Symptomatic relief in medial opening wedge high tibial osteotomies for the treatment of knee osteoarthritis is influenced by concurrent procedures and preoperative pain level

Francisco Figueroa,1,2,3 Vikram Mhaskar,2 Corey Scholes,2 Alice Pearlman,2 Myles Coolican,2 David Parker,2 Brett Fritsch2

ABSTRACT

Objectives Medial compartment osteoarthritis (OA) in the younger patient is technically challenging to treat. Medial opening wedge high tibial osteotomy (MOWHTO) is an option for surgical treatment; however, there remains a lack of evidence to establish the procedure as the preferred treatment option. The literature remains inconsistent with regard to patient characteristics and surgical factors that determine patient outcomes, particularly with respect to procedure survival and pain relief. The purpose of this study is to (i) describe the patient demographics and surgical outcomes of a consecutive series of MOWHTOs for treatment of medial knee OA; (ii) determine the procedure survivorship up to 10 years postsurgery and (iii) identify patient and surgery-related factors associated with pain relief following MOWHTO.

Methods A cohort of 210 patients was identified that underwent MOWHTO between 2002 and 2013. Patient demographics and complications were extracted from the clinical research database. Procedure survival analysis was conducted using a Kaplan-Meier analysis. All patients completed the Knee Injury and Osteoarthritis Outcome Score (KOOS) questionnaire preoperatively and postoperatively with pain relief identified as the difference between pre- and postoperative KOOS-pain subscale. A partial least square regression model was fitted to identify predictors of pain relief.

Results Males comprised 84% of the cohort, which had a median age of 51 years (95% CI 42 to 57 years). Patients were overweight on average, with a median BMI of 28.9 kg/m2 (95% CI 23 to 36 kg/m2) and 36% of patients underwent concomitant procedures. A complication rate of 3.8% was observed. Survivorship was 97.7% at 5 years and 80% at 10 years, with median time to conversion in those requiring total knee replacement of 7 years (95% CI 5 to 8). Patients undergoing cartilage treatment and bilateral procedures experienced increased pain relief compared with average, while there was reduced pain relief in patients with lower preoperative pain.

Conclusion MOWHTO is an effective procedure for relief of pain associated with medial knee OA, even in older and heavier patients. Patients and clinicians can expect an average procedure survival of 12.5 years and a maximum of 21 years, with effective pain relief influence by cartilage treatment and preoperative pain score.

Level of evidence IV. Case series.

What are the new findings

- Patients undergoing medial opening wedge high tibial osteotomy should expect a low risk of serious complications, independent of age or body mass index.
- Patients with lower preoperative pain demonstrated reduced pain relief compared with patients with higher preoperative pain.
- Patients undergoing cartilage treatment and patients receiving bilateral osteotomies reported improved pain relief compared with the rest of the patients not having additional procedures.

INTRODUCTION

Knee osteoarthritis (OA) is one of the most prevalent joint diseases and preserving the native structures is a priority in its surgical treatment, especially in younger patients in whom the disease is restricted to the medial compartment of the knee.1 Despite the limited treatment options available for patients in this category, medial opening wedge high tibial osteotomy (MOWHTO) has demonstrated efficacy in treating the clinical symptoms of medial knee OA.2 However, the potential of MOWHTO to be considered a viable first-line surgical treatment that consistently delays the need for total knee replacement (TKR) has yet to be realised. Despite its demonstrated versatility as a procedure that can be paired with cartilage repair, ligament reconstruction or meniscal salvage to restore function in the osteoarthritic knee, there remains substantial gaps in the knowledge required to maximise patient function and procedure survival.

