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Original article

Evaluation of benefits and accuracy of a mobile application in planning total knee arthroplasties☆

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ABSTRACT

Objective: To evaluate the usefulness of an application when planning total knee arthroplasties (TKA), besides the accuracy when measuring the anatomical-mechanical femoral angle (AMFA), comparing, also, the time spent during planning a TKA manually and by using the application.

Methods: An interdisciplinary team involving health and computer science areas established activities in order to develop the application. After development, 24 physicians underwent an application usability test. Each one planned a primary total knee arthroplasty (TKA) initially, in a conventional manner and then by using the application. Data concerning AMFA measurement and time spent during planning were collected, in both manners. The Mann–Whitney and Wilcoxon tests were used to evaluate statistical significance related to angle and time.

Results: Users considered it important checking AMFA and drawing the bone cut lines orthogonal to the mechanical axis, when planning TKAs. They also assessed that the application could be useful for training surgeons and for specialists. There was no statistically significant difference between the AMFA, as measured by the application and by the conventional manner. The planning time was shorter when the application was used (39% of the time spent manually).

Conclusions: The application has proved to be useful in planning TKAs and has revealed accuracy when measuring the AMFA when it was compared to the manual form of preoperative planning. The application was able to reduce planning time by more than half and it demonstrated reliability in measuring the AMFA.

☆ Study conducted at Santa Casa da Misericórdia de Fortaleza, CE, Brazil.

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Avaliação de utilidade e acurácia de aplicativo móvel no planejamento de artroplastias totais do joelho

RESUMO

Palavras-chave:
Aplicativos móveis
Artroplastia do joelho
Tempo de cirurgia

Objetivo: Avaliar a utilidade de aplicativo no planejamento de artroplastias totais do joelho (ATJ), além da acurácia em relação à aferição do ângulo anatômico-mecânico femoral (AAMF), e comparar o tempo dispendido no planejamento de ATJ através da forma manual e do aplicativo.

Métodos: Uma equipe interdisciplinar das áreas de saúde e ciências da computação estabeleceu um fluxo de atividades, a fim de desenvolver um aplicativo. Após desenvolvido, 24 médicos participaram de um teste de utilidade desse. Cada usuário planejou uma cirurgia de ATJ, inicialmente, de forma convencional e, posteriormente, através do aplicativo. Foram coletados dados de aferição do AAMF e do tempo dispendido durante o planejamento entre as duas formas. Os testes de Mann–Whitney e Wilcoxon foram usados para avaliar a significância estatística entre os resultados de medição de ângulo e tempo.

Resultados: Os usuários julgaram importantes a aferição do AAMF e o traçado de linhas de corte ósseo ortogonais aos eixos mecânicos, no âmbito do planejamento de ATJ. Também avaliaram que o aplicativo poderia ser útil para cirurgiões em formação e especialistas. Não houve diferença estatisticamente significante entre o AAMF aferido através do aplicativo e da forma convencional. O tempo de planejamento foi menor quando o aplicativo foi usado (39% do tempo gasto pela forma manual).

Conclusões: O aplicativo evidenciou-se útil no contexto de planejamento de ATJ, mostrou-se acurado quanto à medição do AAMF. Foi capaz de diminuir em mais da metade o tempo de planejamento, mostrou-se, mesmo assim, confiável quanto à medição do AAMF.

Introduction

Total knee arthroplasty (TKA) surgery is one of the most frequently performed orthopedic interventions. This procedure has many goals, among which pain reduction and the gain of joint mobility are noteworthy.[1,2] The main cause of failure in TKA continues to be poor alignment of the prosthetic components.[3]

Preoperative surgical planning may contribute to a shorter surgical procedure and longer survival of the prosthetic implants. During planning, the surgeon usually estimates the anatomical and mechanical axes of the femoral and tibial bones. The angle formed between the anatomic and mechanical axes of the femur (AMFA) is also measured, and the bone cutting planes are estimated.[4]

There are several methods of estimating bone alignment, including clinical examination, computed tomography (CT), magnetic resonance imaging (MRI), conventional knee radiographs (CKR), fluoroscopy, and intraoperative navigation. The use of lower limb panoramic radiography (LLPR) is a well-established method for measuring bone alignment.[5] The manual preoperative planning uses marking and measuring instruments, such as a 2B pencil, a 50 cm ruler, a protractor, and a negatoscope, as well as printed radiographs. These tools may not be widely available in all environments where surgical planning occurs.

