osteoarthritis is among the most common joint diseases worldwide. It occurs progressively and is considered a chronic musculoskeletal disorder. Approximately 6% of all adults in Greece, corresponding to approximately 5 million people in Germany, suffer from clinically significant osteoarthritis of the knee.1,2

Ultimate surgical treatment is the implantation of a total knee arthroplasty (TKA).3-5 Younger patients may benefit from an osteotomy. The high tibial osteotomy (HTO) is primarily used for varus knee osteoarthritis. Supracondylar distal femoral osteotomy may be performed for valgus knee osteoarthritis. The goal of axial correction is to relieve the strain on the affected compartment, reduce pain, and improve mobility.6 Subsequent to osteotomies, the majority of patients do, however, require a TKA.

In Germany, approximately 165,000 knee prostheses were implanted in 2011.1 Numerous studies investigated the outcome of patients after osteotomy and secondary manually implanted TKA compared with patients with primary TKA.7-10 The outcome of patients with computer-navigated TKA implantation following osteotomy has not been investigated to date.

The objective of the current authors’ study was to compare patients with secondary computer-navigated TKA implantation following distal femoral or HTO vs patients with primary computer-navigated TKA in terms of ligamentous stability, daily function, patient satisfaction, and radiological outcome within a matched-pair analysis.

**Material and Methods**

The patients underwent surgery between July 2006 and February 2012 at the

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BG Trauma Center in Tübingen. A total of 58 patient legs were studied (23 female, 35 male) (Figure 1). In the study group, the average age at time of osteotomy was 49.0±8.8 years (range, 18-65). Of the 29 legs investigated in the study group, 23 were treated by an HTO, and 6 were treated by a distal femoral osteotomy. An average 115.2±79.3 months (range, 13-387) elapsed until implantation of the cemented Columbus knee prosthesis with deep-dish, cruciate-retaining inlay (Aesculap AG, Tuttlingen, Germany) using Orthopilot navigation (Aesculap AG) with the software module TKA 4.2.

After a midline skin incision, the standard medial parapatellar capsular approach was used in all cases. Based on intraoperatively recorded kinematic data of the leg, the navigation computer determines the leg’s load axis. Palpating relevant anatomic structures with the pointer, the implant bed and the implant position can be calculated precisely, ensuring precise, computer-controlled positioning of the cutting blocks. Using the tibia-first technique, the tibial resection was performed with 0° varus/valgus slope (90°, mechanical medial proximal tibial angle [mMPTA]) and 0° anterior/posterior slope. After the removal of the osteophytes, the extension and flexion gap were measured and the femur resection was planned. The bone resections were matched to implant thicknesses to restore the original joint line level. If a soft tissue release was necessary, the gaps were registered again. The main focus in this planning step was placed on ligamentous balancing and less focus was on achieving the safe zone (≤3° varus or valgus deviation of the femoral component from the 0° mechanical femoral axis). As a consequence of this compromise, soft tissue problems of medio-lateral collateral ligaments were solved with bone resections if necessary. Patellar resurfacing was not undertaken.

The age of the patients at the time of TKA implantation was 59.5±7.5 years (range, 48-76). Patients in the control group were 59.1±7.2 years (range, 49-74) at the time of TKA. The patients in both groups were matched by age at TKA implantation (±12 months), follow-up period (±2 months), indication for TKA implantation (varus/valgus osteoarthritis), and body mass index (±2.5 kg/m²).

The patients were examined clinically and radiologically. The Oxford Knee Score (OKS), activity score according to Tegner and Lysholm, and the Knee Society Score (KSS) were also determined.

As part of the physical examination, the range of motion (ROM) was measured using a goniometer. The ligamentous stability was verified by varus and valgus stress as well as anterior and posterior drawer test. Mediolateral stability was determined with the knee slightly bent and categorized into 4 levels according to opening (≤ 5°, 6°-9°, 10°-14°, and ≥15° deviation). The sagittal ligamentous stability was tested with knee bent at 90° and classified into 3 grades (<5 mm, 5-10 mm, and >10 mm translation). The investigations were performed by an examiner independently from the treatment process.

For radiological assessment, the radiographs from the study group were assessed before and after osteotomy, as well as before and after navigated TKA implantation. Radiographs for the control group were evaluated preoperatively and postoperatively. For each case, biplanar knee joint, tangential patella and long-leg standing radiographs were used. Based on the radiographs, the following parameters were defined: mechanical leg axis, mechanical lateral distal femur angle (mLDA), mMPTA, and the Insall-Salvati index.11 Signs of loosening and ossification were also assessed.

