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Midterm follow-up results of two different types of implants in opening wedge high tibia osteotomy

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ABSTRACT

Background: This retrospective study investigated the midterm results of medial opening wedge high tibia osteotomy, with a monoplanar or a biplanar osteotomy using two types of implant system.

Methods: Osteotomies were performed on 241 knees (231 patients). The mean follow-up period was 6.0 years (SD 3.0, range 0.2–12.8 years). Two types of implant system were used, a precountered non-locking plate (PP) (n = 74) and a precountered locking plate (LP) (n = 167). A Kaplan-Meier cumulative survival curve and a Cox regression model were used to analyse and revise survival and risk factors.

Results: Cumulative survival estimates for LP were 80% at 5 years, and 64% at 10 years (SE = 0.4, CI 95%: 9.0–10.5), and for PP, they were 68% at 5 years and 49% at 10 years (SE = 0.5, CI: 95% 6.3–8.2) (p = 0.024). The revision rate was 26% (44/167) for the LP group, and 47% (35/74) for the PP group (p = 0.001). Reoperations on LP osteotomies occurred for the tibial monoplanar cut and biplanar cut groups, in 19/52 (37%) and 25/167 (16%) osteotomies, respectively (p = 0.04). Our Cox regression model showed that PP had a higher risks (RR = 1.7; CI: 95% 1.1–2.6) of revision, when compared with LP (p = 0.026).

Conclusions: The risk of revision for any reason and that of early conversion to total knee arthroplasty (TKA) after high tibia osteotomy were significantly increased for PP, when compared with LP.

1. Introduction

A typical symptom of knee osteoarthritis (OA) is medial knee pain. Medial open-wedge high tibial osteotomy (MOWHTO) is an accepted treatment for active patients with symptomatic isolated medial compartment OA of the knee [1]. The goal of MOWHTO is to relieve medial compartment knee pain and slow arthritic progression. This is achieved by overcorrecting the limb mechanical axis, to unload the medial compartment of the knee and load a non-osteoarthritic lateral compartment [2].

MOWHTO is an effective procedure [1–3]. Patient selection for MOWHTO is crucial to achieving good results, however several variables can impact on these results. An ideal MOWHTO patient is moderately active, young (age < 60 years), with

Abbreviations: MOWHTO, medial open wedge high tibia osteotomy; LP, precountered locking plate; PP, precountered non-locking plate.

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isolated medial joint line tenderness and mild or moderate OA, body mass index (BMI) < 30, mal-alignment < 15°, metaphyseal varus (MBTA > 5°), full range of motion (ROM), without ligamentous instability and near-normal lateral and patellofemoral compartments [4–8]. The literature shows that a poorer prognosis is expected with severe articular destruction, advanced age, female gender, patellofemoral arthrosis, markedly decreased preoperative ROM, joint instability and lateral tibial thrust [7–12]. Therefore, good results are related to correct patient selection, surgical technique, rigid fixation and an effective post-operative rehabilitation protocol [13]. The impact of BMI on MOWHTO survivorship is also controversial; several studies have suggested that a BMI < 25 kg/m^2 is associated with poorer results, whilst others have suggested that being overweight (BMI $\geq$ 25.0) is associated with poor survivorship [5,10,14,15]. Filling the osteotomy gap with a bone autograft, allograft or bone substitute has been advocated for improved bone healing, but it is somewhat controversial as to whether the graft improves the results of MOWHTO and whether it is needed at all for osteotomy healing [8]. Different surgical techniques can be used to perform open wedge osteotomy, and a uniplanar or biplanar cut is often used. Some studies suggest that a biplanar bone cut may be beneficial for osteotomy healing [16,17].

In this study, two different plate types were compared with respect to variables known to affect MOWHTO results [4–8,18]. Plates were distinct in terms of material type, fixation to bone and rigidity. The first was a low-profile implant, non-locking four-hole precountered plate (PP) (Puddu, Arthrex, Naples, Florida, USA), with a spacer for the osteotomy gap. The second was a precountered locking compression plate (LP) (Tomofix, Synthes, Umkirch, Germany) (Figure 1). The PP is made from stainless steel and it is fixed with cortical screws, whereas the LP is made from titanium and is fixed with locking screws. The locking plate concept provides a rigid fixation, and earlier full-weight bearing, when compared with the spacer plate [18,19]. The aim of this retrospective comparative study was to evaluate midterm results in medial knee OA patients, treated by MOWHTO at a single centre using these implants.

2. Material and methods

2.1. Study information and patient population

A retrospective analysis was performed on all patients who had undergone MOWHTO for OA between January 2004 and December 2014. The inclusion criterion for this study was MOWHTO performed during the study period. Two MOWHTO implant systems were used and formed the basis of our study groups: a PP and a LP groups. The choice of a plate for operation was made according to the surgeon's preference; moreover, in the early study years, PP was the only available option. In the PP group, there were 74 knees (70 patients), and in the LP group there were 167 knees (157 patients). Associated procedures, such as partial meniscectomy or microfractures, were only performed for a few patients in both groups when rupture of the meniscus or moderate OA was found, so they were not studied due to low statistical and clinical values caused by the small sample sizes.

