fibula was performed to avoid peroneal nerve palsy.

The postoperative rehabilitation regimen was the same in both groups. Briefly, full weight-bearing standing was permitted, and physiotherapy with no range of motion restrictions began one day after surgery. Partial weight-bearing walking with crutches was allowed two days after surgery, but was dependent on the level of pain. Full weight-bearing walking was allowed two weeks after surgery. No patients in either cohort had any serious complications during the acute surgical period.

2.3. Statistical analysis

Numerical values were expressed as a mean $\pm$ standard deviation. Paired t-tests were performed to compare pre-operative and postoperative TTA variables in each surgical group. Student t-test was used to compare the torsional change at the tibia (ΔTTA). Single linear regression analysis was used to investigate the association between each parameter and the correction angle in each surgical group. JMP statistical software (version 12; SAS Institute, Inc., Cary, NC) was used to analyze the data, with the level of significance set at $P < 0.05$.

3. Results

The mTFA change in the CWHTO and OWHTO groups was $-5.6 \pm 3.5°$ to $3.6 \pm 2.8°$ and -4.8 ± 2.9 to $5.0° \pm 1.9°$, respectively. The mean correction angle among the CWHTO and OWHTO study subjects was $9.4° \pm 2.4°$ and $8.7° \pm 2.9°$, respectively (Table 2). No lateral hinge fracture was observed in OWHTO group. In contrast, external torsion was significantly altered in the CWHTO group from $23.9 \pm 7.8°$ to $18.2 \pm 7.0°$ but not significantly changed in the OWHTO group (Table 2). The ΔTTA from the pre-operative to postoperative period thus showed a significant difference between the CWHTO and OWHTO groups ($P < 0.001$).

Table 2
Comparison of pre-operative and postoperative alignments in the coronal and axial planes following CWHTO and OWHTO.

	CWHTO	OWHTO	P
Pre-operative mTFA (°)	−5.6 ± 3.5	−4.8 ± 2.9	0.554
Postoperative mTFA (°)	3.6 ± 2.8	5.0 ± 1.9	0.510
Pre-operative TTA (°)	23.9 ± 7.0.8	27.9 ± 6.9	0.146
Postoperative TTA (°)	18.2 ± 7.0	26.8 ± 7.7	0.003
ΔTTA (°)	−5.7 ± 2.6	−1.1 ± 3.3	<0.001

Positive and negative values indicate external and internal rotation of the distal fragment of the tibia, respectively.
CWHTO, closed wedge high tibial osteotomy; OWHTO, open wedge high tibial osteotomy; mTFA, mechanical tibiofemoral angle (negative value means varus); TTA, tibial torsion angle; ΔTTA, the torsional change at the tibia (postoperative TTA − pre-operative TTA).
Statistical significance was set at $P < 0.05$.

However, there was a significant correlation between the ΔTTA and the correction angle in both procedures (CWHTO: $r = −0.538$, $P = 0.038$; OWHTO: $r = −0.584, P = 0.022$) (Figure 5).
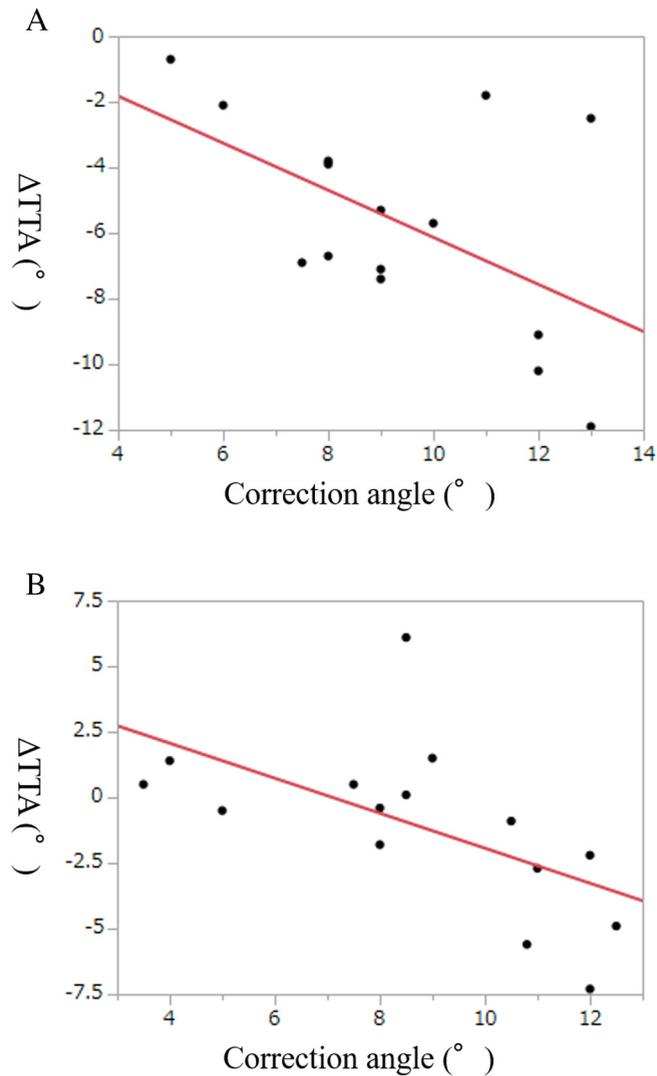

Figure 5. Correlation between the torsional change at the tibia and the correction angle. A significant correlation was found following both CWHTO (A) and OWHTO (B). ΔTTA, torsional change at the tibia.

