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The effect of computerized navigation on component alignment in total knee arthroplasty

Luiz Fernando Machado SOARES[1], Tarcizo Afonso NUNES[2,3], Marco Antônio Percope DE ANDRADE[2,3], Philippe NEYRET[4], Roger BADET[5]

[1]*Madre Teresa Hospital, Belo Horizonte, Brazil;*
[2]*Faculty of Medicine, Federal University of Minas Gerais, Belo Horizonte, Brazil;*
[3]*Federal University of Minas Gerais Hospital, Belo Horizonte, Brazil;*
[4]*Department of Orthopedics, Albert Trillat Center, Lyon Nord Group Hospital, University of Lyon, Lyon, France;*
[5]*St. Vincent de Paul Clinic, Bourgoin-Jallieu, France*

Objective: The aim of this retrospective cross-sectional study was to evaluate the effect of computer-assisted total knee arthroplasty (TKA) on component alignment.

Methods: The radiographs of 20 patients who underwent computer-assisted TKA within a two-year period were analyzed with respect to the mechanical femorotibial, mechanical femoral, mechanical tibial angles (mFTA, mFA and mTA, respectively) and the tibial slope (σ).

Results: The mean postoperative mFTA (179.7°) was significantly improved when compared to the preoperative value (175.45°) (p=0.012). The mean postoperative mFA was significantly reduced (p=0.035) in comparison with the preoperative mean (89.1° and 90.6°, respectively). The mean postoperative mTA was exactly 90.0°, while the preoperative mean was significantly lower (87.7°; p=0.003). Mean tourniquet time during TKA was 109.5 minutes.

Conclusion: Computer navigation in TKA appears to be a reliable system which facilitates implant positioning and component alignment.

Key words: Computer navigation; gonarthrosis; implant positioning; ligament balancing; total knee replacement.

Primary and secondary arthrosis and inflammatory arthritis of the knee represent serious health problems for elderly individuals, typically those over 60 years of age. Total knee arthroplasty (TKA) has been shown to be an effective surgical treatment option for this condition with its reliable results.[1] However, the success of the procedure depends on a number of factors, including patient profile, implant type, adequate ligament balancing, recovery of the femorotibial axis, and the level of joint line at the end of intervention.

Long-term survival of the total knee prosthesis is greatly improved when the femorotibial mechanical angle is around 180°.[2] Correction of this angle is performed by cutting the bone orthogonally to the femorotibial mechanical axis using intra- or extra-medullary jigs in order to minimize positioning errors.

Correspondence: Luiz Fernando Machado Soares, MD. Hospital Madre Teresa Av. Raja Gabaglia 1002, Gutierrez 30430-142, Belo Horizonte, MG, Brazil.

Tel: +55-31 3291 81 82 e-mail: lfmsbh@hotmail.com

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However, these mechanical devices are not perfect and the final positioning of the prosthesis may not be optimal.[2] The most common problems that occur following knee replacement arise from technical failures, particularly those relating to the unsatisfactory positioning of the implant in the three spatial planes which can lead to abnormal wear of the implant, limitations in the range of motion and instability of the prosthesis.[3,4] The incidence of complications of this type typically ranges from 5 to 8%.[5-7]

The accuracy of implant positioning in TKA can be improved considerably by application of computer-assisted navigation.[8,9] However, few studies have compared the outcomes of computer-assisted surgeries with those of conventional procedures.

This study aimed to evaluate the validity of computer navigation in TKA and to assess whether this novel technique provides a reliable method of improving implant positioning.

Patients and methods

This retrospective cross-sectional study (evidence level 3) included the medical records of 20 patients (6 male, 14 female; mean age: 71.2 years; range: 54 to 81 years) who underwent TKA between February 2002 and February 2004 at the Department of Orthopedic Surgery in Croix-Rousse Hospital, Lyon, France (Table 1). The study was conducted in full accordance with the rules of the Ethics Committee of the Croix-Rousse Hospital, and with the consent of the directors of the Service and of the Medical Archives.

