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Determination of the accuracy of navigated kinematic unicompartmental knee arthroplasty: A two year follow-up

Short Title: Accuracy of Navigated UKA

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ABSTRACT

Background: Unicompartmental Knee Arthroplasty (UKA) lacks history of patient satisfaction and research addressing validity of techniques. The aim of this study was to determine minimally invasive navigated kinematic UKA accuracy by comparing postoperative limb alignment with preoperative stress values.

Methods: A single-centre retrospective study was conducted on 53 consecutive patients (postoperative alignment: varus n=51, valgus n=2) who underwent UKA assisted by Computer Navigation. Two patient groups (A and B) predetermined by joint deformity cut-off points (group B included valgus deformity) underwent preoperative Magnetic Resonance Imaging and X-ray evaluation to assess the limb alignment and to exclude lateral and patellofemoral osteoarthritis. Pre and postoperative joint alignment, stress value and range of movement (ROM) were recorded with navigation. Outcome measures include comparison of postoperative alignment to the preoperative stress values for varus and valgus postoperative alignment groups and pre/postoperative WOMAC and KSS score evaluations.

Results: Minor systematic bias was found between stress value and postoperative alignment; however, the magnitude of this difference was clinically acceptable. Score evaluations, prosthesis size or alignment did not differ between alignment groups A and B. Furthermore there was no significant increase in ROM at two years. There was a high degree of agreement between stress value and the postoperative alignment values suggesting strong validity for the surgical technique to determine the optimal postoperative alignment.

Conclusions:
This study validates our surgical technique. Our minimally invasive navigated UKA technique allows us to predict the pre disease alignment and recreates it with high accuracy. Our clinical results at two years are comparable to other published data.

**Key Words:**

Partial knee, validity, medial compartment, minimally invasive, responsiveness
Introduction

Unicompartmental Knee Arthroplasty (UKA) continues to be an evolving procedure with highly specific indications that are closely associated with clinical outcomes, patient satisfaction and survivorship. Popularity and usage declined following reports of high early conversion rates to Total Knee Replacement (TKA) in the 1980s [1]. In the 1990s, as surgical techniques and implant designs improved, the indications for UKA continued to expand and their successes improved [2, 3] More recent investigations with long-term follow-up report that fixed bearing UKA are lasting well into the second decade with greater than 90% implant survivorship [4-6].

Based on reported data, UKA is considered by many as a “successful” procedure although a number of issues remain concerning frequent and early failure rates and patient dissatisfaction postoperatively [6-8]. Early failures following UKA have been attributed to faulty surgical technique [9] and inaccurate position of the components leading to over-correction or under-correction of the final limb alignment [6-8]. Malalignment of the leg is associated with increased polyethylene wear [9], disease progression to the opposite compartment [9, 10] and aseptic implant loosening [11, 12] Plate et al [13] propose UKA component position and alignment are intricately associated with soft-tissue balancing. A comprehensive understanding of these issues and their relationship to patient selection, diagnosis, and management is crucial for maximising successful long-term prognosis. Although traditional criteria limit UKA to low-demand patients, there has been an expansion of indications to treat younger or higher-demanding patients who would benefit from the functional advantages of retained cruciate ligaments and improved proprioception that UKA offers [12, 14]. Howell and colleagues even suggest a selection bias exists towards the use of a UKA procedure instead of a TKA, in patients with a “better” preoperative function [8]; however we feel this view remains controversial as clinicians may also base procedural decisions based on circumstances outside of the described selection criteria.
UKA in such cases ultimately buys time, delaying the more-invasive TKA. Debate also continues around the degree of postoperative alignment that surgeons should aim for, in order to achieve longevity of prostheses and patient satisfaction. Computer-assisted surgical (CAS) navigation has been introduced to improve accuracy in implant positioning and postoperative alignment. Due to limited exposure when performing minimal invasive surgery, the navigation system is helpful in achieving precise positioning [15]. When combined with CAS navigation, UKA has been shown to produce more accurate and reproducible alignment than with a conventional UKA [16, 17].

