Original Article

Encouraging treatment algorithm for computer-assisted navigated total knee arthroplasty (TKA)[☆] A retrospective cohort analysis

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ABSTRACT

Objective: Navigated computer-assisted total knee arthroplasty (TKA) shows inconclusive mid- to long-term outcome results and is limited by increased costs, surgery-time and an additional learning curve. We introduced a treatment algorithm preserving computer-assisted TKA for patients with adipositas-per-magna, posttraumatic leg-deformities, osteosynthetic material in-situ or reduced preoperative X-ray quality.

Methods: 237 primary unilateral TKA were allocated based on the treatment concept described above. A retrospective pre- and postoperative radiological analysis was performed.

Results: 222 TKA (93.7%) were within 3° varus/valgus of mechanical-lower-limb axis (mean absolute deviation: 1.8° ± 1.3°).

Conclusion: This algorithm showed an excellent postoperative implantation-accuracy based on an accurate preoperative surgery-planning.

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1. Introduction

Computer-assisted navigation systems for total knee arthroplasty (TKA) were introduced mainly to improve implantation accuracy and ligament balancing management. A better clinical and functional outcome with a higher long-term survival rate was expected. Over the past five to ten years, several studies were published comparing navigated computer-assisted TKA with the conventional non-navigated technique.^{1–5} Many authors verified an improved implantation accuracy when using the navigation technique.^{1,3,4,6} This was even confirmed by recent published

meta-analyses.^{7–10} However, there are also several articles available reporting no improved reconstruction of mechanical lower limb axis when using computer-assisted navigation systems.^{11–13} Although a maximum deviation of 3° varus or valgus was recognized as fundamental for long-term survival,^{14–16} recent published articles verified that there is no direct influence of exact reconstructed mechanical axis within 3° varus/valgus on TKA long-term survival rate.^{17,18}

In addition, there are only few trials available comparing navigated with conventional TKA with a postoperative follow-up term of 5 to 10 years or more.^{5,19–23} Kim et al. ²² reported no difference in implant survival rate after a mean follow-up term of 10.8 years. Similar results were reported by Hernandez-Vaquero et al. ²¹ after a mean postoperative follow-up of 8.3 years. Both authors verified no significant differences in femoro-tibial angle alignment between navigated and conventional TKA group.^{21,22} Lützner et al. ²⁰ showed no clinical benefit for computer-assisted technique in terms of functional or patient perceived outcome after 5 years postoperatively. Similar results were published by Harvie et al. ¹⁹. Hoffart et al. ²³ revealed a better Knee Society Score for navigated TKA after 5 years. In a randomized controlled

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trial Cip et al. obtained a significant improved lower limb axis with partially better score results for the navigated cohort.⁵ However, no benefit on implant survival rate after a minimum postoperative follow-up of 5 years was found.⁵

Due to obvious limitations of the navigated computer-assisted technique (e.g. additional learning curve,^{24,25} additional costs,²⁶ an enhanced surgery time²²) and the inconclusive study results published so far, the benefit of navigation systems for TKA is still not clear. Hence, a treatment algorithm was introduced in our institution where the computer-assisted technique was only used for primary TKA in case of adipositas per magna, posttraumatic leg deformities, osteosynthetic material in situ or reduced preoperative radiological X-ray quality due to flexion contracture or rotational disorders. In all other cases, the conventional non-navigated technique was used for primary TKA.

In the current study, the main aim was to evaluate, whether optimal TKA alignment was achieved even when the navigated technique was preserved for the described indications above. In addition, we also compared computer-assisted navigated TKA (navigated: group NAV) with the conventional non-navigated TKA (regular: group REG) to reveal differences in postoperative implantation accuracy.

2. Methods

This study represents a retrospective radiological analysis of all primary TKA implanted consecutively within 6 years (July 2005–June 2011). In order to address influences by any learning curve, all procedures were performed by one single surgeon (AM) who was well-experienced in both conventional and navigated computer-assisted technique. Inclusion criteria for this trial were defined as follows: primary, unilateral TKA; only non-constraint TKA; procedure performed by one single surgeon (AM). Patients with a bilateral or constraint TKA and all revision procedures as well as subjects with missing pre- or postoperative long-leg weight bearing radiographs were excluded for this analysis. Overall, 256 primary non-constraint unilateral TKA were performed within July 2005 to June 2011. 19 patients were excluded due to missing pre- and/or postoperative radiologic data. Hence, we were able to include 237 TKAs (92.6%) for this retrospective data analysis. This study was approved by the institutional review board.