Patient selection is a key factor in maximising procedure success and patient outcomes after MOWHTO; however, previous findings are inconsistent with regard to the effect of patient characteristics such as age, gender and body mass index (BMI). These issues need to be addressed to establish a baseline comparison for future work to guide patient selection. Although Harris et al1 documented survival at a minimum of 90.9% at 5 years, variations in patient selection and follow-up, as well as evolution of the surgical techniques, may explain the variable procedure survival reported beyond 5 years. In addition, the definition of failure has been variably reported and few studies have
reported large series of MOWHTO only, with many studies reporting combined survival of opening and closing wedge techniques.2–5

The primary reason for performing a MOWHTO on a patient with medial knee OA is to relieve pain. Pain is a major symptom of knee OA and may be closely related to procedure survival; however, the efficacy of MOWHTO to achieve satisfactory pain relief has been poorly documented and while procedure survival has been defined using threshold values of pain scores, the factors associated with pain relief are yet to be elucidated. Identifying factors that may predict the magnitude of pain relief in individual patients could aid in improved patient selection in the future.

The clinical success of MOWHTO in the surgical treatment of knee OA is well established3; however, its potential to be considered a viable treatment to delay TKR in appropriate patients remains unrealised. To address the limitations in the current knowledge, the aims of this study were threefold; (i) to describe the characteristics and surgical outcomes of patients that present to a private orthopaedic clinic for medial knee OA and undergo MOWHTO, (ii) to describe the procedure survival up to 10 years after surgery and (iii) to describe the self-reported pain relief following MOWHTO and identify preoperative, surgical or postoperative predictors of pain relief associated with this procedure.

**METHODS AND MATERIALS**

A series of MOWHTOs was extracted from a clinical research database (Socrates, V.3.5, Ortholink, Sydney, Australia). Clinical and operative notes were reviewed and data extracted for further analysis.

**Inclusion criteria**

1. Patients with symptomatic medial compartment OA on X-ray that underwent medial opening wedge high tibial osteotomy with internal fixation and a bone graft.
2. Operated by one of the three surgeons (DR, MC, BF) at our centre between December 2002 and November 2013.
3. Patients who underwent any concomitant procedures such as ligament reconstruction (anterior cruciate ligament (ACL), posterior cruciate ligament (PCL)), meniscus surgery (meniscectomies) or cartilage surgery (microfracture, chondroplasty, Matrix-Induced Autologous Chondrocyte Implantation (MACI)) were included.

**Exclusion criteria**

1. Osteotomies around the knee other than medial opening wedge osteotomies, for example, closing wedge osteotomies, distal femoral osteotomies, tibial tubercle osteotomies or fibular osteotomies.
2. Patients operated in the public hospital.
3. Patients who underwent multi-ligament reconstruction along with a high tibial osteotomy.
4. Patients who received external fixation of the osteotomy.

**Surgical technique**

Medial opening wedge high tibial osteotomies were performed under tourniquet control, as previously described,7 at two private hospitals. A combination of flexible osteotomes and laminar spreaders were used to enlarge the osteotomy for the required correction. Femoral head allograft, iliac crest allograft or bone substitute was used to fill in the gap and the osteotomy was internally fixed with a plate and screws. Prior to 2009, X-rays and alignment rods were used to monitor correction. The line of weight bearing was shifted to the Fujisawa’s point8 in these cases. In the remaining cases, alignment was verified intraoperatively using imageless navigation (OrthoMap Precision Navigation Software (Stryker, Mahwah, New Jersey, USA) and ORTHOsoft Zimmer Computer Assisted Solutions (Zimmer Biomet, Warsaw, Indiana, USA)) in 61% of cases. The osteotomy gap was filled with femoral head allograft alone in the majority (89.5%) of cases, with the remainder comprising allograft and bone substitutes (0.95%), autograft (4.8%) or bone substitute alone (2.4%). The median plate tooth size (in plates with tooth) was 11.25 mm (95%CI 11 to 12.5 mm), with the majority of osteotomies internally fixed with VS Osteotomy (Zimmer Biomet) (46.2%) or Puddu plates (Arthrex, Naples, Florida, USA) (30%), with the remainder (23.8%) comprising ContourLock HTO Plate (Arthrex) Tomofix (Depuy Synthes, West Chester, Pennsylvania, USA), ELIX (Biotec, Wiesbaden, Germany) iBalance (Arthrex) and Targon (Aesculap, Tuttingen, Germany). Concurrent surgeries were performed with the HTO to reconstruct the ACL (5.7%), as well as treat cartilage lesions using chondroplasty (9.5%), microfracture (22.5%) or MACI (11%) or partial meniscectomy (17.7%). The indication to make a chondral resurfacing technique was related to the presence of focal lesions. Lesions smaller than 2 cm² were treated with microfracture and larger lesions were treated using MACI.