Another deviation from the conventions of traditional UKA is the use of kinematic alignment in place of a mechanical approach. The kinematic (alignment) principal for knee replacement is based on rotating the tibia around a fixed femoral rotational axis [18]. This axis is created by resecting the femur equal to the thickness of the prosthesis on the unaffected side and under-resecting the affected side equal to the estimated cartilage and bone loss thickness [6]. This places the femoral prosthesis onto the host bone precisely at the native articular surface with the patella and tibia tracking around the native femoral rotational axis. The tibia is resected to compensate for the native alignment of the knee to equalise the lateral and medial gaps, thus leaving the medial and lateral soft tissue envelope at their native lengths. UKA lends itself to the kinematic principal. The concept of replacing the affected medial compartment within its natural soft tissue envelope, without the need to release the soft tissue, is the fundamental principal when performing a UKA. Despite evidence to support combining these surgical concepts and theories [13], validation studies are lacking.

Therefore, the aim of this study was to validate the use of minimally invasive navigated kinematic UKA by comparing postoperative limb alignment to preoperative stress values. A minimally invasive surgical technique was adopted to restore the pre-pathological coronal alignment of the
knee. The Stryker Triathlon Partial Knee Replacement (PKR) prosthesis in conjunction with the Stryker Precision Computer Navigation (PCN) system was used in all cases.
Materials and Methods

This was a non-randomised retrospective study of prospectively collected data. Between July 2010 and May 2014, 53 patients underwent the UKA procedure at a single site. Selection criteria included male and female patients with non-inflammatory osteoarthritis, isolated medial compartment involvement only, moderate to severe disease, fixed flexion deformity of less than 10°, a varus deformity of less than 15°, an intact ACL, and a BMI of less than 35. Patient demographic data are presented in Table 1. Patients included in the current study had preoperative x-ray and MRI evaluation to assess the limb alignment and to exclude lateral and patellofemoral osteoarthritis respectively. Confounding pathologies were excluded by conducting physical examinations and collection of patient history. All patients underwent arthroscopic examination of the knee at the time of surgery to exclude lateral and patellofemoral joint disease prior to receiving a navigated kinematic UKA. The Stryker Triathlon PKR prosthesis was used in all surgical cases in the current study.

All patients provided consent prior to the UKA procedure, which included the arthroscopy and the secondary surgical plan of a total knee arthroplasty (TKA). Patients received a knee arthroscopy simultaneously to assess the lateral and patellofemoral compartments of the knee. During the arthroscopy, if the cartilage disease in the lateral or patellofemoral compartment was found to have an Outerbridge grade three or higher score, then the patient was deemed unsuitable for UKA and the procedure was converted to a TKA and the patient was excluded from the study. If a patient had a fixed varus deformity that the surgeon felt would require ligament release then a unicompartmental knee was contraindicated.

Patient Demographic and Surgical Outcomes Data
All patients were evaluated for the WOMAC and KSS scores preoperatively along with BMI and haemoglobin values. Preoperative alignment in terms of varus, valgus, fixed flexion deformity and ROM was recorded with navigation as was post-operative limb alignment. Total surgical, tourniquet time and blood loss was recorded for each patient where possible as well as haemoglobin post-operatively on day one and day two. The indication for UKA was followed with a low threshold for exclusion. Complete data sets for ROM and scores was available for n=38. Patients who were unable to revisit the clinic were excluded to ensure complete set of data for statistical analysis. If a patient at the six week review had less than 80% of the preoperative flexion range then an MUA was performed. This study received ethics approval from the local Human Research Ethics Committee prior to UKA patient registry search. Governance approval number is MHS20160415-01.