All implants were non-constraint NexGen[®] Legacy Posterior Stabilized Flex mobile or fixed bearing knees (LPS Flex; Zimmer Inc., IL, USA). All surgeries were performed with a tibia first technique. For the alignment of the tibial tray an extramedullary instrument system was used. An intramedullary technique was used for implantation of the femoral component. Due to our treatment algorithm, navigated computer-assisted TKA was preserved for patients with adipositas per magna (BMI ≥ 40),

posttraumatic leg deformities, osteosynthetic material in situ (e.g. femur nail), a reduced preoperative X-ray quality in case of flexion contracture of the knee or rotational disorders.

The CT-free VectorVision[®] knee navigation system (BrainLAB, Munich, Germany) was used for computer-assisted TKA. In case of a severe valgus deformity ($>10^\circ$) in conjunction with a contract lateral collateral ligament situation a lateral surgical approach was performed.²⁷ Baseline characteristics at time of primary TKA were obtained including gender (female, male), age (years), body mass index (BMI, kg/m²), side of implantation (right, left) and the American Association of Anesthesia (ASA) Classification (Table 1).²⁸

For radiological investigation conventional X-rays of TKA were taken in anterior-posterior (including a long leg weight-bearing X-ray), lateral and axial view. Radiographs taken 6 months pre- and at least 3 months postoperatively were included for radiological analysis. If long-leg weight bearing X-rays were missing patients were excluded for this report. Preoperative radiological data is listed in Table 2.

We measured the mechanical lower limb axis (mechanical femorotibial angle), lateral distal femoral angle (LDFA) and medial proximal tibial angle (MPTA) in frontal plane.^{5,29} In addition the tibial slope in sagittal plane and patella alpha (α) tilt angle in 45° flexion in transversal view was observed.^{30,31}

A mechanical lower limb axis within 3° varus or valgus deformity was defined as optimum.^{14–16} Tibial slope of 7° (within 4° – 10°) respectively 83° (86° – 80°) in relation to mechanical axis of the tibia was considered as reference value. For patella alpha angle a positive angle was declared as normal, 0° or negative angles were considered as subluxation or luxation of the patella.^{30,31} Data was also compared within conventional and computer-assisted navigated technique.

For statistical analysis SPSS software (Version 17, IL, USA) was used. To assume normal distributed data the Kolmogorov-Smirnoff test was performed. If data was normal distributed Levene's test followed by an independent *t*-test was used. Skewed and categorical data was compared using Mann-Whitney *U* test. Fisher's exact test or Chi-square test was performed comparing nominal data. Intra- and interobserver reliability was calculated using the Intraclass Correlation Coefficient (ICC, two-way mixed model).

3. Results

Overall 222 (93.7%) of 237 TKA were within an optimal mechanical lower limb axis with a maximum deviation of 3° varus or valgus. Considering a maximum deviation of 4° varus/valgus, 227 (95.8%) of 237 TKA were within this range. The absolute deviation from neutral mechanical lower limb axis was $1.8^\circ \pm 1.3^\circ$

Table 1
Demographic Data.

Parameter		Overall (n = 237)	Navigated Group (n = 60)	Conventional Group (n = 177)	p-value
Gender (n)	female	155 (65.4%)	46 (76.7%)	109 (61.6%)	p = 0.041*
	male	82 (34.6%)	14 (23.3%)	68 (38.4%)	
Side of TKA (n)	right	124 (52.3%)	33 (55.0%)	91 (51.4%)	p = 0.656
	left	113 (47.7%)	27 (45.0%)	86 (48.6%)	
ASA Classification (n)	ASA I	42 (17.7%)	5 (8.3%)	37 (20.9%)	p = 0.158
	ASA II	165 (69.6%)	48 (80.0%)	117 (66.1%)	
	ASA III	30 (12.7%)	7 (11.7%)	23 (13.0%)	
Age (years)		69.3 $\pm$ 8.8 (40.9–87.3)	67.4 $\pm$ 8.6 (46.2–85.3)	70.0 $\pm$ 8.8 (40.9–87.3)	p = 0.055
Body Mass Index (kg/m²)		30.6 $\pm$ 6.4 (19.7–56.9)	34.8 $\pm$ 8.3 (21.8–56.9)	29.2 $\pm$ 4.8 (19.7–44.3)	p < 0.001*

Values are presented as mean $\pm$ standard deviation (minimum–maximum).