Data were sorted using an Excel table (Microsoft Corp, Redmond, Washington) and subsequently transmitted to GraphPad Prism version 5.0b statistical software (GraphPad Software Inc, La Jolla, California), and analyzed using JMP statistical discovery software (SAS Institute, Inc, Cary, North Carolina). The level of significance was defined as P<.05.

RESULTS
Clinical Examination
At the point of latest follow-up, ROM was comparable in both groups. In the study group, the extension was 0.8°±2.2° (range, 0°-5°) (control group: 0.6°±1.7° [range, 0°-5°]; P=.062) and flexion was...
115.0°±18.3° (range, 45°-150°) (control group: 108.0°±14.9° [range, 60°-130°]; P=0.087). The examination of the mediolateral ligamentous stability showed significant differences in both groups. In the study group, 3 legs were stable with ≤5° mediolateral deviation, 1 leg showed an opening of 6°-9°, 12 legs up to 14°, and 13 legs ≥15° (control group: 14 legs ≤5°, 9 legs 6°-9°, 5 legs up to 14°, and 1 leg ≥15° mediolateral deviation; P<0.001) (Figure 2). With respect to the sagittal ligamentous stability, 21 legs of the study group showed a translation of <5 mm, 7 legs a translation between 5 and 10 mm, and 1 leg >10 mm (control group: 18 legs <5 mm, 10 legs 5-10 mm, and 1 leg >10 mm translation; P=0.163) (Figure 3).

Responding to the question on general satisfaction, 9 patients in the study group stated they were extremely satisfied with the implanted knee prosthesis. Eight were very satisfied, 9 were satisfied, and 3 patients stated they were dissatisfied with the outcome of the implanted TKA. In the control group, 11 patients were extremely satisfied at the follow-up examination, 9 were very satisfied, 6 were satisfied, and 3 were dissatisfied (P=0.115) (Figure 4). The results of the OKS were 26.8±5.1 points (range, 20-42) in the study group and 27.0±6.1 points (range, 20-45) in the control group (P=0.604) (Figure 5). The results of Tegner and Lysholm activity score were comparable in both groups (study group: 3.0±1.1 points [range, 0-5]; control group: 3.1±1.1 0-5 points; P=0.331) (Figure 6). In the study group, the examined legs achieved 67.8±15.1 points (range, 36-95) in the KSS knee score (control group: 72.8±19.1 points [range, 33-100]; P=0.116) and 84.8±17.0 points (range, 45-100) in the KSS function score (control group: 85.5±14.1 points [range, 50-100]; P=0.982) (Figure 7).

Radiological Examination

In both groups, the axes were measured before and after TKA implantation. In particular, the varus valgus deviation of the mechanical 0° leg axis was evaluated. Preoperatively, the study legs showed an average varus valgus deviation of 4.2°±2.7° (range, 0°-11°) (control group: 5.3°±3.6° [range, 1°-14°]; P=0.153). After TKA implantation, the varus valgus
The current authors’ study showed no differences in patient satisfaction for the investigated groups. The main causes of dissatisfaction in both groups were primarily persistent pain and the resultant impairment of quality of life. The scores investigated (OKS, Tegner and Lysholm, and KSS) also showed no statistically relevant differences. Efe et al observed a significantly improved value in the KSS knee score in his control group.\(^8\) van Raaij et al and Amendola et al, in contrast, also showed no significantly different values when comparing their study and control groups.\(^12,13\)

Karabatsos et al and van Raaij et al observed a longer operation duration and associated complications in their study groups with TKA after prior osteotomy.\(^12,14\) Karabastos et al and Kazakos et al recorded a longer operation duration averaging 25 minutes.\(^14,15\) van Raaij et al documented more blood loss in the study patients and complications such as tibial tuberosity avulsions and a required increased lateral release.\(^12\) The study by Kossashvili et al, on the other hand, showed no significant difference in peri- and postoperative follow-up as well as in function or durability of the prosthesis.\(^16\) Farfalli et al described results showing 35% of patients who received a TKA following osteotomy experienced complications in follow-up.\(^9\) Notably, infection, instabilities, and persistent pain were among the main problems. In general, a longer operation time also means a longer duration of anesthesia. Particularly in older patients, the duration of surgery and anesthesia should be kept as short as possible to avoid transitional syndrome and other complications. Furthermore, the risk for infection increases with the duration of an operation.\(^17\)