Patients who presented with mono-, bi- or tri-compartmental knee arthrosis that could be classified according to the modified Ahlbäck criteria as advanced stages 3 or 4 were included in the study while those with contraindications for surgery or for whom computer-assisted TKA had not been completed were excluded. In all cases, TKA was performed with the aid of a Surgetics® (Praxim, Grenoble, France) computer-assisted navigation system by the same surgeons (PN and RB), and HLS Evolution Rotatoire® (Tornier, Grenoble, France) prostheses were implanted. The system employed allowed perioperative collection of data relating to the articular kinematics of the hip and the anatomical features of the knees and ankles, thus circumventing the need for preoperative imaging assessment. A graphical reconstruction of the patient's knee was performed by digitizing a set of random points on the surfaces of the femur and tibia, selected with the aid of a pointer with a spherical tip, which were subsequently merged with bone templates available in the computer (femorotibial bone morphing; Fig. 1). Bone cutting was then calculated in the con-

Table 1. Characteristics of patients submitted to computer-assisted total knee arthroscopy in Croix-Rousse Hospital during 2002-2004.

Patient	Sex	Age at date of surgery (years)	Date of surgery	Diagnosis
1	Female	65.8	7 Feb 2002	MFTA
2	Female	54.2	30 May 2002	MFTA
3	Male	67	6 Apr 2002	MFTA
4*	Female	75.1	6 Nov 2002	MFTA
5	Female	68.8	15 Oct 2002	MFTA
6	Female	73.4	9 May 2002	MFTA/VTO
7	Male	78.11	17 Oct 2002	MFTA
8	Male	66.9	29 Jan 2004	EFTA
9*	Female	81.8	20 Jun 2002	MFTA
10*	Female	76.11	21 Jun 2002	MFTA
11	Female	77.8	9 Dec 2002	MFTA
12	Male	74	26 Sep 2002	OMFC
13	Female	72.9	23 Jan 2003	OMFC
14	Female	64.2	27 Mar 2003	EFTA
15	Male	71.10	13 Feb 2003	MFTA
16*	Female	76.10	22 May 2003	MFTA
17	Female	72	2 Jun 2004	MFTA
18	Female	77.10	20 Nov 2003	MFTA
19	Male	68.8	12 Nov 2003	MFTA
20	Female	70.4	20 Jan 2004	MFTA

MFTA: medial femorotibial arthrosis; EFTA: external femorotibial arthrosis; MFTA/VTO: patient had been previously submitted to valgus tibial osteotomy due to MFTA; OMFC: osteonecrosis of the medial femoral condyle.

ventional manner and the most adequate position and orientation of the implant determined with the aid of the graphic interface. Real-time progress of the procedure was presented on the computer monitor and differences between planned and actual locations of the implant were taken into consideration during all stages of femoral and tibial cutting. The cutting of bone was carried out in the sequence of tibia, femur and patella, although patella cutting was performed in the conventional manner without the use of computer navigation. Ligament balancing was achieved following completion of the tibial and posterior femoral cuts. Flexion gap balancing was performed with the aid of the three-dimensional locator. The geometric relationship used was based on calculating the distance from the bottom of the depressed tibial subchondral bone projected onto the planned tibial cut, to the plane of the posterior femoral cut. This measurement was calculated in real time. The ligament balance, held in 90° of flexion and in full extension, was the result of the relationship between two vectors represented by the femoral and tibial mechanical axes. The angle obtained was interpreted in the anatomical sagittal plane. With the trials in place, it was possible to visualize the axis of the entire lower limb on the monitor and to verify in real time the accuracy of the estimated measurements and of the final position of the implant.

Pre- and postoperative angular measurements were estimated from contemporary X-rays by an author (LFMS) who did not take part in the surgical interventions. Axial parameters were evaluated from standing panoramic anteroposterior as well as from lateral and patellofemoral axial (at 30° flexion) views. All measurements were made using a 360° graduated goniometer (Futura Saúde®; Futura Saúde, Bauru, Brazil) and an X-ray film marker (Pilot®; Jacksonville, FL, USA).