* = significant different; ASA = American Society of Anesthesiologists; TKA = Total Knee Arthroplasty

Table 2
Preoperative Radiologic Data .

Parameter	Overall (n = 237)	Navigated Group (n = 60)	Conventional Group (n = 177)	p-value
Relative deviation of neutral mechanical limb axis (- val; + = var)				
mean ± SD	5.4 ± 6.9	6.6 ± 6.7	4.9 ± 6.9	p = 0.103
max. valgus; max. varus	−16.0; 26.0	−11.0; 24.0	−16.0; 26.0	
Absolute deviation of neutral mechanical limb axis				
mean ± SD	7.3 ± 4.7	7.7 ± 5.3	7.2 ± 4.4	p = 0.484
min.; max.	0.0; 26.0	0.0; 24.0	0.0; 26.0	
neutral	6 (2.5%)	2 (3.3%)	4 (2.3%)	p = 0.858
varus	188 (79.3%)	48 (80.0%)	140 (79.1%)	
valgus	43 (18.1%)	10 (16.7%)	33 (18.6%)	

(0–8°). Accordingly, the relative deviation was $0.7^\circ \pm 2.1^\circ$ with a maximum valgus deviation of 5.0° and a maximum varus deviation of 8.0° .

Mean postoperative LDFA was $90.7^\circ \pm 1.5^\circ$ (86–96°) with an absolute deviation of $1.2^\circ \pm 1.1^\circ$ (0–6°) from 90° LDFA. 230 (97.0%) of 237 TKA were within 3° varus/valgus deformity and 235 (99.2%) within 4° varus/valgus deviation. For MPTA a mean postoperative value of $89.9^\circ \pm 1.7^\circ$ (81–96°) was obtained with a mean absolute

deviation from 90° MPTA of $1.2^\circ \pm 1.2^\circ$ (0–9°). 230 (97.0%) of 237 TKA were within 3° varus/valgus inaccuracy and 234 (98.7%) were within 4° varus/valgus deviation.

Postoperative tibial slope evaluation revealed a mean value of $6.3^\circ \pm 2.0^\circ$ (2–12°) with an absolute deviation of $1.7^\circ \pm 1.4^\circ$ (0–5°). For patella alpha angle a mean value of $10.0^\circ \pm 3.9^\circ$ (1–22°) was found. (Table 3)