**Concurrent arthroscopy**

A diagnostic arthroscopy was performed in 68% of the patients based on MRI results and the presence of treatable lesions (unstable menisci lesions, unstable chondral flaps) and the cartilage was graded according to the International Cartilage Repair Society (ICRS) classification. This was reviewed either at the time of surgery via arthroscopy or retrospectively by one of the authors using the video recordings from surgery.

**Postoperative rehabilitation**

Patients were kept non-weight bearing for 6 weeks with a knee brace and crutches then gradually allowed to increase the amount of weight passing through the operated limb from 6 to 12 weeks. Full weight bearing commenced at 12 weeks. Quadriceps strengthening exercises, range of motion exercises and gait training were begun on post-operative day 1. During their hospital stay, patients were strictly supervised by the physiotherapist, this was continued on a daily basis for 2 weeks once discharged, then twice a week for the next month. The patients were discharged 3 days postoperatively.

**Complications and failure**

Complications were identified through review of patients’ clinical notes. Included were those that required medical or surgical intervention or review, such as treatment for an infection, a deep vein thrombosis (DVT) or pulmonary embolism (PE). Re-intervention due to patient discomfort or non-union was determined by both clinical notes and serial X-rays at 6 and 12 weeks. Failures were identified by detailed review of the clinical database and clinical notes, with failure defined as a conversion to a TKR. The Australian National Joint Replacement Registry was queried to account for conversions in any cases lost to follow-up.

**Patient-reported outcome measures**

A KOOS questionnaire was used to measure patient-related outcomes for pain, symptoms, activities of daily living, sports and quality of life components. These scores were collected...
preoperatively and a minimum of 1 year postoperatively. Cohort results were compared with aged-matched scores for each KOOS subscale.9 Pain relief was defined as the difference between the preoperative and postoperative score from the KOOS-pain subscale. A positive value in these scores indicated pain relief following MOWHTO.

### Table 1

<table>
<thead>
<tr>
<th>Main effects</th>
<th>Interactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1, 2, 3) Bilateral</td>
<td>(2, 3) Age*Bilateral</td>
</tr>
<tr>
<td>(1, 2, 3) Gender</td>
<td>(2, 3) Age*Gender</td>
</tr>
<tr>
<td>(1, 2, 3) Age at surgery (years)</td>
<td>(2, 3) Age*Ligament reconstruction</td>
</tr>
<tr>
<td>(2, 3) BMI at surgery (kg/m²)</td>
<td>(2, 3) Age*Cartilage</td>
</tr>
<tr>
<td>(2, 3) KOOS Pre</td>
<td>(2, 3) BMI*Gender</td>
</tr>
<tr>
<td>(1, 2, 3) MFC ICRS Grade</td>
<td>(2, 3) KOOS Pre*Bilateral</td>
</tr>
<tr>
<td>(1, 2, 3) Ever smoked</td>
<td>(2, 3) KOOS Pre*Gender</td>
</tr>
<tr>
<td>(1, 2, 3) Ligament reconstruction</td>
<td>(2, 3) KOOS Pre*Cartilage treatment</td>
</tr>
<tr>
<td>(1, 2, 3) Cartilage treatment</td>
<td>(2, 3) KOOS FU*Bilateral</td>
</tr>
<tr>
<td>(2, 3) KOOS follow-up (years)</td>
<td>(2, 3) KOOS FU*Gender</td>
</tr>
<tr>
<td>(3) Preop alignment</td>
<td>(3) Preop alignment *gender</td>
</tr>
</tbody>
</table>