In turn, with the increase in the number of computing resources applied to healthcare (mHealth), various solutions have been developed in order to assist the surgeon in his routine. This study is aimed at evaluating whether the mobile application, developed by the present authors, was useful in TKA planning and was capable of making an accurate measurement of the AMFA. The preoperative planning time, both manually and through the application, was also compared, and the speed of planning through the application was ultimately evaluated.

Materials

The study included 24 physicians, divided into three groups: eight knee surgeons, members of the Brazilian Society of Knee Surgery (Sociedade Brasileira de Cirurgia do Joelho [SBCJ]); eight non-SBCJ orthopedists; and eight third-year residents of orthopedics and traumatology. The exclusion criterion was orthopedists who were not members of the Brazilian Society of Orthopedics and Traumatology (Sociedade Brasileira de Ortopedia e Traumatologia [SBOT]).

A conventional negatoscope and a printed LLPR originating from one of the authors' clinical cases was presented to the participants; the LLPR had not been modified in its request or execution to fit the study in any way. In addition, manual preoperative planning tools such as a 2B pencil, 40 cm ruler, protractor, goniometer and eraser were available during a utility test.

A smartphone with the Android operating system and the developed application installed was offered to the users, who were then allowed to plan as proposed.

Methods

For the purpose of developing the ATJ App® application, an interdisciplinary team from the areas of healthcare and computer science established a stream of activities. The characteristics that should be included in this solution were listed: registration data collection field; image acquisition from the device's camera; a tutorial, in order to assist the user during each phase of preoperative planning; ability to mark points and draw lines; ability to automatically identify, from the traced lines, the type of knee deformity (varus or valgus); ability to position movable lines, perpendicular to the mechanical axes of the femur and the tibia, to represent bone cut lines; ability to anticipate to the possible difficulties in the intraoperative period, providing orientation regarding soft tissue balance for each type of deformity. Fig. 1 features a diagram showing the simplified organization of these features. The following tools were used for software programming: Integrated Development Environment (IDE) Android Studio; Android SDK (Software Development Kit) Library; Android Emulator System with Google's Application Programming Interface (APIs); and the Open Source Computer Vision Library (OpenCV).

After the creation, the ATJ® application underwent a usefulness test, based on Davis's Technology Acceptance Model (TAM; 1989), that allows to quantify the degree of usefulness perceived by users of an application.[6] An evaluation questionnaire was then created and adapted to the context of TKA planning (Fig. 2).

During the application of the usefulness test, different moments were perceived. In a first phase, the user received explanations about the methodology adopted, through a printed tutorial (Fig. 3). Two persons were involved: the evaluator, author of this study, and the volunteer physician. The process began with the presentation of a standardized preoperative TKA planning model, through a logical step-by-step, which should be initially followed in a manual planning with the use of a printed LLPR. In addition to measuring the AMFA, the user should position a bone cutting line perpendicular to the mechanical axis of the femur and tibia. In primary TKA, the exact positioning usually corresponds to the thickness of the femoral implant for the femoral bone (*e.g.*, 9 mm above the first point of femoral bone contact) and about 10 mm from