Research design

Stress value (pre-disease alignment) was recorded and compared with postoperative alignment following UKA. WOMAC and KSS scores and range of movement was recorded preoperatively and at two years following UKA. Analyses were performed on all surgical patients as a whole. In addition, further measures of central tendency and dispersion were performed following subgrouping of patients into -5.0° to -2.5° (Group A) and -2.0° to 5° (Group B) categories. The sub-groupings were established by determining a cut-off using postoperative alignment that allowed equal distribution of patients between each alignment group (i.e. Group A and Group B). Subsequently, -5.0° to -2.5° (Group A) and -2.0° to 5° (Group B) allowed allocation of 17 patients in Group A and 19 patients in Group B. However, when reporting the descriptive data, patients with valgus deformity were separated from Groups A and B (adjusted to 17 patients) and classified as Group C (2 patients; see below under Statistics for further information).
Surgical technique

The primary focus of the minimally invasive navigated UKA was to emphasise the surgical technique, with particular attention paid to the assessment of pre-disease alignment, appropriate cover of anteromedial tibial cortex by tibial base plate and balanced flexion and extension. The Stryker Triathlon PKR single radius femoral prosthesis was used with anatomical lateral curve. A metal anatomical tibial base plate wide anteriorly allowed for anteromedial coverage.

In addition to the knee arthroscopy providing the final diagnostic view of the patellofemoral and lateral compartment, the procedure also provided the surgeon with the ability to register the knee using the PCN system. This allowed for minimally invasive approach. Infrared active trackers were attached to two metal pins in the distal femur and proximal tibia as part of the Stryker PCN system. Once the registration of the trackers had been completed, a minimally invasive skin incision of 8-12cm was made, centred over the medial femoral condyle using a scalpel blade. Joint capsule was incised in-line with the skin incision using electro-cautery. Osteophytes interfering with medial collateral ligament function were removed.

Soft tissue tension in the medial collateral ligament was assessed. Manual application of a valgus stress to the knee (Figure 1) was used to open the medial compartment to allow placement planning for the components to fill the articular gap left by the loss of articular cartilage. By applying a preoperative valgus moment the native (natural) knee alignment is predicted. Assessments were conducted in full extension and 90° of flexion. The Stryker PCN records varus and valgus values in neutral and stress positions. For example, a knee in neutral position may record 7° varus and under valgus stress it may record 3.5° varus, (Figure 2a) whereby the difference reflects the cartilage and bony wear. The most common wear pattern in a medial knee
osteoarthritis is anteromedial in the tibia [7] and distal in the femur [6]. The surgical aim was to restore the preoperative stress value as the final alignment of the knee.

The amount of bone resected under navigation was 8mm (minimum thickness of tibial component) minus estimated tibial cartilage loss. (Figure 2b) Following PCN registration of tibial cut an 8mm spacer block was inserted and the alignment checked in extension. Resection was deemed adequate if the alignment value approximates that of the stressed value in extension. In most circumstances there will be a small varus residual value that will now be corrected by manipulating the distal femoral resection. Subsequent to tibial resection, cartilage loss was estimated on the distal femur with the total amount of resection considered as 7mm (Thickness of the distal femoral component) minus estimated loss (Figure 2c). Once the distal cut has been completed a 15mm spacer was then inserted in extension to achieve the desired stressed alignment following a distal cut.

A posterior and chamfer cut is performed next. A two-in-one cutting block was positioned on the distal femoral surface to resect 7mm minus the estimated cartilage loss off the posterior condyle. Once cuts were made a 15mm spacer block was inserted into the knee to replicate the final limb alignment using Navigation (unstressed) and to compare with the stress value alignment recorded preoperatively using valgus stress method (Figure 2d) and the process repeated with trial implants. The final steps of implantation are carried out according to the Stryker PKR surgical technique [19] with the exception of order of insertion of prosthesis. Validation of the limb alignment using Navigation was performed following implantation of both trial and definitive prosthesis prior to closing the joint capsule. There was no further valgus stress applied to the limb as the aim of the technique is to replicate the stress value as the pre-disease natural alignment.
Statistical analyses