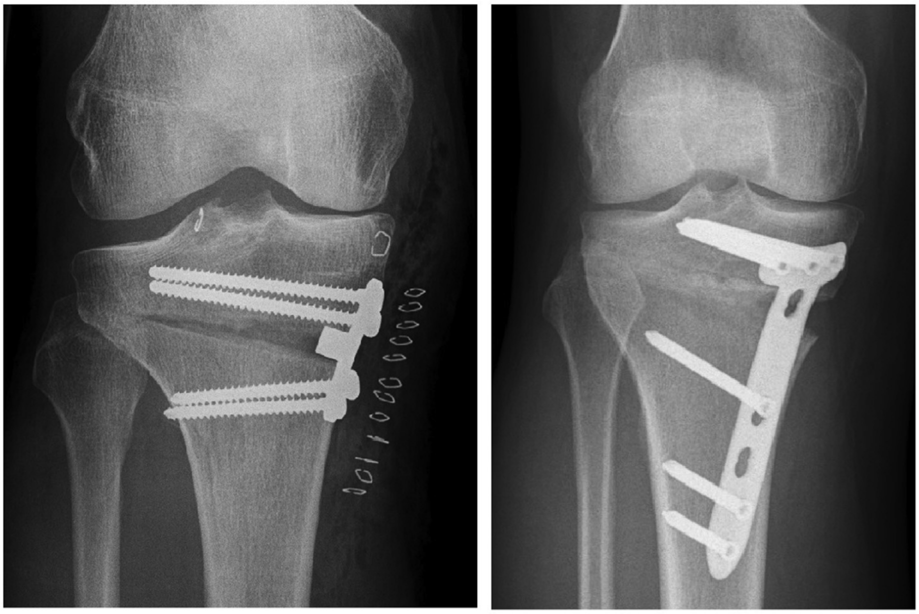

Figure 1. Radiographic pictures of the studied high tibia osteotomy plates. On the left is the low profile implant, non-locking 4-hole precountered plate (Puddu, Arthrex, Naples, Florida, USA), with a spacer for the osteotomy gap. On the right is the precountered locking compression plate (Tomofix, Synthes, Umkirch, Germany).

The mean follow-up time was 6.0 years (SD = 3.0, range 0.2–12.8 years). In the PP group, the mean follow-up time was 6.2 years (SD = 3.4, range 0.2–10.8 years), and in the LP group, it was 5.8 years (SD = 2.8, range 0.4–12.8 years) ($p = 0.08$), respectively. Follow-up times were time matched to six years due to similarity and therefore follow-up for the PP group ended in December 2014, and follow-up for the LP group ended in December 2018 or if revision surgery was performed for any reason.

Patient data were collected from hospital medical records, including demographics (gender, age, operation side and BMI) and surgical details (operation times, type of bone cut and use of bone graft or bone substitution). Intraoperative complications and adverse events leading to revision were evaluated. In this study, revision was defined as an extra operation such as implant removal, TKA, anterior cruciate ligament reconstruction or implant exchange. Revised patients were compared with non-revised patients with regard to demographic data and radiological measurements. The time from the first revision due to pain, or hardware causing discomfort due to later total knee arthroplasty (TKA) was evaluated.

2.2. Radiological analysis and indications for MOWHTO

Radiographic grading of the OA knee was performed according to the Kellgren-Lawrence (K-L) scale [20]. In this study, the indications and criteria for MOWHTO were medial knee pain, varus mechanical axis, OA K-L 1–3 for the medial compartment and/or mild to moderate cartilage defects in the medial OA compartment in perioperative or previous arthroscopy and K-L 0–1 OA for patellofemoral (PF) or lateral tibiofemoral joints on radiographs. Patients with significant OA changes in the lateral compartment and/or PF joint on radiographs or in perioperative arthroscopy were not suitable for MOWHTO.

Radiological assessments were made from anteroposterior and lateral full weight-bearing radiographs. The preoperative and postoperative (6 and/or 12 weeks) mechanical axes of the lower extremity (hip-knee-ankle angle = HKA) and medial proximal tibia angle (MPTA) were measured via long leg weight-bearing anteroposterior native radiographs. A normal HKA is 1.0–1.5° of varus angulation (180°, ±3°), and a normal MPTA is 87° (range 85–90°) [21,22]. The change in HKA from varus to valgus was evaluated, as well as the change in MPTA. The posterior proximal tibial angle (PPTA) and its change was measured pre- and postoperatively. A normal PPTA is 81° (range 77–84°) [21]. The size of the opening wedge was measured from the postoperative radiographs. Only patients with varus HKA were operated on with MOWHTO. The aim of the HKA correction was to change the varus to valgus angle.