The pre- and postoperative anteroposterior radiographs permitted evaluation of the following parameters; (1) the mechanical femorotibial angle (mFTA) formed by the intersection of the mechanical femoral and tibial axes, (2) the mechanical femoral angle (mFA) formed by the intersection of the mechanical femoral axis and the axis perpendicular to a line that passes by the distal femoral condyles, and (3) the mechanical tibial angle (mTA) formed by the intersection of the mechanical tibial axis and the line perpendicular to the tibial plateau (Fig. 2a). The tibial slope angle (σ) was evaluated in preoperative lateral radiographs by considering the intersection of a line perpendicular to the

Fig. 1. Surgical procedures. **(a)** Bone morphing (femur). **(b)** Digitized area (femur) in real time. **(c)** Bone morphing (tibia). **(d)** Digitized area (tibia) in real time. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

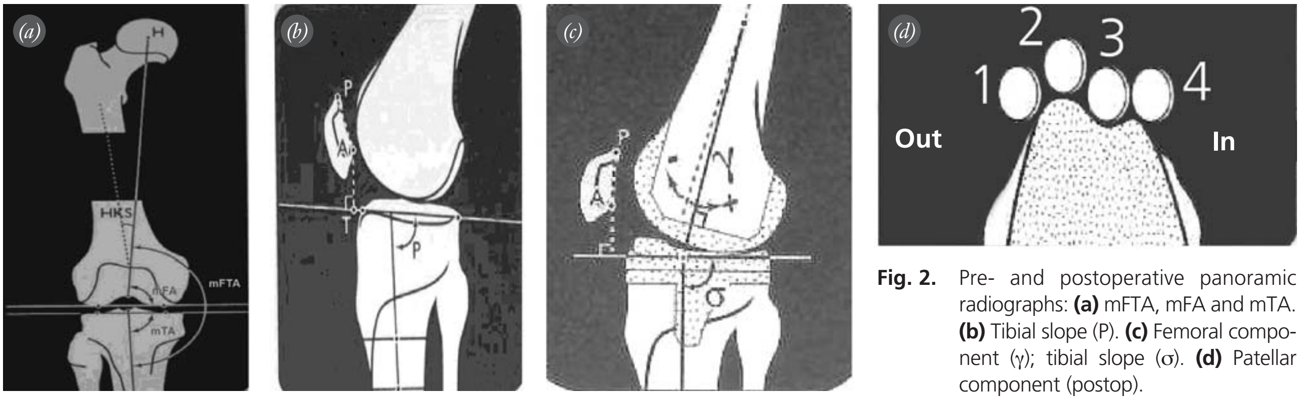

Fig. 2. Pre- and postoperative panoramic radiographs: **(a)** mFTA, mFA and mTA. **(b)** Tibial slope (P). **(c)** Femoral component (γ); tibial slope (σ). **(d)** Patellar component (postop).

articular surface of the medial tibial plateau and the anatomical mediolateral axis (i.e. the line between points situated at 10 and 20 cm from the plateau and located midway between the two cortices) (Fig. 2b). In postoperative radiographs, σ was determined as the angle formed by the intersection of the anatomical tibial axis and the horizontal axis of the tibial component (Fig. 2c), while the deviation (in flexion) of the femoral component (γ) was evaluated as the angle formed by the intersection of the anatomical femoral axis and the line perpendicular to the base of the femoral component.

Radiographs of the patellofemoral joint (at 30° flexion) indicated the position of the patellar component, with position 3 being considered ideal (Fig. 2d). Although the position of the patellar component is another important parameter for the perfect functioning of the knee arthroplasty, this parameter was not used in the present study.

Verification of the normal distribution of the pre- and postoperative parameters was performed, and mean values were compared using the Student's t-test with the level of significance of 95% ($p<0.05$).

Results

The means, standard deviations and value ranges of the pre- and postoperative radiological parameters of the study population are shown in Table 2.

Anteroposterior radiographs revealed that nearly 50% of patients exhibited acceptable postoperative mFTAs with values around 180° (Fig. 3). Moreover, the postoperative mFTA mean value (179.7°) was much closer to 180° in comparison with the preoperative mean value (175.45°), and the difference between the two was statistically significant ($p=0.012$).