In the current authors’ study, no relevant differences regarding the sagittal ligamentous stability was observed. A statistically relevant mediolateral ligamentous instability was apparent within the study group, however. Only 3 examined legs here were rated stable
deviation from the mechanical 0° leg axis for the study legs was 3.0°±2.3° (range, 0°-10°) (11 outliers with mechanical leg axis >3° varus or valgus). For the control legs, it was 3.4°±3.1° (range, 0°-11°) (15 outliers with mechanical leg axis >3° varus or valgus, \(P=.816\)). The study legs underwent an axis correction of 4.2°±2.7° (range, 0°-10°) preoperatively to 3.0°±2.3° (range, 0°-10°) postoperatively (\(P=.001\)). The control legs underwent correction from 5.3°±3.6° (range, 1°-14°) preoperatively to 3.4°±3.1° (range, 0°-10°) postoperatively (\(P<.001\)) (Table). In the study group, the mLDFA was corrected from 87.2°±4.4° (range, 82°-100°) preoperatively to 90.4°±3.2° (range, 82°-94°) postoperatively (\(P=0.009\)) (control group: 87.7°±5.2° [range, 82°-94°] preoperatively to 90.1°±3.0° [range, 88°-97°] postoperatively; \(P<.0001\)). Regarding mMPTA, the study legs underwent a correction from 91.1°±3.9° (range, 86°-97°) preoperatively to 87.5°±3.1° (range, 85°-92°) postoperatively, (\(P=0.0708\)); and the control legs from 86.7°±4.2° (range, 86°-94°) to 87.8°±3.2° (range, 85°-92°), (\(P=.432\)) (Table).

The assessment of the patella was based on the Insall-Salvati index. Comparison of the study and the control group showed no significant differences pre- and postoperatively (Table).

**DISCUSSION**

Osteotomies are applied more and more frequently in younger patients with unilateral osteoarthritis of the knee. The TKA implantation should be avoided or deferred. Some studies yield highly variable results. Some, such as Bae et al\(^7\), describe significantly improved leg axes after correction. Conversely, Meding et al could not establish a difference in outcome between the groups (TKA following osteotomy vs primary TKA).\(^10\)
in study group with ≤5° opening. In the control group, 14 examined legs were stable. In the study group, 12 legs had a mediolateral instability up to 14°, and 13 even had a mediolateral instability ≥15°. In the control group, only 5 legs showed a mediolateral instability up to 14°, and 1 leg had ≥15°. One certain cause of this is, firstly, a ligamentous release during the osteotomy. Second, when cutting and separating the bones, (open wedge) there is a large tensile load on the ipsilateral ligament. When closing an osseous gap (closed wedge), there is a tensile load on the contralateral ligament. In both cases, the overstressed ligament may provide insufficient support. These results correlate with a number of other studies such as Noda et al, Nelson et al, and Karabatsos et al.\(^ {14,18,19}\) In these studies, a significant ligamentous instability was shown in the study group as well, but no statistical significance could be shown.\(^ {14,18,19}\)

In the current authors’ study group, the mMPTA angle was 91.1°±3.9° (range, 86°-97°) (18 patient legs with mMPTA prior to TKA >90°). Experience has shown that in extreme purely high tibial osteotomies, an appropriate ligamentous release is necessary to prevent a medial hypercompression. This may explain the ligamentous instabilities found in both the current authors’ study and others.\(^ {12,14,18,19}\) It should be noted that a differential soft tissue release may subsequently be presented within the context of the osteotomy. When planning osteotomies, it is important to consider the mechanical leg alignment and the joint line. In the past, the current authors performed the osteotomies only regarding the mechanical alignment. This may be another reason that the current authors found in the current authors’ study significant laxity. In certain cases, a double osteotomy if applicable (combination of supracondylar distal femoral osteotomy and high tibial osteotomy) must also be considered to avoid generating pathological joint angles (mLDFA, mMPTA) that subsequently make the implantation of a properly balanced bicondylar TKA difficult or impossible.\(^ {20,21}\) It was striking in the current authors’ study that many patients did not display a subjective perception of instability. However, all patients describe an occasional