**Data and statistical analysis**

Patient demographics, intraoperative data, patient-reported outcomes were collated in SOCRATES (Ortholink) and exported in ASCII format for further analysis in Minitab (V.17, Minitab, USA). Mann-Whitney t-tests were used to determine significant differences between preoperative and postoperative KOOS scores for each subscale. Probability of survival was estimated as a function of time using the Kaplan-Meier survival method with 95% CIs. Conversions to TKR were deemed failures and the remaining patients were censored. A normal distribution with least squares estimates was fitted to the survival data and a curve with 95% CIs used to extrapolate the complete survival period of the sample. A multivariate cox proportional hazards model (model 1) of risk factors for conversion to TKR conversion was performed. All categorical variables were converted into dummy variables. Survival times were converted to years and incorporated into the model with censorship status (converted, censored). The HR, 95% CI and P value for each variable in the model were calculated.

Partial least squares regression with up to 10 components was performed to associate patient demographics, arthritis severity and surgical options with change in KOOS-pain (pain relief) between preoperative and postoperative measurements. Due to missing data in some patients, two other models...
(models 2 and 3) were constructed for this case using a partial least squares regression model (table 1), with model 3 including preoperative alignment measures. Previous studies have investigated the relationship between these factors and procedure survival, but not pain relief. In the case of alignment, the reason to include only preoperative alignment in the analysis was mainly due to the fact that postoperative alignment is not a useful predictive measure, as it is not a fixed value and it will change during follow-up due to progression of the osteoarthritic disease. The efficacy of the models was assessed by comparing the predicted values to actual values and examining the model SE and predicted R². Individual predictor variables were assessed for influence with the dependent variable by the magnitude of the standardised coefficient.

RESULTS
Patient demographics
A total of 210 medial open wedge high tibial osteotomies (MOWHTO) that fulfilled the inclusion and exclusion criteria (figure 1) were performed over a period of 11 years between 2002 and 2013. Eighty-one per cent of the patients received unilateral surgery and 19% received bilateral surgery, all of them staged at a mean 2.2 years (range 0.5–5.2) since the index procedure. The patient population was predominantly male (84%) with a median age of 51 years (95% CI 42 to 57 years) and overweight on average, with a median BMI of 28.9 kg/m² (95% CI 23 to 36 kg/m²). A total of 17% of the sample were of normal weight, 40% were overweight, 37% mildly obese and 4.6% moderately obese. In addition, 14.8% of patients indicated that they had smoked regularly at some point in their lives and 5.4% were treated through workers compensation.

Intraoperative results
On arthroscopy 75% of patients displayed grade 4 changes in the medial femoral condyle and 61% in the medial tibial plateau, while the lateral compartment was predominantly normal (61% normal femoral lateral condyle) (figure 2). Sixty per cent of patients displayed grade 2 changes in the patella and 31% in the trochlea, with a small number of patients with grade 4 lesions on their patella (1%) or trochlea (5%) (figure 2); however, these were small and isolated.

KOOS score
The patients were administered the KOOS at a median of 47 days preoperatively (95% CI 36 to 60 days). The median follow-up period for the KOOS questionnaire postoperatively was 2.1 years (95% CI 2 to 2.3 years). Preoperatively the KOOS score was higher for symptoms, pain and daily living components and lower for sports and quality of life (figure 3). At the latest postoperative follow-up, significant (P<0.01) improvements were observed for all components of the KOOS scoring system; however, none returned to age-matched normative scores (figure 3).

Alignment
All patients presented with varus deformity preoperatively (navigated cases—median 5°; 95% CI 4.5 to 6). Navigated cases were corrected into valgus at the conclusion of the procedure (2.5°; 95% CI 2 to 2.5). Full-length standing radiographs were available for 103 patients postoperatively at a median follow-up of 195 days (95% CI 184 to 223) with a median valgus alignment of 3.6° (95% CI 3.3 to 4.4).