4. Discussion

The most important finding of this study was that the distal fragment of the tibia was significantly internally rotated after CWHTO but there were no tibial torsional changes after OWHTO. Postoperative torsional changes are correlated to the extent of correction in the coronal plane. This study was the first to compare the tibial torsion outcomes of CWHTO and OWHTO.

Several previous studies have reported a torsional change at the tibia after OWHTO [6,8–10]. However, the cadaver study by Jacobi et al. reported only small changes at an opening angle of 10° of 1.2 ± 2° [6]. Although these findings were not significant, the total amount was comparable to the present findings. Kendoff et al. reported external rotation after OWHTO in another cadaver study [9]. Although the difference in this case was not significant, it contrasts with the findings of the present study and other previous reports. The surgical technique could explain this anomaly, as Kendoff et al. conducted a single plane OWHTO. Jang et al. reported internal rotation of 3.0 ± 7.1° using CT-based analysis [8]. These authors used the same method of measuring tibial torsion that was used in the present study but seem to have obtained different findings. Given that a correlation between the TTA differences and correction angle was also observed, the current results confirm these previous findings. The current study observed a TTA difference in the OWHTO group of −1.1 ± 3.3° but with a mean correction angle of 8.7 ± 2.4°, whereas Jang et al. had a mean correction angle of 11.8 ± 3.6° [8].

The distal fragment of the tibia rotated internally in all of the current CWHTO patients, and the TTA change of −5.7 ± 3.3° was significant. In OWHTO, the lateral hinge is generally preserved, whereas, the medial cortical hinge is cut completely in the hybrid CWHTO procedure. A flange is cut obliquely to the tibial axis (100° to the horizontal osteotomy) and the distal fragment is advanced proximally and anteriorly by the thickness of the flange after the osteotomy is completed in hybrid CWHTO [16]. This complete transverse cut may cause the distal fragment of the tibia to rotate internally. However, no previous study has examined the factors that affect torsional change variations after CWHTO. Lee et al. reported that the torsional change at the tibia after OWHTO is related to the hinge axis and gap ratio [10]. These factors can cause a wide range of torsional variance after OWHTO. Current analyses indicate that a correlation exists between the torsional change at the tibia and the correction angle. Further studies will be needed to elucidate predictors of torsional change in the CWHTO procedure and how to control them.

The effects of OWHTO on the patellofemoral joint have been reported in a number of prior studies [5,18–20]. Kim et al. reported that the International Cartilage Repair Society (ICRS) grading progressed, as assessed by second-look arthroscopy, on the patellar ridge and femoral trochlea in 21.9% and 41.2% of OWHTO patients, respectively, at a mean of two years after surgery [18]. Goshima et al. also reported a progression of cartilage degeneration in 45% of their OWHTO patients as assessed by ICRS grading via second-look arthroscopy, with a low incidence of anterior knee pain in their cohort at a mean follow-up of five years [5]. These authors suggested that altered patellofemoral congruency and contact stress can eventually lead to a progression in patellofemoral OA. One reported theory in this regard is that changes in the patella height after HTO will influence patellofemoral OA [5,21]. However, the impact of cartilage degeneration at the patellofemoral joint on long-term clinical outcomes remains unclear. It is therefore also uncertain if the observed internal rotation of the distal fragment in the current CWHTO group will have an effect on patellofemoral joint OA.

Gaasbeek et al. previously reported that HTO leads to significant changes in patellar tracking, and that these effects are more profound after OWHTO than CWHTO [4]. Furthermore, these authors found that CWHTO caused elevation and proximalization of the tibial tuberosity. The causes of anterior knee pain are multifactorial, and can include patellar maltracking and chondral or osteochondral damage [22]. However, analysis of the patella height after HTO is still controversial [23]. As a result of internal rotation found in this study and proximal elevation of the tibial tuberosity, a hybrid CWHTO procedure may provide greater benefit to the patellofemoral joint. Further studies will be needed to evaluate the arthroscopic and clinical outcomes of hybrid CWHTO on the patellofemoral joint, in direct comparison with the OWHTO approach.

The current study had some limitations of note. First, a cross-sectional analysis was undertaken without assessing clinical outcomes. Hence, the clinical significance of the observed torsional changes is not yet known and will require further study. Second, the sample size was relatively small. However, a normal distribution was found in all of the measurements for both procedures. Third, a randomized study could not be used to compare these surgical procedures because CWHTO was performed instead of OWHTO if the patient had patellofemoral OA. However, there were no significant pre-operative differences in demographic data between the two groups. Finally, the participants were not treated by the same surgeon. However, all of the cases were treated by highly experienced surgeons via identical CWHTO or OWHTO methods at a single institution.

5. Conclusions

The distal fragment of the tibia rotates internally to a significantly different extent after CWHTO than after OWHTO.

Source of funding

Conflict of interest

The authors declare that they have no conflict of interest.

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