2.3. Operation techniques

Seven experienced consultant orthopaedic surgeons performed operations; however, half the operations were performed by one orthopaedic surgeon alone or together with the others. All patients had epidural or spinal anaesthesia, but some had additional general anaesthesia. Preoperative intravenous antibiotic prophylaxis (single dose of cefuroxime 1.5 g or clindamycin 600 mg) was also used. The target of adjustment of the mechanical axis of the lower extremity was to pass through 62% of the tibial plateau from the proximal tibial edge, the so called 'Fujisawa point' [23]. An open wedge osteotomy was performed on all patients, approximately 3–4 cm medially below the joint line. The pes anserinus tendons were dorsally retracted, and the medial collateral ligament was released distally. Under fluoroscopy guidance, a guide wire was advanced obliquely, superiorly medially, aiming 1–2 cm distal to the lateral joint line. Osteotomy was performed using an oscillating saw, with the blade cooled by saline, while care was taken to avoid the lateral cortex. Osteotomy cuts were either monoplanar or biplanar according to the surgeon's preference (Table 1). Biplanar cutting was performed along the same horizontal cut line as monoplanar cutting but also included an anterior vertical cut line upwards, posterior to the tibial tuberositas and patella tendon, making MOWHTO rotationally more stable and producing a primary bone bridge between osteotomy surfaces. Both monoplanar and biplanar horizontal medial osteotomies were gradually opened with stacked chisels to preserve an intact bony bridge on the lateral side. Biplanar osteotomy was more common in the LP group during later the study period; by that time, it was shown that it increases primary stability when compared with the monoplanar osteotomy [24]. The osteotomy gap was filled in 121/241 (50%) knees (Table 1) with an iliac crest bone graft (autograft) or fresh-frozen corticocancellous structural grafts (allograft) and, in some cases, with bone substitutions (Actifuse™, Baxter Healthcare, Deerfiled IL, USA, or DBX Putty™, Synthes Inc., West Chester, PA, USA, or ChronOS™, Synthes, Umkirch, Germany). The indications for use of a bone graft or a substitute could not be studied retrospectively, as they were not usually mentioned in medical records. Limited-weight bearing for six to eight weeks was permitted for all PP patients and for LP patients a with monoplanar cut. Full-weight bearing was permitted for patients with biplanar osteotomy and LP. Full range of motion was allowed for all patients after MOWHTO. If lateral hinge fracture occurred, a non-weight bearing was ordered for six weeks.

2.4. Outcome measures

Primary outcome measures included the midterm survival of MOWHTO patients, where the end-point was any adverse event leading to revision and, initial or later conversion (after plate removal) to TKA. The secondary aim of this study was to determine the risk factors for revision. Radiological outcomes included pre- and postoperatively measured mechanical axis deviation, MPTA and posterior tibial slope and changes.

Table 1
Preoperative radiological osteoarthrosis classification of the knee and use of bone or bone substitution.

	Precountered locking plate (n = 167) n (%)	Precountered non-locking plate (n = 74) n (%)	*p*-value
Gender			0.01
Male	138 (83)	70 (68)	
Female	29 (17)	24 (32)	
Kellgren-Lawrence Classification			0.47
1	32 (19)	19 (26)	
2	107 (64)	42 (57)	
3	28 (17)	13 (18)	
Type of bone and substitution grafting			<0.001
None	120 (72)	0	
Autograft from iliac crest	10 (6)	30 (41)	
Actifuse bone substitute	29 (17)	26 (35)	
Chronos bone substitute	2 (1)	0	
DBX bone substitute	2 (1)	0	
Autograft from iliac crest and Actifuse bone substitute	2 (1)	0	
Autograft from iliac crest and DBX bone substitute	1 (1)	0	
Autograft from iliac crest and Chronos bone substitute	1 (1)	1 (1)	
Allograft bone	0	11 (15)	
Allograft bone and autograft bone	0	6 (8)	
	Mean (SD, range)	Mean (SD, range)	
Age (years)	48.2 (8.2, 16.0–60.5)	50.3 (8.0, 23.3–63.3)	0.05
Body Mass Index	29.7 (5.1, 21.4–44.2)	30.4 (5.4, 22.4–41.7)	0.39
Operation time (minutes)	66 (20.0, 33–133)	78 (20.2, 34–127)	0.01

2.5. Statistical methods

Kaplan-Meier and log-rank tests were used to study post-operative survival. Comparisons of continuous data were performed using Mann-Whitney U tests. For categorical data, a chi-square test was used. Independent-sample t-tests were used for parametric data comparisons. A large number of potentially relevant risk factors (e.g. age, gender, mechanical axis correction, implant type, grade of OA and surgeon volume) for revision after MOWHTO have been recognised [1,2,13]. BMI is a controversial factor as some studies report higher failure rates in lighter patients, while some others state the opposite [2]. In this study, Cox regression models were used for both univariate (single risk factors) and multivariate (combinations of risk factors) analyses to evaluate the most common risk factors for revision according to the literature [1,2,13]. These risk factors were age, BMI, pre-operative mechanical limb axis, type of plate, gender, type of osteotomy, use of bone grafts or bone substitutions, radiographic grading of OA and surgeon volume. The number of MOWHTOs performed per single surgeon were analysed by forming three groups based on the total number of operations performed during the study period. These groups were formed as i) Surgeon 1 (n = 124 MOWHTOs), ii) Surgeons 2–4 (n = 11–29 MOWHTOs and iii) Surgeons 5–7 (n = 1–5). A post hoc power analysis was performed (sample sizes of 74 and 167 observations per study group) and, assuming a moderate size effect (Cohen's h = 0.50) between the groups, gave a power of 0.94 and an alpha of 0.05. Therefore, our data had sufficient power to obtain statistically significant results. All p values $\leq$ 0.05 were considered statistically significant. All data were analysed using SPSS Statistics, Version 25 (IBM Corp; Armonk, NY).

2.6. Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The Ethical board of the hospital approved the study (72/13.02.00/172/2016). The Organisational Board of the hospital gave permission for the study (128/2016).