Complications
Complications requiring medical or surgical intervention were identified in eight patients (3.9%). One patient had a reported superficial infection within the first week due to infection of the sutures, these were subsequently removed and no additional events were reported. There were no reported deep hardware infections and no reports of hardware failures. Three patients had delayed union. These patients had serial radiographs taken to monitor bone formation. Three patients developed a DVT, which was managed by anticoagulation and progressed to pulmonary embolism in two patients after 6 weeks. These patients were both admitted to the emergency department or via the surgeon at...
the primary treating hospital, and were managed with anticoagulation without any adverse sequelae. One patient had a planned postoperative admission to intensive care unit, due to concerns regarding effective pain management and enjoyed an uneventful recovery. Other complications included superficial wound haematoma, paraesthesia and irritation with tenderness over the hardware. Of the 24 reported hardware-related complaints, 16 patients had their hardware removed at an average of 2.8 years. Only one of these patients was subsequently converted to TKR, 5.5 years after the initial surgery, due to progression of OA.

Survivorship

A total of 13 conversions to TKR (6.3%) occurred. Median time to failure was 7.0 years (95% CI 5.0 to 8.0). Kaplan-Meier analysis revealed 97.7% survival at 5 years (95% CI 95% to 100%) and 80% at 10 years (95% CI 69% to 92%) (figure 4). The Cox proportional hazards model (model 1) identified cartilage treatment as a significant protective factor against conversion to TKR, with those receiving treatment 5.3 times less likely to undergo conversion, with all other factors held constant (table 2). Parametric analysis allowed for extrapolation of the survival curve and indicated that the estimated mean time to failure (50th percentile) was 12.5 years (95% CI 10.5 to 14.6 years) and none would be expected to survive past 21 years (99th percentile 20.6 years; 95% CI 15.7 to 25.6 years).

Predictors of pain relief

The subset of patients with available data (n=111) displayed median pain relief (ΔKOOS-pain) following MOWHTO of 25 points (95% CI 19 to 31). The partial least squares regression model (model 2, n=91) of pain relief was significant (P<0.01) with a predicted R² (adjusted) of 17% and SE of 15.5 points (figure 5A). Model 2 identified two components (PC1 and PC2) as predictors of pain relief, with PC1 dominated by cartilage treatment, and the interaction between preoperative KOOS-pain and cartilage treatment. The second component (PC2) was influenced by ICRS grade of the medial femoral condyle cartilage and lifetime smoking status. The second PLSR model (model 3, n=41) incorporated preoperative frontal alignment (measured by navigation) and generated a significant (P<0.01)

Table 2

<table>
<thead>
<tr>
<th>Factor</th>
<th>HR</th>
<th>95% CI</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bilateral</td>
<td>0.8</td>
<td>0.2 to 4.2</td>
<td>0.835</td>
</tr>
<tr>
<td>Gender</td>
<td>1.4</td>
<td>0.2 to 11.1</td>
<td>0.778</td>
</tr>
<tr>
<td>Age</td>
<td>1.0</td>
<td>0.97 to 1.1</td>
<td>0.343</td>
</tr>
<tr>
<td>Ever smoked</td>
<td>2.8</td>
<td>0.9 to 9.0</td>
<td>0.088</td>
</tr>
<tr>
<td>Ligament reconstruction</td>
<td>&lt;0.01</td>
<td>–</td>
<td>0.995</td>
</tr>
<tr>
<td>Cartilage treatment</td>
<td>5.3</td>
<td>1.2 to 22.8</td>
<td>0.025</td>
</tr>
<tr>
<td>Meniscectomy</td>
<td>0.3</td>
<td>0.0 to 2.4</td>
<td>0.234</td>
</tr>
</tbody>
</table>
The model explained 50% of the variance in the response ($R^2$, with an SE 11.8 KOOS points (figure 5B). Model 3 also identified two principal components, with cartilage treatment dominating PC1, together with the interaction between age at surgery and cartilage treatment. PC2 was influence by preoperative KOOS-pain score, as well as the interaction between preoperative KOOS-pain and age at surgery.