All data were analysed using the Statistical Package of Social Sciences (SPSS, Version 22). The measure of central tendency and dispersion for alignment groups and ROM are reported as mean ± SD. The Shapiro-Wilk’s test indicated that the data was not normally distributed and thus were log transformed prior to performing statistical analyses. Given the potential for the stress value and post-operative alignment data to be negative values a value of 360° was added as a constant to these measures for each patient’s data prior to log-transformation. Following log-transformation, the validity of the stress value was determined by comparing its measures with postoperative alignment using the intraclass correlation coefficient (ICC, SPSS 2-way mixed, 95%). The ICC is commonly used to determine inter- and intra-rater reliability by indicating the strength to which individuals or data points within individuals resemble each other with values above 0.9, between 0.8-0.89 and below 0.80 were considered excellent, moderate and questionable, respectively [20]. The limits of agreement (LOA) were calculated and expressed using the Bland and Altman Plot [20]. In this instance, the LOA was used determine the level of agreement between the stress value and postoperative alignment measures under the assumption that any two methods that are developed to measure the same parameter should have acceptable correlation. Given presence of heteroscedasticity (i.e. skewness of the data), ratio LOA was calculated with values in proximity to $\frac{X}{\pm}$ 1.06 classified as excellent whereas $\frac{X}{\pm}$ 1.29 was unacceptable [21]. Subsequently, these ranges of agreement ratios in conjunction with ICC were used to establish delimitations (i.e. acceptable standards) for the validity of stress values [22].

To determine whether potential differences between Group A and B influenced systematic bias between the stress value and postoperative alignment, a two-way (Group x time) repeated measures analysis of variance (ANOVA) was calculated, with ‘time’ as a main effect and ‘group’
treated as a covariate. A two-way repeated measures ANOVA was also used to determine
differences in WOMAC, KSS and range of motion scores from preoperative alignment to 1 and 2
year follow up post-surgery with post hoc tests using Bonferroni’s pairwise adjustments to
determine the location of the difference between time points. An a priori sample size calculation
was conducted (G*Power 3.1.9.2, a statistical software for a priori sample size calculation) for
repeated measure ANOVA with within-between interactions for two independent groups. The
effect size, power and nonsphericity correction was set at a default of 0.25, 0.95 and 1 which
generated a total sample size of 36. Whilst patients were separated into groups A and B according
to predetermined joint deformity cut-off points, the patients with valgus deformity were included
into group B as a pooled data given that there were only two of these patients. Statistical
significance was established at the 0.05 level.
Results

The cohort of patients in this study consisted of 17 males (32%) and 36 females (68%). The mean age and BMI at time of surgery was 62.3 (range, 48-76 years; SD = 7.6) and 31.7 (range, 24.9 – 41.5 kg/m$^2$; SD=4.7), respectively (Table 1). Figure 3 represents the number of patients measured by navigation at time points preoperative, intraoperative (stress value) and postoperative. Postoperatively, the majority of the patients (75%) received the smallest poly insert (size 8).

Figure 4 displays the distribution of implant sizes.

When determining the validity of stress value by correlating its measures with postoperative alignment, the ICC was 0.92 (0.84-0.96). According to the 2-way ANOVA, there was no main effect of time (p > 0.05) between stress value (-1.79 ± 1.55°) and postoperative alignment (-2.40 ± 1.53°; refer to Figure 5 for log-transformed data of each measure and Figure 6 for log-transformed and raw data of between-group comparisons for each measure. Furthermore, there was no group x time interaction effect when group was treated as a covariate (p > 0.05). Bland and Altman Plots indicated upper and lower 95% confidence limits of 2.20 and -1.03, respectively (Figure 7). The ratio limits of agreement between the stress value and post-op alignment was 1.00 */÷ 1.01.