3. Results

The mean age of the included patients was 48.8 years (SD = 8.0, range 16.0–63.3 years). There were 188/241 (78%) males and 125/241 (52%) left knees. Monoplanar osteotomy was performed for 52/167 (31%) knees in the LP group, and for all 74 knees in the PP group (p = <0.001). Bone graft and bone substitution were used in 47/167 (28%) knees in the LP group, and for all 74 knees in the PP group (Table 1). Demographic data for both groups are given in more detail in Table 1.

Pre- and postoperative radiological analyses were performed on all knees (Tables 1 and 2). The varus mechanical axis changed to valgus in 104/167 (62%) knees in the LP group, and in 47/74 (63%) knees in the PP group (p = 0.08). The mean

Table 2
Radiological measurements.

	Precountered locking plate Mean (SD, range)	Precountered non-locking plate Mean (SD, range)	*p*-value
Mechanical axis (°)			
Preoperatively	5.8 (2.9, 1.0–14.2)	6.0 (3.0, 0.8–16.7)	0.20
Postoperatively	−2.9 (3.0, −11.3–5.5)	−1.2 (4.3, −10.0–13.0)	0.36
Change of axis angle	8.7 (3.3, 0.5–18.8)	7.4 (4.3, −3.0–18.1)	0.08
MPTA (°)			
Preoperatively	85.6 (2.2, 80.4–92.5)	86.7 (2.5, 78.5–92.1)	0.37
Postoperatively	92.2 (3.1, 79.8–100.6)	91.1 (4.2, 79.2–99.8)	0.55
Change of MPTA angle	6.5 (3.3, −5.3–17.4)	4.5 (4.0, −9.7–12.7)	0.40
Tibial slope (°)			
Preoperatively	8.9 (3.4, 0.0–19.0)	7.7 (4.6, 0.0–21.6)	0.26
Postoperatively	9.6 (4.5, −1.8–20.0)	11.5 (4.9, 2.1–30.5)	0.51
Change of slope angle	0.7 (4.5, −16.9–15.4)	3.9 (4.3, −5.7–16.0)	0.37
Osteotomy gap opening (mm)	10.7 (2.6, 5.0–17.0)	11.2 (2.0, 7.5–15.3)	0.001

Table 3
Radiological comparison of revised patients to non-revised patients in terms of plate type.

	Precountered locking plate (n = 167)			Precountered non-locking plate (n = 74)		
	No revision (n = 123) Mean (SD, range)	Revision (n = 44)	p-value Mean (SD, range)	No revision (n = 39)	Revision (n = 35)	p-value
Mechanical axis (°)						
Preoperatively	6 (3.0, 1.0–14.2)	6 (2.6, 2.0–12.6)	0.24	7 (3.3, 0.8–16.7)	5 (2.3, 1.6–10.8)	0.33
Postoperatively	−3 (3.0, −11.3–5.5)	−2 (2.9, −8.2–4.0)	0.29	−2 (4.4, −10.0–9.7)	−1 (4.4, −7.7–13.0)	0.36
Change of axis angle	9 (3.4, 3.6–18.8)	8 (3.0, 0.5–15.6)	0.49	9 (4.4, 0.9–18.1)	6 (4.0, −3.0–15.7)	0.37
MPTA (°)						
Preoperatively	86 (2.3, 80.6–92.5)	85 (2.0, 80.4–89.5)	0.15	87 (2.4, 81.6–91.1)	86 (2.4, 78.5–90.0)	0.71
Postoperatively	92 (3.1, 79.8–99.3)	92 (3.2, 86.5–100.6)	0.89	92 (34.0, 79.2–99.8)	89 (4.1, 80.4–97.9)	0.31
Change of MPTA angle	7 (3.4, −5.3–13.8)	7 (3.0, 2.0–17.4)	0.89	5 (4.4, −9.7–11.6)	4 (3.6, −4.4–12.7)	0.44
Tibia slope (°)						
Preoperatively	9 (3.3, 0.0–16.9)	9 (3.7, 1.4–19.0)	0.58	8 (5.3, 0.0–21.6)	7 (3.8, 0.0–15.8)	0.53
Postoperatively	9 (4.4, −1.8–18.8)	11 (4.7, 1.9–20.0)	0.54	12 (5.5, 2.1–30.6)	10 (3.8, 3.2–16.7)	0.56
Change of slope angle	3 (4.5, −16.9–11.6)	2 (4.5, −7.2–15.4)	0.70	4 (4.5, −5.7–16.0)	3 (4.0, −4.2–11.0)	0.22
Osteotomy gap opening (mm)	11 (2.6, 6.0–17.0)	11 (2.4, 5.0–15.0)	0.49	11 (2.0, 7.5–15.0)	11 (1.9, 7.5–15.3)	0.24

Table 4
Comparison of complication and revisions in the subgroup analysis in terms of plate type.

	Precountered locking plate (n = 167) n (%)	Precountered non-locking plate (n = 74) n (%)	*p*-value
Intraoperative complication			0.02
Yes	4 (2)	7 (9)	
No	163 (98)	67 (91)	
Type of complication			0.05
Nerve injury	1 (1)	1 (1)	
Lateral cortex fracture	3 (2)	6 (8)	
Revision			0.001
Yes	44 (26)	35 (47)	
No	123 (74)	39 (53)	
Reason for revision			0.02
Pain	22 (13)	14 (19)	
Progression of osteoarthrosis	17 (10)	18 (24)	
Non-union	2 (1)	2 (3)	
Instability	2 (1)	0	
Infection	1 (1)	1 (1)	
Type of revision			0.01
Implant removal	23 (14)	13 (18)	
Total knee arthroplasty	18 (11)	21(29)	
Anterior knee cruciate ligament reconstruction	2 (1)	0	
Implant exchange	1 (1)	1 (1)	

Table 5
Comparison of revised and non-revised patients in the subgroup analysis in terms of plate type.