**DISCUSSION**

The appeal of the MOWHTO is that younger, more active patients are able to experience pain relief and functional improvement while retaining their native joint, as well as maintain their ability to remain active and avoid TKR at a relatively young age. This study is one of the largest single case series compared with past studies of MOWHTO with patient demographics, reported survivorship, complications and pain relief (table 3). The main findings were that patients undergoing MOWHTO should expect a low risk of serious complications and the procedure can be expected to last over 10 years on average and up to 20 years in some patients. The factors predicting conversion to TKR and pain relief remain to be fully elucidated, although cartilage treatment appears to play both a role in improving pain relief, and delaying the rate of conversion to TKR.

**Figure 5** Measured pain relief with least squares regression and 95% prediction intervals plotted against model-predicted pain relief excluding (model 1—A, n=91) and including (model 2—B, n=41) preoperative alignment as a predictor.
The present cohort was overweight (BMI 28.9), and predominantly male (84%) with a median age of 51 years, and 19% of procedures were bilateral. The cohort in this study displayed a comparable average BMI and age (including variability) to previous studies (table 3); however, there were considerably fewer females included (16%) compared with the average of other studies (table 3). The reason for the discrepancy in gender proportion is unclear; however, in our experience, reluctance to perform a simultaneous bilateral procedure cannot be ruled out due to the perception that MOWHTO can provide symptom relief for extended periods. The incidence reported in the present study (3.8%) of complications requiring readmission for medical or surgical intervention is difficult to compare with previous studies (table 3) due to the lack of standardized reporting, follow-up and the threshold for intervention. Floerkemeier et al 13 used a similar surgical approach in a larger cohort (n=533) and reported a higher complication rate (6%). Four of their reported complications occurred intraoperatively due to technical issues. The majority occurred due to soft-tissue complaints, although there was no reported hardware-related irritation, discomfort or infection. There remains a lack of data regarding the relationship between complications occurrence and long-term patient-reported outcomes, although deleterious effects have been reported with regard to KOOS scores at short-term follow-up. 11 12 The present findings indicate that a well-guided surgical technique, despite