Table 3
Postoperative Radiologic Data

Parameter	Overall Group (n = 237)	Navigated Group (n = 60)	Conventional Group (n = 177)	p-Values
Postoperative mechanical lower limb axis				
within 3° varus/valgus	222 (93.7%)	57 (95.0%)	165 (93.2%)	p = 0.766
> 3° varus/valgus	15 (6.3%)	3 (5.0%)	12 (6.8%)	
within 4° varus/valgus	227 (95.8%)	58 (96.7%)	169 (95.5%)	p > 0.999
> 4° varus/valgus	10 (4.2%)	2 (3.3%)	8 (4.5%)	
neutral	32 (13.5%)	8 (13.3%)	24 (13.6%)	p = 0.948
varus	130 (54.9%)	32 (53.3%)	98 (55.4%)	
valgus	43 (31.6%)	20 (33.3%)	55 (31.1%)	
Relative deviation of neutral mechanical lower limb axis (- val; + = var;)	0.7 $\pm$ 2.1 (-5 to 8)	0.4 $\pm$ 2.2 (-5 to 8)	0.8 $\pm$ 2.0 (-5 to 7)	p = 0.157
Absolute deviation of neutral mechanical lower limb axis	1.8 $\pm$ 1.3 (0–8)	1.8 $\pm$ 1.4 (0–8)	1.8 $\pm$ 1.3 (0–7)	p = 0.950
Lateral Distal Femoral Angle (LDFA)				
within 3° varus/valgus	90.7 $\pm$ 1.5 (86–96)	90.4 $\pm$ 1.6 (87–95)	90.8 $\pm$ 1.5 (86–96)	p = 0.053
> 3° varus/valgus	230 (97.0%)	58 (96.7%)	172 (97.2%)	p > 0.999
	7 (3.0%)	2 (3.3%)	5 (2.8%)	
within 4° varus/valgus	235 (99.2%)	59 (98.3%)	176 (99.4%)	p = 0.443
> 4° varus/valgus	2 (0.8%)	1 (1.7%)	1 (0.6%)	
neutral	65 (27.4%)	18 (30.0%)	47 (26.6%)	p = 0.425
varus	127 (53.6%)	28 (46.7%)	99 (55.9%)	
valgus	45 (19.0%)	14 (23.3%)	31 (17.5%)	
Relative deviation of 90° LDFA (- = val; + = var)	0.7 $\pm$ 1.5 (-4 to 6)	0.4 $\pm$ 1.6 (-3 to 5)	0.8 $\pm$ 1.5 (-4 to 6)	p = 0.053
Absolute deviation of 90° LDFA	1.2 $\pm$ 1.1 (0–6)	1.2 $\pm$ 1.1 (0–5)	1.3 $\pm$ 1.1 (0–6)	p = 0.637
Medial Proximal Tibial Angle (MPTA)				
within 3° varus/valgus	89.9 $\pm$ 1.7 (81–96)	90.0 $\pm$ 1.6 (87–96)	89.9 $\pm$ 1.8 (81–94)	p = 0.737
> 3° varus/valgus	230 (97.0%)	59 (98.3%)	171 (96.6%)	p = 0.682
	7 (3.0%)	1 (1.7%)	6 (3.4%)	
within 4° varus/valgus	234 (98.7%)	59 (98.3%)	175 (98.9%)	p > 0.999
> 4° varus/valgus	3 (1.3%)	1 (1.7%)	2 (1.1%)	
neutral	67 (28.3%)	19 (31.7%)	48 (27.1%)	p = 0.795
varus	95 (40.1%)	23 (38.3%)	72 (40.7%)	
valgus	75 (31.6%)	18 (30.0%)	57 (32.2%)	
Relative deviation of 90° MPTA (- = var; + = val)	-0.1 $\pm$ 1.7 (-9 to 6)	0.0 $\pm$ 1.6 (-3 to 6)	-0.1 $\pm$ 1.8 (-9 to 4)	p = 0.737
Absolute deviation of 90° MPTA	1.2 $\pm$ 1.2 (0–9)	1.1 $\pm$ 1.1 (0–6)	1.3 $\pm$ 1.2 (0–9)	p = 0.400
Tibial slope	6.3 $\pm$ 2.0 (2–12)	6.1 $\pm$ 2.2 (2–12)	6.3 $\pm$ 2.0 (2–12)	p = 0.406
Absolute deviation to 7° tibial slope	1.7 $\pm$ 1.4 (0–5)	1.8 $\pm$ 1.5 (0–5)	1.6 $\pm$ 1.3 (0–5)	p = 0.473
Patella alpha angle	10.0 $\pm$ 3.9 (1–22)	10.4 $\pm$ 4.0 (1–18)	9.9 $\pm$ 3.9 (1–22)	p = 0.408

Values are presented as mean $\pm$ standard deviation (minimum–maximum).

val = valgus; var = varus.

Postoperatively there were no significant differences within navigated and conventional group. There were no statistical differences regarding absolute ($1.8^\circ \pm 1.4^\circ$ in group NAV versus $1.8^\circ \pm 1.3^\circ$ in group REG, $p=0.950$) or relative deviation ($0.4^\circ \pm 2.2^\circ$ versus $0.8^\circ \pm 2.0^\circ$ in group REG, $p=0.157$) from postoperative neutral mechanical lower limb axis. Same number of patients were within a maximal deviation of 3° varus or valgus from neutral mechanical lower limb axis ($p=0.766$) respectively within a maximum deviation of 4° varus/valgus ($p > 0.999$). (Fig. 1)

Mean postoperative LDFA was $90.4^\circ \pm 1.6^\circ$ in navigated versus $90.8^\circ \pm 1.5^\circ$ in conventional group ($p=0.053$). There were also no statistical differences within mean absolute deviation ($1.2^\circ \pm 1.1^\circ$ versus $1.3^\circ \pm 1.1^\circ$, $p=0.637$) from 90° LDFA. Same number of patients were within a maximum deviation of 3° respectively 4° varus/valgus inaccuracy ($p > 0.443$). (Fig. 2)