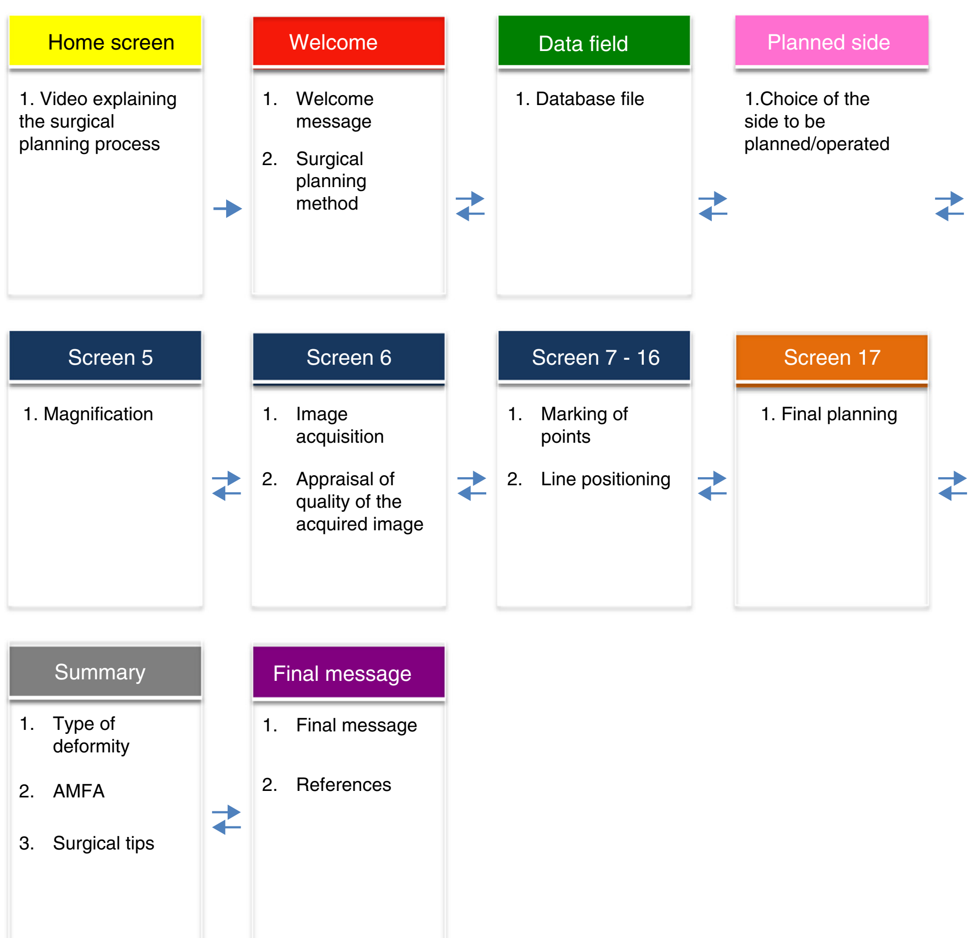

Fig. 1 – Simplified diagram of screens and features of the proposed application.
***Source*: Prepared by the author.**

Evaluation instrument - adapted TAM questionnaire

1) The identification of bone cut lines on the femur and the tibia in the coronal plane may help the surgeon to make decisions during TKA planning
( ) I agree ( ) I disagree ( ) I do not know how to answer

2) The measurement of the angle between the mechanical axis and the anatomical axis of the femur (AAF) may help in the surgery as to the choice of angulation of the femoral cut guide when using the intramedullary femoral guide
( ) I agree ( ) I disagree ( ) I do not know how to answer

3) I believe that the standardization through a step-by-step approach proposed by the app can aid in the learning process of residents of Orthopedics and Traumatology regarding TKA surgical planning
( ) It helps a lot ( ) It helps ( ) It helps a little ( ) It does not help

4) I believe that the standardization through a step-by-step approach proposed by the app can aid in the learning process of Knee Surgery interns regarding TKA surgical planning
( ) It helps a lot ( ) It helps ( ) It helps a little ( ) It does not help

5) I believe that the standardization through a step-by-step approach proposed by the app can aid in the planing process of knee surgeons regarding TKA surgical planning
( ) It helps a lot ( ) It helps ( ) It helps a little ( ) It does not help

6) It appears to be a useful technology for TKA surgical planning
( ) I strongly disagree ( ) I disagree ( ) I am indifferent ( ) I agree
( ) I strongly agree

It has helped me to better understand the concepts related to TKA planning
( ) I strongly disagree ( ) I disagree ( ) I am indifferent ( ) I agree
( ) I strongly agree

Fig. 2 – Usefulness questionnaire, based on Davis' technology acceptance model, 1989. *Source*: Prepared by the author.