### Table 3 Patient demographics and surgical details of studies investigating HTO outcomes

<table>
<thead>
<tr>
<th>Study</th>
<th>Total sample (N) analysed (A)</th>
<th>Patient characteristics</th>
<th>Type of osteotomy</th>
<th>Follow-up period</th>
<th>Complication rate</th>
<th>Survivorship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current study</td>
<td>N: 211</td>
<td>51 years (95% CI 42 to 57) F: 16% M: 37.9 kg/m² (95% CI 23 to 36.9 kg/m²)</td>
<td>Medial opening wedge</td>
<td>5 years (3–8)</td>
<td>13.3%</td>
<td>97.8% at 5 years, 80% at 10 years</td>
</tr>
<tr>
<td>Spahn et al 12</td>
<td>N: 94; A: 84</td>
<td>48.5 years (31–67) F: 44% M: 27.1 ± 3.6 kg/m²</td>
<td>Medial opening wedge</td>
<td>45.9 ± 7.6 months (34–60)</td>
<td>6.4%</td>
<td>NR</td>
</tr>
<tr>
<td>Asik et al 13</td>
<td>N: 65</td>
<td>54 years (39–76) F: 72%</td>
<td>Medial opening wedge</td>
<td>36 months (18–60)</td>
<td>9.2%</td>
<td>NR</td>
</tr>
<tr>
<td>De Meo et al 14</td>
<td>N: 20</td>
<td>49.4 years (36–67) F: 30%</td>
<td>Medial opening wedge</td>
<td>8.3 years (5.8–7.5)</td>
<td>20%</td>
<td>70% at 8 years</td>
</tr>
<tr>
<td>Robinson et al 15</td>
<td>N: 9</td>
<td>49.3 years (37–59) M: 100%; BMI &lt;35</td>
<td>Medial opening wedge + external fixation</td>
<td>19 months (15–35)</td>
<td>6%</td>
<td>88.9% at 19 months</td>
</tr>
<tr>
<td>Schallberger et al 16</td>
<td>N: 72; A: 54</td>
<td>40 years (31–58) F: 31%</td>
<td>Opening and closing</td>
<td>16.5 years (13–21)</td>
<td>NR</td>
<td>98% at 5 years, 92% at 10 years, 71% at 15 years</td>
</tr>
<tr>
<td>Bode et al 17</td>
<td>N: 43 A: 19</td>
<td>40.2 ± 9.9 years, 25.2 ± 3.1 kg/m²</td>
<td>Medial opening wedge + ACS</td>
<td>71.88 ± 23.99 months</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>W-Dahl et al 18</td>
<td>N: 3161</td>
<td>52 ± 7.5 years F: 31%</td>
<td>Opening and closing</td>
<td>8.7 years (3–13)</td>
<td>NR</td>
<td>70% at 10 years</td>
</tr>
<tr>
<td>Floerkemeier et al 19</td>
<td>N: 533; A: 386</td>
<td>49.3 years (18–84) F: 31% M: 27.2 ± 4.0 kg/m² (n=504)</td>
<td>Medial opening wedge</td>
<td>3.6 years (2.6–4.7)</td>
<td>6%</td>
<td>NR</td>
</tr>
<tr>
<td>Harris et al 20</td>
<td>N: 496</td>
<td>54.2 ± 8.1 years F: 54%, M: 44% M: 26.1 ± 2.85 kg/m²</td>
<td>Opening and closing</td>
<td>9.2 ± 5.2 years</td>
<td>NR</td>
<td>92.4% at 5 years</td>
</tr>
<tr>
<td>Harris et al 21</td>
<td>N: 399</td>
<td>47 ± 10.7 years F: 41% M: 27.3 ± 0.35 kg/m²</td>
<td>Opening and closing + ACS</td>
<td>5.0 ± 2.3 years</td>
<td>NR</td>
<td>97.7% at 5 years</td>
</tr>
<tr>
<td>Harris et al 22</td>
<td>N: 113</td>
<td>33.6 years Not fully reported</td>
<td>Opening and closing + MAT</td>
<td>6.8 ± 5.2 years</td>
<td>NR</td>
<td>90.9% at 5 years</td>
</tr>
<tr>
<td>Giuseffi et al 23</td>
<td>N: 100; A: 83</td>
<td>48.1 years</td>
<td>Medial opening wedge</td>
<td>4.0 years (1–10)</td>
<td>7%</td>
<td>60% at 10 years</td>
</tr>
<tr>
<td>Schuster et al 24</td>
<td>N: 91</td>
<td>50.4 ± 8 years F: 13.2%</td>
<td>Medial opening wedge</td>
<td>5.6 years (5–7.3)</td>
<td>6.6%</td>
<td>95.2% at 5 years</td>
</tr>
<tr>
<td>Duivenvoorden et al 25</td>
<td>N: 412</td>
<td>49.2 ± 9.3 years F: 40.8%</td>
<td>Opening and closing</td>
<td>9.8 ± 4.9 years</td>
<td>17%</td>
<td>75% at 10 years for CW, 90% at 10 years for OW</td>
</tr>
</tbody>
</table>

* Only those with an HTO (HTO vs non-HTO group). † Broken up for ease of interpretation. ACS, articular cartilage surgery; MAT, meniscus allograft transplantation; NR, not recorded; OW, opening wedge; CW, closing wedge.

The present data indicate that these perceptions are unfounded, and that MOWHTO can provide symptom relief for extended periods.

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variations over time, as well as consistent perioperative care can contribute to a low rate of complications.