Figure 8 depicts log-transformed measures and raw data for each time point for WOMAC, KSS and range-of-motion scores and Figure 9 depicts log-transformed measures and raw data for each time point of each group for WOMAC, KSS and range-of-motion scores. For determination of the effectiveness of the surgical intervention, a main effect of time was found for the WOMAC scores (p < 0.05) and KSS scores (p < 0.05). Post hoc analyses for WOMAC and KSS scores showed that preoperative measures (48.2±12.9) were significantly greater than 1 year (7.28±8.0) and 2 year (4.9±8.6) postoperative whereas no differences were found between 1 year and 2 year postoperative measures (p>0.05). There was no main effect of time for the ROM scores (p>0.05).
when compared between preoperative measures (119.5°±7.7°), 1 year (121.0°±7.3°) and 2 year (121.1°±6.5°) postoperative measures. When group was treated as a covariate, there was a group x time interaction effect for WOMAC and KSS scores (p < 0.05) although this was not found for the range-of-motion scores (p > 0.05).
Discussion

Over the past few years there has been heightened interest in minimally invasive navigated kinematic UKA [16, 17]. Navigated kinematic UKA aims at achieving the natural ligament balance and restoring the pre-disease alignment of the knee. The present study indicates that this technique accurately reproduces preoperative stress values and has comparable postoperative satisfaction scores for varus and valgus alignment. It further shows that CAS navigation for kinematic UKA is a useful technique to accurately position and aligns implants thereby improving patient outcomes.

Compared to TKA the use of computer navigation to improve surgical accuracy is not well validated in UKA. [23] In addition, the incorporation of minimally invasive techniques for Navigated UKA reportedly increases the risk for loss of accuracy [13]. A previous study suggested that deviations from pre-planned alignment could occur from: 1) improper restoration of compartment height, and 2) poor ligamentous balance which may be set by a surgeon’s “feel” without quantification [13]. Contrary to these concerns, which suggest poor correlation between the intraoperative navigation system measurements and postoperative radiological measurements [23], the present study demonstrates that minimally invasive navigated kinematic UKA is a valid surgical technique, supported by a strong agreement between stress value and postoperative alignment. In addition, the comparative measures between stress value and postoperative alignment suggest minimal systematic bias providing further validation of this technique. In the current study the mean difference between stress value and postoperative alignment was 0.6°, which falls within the range currently considered clinically acceptable; the acceptable difference between the intraoperative and postoperative alignment for kinematic aligned medial UKAs has been reported at 1.33° [24] which aligns with the upper and lower LOA findings of the current
study. Furthermore, the ratio LOA was 1.00 */÷ 1.01 in the current study, which is well within the range and considered an excellent agreement [21].

There were a number of limitations with the current study. Whilst the findings of the present study indicate a favourable improvement in patient outcomes and satisfaction at two years post-surgery, no significant difference were observed for ROM. Most study participants had an excellent ROM to begin with, where most of the patients maintained ROM at two years. Walker et al [25] compared pairs of similar patients from TKA to UKA procedures for lateral osteoarthritis and found the change in ROM was statistically significantly 18% higher in patients following the UKA procedure compared to patients following the TKA procedure [25]. Our findings of increased patient satisfaction in the absence of a significant change in ROM were not unusual considering the high preoperative ROM for this study cohort.

In the present study, two patients (3%) were in the cohort with postoperative valgus alignment of the knee, which reflects the infrequency seen within the general population for this alignment subset; (~2.8%) [26]. Due to the small sample ICC values were unable to be calculated independently. However the percentage difference between stress value and postoperative alignment was 1.0° falling within clinical acceptable levels [24] patients with valgus deformity (Group C) were included with varus aligned patients as pooled data (Group B), future studies with a larger sample size are warranted to investigate the validity of the surgical procedure specifically for patients with valgus deformity.

The valgus force applied to the knee by the surgeon during preoperative planning was not validated in this study through repeated measures, nor ‘checked’ for possible residual varus thus is considered a limitation. It is very difficult to apply reliability measures for valgus stress given the stress value is obtained preoperative as a subjective measure. Currently there is no device
which measures the force applied to the joint or measures the tension of medial collateral
ligaments prior to bone resection. However, if such a device were incorporated into the surgical
technique it would serve to improve reliability and method of replicating the stress value.
Residual varus could be of concern for a surgeon when planning varus correction by reaching the
tension point of the MCL as described in the protocol. In our cohort the maximum postoperative
varus alignment was 5° and maximum valgus was 3°. The majority of our patients ranged
between neutral +/- 3°. This value is well accepted in the literature as being within a normal range
[28, 29].