Similar results were found for postoperative MPTA in frontal plane. Mean MPTA was $90.0^\circ \pm 1.6^\circ$ versus $89.9^\circ \pm 1.8^\circ$ in group REG ($p=0.737$). Mean absolute deviation of 90° MPTA was $1.1^\circ \pm 1.1^\circ$ versus $1.3^\circ \pm 1.2^\circ$ in group REG ($p=0.400$). Same number of patients were within 3° respectively 4° varus/valgus MPTA deformity ($p > 0.682$). (Fig. 3)

No statistical differences were found for both tibial slope and patella alpha angle. Tibial slope showed a mean value of $6.1^\circ \pm 2.2^\circ$ in group NAV versus $6.3^\circ \pm 2.0^\circ$ in group REG ($p=0.406$). Mean absolute deviation from 7° tibial slope was $1.8^\circ \pm 1.5^\circ$ versus $1.6^\circ \pm 1.3^\circ$ in group REG. ($p=0.473$). Patella alpha angle showed a mean value of $10.4^\circ \pm 4.0^\circ$ in group NAV versus $9.9^\circ \pm 3.9^\circ$ in group REG ($p=0.408$). (Table 3)

Intra- and interobserver reliability was measured with Intra-class Correlation Coefficient (ICC; two-way mixed model) and showed a high correlation of 0.9493 and 0.8770, respectively.

4. Discussion

Computer-assisted navigated total knee arthroplasty (TKA) was shown to result in higher implantation accuracy compared to the conventional TKA technique.^{1,3,4,6–10} This was in contrast to the

findings of several other studies.^{11–13} However, there is still no consensus, whether an exact reconstructed mechanical lower limb axis is essential to end up in a higher long-term survival rate with an improved clinical outcome.^{14–18} To the best of our knowledge, there are only few recent published articles available reporting on clinical outcome data and survival rate after a postoperative follow-up rate of 5–10 years or more.^{5,19–22} Kim et al.²² and Hernandez-Vaquero et al.²¹ could not find any differences when comparing conventional with navigated TKA after 10.8 respectively 8.3 years postoperatively. Lützner et al. verified no differences in terms of functional or patient perceived outcome after 5 years postoperatively.²⁰ Due to inconclusive study results and obvious limitations of the navigated implantation technique (increased surgery time²², relevant costs²⁶, additional learning curve^{24,25}) we introduced a treatment algorithm for navigated computer-assisted TKA in our institution. To the best of our knowledge, this is one of the first studies published so far reporting on radiological outcome data where navigated TKA was preserved for special indications as described above.

This trial was restricted by several limitations. First, this report is limited due to the retrospective study design. However, for our main study question a high follow-up rate of 92.6% was achieved. Second, because we performed a retrospective radiological analysis, no clinical data or survival rate was collected. Nevertheless, the results of the current trial based on its study design are unique and have not been published before. Hence, we think that our retrospective radiological outcome data is an important addendum to the current available literature about navigated TKA. Both conventional and computer-assisted implantation techniques have a learning curve that was accounted for in the current trial.^{24,25} All procedures were performed by one orthopedic surgeon (AM) who was well experienced with both the conventional and navigated technique. Confalonieri et al.²⁵ described that the break-even point after which no difference is observed within a beginner and an expert surgeon using computer-assisted TKA occurs after a learning curve of at least 16 cases. However, our results and the described concept for

Fig. 1. Postoperative Deviation from Neutral Mechanical Lower Limb Axis.

Postoperative Deviation from Neutral Lateral Distal Femoral Angle (LDFA)

Fig. 2. Postoperative Deviation from Neutral Lateral Distal Femoral Angle (LDFA).

Postoperative Deviation from Neutral Medial Proximal Tibial Angle (MPTA)

Fig. 3. Postoperative Deviation from Neutral Medial Proximal Tibial Angle (MPTA).

computer-assisted TKA may not be conferrable for surgeons, who are still within the learning curve of both the conventional or navigated technique.

There may be institutions where primary TKA is only performed under support of the navigated technique. Nicholson et al. 32 already described a re-learning curve for returning to conventional total knee arthroplasty after performance of a series of computer-assisted TKA. We think that the computer-assisted TKA is no substitution of conventional surgical technique for TKA but an additional tool for primary total knee replacement. There may occur situations, where navigated TKA may fail during surgery and conversion to the conventional implantation technique is necessary. Hence, all surgeons offering computer-assisted TKA should be familiar with the conventional technique and vice versa. We see the navigated TKA as an important adjuvant especially for patients where reconstruction of an exact lower-limb axis with conventional extra- or intramedullary devices may be difficult due to severe obesity, preoperative bone deformity, osteosynthetic implants in situ or reduced preoperative radiological X-ray quality in case of flexion contractures or rotational disorders. For those patients, computer-assisted technique is a helpful tool. Introducing this treatment algorithm, we end up in a perfect postoperative implant alignment, as our data has shown. Including all navigated and conventional TKA we had an excellent implantation accuracy of 93.7% within $\pm 3^\circ$ respectively 95.8% within 4° varus or valgus deviation from neutral mechanical lower limb axis. The mean absolute deviation from neutral lower limb axis was 1.8° .