More than half of the patients submitted to computer-assisted TKA presented with mFA that was close to the ideal value of 90° (Fig. 4). In one case, however, it was necessary to maintain limb alignment in residual valgus of 4° in order to obtain a satisfactory ligament balancing at the end of the procedure. Consequentially, although the mean postoperative mFA was significantly reduced ($p=0.035$) in comparison with the preoperative mean (89.1° and 90.6°, respectively), the value still deviated from the postoperative ideal angle of 90°.

Half of the patients presented with postoperative mTA that was near to the ideal value of 90°, while only 20% of patients presented acceptable mTA prior to TKA (Fig. 5). The mean postoperative TA was exactly 90.0°, while the preoperative mean was significantly lower (87.7°; $p=0.003$) (Fig. 5) demonstrating that TKA produced a notable improvement in this parameter.

No patellofemoral or skin complications were observed among the patients studied. The average tourniquet time during computer-assisted TKA was 109.5 (range: 80 to 130) minutes and peri- and postoperative bleeding was similar to that observed in conventional procedures. Two patients in the study population

Table 2. Pre- and postoperative radiographic parameters of patients submitted to computer-assisted total knee arthroscopy in Croix-Rousse Hospital during 2002-2004.

Parameter	Angular values (°)		
	Minimum	**Maximum**	**Mean±SD**
Preoperative			
mFTA	167	190	175.45±6.29
mFA	77	95	90.6±3.88
mTA	83	94	87.7±2.83
σ	0	24	6.75±5.7
Postoperative			
mFTA	175	185	179.7±2.57
mFA	85	94	89.1±1.91
mTA	87	94	90±1.59
σ	-2	3	0.3±1.34
γ	-5	4	1.3±2.13

mFA: mechanical femoral angle; mFTA: mechanical femorotibial angle; mTA: mechanical tibial angle; SD: standard deviation; σ: tibial component slope; γ: deviation of the femoral component.

had previously undergone knee arthroscopy for the repair of a meniscal injury and one of them required osteotomy of the anterior tibial tubercle in order to expose the joint. These procedures did not interfere with computer assisted-TKA or the results obtained.

Discussion

The clinical outcomes relating to 20 patients who underwent computer-assisted TKA demonstrated that computer assistance permits precise positioning of the femoral and tibial implants and facilitates correct ligament balancing. The accuracy of implant positioning was revealed by the mean postoperative mFTA, mTA, σ and γ angles (179.7°, 90°, 0.3° and 1.3°, respectively), which were very close to the values considered ideal according to the literature.[5,8-10] While the mean postoperative mFA (89.1°) differed somewhat from the acceptable value (90°), the discrepancy may be explained by the inclusion of one patient who required limb alignment in a residual valgus of 4° in order to reach satisfactory ligament balancing. As the study population was small (n=20), this single case would have had a significant influence on the statistical analysis.[11,12]

The principal reasons for using computer-navigation in the TKA procedure are to reduce surgical trauma and enhance the longevity of the implant.[13] The success of total knee replacement, as measured in terms of the longevity of implant components, depends on correct axial alignment, adequate ligament balancing and equalized flexion and extension gaps.[14,15] In this context, instability and inadequate positioning of implant components represent the key factors responsible for revision surgery with the first two years following TKA.[10,16]

The navigational principle underlying computer-assisted TKA relates to the accurate alignment of the centers of the femoral head, the knee and the ankle according to the anatomical axis of the limb. This task relies on two major steps; (1) the digital reconstruction of the bones, which must be performed prior to bone cutting, and (2) the secure fixation of infrared light-emitting diodes to the femur and tibia in order to track the spatial positions of the implants throughout the procedure. However, these steps may increase tourniquet time and, consequently, overall morbidity. Currently available computer-assisted TKA studies are conflicting and the validity of this procedure is still controversial, particularly in regards to clinical outcome. A number of authors have claimed that computer navigation provides much better results in comparison with conventional TKA.[5,9] Tayot et al.,[17] for example, demonstrated that computer assistance improved implant positioning considerably in 70 patients in comparison with conventional TKA applied to an equivalent number of patients. However, despite the improved alignment in the former group, the clinical status of the two groups was analogous. Improved accuracy in the positioning of the prostheses (n=100) was also reported by Lambilly et al. following computer-assisted TKA.[18] In contrast, Seon and Song found no statistically significant differences between the post-