The protocol was also carried out with the absence of long limb radiographs because poor
correlation exists between the navigation alignment and measured radiographic alignment. The
authors acknowledge long limb radiographs assist in monitoring for loss of correction in short
and long-term follow-up. However the focus of our study was to measure the accuracy of our
surgical technique and for this we chose to use navigation as our alignment tool; we did not use
the preoperative MRI scans for geometry validation. We acknowledge that postoperative long
limb radiograph could be used to further validate our technique. Previous research by Lonner et
al in 1996 used bone models to demonstrate radiographic alignment was significantly affected by
rotation and knee flexion [16]. This is supported with clinical evidence by Wilcox et al who in
2012 showed that the intraoperative alignment measured on navigation did not necessarily
compare with the standing radiograph pre or post-operatively [14]. Thus based on the literature
the postoperative reviews included standard AP and lateral knee radiographs taken at six weeks,
one and two year mark, without long limb films. With respect to the validity of the Stryker
Navigation PCN, preoperative MRI scans could be used to validate the centre of femoral
alignment. However, we did not use the MRI scans for that purpose.
Postoperative reviews revealed five patients who underwent manipulation under anaesthetic (MUA) and two failures requiring revision. As mentioned previously our MUA protocol meant that any patient less than 80% of preoperative flexion range at 6 weeks received an MUA. Since most UKR patients have a high preoperative range this may have led to increased cases of MUA. In our cohort of patients the five patients collectively had preoperative average range of 125° and at the 12 months postoperative review the average range was 124°.

One of the revision cases was a technical error by the surgeon while the second a subsidence of the tibial implant. The first patient was revised 13mths after the primary procedure. At the primary operation the surgeon had difficulty seating the tibial prosthesis. The surgical technique describes insertion of the femoral component followed by the tibial. Once the femoral component was inserted it was difficult to insert the tibial component and it is suspected that the cement mental was breached with subsequent loosening. The surgeon now cements the tibia first and then the femur.

The second patient was a 72 year old female who had her UKR revised to a TKR after 14 months. This patient had a proximal tibial articular width of 6.11cm. The smallest tibial component is 2.5cm at it widest medio-lateral diameter. This leaves 3cm for each hemi tibia proximally. Taking into account the tibial spine being 1cm in each half, the 2.5cm tibia was set on 1.91cm of surface area. Due to inadequate bone the tibial component came loose prematurely. The surgeon does not perform UKR on patients with proximal tibial diameter less than 7cm. There was no option to downsize the tibia, therefore this complication was unrelated to the technique and attributed to implant size. Whilst the thickness of the tibial implants was variable in the current study the femoral components remained constant for thickness across the range of sizes. The smallest tibial insert, which includes the base-plate and Polyethylene insert, is 8mm. The femoral component
distally and posteriorly is 7mm in thickness. The smallest combination of UKA results in 15mm thickness. An increase in the tibial base-plate and the polyethylene insert results in increased thickness of the total of the two components. Despite the inclusion of the two reported aforementioned outliers there was a strong correlation between stress value and postoperative alignment. Suffice to say on a whole, with the majority of patients successfully received the smallest polyethylene insert in the range which demonstrates reproducibility of the minimally invasive navigated kinematic surgical technique.

Notwithstanding the small number of patients in the study, another limitation of the present study was that it represented a short-term retrospective study. In addition, patients were not randomised, not compared to a control group, and two patients in our patient cohort had BMI of above 35. One patient was a 67yr old active gentleman who developed sudden onset of knee pain. His MRI showed intense medial femoral condyle marrow oedema with subchondral collapse. A provisional diagnosis of Spontaneous Osteonecrosis of the Knee (SONK) was made. Short to medium term literature supports UKR as treatment of SONK [30, 31]. The second patient was a 55yr old nurse who was very active and wanted to retain her range of motion. MRI and knee arthroscopy revealed unaffected lateral and patello-femoral joint. She proceeded to having bilateral UKR in the same setting. These exceptions were made after thorough consultation with the patient on their need to lose weight. Larger prospective, randomized multi-centre trials with five to ten year outcomes are required before definitive conclusions can be drawn. What our study highlights is future trials must have a very strict patient selection criteria and an accurate evaluation of the pre-
disease alignment of the knee during the execution of the intraoperative balance plan.
Conclusion