Kim et al. 22 reported a lower amount of patients to be within 3° varus/valgus of lower limb alignment in both navigated (89%) and conventional (87%) group. Hoffart et al. 23 published 86.5% in the conventional group and 87.6% in the navigated cohort to be within 3° varus/valgus of lower limb alignment. The encouraging radiological results of the current study may confirm our treatment concept that navigated computer-assisted TKA can be favored especially for those patients as described before. In all other cases optimal component alignment can also be achieved with the conventional non-navigated technique.

Encouraging results were also found for both LDFA and MPTA. All evaluations showed at least 97.0% to be within 3° or 4° varus/valgus deviation from 90° LDFA or MPTA. The absolute mean deviation of 90° LDFA or MPTA was 1.2° . These results were superior in comparison to both conventional and navigated cohort of Kim et al. 22. In contradiction Hernandez-Vaquero et al. 21 published an improved mean deviation of 0.69° for the femoral and 0.96° for the tibial component in coronal plane. In the current analysis we revealed a mean absolute deviation of 1.7° from 7° tibial slope. However, due to different definitions of an optimal tibial slope comparison of literature is difficult.

The comparison of conventional with navigated TKA in the current analysis revealed no differences for all parameters. Excellent implantation accuracy was achieved in both study cohorts in both frontal and sagittal plane. In both groups mean absolute deviation of neutral mechanical lower limb axis was 1.8° . At least 95.8% were within 3° or 4° varus or valgus deviation. Similar results were found for MPTA, LDFA and tibial slope. However, in both groups there were preoperative lower limb deformities with a deviation of at least 24° varus or valgus. Nevertheless, postoperative data showed no statistical differences in frontal plane within both groups. This may confirm, that even for strong valgus or varus deviations an excellent postoperative alignment can be achieved with the conventional implantation technique as good as with the navigated technique. In a previously published randomized controlled trial Cip et al. compared 100 navigated with 100 conventional TKA. 5 A significant better reconstruction of the mechanical lower limb axis was found for the computer-assisted navigated TKA group. 5 This was in

contradiction to the current study results. The single surgeon study design, the treatment concept that navigated TKA was preserved for special indications and the different amount of navigated respectively conventional TKA in the current analysis may account for differences in study results. However, we performed an inter- and intraobserver reliability analysis that showed an excellent match with 0.9493 and 0.8770, respectively. This data may underline the accuracy of our postoperative radiological outcome measurements.

To summarize, we are reporting on data based on a treatment concept for TKA where the navigated computer-assisted technique was only used in patients with adipositas per magna, posttraumatic leg deformities, osteosynthetic material in situ or reduced preoperative radiological X-ray quality due to flexion contracture or rotational disorders. The encouraging current study results underline that this algorithm is an excellent treatment option for orthopedic surgeons in order to address obvious limitations of the navigated computer-assisted implantation technique. With conventional implantation technique, excellent TKA implantation results are possible based on an accurate preoperative surgery planning. Further clinical and survival rate analyses are necessary to confirm these radiological study results.

Conflict of interests & funding

On behalf of all authors, the corresponding author states that there is no conflict of interests.

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Compliance with ethical standards

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. Due to the retrospective study design, no informed consent was necessary.