	Precountered locking plate (n = 167)			Precountered non-locking plate (n = 74)		
	No revision (n = 123) n (%)	Revision (n = 44)	p-value n (%)	No revision (n = 39)	Revision (n = 35)	p-value
Gender			0.12			0.24
Male	105 (85)	33 (75)		24 (62)	26 (75)	
Female	18 (15)	11 (25)		15 (38)	9 (26)	
Osteotomy			0.04			–
Monoplanar	33 (27)	19 (43)		39 (100)	35 (100)	
Biplanar	90 (73)	25 (57)		0	0	
Bone / substition grafting			0.03			0.05
No	92 (75)	28 (64)		0	0	
Yes	31 (25)	16 (36)		39 (100)	35 (100)	
Autograft from iliac crest	7 (6)	3 (7)		13 (33)	17 (49)	
Actifuse bone substitute	22 (18)	7 (16)		14 (36)	12 (34)	
Chronos bone substitute	0	2 (5)		0	0	
DBX bone substitute	0	2 (5)		0	0	
Autograft from iliac crest and Actifuse bone substitute	1 (1)	1 (2)		0	0	
Autograft from iliac crest and DBX bone substitute	0	1 (2)		0	0	
Autograft from iliac crest and Chronos bone substitute	1 (1)	0		0	1 (3)	
Allograft bone	0	0		10 (26)	1 (3)	
Allograft bone and autograft bone	0	0		2 (5)	4 (11)	
	Mean (SD, range)		Mean (SD, range)			
Age (years)	49.0 (7.2, 25.8–60.5)	45.9 (9.5, 16.0–68.7)	0.06	48.9 (7.7, 23.3–59.4)	51.9 (8.2, 27.9–63.3)	0.10
Body Mass Index	28.8 (5.1, 22.0–44.2)	31.1 (4.8, 21.4–40.5)	0.10	31.9 (5.5, 23.5–41.7)	28.9 (5.0, 22.4–36.8)	0.12

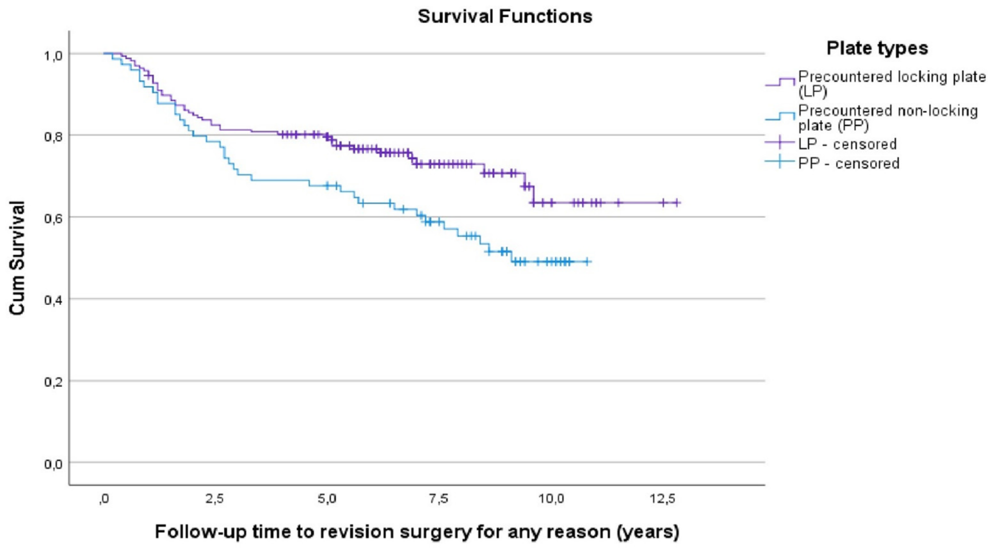

Figure 2. Kaplan-Meier survival analysis of time to revision surgery due to any adverse event. The estimates for the cumulative survival of the precountered non-locking plate were 68% at 5 years and 49% at 10 years (SE 0.5, CI95% 6.3–8.2) and for the precountered locking plate they were 80% at 5 years and 64% at 10 years (SE 0.4, CI95% 9.0–10.5). Log-rank test, $p = 0.02$.

postoperative MPTA was < 85° in 13/74 (18%) and > 90° in 20/74 (27%) knees in the PP group; in the LP group, it was < 85° in 28/167 (18%) and > 90° in 23/167 (14%) knees (p = n.s.). Radiological subgroup comparisons were performed for revised and non-revised patients, but no statistically significant differences were observed (Table 3).