Reproducing pre-planned limb alignment postoperatively for minimally invasive navigated kinematic UKA can be achieved contrary to many reports covered in the literature. A comprehensive understanding of patient factors, knee pathology, implant design and the described surgical technique may help guide surgical management with improved clinical outcomes, patient satisfaction and survivorship following UKA. Further long-term follow-up prospective trials especially on valgus knees could help define the most appropriate postoperative alignment of Unicompartmental Knee Arthroplasty.
Literature Cited


[21] Triathlon® PKR Partial Knee Resurfacing Surgical Protocol. Literature number LTPKR-SP Rev. 4 Copyright © 2011 Stryker 325 Corporate Drive Mahwah, NJ 07430


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Finally, thank you to Dr Ryan Faruque for providing the sketch images used in this manuscript.
Figure Legend

**Figure 1** Preoperative planning – valgus stress assessment

**Figure 2** PCN reported alignment with neutral and stress valgus alignment following valgus stress moment (a), tibial resection – estimated loss (b), femoral resection – estimated loss (c), and (d) final alignment.

**Figure 3** Navigated alignment data recorded perioperatively for stress value (a), postoperative alignment (b) and differences between alignments (c)

**Figure 4** Frequency of implanted prosthesis for Femoral, Tibial and Polyethylene insert

**Figure 5** Comparison of Stress value and Postoperative measures (for pooled data/combined groups) of all patients who underwent minimally invasive navigated kinematic UKA (n=53). Raw data (a) and log-transformed data (b) is presented as mean ± SD

**Figure 6** Comparison of Stress value and Postoperative measures of Groups A, B and C (including valgus deformity) of all patients who underwent minimally invasive navigated kinematic UKA (n=53). Raw data (a) and log-transformed data (b) are presented as mean ± SD

**Figure 7** Bland and Altman Plot of the absolute difference between the stress value and postoperative alignment measures against the mean of the stress value and the postoperative alignment measures

**Figure 8** The mean ± SD of the log-transformed measures (left column) and raw data (right column) of the pooled data (i.e. combined groups) for WOMAC (a), KSS (b) and range-of-motion (c) scores
Figure 9 The mean ± SD of the log-transformed measures (left column) and raw data (right column) of WOMAC (a), KSS (b) and range-of-motion (c) scores for each group.

Table 1 Demographic data of minimally invasive kinematic navigated UKA patients.
Table 1

Table 1. Demographic data of all patients (n=53)

<table>
<thead>
<tr>
<th></th>
<th>Cumulative Frequency</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>62.3 ± 7.6 (48-76)*</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>- Male</td>
<td>17 (32%)</td>
</tr>
<tr>
<td>- Female</td>
<td>36 (68%)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>31.7 ± 4.7 (24.9 – 41.5)*</td>
</tr>
<tr>
<td>Diagnosis</td>
<td></td>
</tr>
<tr>
<td>- Osteoarthritis</td>
<td>53</td>
</tr>
<tr>
<td>ROM (degrees)</td>
<td></td>
</tr>
<tr>
<td>- Preoperative</td>
<td>120.0 ± 5.9 (100 – 130)*</td>
</tr>
<tr>
<td>- Postoperative</td>
<td>121.6 ± 4.9 (108 – 132)*</td>
</tr>
</tbody>
</table>

*Values are written as mean ± SD (range min to max)

BMI body max index.
Figure 1. Preoperative planning – valgus stress assessment
Figure 2. PCN reported alignment with neutral and stress valgus alignment following valgus stress moment (a), tibial resection – estimated loss (b), femoral resection – estimated loss (c), and (d) final alignment.
Figure 3. Navigated alignment data recorded perioperatively for stress value (a), postoperative alignment (b) and differences between alignments (c).
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