References

1. Martin A, Wohlgenannt O, Prens M, Oelsch C, von Strempel A. Imageless navigation for TKA increases implantation accuracy. *Clin Orthop Relat Res*. 2007;460:178–184. [10.1097/BLO.0b013e31804ea45f](https://doi.org/10.1097/BLO.0b013e31804ea45f).
2. Matziolis G, Krockner D, Weiss U, Tohtz S, Perka C. A prospective, randomized study of computer-assisted and conventional total knee arthroplasty. Three-dimensional evaluation of implant alignment and rotation. *J Bone Joint Surg Am*. 2007;89(2):236–243. [10.2106/JBJS.F.00386](https://doi.org/10.2106/JBJS.F.00386).
3. Hernández-Vaquero D, Suarez-Vazquez A, Sandoval-García MA, Noriega-Fernández A. Computer assistance increases precision of component placement in total knee arthroplasty with articular deformity. *Clin Orthop Relat Res*. 2010;468(5):1237–1241. [10.1007/s11999-009-1175-1](https://doi.org/10.1007/s11999-009-1175-1).
4. Haaker RG, Stockheim M, Kamp M, Proff G, Breitenfelder J, Ottersbach A. Computer-assisted navigation increases precision of component placement in total knee arthroplasty. *Clin Orthop Relat Res*. 2005;433:152–159. <http://www.ncbi.nlm.nih.gov/pubmed/15805951>. Accessed 12, March, 2014].
5. Cip J, Widemschek M, Luegmair M, Sheinkop MB, Benesch T, Martin A. Conventional versus computer-Assisted technique for total knee arthroplasty: a minimum of 5-Year follow-up of 200 patients in a prospective randomized comparative trial. *J Arthroplasty*. 2014;29(May):1795–1802. [10.1016/j.arth.2014.04.037](https://doi.org/10.1016/j.arth.2014.04.037).
6. Sparmann M, Wolke B, Czupalla H, Banzer D, Zink A. Positioning of total knee arthroplasty with and without navigation support. A prospective, randomised study. *J Bone Joint Surg Br*. 2003;85(6):830–835. <http://www.ncbi.nlm.nih.gov/pubmed/12931800>. Accessed 08, March 2014].
7. Bauwens K, Matthes G, Wich M, et al. Navigated total knee replacement. A meta-analysis. *J Bone Joint Surg Am*. 2007;89(2):261–269. [10.2106/JBJS.F.00601](https://doi.org/10.2106/JBJS.F.00601).
8. Burnett RSJ, Barrack RL. Computer-assisted total knee arthroplasty is currently of no proven clinical benefit: a systematic review. *Clin Orthop Relat Res*. 2013;471(1):264–276. [10.1007/s11999-012-2528-8](https://doi.org/10.1007/s11999-012-2528-8).