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<td><strong>Radiological Examination</strong></td>
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<th>Study Group Preoperative (N=29)</th>
<th>Control Group Preoperative (N=29)</th>
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<th>Study Group Postoperative (N=29)</th>
<th>Control Group Postoperative (N=29)</th>
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<tr>
<td>Deviation of mechanical leg axis from 0° alignment, mean±SD (range), deg</td>
<td>4.2±2.7 (0-11)</td>
<td>5.3±3.6 (1-14)</td>
<td>.153</td>
<td>3.0±2.3 (0-10)</td>
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<td>mL DFA, mean±SD (range), deg</td>
<td>87.2±4.4 (82-100)</td>
<td>87.7±5.2 (82-94)</td>
<td>.081</td>
<td>90.4±3.2 (86-92)</td>
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<td>mMPTA, mean±SD (range), deg</td>
<td>91.1±3.9 (86-97)</td>
<td>86.7±4.2 (86-94)</td>
<td>.053</td>
<td>87.5±3.1 (85-92)</td>
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<td>87.8±3.2 (85-92)</td>
<td>.0708</td>
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<td>Insall-Salvati Index, mean±SD (range), deg</td>
<td>0.9±0.2 (0.8-1.1)</td>
<td>0.8±0.2 (0.7-1.1)</td>
<td>.058</td>
<td>0.9±1.0 (0.8-1.1)</td>
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<td>0.9±0.8 (0.7-1.2)</td>
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<td>Abbreviations: mL DFA, mechanical lateral distal femur angle; mMPTA, mechanical medial proximal tibia angle. The results are shown as mean±SD (minimum - maximum) as well as P values. In the respective first line, the study group is compared with the control group pre- and/or postoperatively. In the respective second and third lines, the study group is compared with the control group. The intragroup comparisons of pre- and postoperative results are shown.</td>
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buckling of the affected leg when asked targeted questions.

The purely clinical examination of ligamentous stability in the current authors’ study, as in other studies, is certainly a weakness in the study design.\(^8\mn10\mn12\) However, all investigations within the current authors’ study were performed by the same experienced examiner.

During the assessment of ligamentous stability after TKA with or without prior osteotomy, the respective implanted knee arthroplasty system must also be evaluated. For this reason, various working groups, such as Efe et al., routinely implanted prostheses systems with a posterior-stabilized design.\(^8\) In the current authors’ patient population as well as in the study by Raaij et al., a CR inlay was used as the standard.\(^12\)

There was a larger varus/valgus deviation from the neutral mechanical leg axis shown from preoperative radiology in the control legs (5.3°±3.6° [range, 1°-14°]) as well as in the study legs (4.2°±2.7° [range, 0°-11°]) before TKA implantation. This can certainly be explained by the prior osteotomy in the study group. The desired alignment (≤3° varus or valgus deviation from the 0° mechanical leg axis) was achieved in 18 legs in the study group and 13 legs in the control group during the navigated TKA implantation. A comparison with the literature is difficult here as, in the studies by Efe et al and van Raaij et al, the deviation from the anatomical axis was evaluated.\(^8\mn12\) In addition, neither the anatomical axes after TKA implantation nor the outliers from the desired alignment were specified in the 2 studies.\(^8\mn12\)

In the current authors’ patient population, in the past, the main focus during TKA implantation was placed on ligamentous balancing and less focus was placed on achieving the safe zone (≤3° varus or valgus deviation from the 0° mechanical leg axis). This explains the number of outliers, particularly in the study group.

The frequency of nonprogressive 1- to 2-mm radiolucent lines in the region of the proximal medial tibial plateau in 16 legs in the study group and 12 legs of the control group was striking in comparison to the study by Efe et al.\(^8\) Generally the occurrence of radiolucent lines has been discussed as the sclerotic process of the bone in the context of osteoarthritis development, resulting in the insufficient interdigitation of the cement during TKA, for example in the control group. In the study group, the medial radiolucent lines could also be a consequence of the osteotomy as the newly formed bone may be more dense and sclerotic in the context of bone healing after medial tibial osteotomy.

**CONCLUSION**

In the future, the current authors certainly need further randomized and prospective studies with higher numbers of cases to verify the data. In principle, however, a sophisticated surgical plan must be undertaken for the osteotomy to avoid generating pathological joint angles (mMPTA, mL DFA) due to an extended ligamentous release during the osteotomy. The possibility of subsequent TKA implantation should be considered at the time of osteotomy and included in the osteotomy planning.

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