A total of 11/241 (4.6%) intraoperative complications were recorded and there were statistically significantly more complications in the PP group (9%), compared with the LP group (2%) (p = 0.02) (Table 4). In total, 79/242 (33%) revision surgeries were performed, with a revision rate of 26% (44/167) in the LP group, and 47% (35/74) in the PP group (p = < 0.01) (Table 4). The mean time to revision surgery for any reason was 3.4 years (SD = 3.1; range 0.2–13.7 years). The mean time to revision surgery for any reason was 3.5 years (SD = 2.7, range 0.2–9.1 years) in the PP group and 2.7 years (SD = 2.4, range 0.4–9.6 years) in the LP group (p = 0.12). In the LP group 9 patients and in the PP group 3 patients had implant removal prior to TKA. Time from the implant removal operation to TKA was 1.9 (SD 1.4, range 0.1 – 4.0) years in the LP group and 2.2 (SD 1.5, range 1.0 – 4.0) years in the PP group (p = 0.70). Subgroup analyses of demographic data and radiological measure-

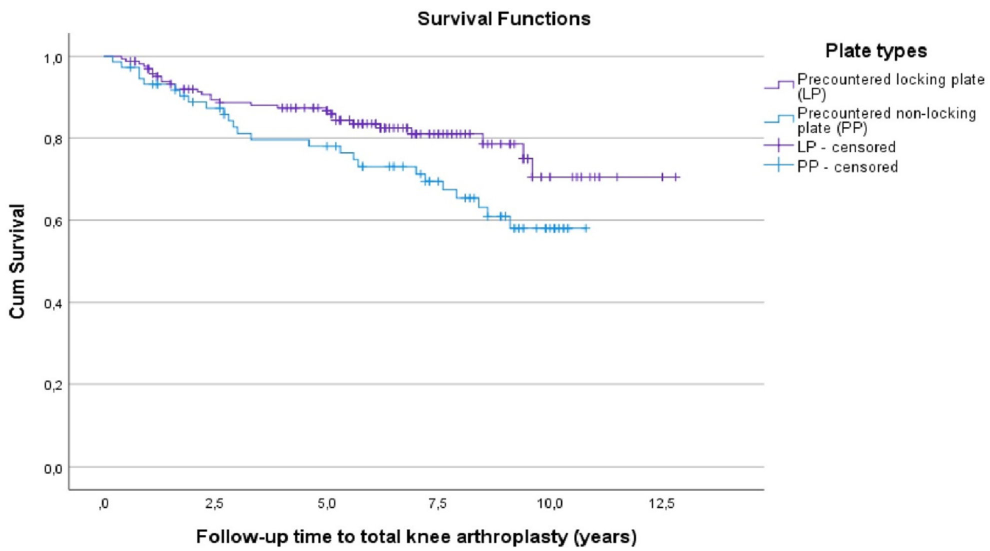

Figure 3. The conversion to total knee arthroplasty after high tibia osteotomy was set as endpoint. The estimates for the cumulative survival consider with no need for total knee arthroplasty after high tibia osteotomy in the precountered non-locking plate were 78% at 5 years and 58% at 10 years (SE 0.4, CI95% 7.3–9.1) and in the precountered locking plate they were 87% at 5 years and 71% at 10 years (SE 0.4, CI95% 9.9–11.3). Log-rank test, $p = 0.05$.

Table 6
The Cox regression univariate (single risk factors) and multivariate (combinations of risk factors) model in terms of risk factors for revision.

	Univariate				Multivariate			
	HR	95%CI		*p* - value	HR	95%CI		*p* - value
Age	0.99	0.97	1.02	0.69	0.99	0.96	1.02	0.43
Body mass index*	0.99	0.93	1.05	0.66				
Preoperative mechanical axis	0.99	0.91	1.06	0.70	0.96	0.88	1.04	0.32
Type of plate								
Precountered locking plate	1				1			
Precountered non-locking plate	1.66	1.06	2.6	0.03	1.11	0.60	2.08	0.73
Gender								
Male	1				1			
Female	1.15	0.69	1.91	0.60	0.79	0.45	1.38	0.40
Type of osteotomy								
Monoplanar	1				1			
Biplanar	0.62	0.38	1.01	0.06	0.19	0.05	0.70	0.01
Type of bone and substitution grafting								
None	1				1			
Autograft from iliac crest	1.80	1.01	3.23	0.05	0.30	0.08	1.19	0.09
Actifuse bone substitute	1.11	0.61	2.02	0.74	0.21	0.05	0.83	0.03
Others	1.53	0.77	3.06	0.23	0.33	0.08	1.42	0.14
Radiographic grade of osteoarthrosis [20]								
Grade 1	1				1			
Grade 2	0.80	0.47	1.39	0.43	0.92	0.51	1.66	0.78
Grade 3	0.95	0.48	1.88	0.87	1.25	0.58	2.68	0.56
Orthopaedic surgeon								
Surgeon 1	1				1			
Other Surgerons 2–7	1.92	1.21	3,03	0.01	2.1	1.26	3.52	<0.01
The total number of performed MOWHTOs per surgeon								
i) Surgeon 1 (n = 124)	1				1			
ii) Surgeons 2–4 (n = 11–29)	1.66	0.99	2,78	0.06	1.85	1.04	3.27	0.04
iii) Surgeons 5–7 (n = 1–5)	2.36	1.35	4.15	<0.01	2.52	1.36	4.69	<0.01

* Only univariate analysis was done for BMI due to larger number of missing values.

ments were performed in revised and non-revised patients for both PP and LP groups (Tables 3 and 5). In the LP group, we observed significantly more revisions in the monoplanar osteotomy group when compared with the biplanar osteotomy group (p = 0.03) (Table 4). However, in a subgroup analysis where monoplanar osteotomies of the PP group (n = 74) were compared with those in the LP group (n = 52), there was no statistically significant difference in comparison of revisions (p = n.s.) or in cumulative survival in between the two groups (p = n.s.). In the LP group, there were significantly more revisions when bone transfer or a substitute were used (Table 5). In the PP group, there were significantly more revisions when autograft was used (Table 5).