9. Cheng T, Zhao S, Peng X, Zhang X. Does computer-assisted surgery improve postoperative leg alignment and implant positioning following total knee arthroplasty? A meta-analysis of randomized controlled trials? *Knee Surg Sports Traumatol Arthrosc.* 2012;20(7):1307–1322.10.1007/s00167-011-1588-8.
10. Hetaimish BM, Khan MM, Simunovic N, Al-Harbi HH, Bhandari M, Zalzal PK. Meta-analysis of navigation vs conventional total knee arthroplasty. *J Arthroplasty.* 2012;27(6):1177–1182.10.1016/j.arth.2011.12.028.
11. Yau WP, Chiu KY, Zuo JL, Tang WM, Ng TP. Computer navigation did not improve alignment in a lower-volume total knee practice. *Clin Orthop Relat Res.* 2008;466(4):935–945.10.1007/s11999-008-0144-4.
12. Kim Y-H, Kim J-S, Choi Y, Kwon O-R. Computer-assisted surgical navigation does not improve the alignment and orientation of the components in total knee arthroplasty. *J Bone Joint Surg Am.* 2009;91(1):14–19.10.2106/JBJS.G.01700.
13. Lützner J, Krummenauer F, Wolf C, Günther K-P, Kirschner S. Computer-assisted and conventional total knee replacement: a comparative, prospective, randomised study with radiological and CT evaluation. *J Bone Joint Surg Br.* 2008;90(8):1039–1044.10.1302/0301-620X.90B8.20553.
14. Lörer I, Plitz W. Tibial malalignment of mobile-bearing prostheses? a simulator study. *Orthopade.* 2003;32(4):296–304.10.1007/s00132-002-0440-8.
15. Rand JA, Coventry MB. Ten-year evaluation of geometric total knee arthroplasty. *Clin Orthop Relat Res.* 1988;232:168–173 [<http://www.ncbi.nlm.nih.gov/pubmed/3383484>. Accessed 02, February 2014].
16. Ritter MA, Faris PM, Keating EM, Meding JB. Postoperative alignment of total knee replacement. Its effect on survival. *Clin Orthop Relat Res.* 1994;299:153–156 [<http://www.ncbi.nlm.nih.gov/pubmed/8119010>. Accessed 06, March 2014].
17. Bonner TJ, Eardley WGP, Patterson P, Gregg PJ. The effect of post-operative mechanical axis alignment on the survival of primary total knee replacements after a follow-up of 15 years. *J Bone Joint Surg Br.* 2011;93(9):1217–1222.10.1302/0301-620X.93B9.26573.
18. Parratte S, Pagnano MW, Trousdale RT, Berry DJ. Effect of postoperative mechanical axis alignment on the fifteen-year survival of modern, cemented total knee replacements. *J Bone Joint Surg Am.* 2010;92(12):2143–2149.10.2106/JBJS.L.01398.
19. Harvie P, Sloan K, Beaver RJ. Computer navigation vs conventional total knee arthroplasty: five-year functional results of a prospective randomized trial. *J Arthroplasty.* 2012;27(5):667–672.10.1016/j.arth.2011.08.009 [e1].
20. Lützner J, Dixel J, Kirschner S. No difference between computer-assisted and conventional total knee arthroplasty: five-year results of a prospective randomised study. *Knee Surg Sports Traumatol Arthrosc.* 2013;21(10):2241–2247.10.1007/s00167-013-2608-7.
21. Hernández-Vaquero D, Suarez-Vazquez A, Iglesias-Fernandez S. Can computer assistance improve the clinical and functional scores in total knee arthroplasty? *Clin Orthop Relat Res.* 2011;469(12):3436–3442.10.1007/s11999-011-2044-2.
22. Kim Y-H, Park J-W, Kim J-S. Computer-navigated versus conventional total knee arthroplasty a prospective randomized trial. *J Bone Joint Surg Am.* 2012;94(22):2017–2024.10.2106/JBJS.L.00142.
23. Hoffart H-E, Langenstein E, Vasak N. A prospective study comparing the functional outcome of computer-assisted and conventional total knee replacement. *J Bone Joint Surg Br.* 2012;94(2):194–199.10.1302/0301-620X.94B2.27454.
24. Manzotti A, Cerveri P, De Momi E, Pullen C, Confalonieri N. Relationship between cutting errors and learning curve in computer-assisted total knee replacement. *Int Orthop.* 2010;34(5):655–662.10.1007/s00264-009-0816-z.
25. Confalonieri N, Chemello C, Cerveri P, Manzotti A. Is computer-assisted total knee replacement for beginners or experts? Prospective study among three groups of patients treated by surgeons with different levels of experience. *J Orthop Traumatol.* 2012;13(4):203–210.10.1007/s10195-012-0205-z.
26. Cerha O, Kirschner S, Günther K-P, Lützner J. Cost analysis for navigation in knee endoprosthesis. *Orthopade.* 2009;38(12):1235–1240.10.1007/s00132-009-1473-z.
27. Keblish PA. The lateral approach to the valgus knee. Surgical technique and analysis of 53 cases with over two-year follow-up evaluation. *Clin Orthop Relat Res.* 1991;271:52–62 [<http://www.ncbi.nlm.nih.gov/pubmed/1914314>. Accessed 08, March 2014].
28. Little JP. Consistency of ASA grading. *Anaesthesia.* 1995;50(7):658–659 [<http://www.ncbi.nlm.nih.gov/pubmed/7653772>. Accessed 08, March 2014].
29. Paley D, Pfeil J. Principles of deformity correction around the knee. *Orthopade.* 2000;29(1):18–38 [<http://www.ncbi.nlm.nih.gov/pubmed/10663243>. Accessed 08, March 2014].
30. Ewald FC. The Knee Society total knee arthroplasty roentgenographic evaluation and scoring system. *Clin Orthop Relat Res.* 1989;248:9–12 [<http://www.ncbi.nlm.nih.gov/pubmed/2805502>. Accessed 21, February 2014].
31. Laurin CA, Lévesque HP, Dussault R, Labelle H, Peides JP. The abnormal lateral patellofemoral angle: a diagnostic roentgenographic sign of recurrent patellar subluxation. *J Bone Joint Surg Am.* 1978;60(1):55–60 [<http://www.ncbi.nlm.nih.gov/pubmed/624759>. Accessed 08, March 8 2014].
32. Nicholson LT, Trofa D, Smith E. Re-learning curve for conventional total knee arthroplasty following 30 consecutive computer-assisted total knee arthroplasties. *Comput Aided Surg.* 2013;18(3–4):63–67.10.3109/10929088.2012.762044.