The present results describe survivorship of MOWHTO from 97.7% at 5 years to 80% at 10 years, which is consistent with previous results in the literature (Table 3). DeMeo et al\textsuperscript{14} reported 70% at 10 years with a smaller sample (n = 20), while Schallberger et al\textsuperscript{13} reported 92% at 10 years, also with a smaller sample (n = 54) to the present study (n = 210). The reasons for the discrepancies between studies are not obvious, but Schallberger et al\textsuperscript{13} included both open and closing wedge osteotomy, with the majority of procedures being closing wedge osteotomy. In addition, the cross-sectional nature of our study may be a contributing factor and cultural differences between cohorts have also been suggested.\textsuperscript{3} Of note in our data is the normal distribution of conversions to TKR, meaning that the frequency of conversion did not change with increased time since surgery. This finding counters the assumption that conversions increase in frequency as OA progresses and highlights the importance of patient selection whereby some convert to TKR earlier, whereas in others the MOWHTO may arrest disease progression entirely. By fitting a normal distribution to the incidence of conversions to TKR in the cohort (n = 13), we were able to estimate the average (50% survival) time to conversion (12.5 years) and the maximum expected survival (21.5 years). While these estimates provide guidance for counselling prospective patients, the factors that dictate the time to conversion remain to be elucidated. We could not replicate the findings of Hui et al\textsuperscript{10} that reported ACL status, age at surgery and BMI as significant predictors of conversion in their study of closing wedge HTOs. This may be because we were unable to perfectly replicate their model with our data. Nevertheless, we were able to test other factors not included in the Hui et al analysis and report a potential protective effect of cartilage treatment (microfracture, chondroplasty, MACI) on likelihood to convert to TKR.

Pain is the most common and debilitating symptom of knee OA and a key driver of surgical intervention.\textsuperscript{3} Our results demonstrate significant pain relief after MOWHTO at 2 years average follow-up, although pain levels do not return to normal. Patient selection is a key factor determining longevity of the procedure and our results provide additional information for that purpose. Specifically, patients that report less pain preoperatively demonstrate reduced pain relief, with those undergoing cartilage treatment and patients receiving bilateral procedures reporting improved pain relief compared with the average. To our knowledge, this is the first study to investigate pain relief following MOWHTO in detail, although with a small sample (n = 41–91) and distinguishes our work from the literature which suffers from a lack of consensus regarding the definition of surgical success or procedure survival. Although reduced pain is a known patient expectation of TKR,\textsuperscript{5} there is limited information regarding this in the context of MOWHTO. Future work should explore the interplay between surgeon and patient expectations, which may not fully align,\textsuperscript{8–20} as well as their interaction with long-term pain relief, disease progression and procedure survival.

The present study contributes important information to the issue of patient selection, pain relief and procedure survival following MOWHTO for medial compartment knee OA. Nevertheless, the findings should be interpreted in light of the limitations of the study. First, the cross-sectional nature of the survival analysis should be considered when interpreting survival rates and the projected time to conversion based on the normal distribution. The width of the CIs at maximum follow-up reflects the diminishing sample size and the analysis should be repeated to confirm these findings when the majority of the current sample has passed 5 or 10 years follow-up. Second, missing data from patient characteristics and patient-reported outcomes pose a considerable challenge in modelling secondary outcomes such as pain relief. The iterative nature of registry research should be taken into account, in that important predictive measures are not always apparent at the commencement of a database and data collection methods have evolved over time. The present results can now be used to inform a new iteration of the ongoing database and inform a future analysis to confirm these findings.

**CONCLUSION**

Medial opening wedge HTO is an effective procedure for relief of pain associated with medial knee OA, even in older and heavier patients. Patients and clinicians can expect an average procedure survival of 12.5 years and a maximum of 21 years. This study provides the first objective guidance with respect to expectations regarding procedure survival and pain relief. Patients should be counselled with an expectation of pain relief, which decreases over time. Future research should be directed towards a cost-benefit analysis of the procedure, with particular attention paid to the minimum period of procedure survival necessary for a favourable cost-benefit ratio.

**Contributors** VM: collecting data. FF: writing process. CS: statistical analysis. AP: collecting data. MC: main idea and writing process. DP: main idea and writing process. BF: writing and reviewing process.

**Competing interests** None declared.

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