Cumulative survival estimates with no need for revision were, for LP patients, 80% at 5 years and 64% at 10 years (SE = 0.4, CI: 95% 9.0–10.5); for PP patients, these estimates were 68% at 5 years and 49% at 10 years (SE = 0.5, CI: 95% 6.3–8.2) (p = 0.02) (Figure 2). In the LP group, 30/167 (18%) patients had TKA during follow-up, and in the PP group, this figure was 25/77 (34%) (p = < 0.01). Furthermore, 12/36 (33%) patients who had implants removed due to pain, had TKA during later follow-up. The mean time to TKA after MOWHTO was 6.4 years (SD = 3.3, range 0.2–10.8 years) in the PP group and 6.0 years (SD = 2.7, range 0.4–12.8 years) (p = 0.29) in the LP group. The mean time to TKA after implant removal was 1.9 years (SD = 1.4; range 0.1–4.0 years) in the LP group and 2.2 years (SD = 1.5, range 1.3–4.0 years) (p = n.s.) in the PP group. In the LP group, cumulative survival estimates with no requirement for a TKA after MOWHTO were 87% in the LP group at 5 years and 71% at 10 years (SE = 0.4, CI: 95% 9.9–11.3 years); in the PP group, these were 78% at 5 years and 58% at 10 years (SE = 0.4, CI: 95% 7.3–9.1 years) (p = 0.05) in the PP group (Figure 3).

The univariate and multivariate Cox regression models showed that age, BMI, preoperative mechanical axis, gender and radiographic grade of OA were not risk factors for revision (p = n.s.) (Table 6). The Cox regression models showed that the PP, osteotomy type (monoplanar) and use of autograft bone were risk factors for revision (Table 6). The multivariate Cox regression showed that use of Actifuse and surgeon volume lowered the risk of revision (Table 6). The estimates for the cumulative survival without revision surgery due to any reason were 81% at 5 years and 71% at 10 years (SE 0.4, CI95% 9.1–10.8), and for the other surgeons, they were 70% at 5 years and 47% at 10 years (SE 0.5, CI95% 7.4–9.2), according to the Log-rank test, p = 0.04.

4. Discussion

This study investigated the factors affecting the survival rate of osteotomy plates, and found that the risk of revision was at an acceptable level. Cumulative survival estimates for the LP group were 80% at 5 years and 64% at 10 years, and for the PP group, they were 68% at 5 years and 49% at 10 years. From the literature, there is considerable variation in reported midterm survival rates of MOWHTOs, ranging from 51% to 96% [10,25–27]. In a recent meta-analysis, the pooled 5-year survival for MOWHTO was as high as 95%, and the 10-year survival was 92% [28]. This wide range of variation in survival rates reflects the heterogeneous nature of MOWHTO patient populations, techniques and implants. In this study, the cumulative survival in the PP group was lower than that in the LP group. One reason may have been patient selection for MOWHTO by the time PP was in use; the high number of females in the PP group is a well-known risk factor for early revision after MOWHTO as recent studies have shown [15,27].

According to the literature, the revision rate following adverse events varies between 28% and 55%; this was in close agreement with our data, where the revision rate was 26% for LP and 47% for PP [1,29,30]. In this study, surgical procedures differed not only with plates but also with the osteotomy technique (uniplanar osteotomy with a spacer plate or biplanar osteotomy with a locking plate) and bone grafting or substitution. In addition, there were few concurrent cartilage procedures during MOWHTOs in this study, but they were not studied because, in a recent meta-analysis, these procedures showed little beneficial effect on clinical and radiological outcomes [31]. Bone-implant construction stability determines rehabilitation protocols and post-operative weight-bearing limitations, which makes it difficult to compare different implant types [32,33]. This study showed that the LP group had more revisions for monoplanar osteotomy cases. A possible reason was that biplanar osteotomy increases primary stability when compared with the monoplanar approach, leading to improved bone union [24]. Another reason for the poorer PP survival may have been that locking implants increased stability, when compared with non-locking implants [34]. Our postoperative weight-bearing protocol was different after PP operations, when compared with LP operations; PP patients were allowed light weight-bearing in the first six to eight weeks postoperatively, but most LP patients were allowed immediate postoperative full-weight bearing. Different rehabilitation protocols were implemented due to the fact that LP was more rigid than PP, permitting earlier full-weight bearing [18,19,35]. It was possible that differences in post-operative rehabilitation may have explained our poor PP results, but unfortunately the data were not available. This study showed that only one of nine patients with intraoperative lateral hinge fracture needed later conversion to TKA. Song et al. showed similar findings in their recent study, where a lateral hinge fracture did not raise the risk of malunion or loss of correction when noticed and treated properly [36].