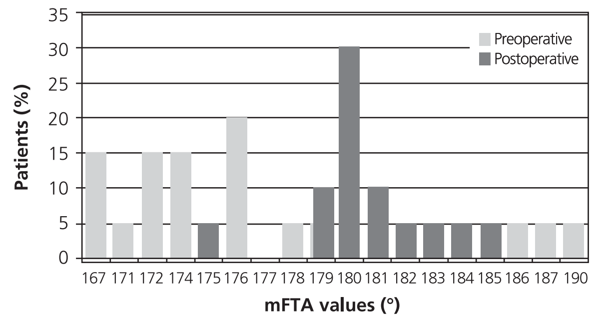

Fig. 3. Preoperative and postoperative data distribution of patients (n=20) according to the mechanical femorotibial angle (mFTA).

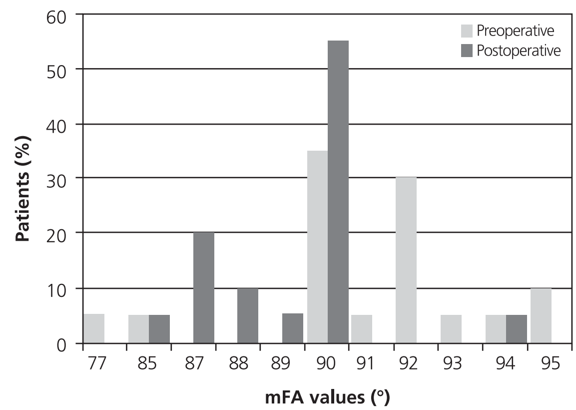

Fig. 4. Preoperative and postoperative data distribution of patients (n=20) according to the mechanical femoral angle (mFA).

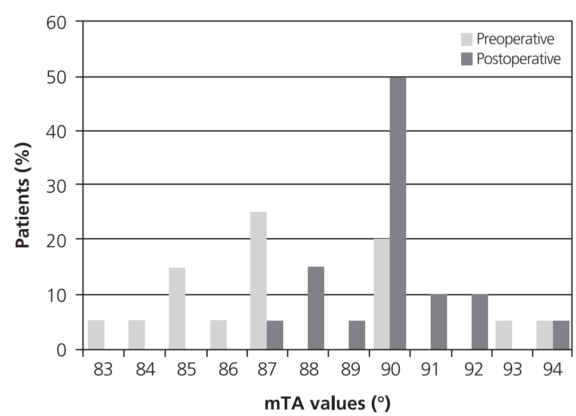

Fig. 5. Preoperative and postoperative data distribution of patients (n=20) according to the mechanical tibial angle (mTA).

operative evaluations of a group of patients submitted to computer-assisted TKA (n=49) and a control group submitted to conventional TKA (n=53).[19] According to Fehring et al., the use of computer-assisted TKA is of the greatest value in difficult situations where traditional instrumentation cannot be used, as in the case of bone deformity located far from the knee joint.[14]

With the computer navigation system used in this study, ligament balancing can be improved using different magnitudes of flexion and extension gaps (which could not be estimated from conventional radiographic views). However, views are presently limited to 20° of flexion and a more dynamic analysis of the restrictors in varus and valgus, and of the mFTA in flexion as well as in extension would be useful. Furthermore, it would be extremely valuable to be able to measure the amplitude of movement at the beginning and end of the surgical procedure.

Various navigation systems are currently available that aim to improve implant positioning in patients undergoing TKA. However, the final decision regarding the most applicable approach must rest with the surgeon as the desired outcome of the intervention may vary depending on the patient. In some cases, total correction of the mechanical axis may be required, while the procedure may comprise adjustment of the tension in the joint in others. Whichever the case, it is clear that the surgeon must have a profound knowledge of knee anatomy and kinematics as well as each step of the procedure in order to circumvent possible complications and to attain a successful outcome.[20]

In conclusion, the Surgetics® system employed in computer-assisted TKA procedures is reliable and allows adequate positioning of the knee prostheses and ligament balancing.

Conflicts of Interest: No conflicts declared.

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