The use of auto- and allograft bone for osteotomy gaps is controversial [37]. Autografts avoid potential exposure to communicable diseases and are comprised of osteoinductive and osteoconductive material to facilitate healing. However, autografts involve a second surgical exposure, increased pain, increased blood loss, and longer surgical times [12,37]. However, autograft results are superior, with fewer complications in comparison with allografts and bone substitutes such as calcium-phosphate ceramic spacers [12,37,38]. In this study, more revisions were performed in the PP group when autografts were used, and fewer when allograft was used, but the reasons for these findings are unclear. One reason could be that PP and crista autograft combinations were not rigid enough, suggesting that PP required more rigid gap filling from a larger volume of allograft bone. In the LP group, our data mostly agreed with Slevin et al. who found that more revision surgeries were needed if bone substitutes were used [38]. Additionally, Slevin et al. suggested that synthetic bone substitutes in MOWHTO could not be recommended [39]. Brosset et al. observed that bone union decelerated when a gap was filled with a some substitute [37]. Their study showed that fixation with a locking plate, without gap filling and early weight-bearing, provided stable MOWHTO [37]. The current study results were similar, as it was shown that there were more adverse events in the PP group, where most patients had a bone graft or substitution. The same trend was also observed in the LP group, where more adverse events occurred with substitutions, when compared with those with no bone transfer or substitute. In the LP group, patients operated on at an earlier follow-up, had more bone substitutions than patients operated on at a later follow-up. This observation may explain the higher LP group survival, as there were more patients who did not receive any gap filling in this group.

The aim of MOWHTO is to achieve a postoperatively normal MPTA and tibial slope and a slightly valgus axis [15,34]. There is a consensus that the mechanical axis in the varus mal-aligned OA knee should be shifted from the varus into a 3°–5° slightly valgus axis, to decrease medial joint space pressure [40,41]. However, in patients with mild medial joint OA, an overcorrection into valgus might not be necessary, whereas patients with advanced medial OA could benefit from a more extensive axis correction into a valgus alignment [41]. In this study, the mechanical axis changed less toward the valgus than previously suggested. In almost a in third of the MOHWTOs, HKA was undercorrected, and this might explain the somewhat inferior results of this study compared with previous studies [25–30]. In the literature, the anatomical mean MPTA is 87.0° ± 3° [42]. In a recent study, the mean anatomical MPTA was 86.0° preoperatively, and 92.0° postoperatively [43]. In this study, the mean anatomical and postoperative MPTA was similar to those in the literature, even though the range of MPTA was wide, and there were many of under- and overcorrections. The tibial plateau is anatomically tilted approximately 10° caudally in relation to the horizontal line in the sagittal plane, and is known as the tibial slope [42]. In this study, the mean anatomical tibial slope angles agreed with the literature, and changes in the tibial slope after MOWHTO were not statistically significant. If the osteotomy gap is > 13 mm, autogenous bone grafts are recommended in order to reduce the risk of non-union [13]. In the current study, the mean osteotomy gap was < 13 mm in both plate groups, as well as in revised and non-revised knees; however, gap filling was used in all PP knees and in 28% of LP knees. The data in this study showed no statistically significant differences in radiological measurements in between group or subgroup comparisons. Based on our radiological findings, our MOWHTO corrections were generally acceptable. Some patients had under- or over-corrections of the mechanical axis, MTPA or tibial slope, which led to adverse events, but in group comparisons, these single findings were not statistically significant. We found that surgeon volume, which refer to surgeon's exprerince, affected the MWOHTO results. Similar results have been found previously when van Wulfften et al. showed in their HTO study that the surgeon and surgical technique were identified as independent predictors of failure [44]. In this study, half of the operations were performed by an experienced surgeon alone or together with another surgeon. Most of the MOWHTOs were performed by other surgeons in the first few years of the study period, whereas towards the end of the study period, MOWHTOs were focused more and more on this one surgeon. This might have affected to the study results, as we found that this one surgeons' patient survival rate was statistically significantly better than that of the other surgeons.

The study strength lies in its detailed demographic and radiologic analysis of MOWHTO patients. To our knowledge, there are not many studies as detailed as ours where patients have been followed for several years after implant removal to determine if they had TKA. However, this retrospective study design had some inherent limitations, which could have been minimised by a prospective study design. The typical retrospective study flaws also limited our study; for example, there might have been selection bias in patient selection by surgeons at the study period. Moreover, researchers were not able to see the patients and had to rely on patients' medical records. In addition, no clinical evaluation could be performed, and there were no patient-reported outcome measurements available. For these reasons, the only endpoint was revision surgery. We attempted to reduce the retrospective study design bias by including all consecutively operated patients during the study period and by selecting several types of accurate data (e.g. patients' demographic data, radiological measurements, post-op rehabilitation, type of implant and bone substitution) to evaluate the differences between the studied groups. The indication for osteotomy filling is usually a gap of > 10 mm; however, in this study, it was not possible to study the indications for use of a bone graft or a substitute retrospectively, as it was not usually mentioned in medical records [13].

Nowdays, in general and also in our clinic, it is a more common technique to use a locking plate concept, which provides more rigid fixation and earlier full-weight bearing when compared with non-locking plates [18,19,45]. The main reason for this change to the use of locking plates instead of non-locking plates is their better overall survival [18,19,45]. Therefore, PP was gradually abandoned and LP preferred more, while at the same time the indications for MOWHTO were also tightened.

5. Conclusions

PP had a statistically significantly higher risk for revision surgery and early conversion to TKA after MOWHTO, when compared with LP. The use of autograft bone was also a risk factor for revision. Accordingly, for MOWHTO, for a biplanar bone cut, we advocate LP for fixation and no bone grafting of the osteotomy gap.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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