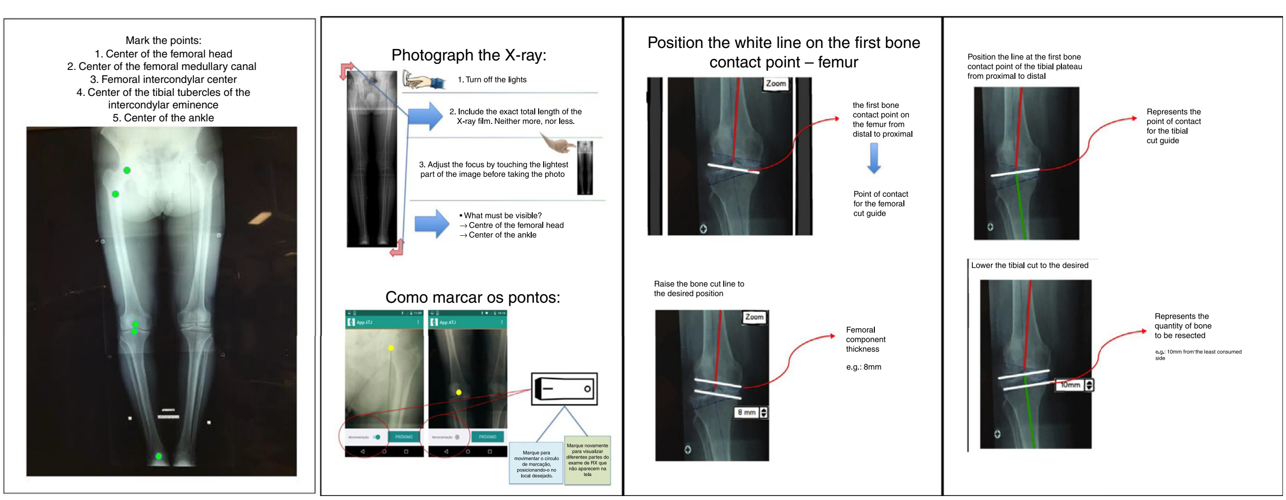

Fig. 3 – Tutorial aimed to explain, in a summarized way, the step-by-step approach adopted in the proposed planning methodology. Offered to the participants of the study before planning by the conventional method and by the application. *Source*: Prepared by the author.

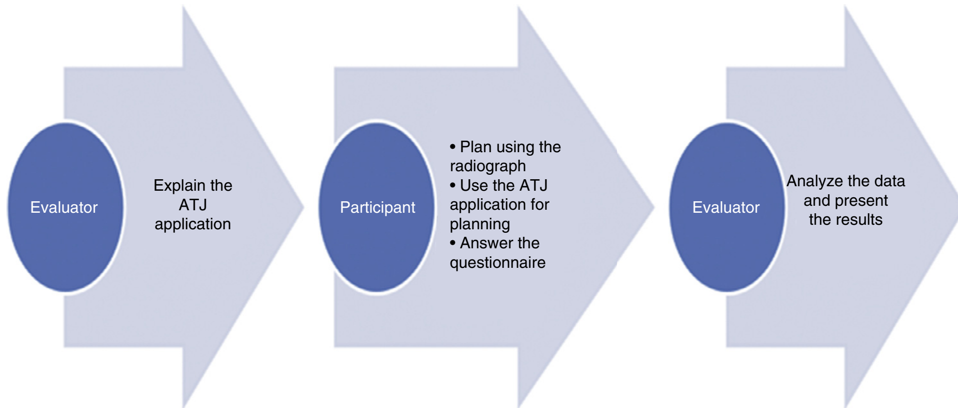

Fig. 4 – Procedure for application evaluation.
***Source*: Prepared by the author.**

the first point of tibial bone contact, considering the convexity region of the tibial deformity.

These parameters can be adjusted according to the necessity of each planned case. During conventional planning, in order to position the cut lines at the desired height, the surgeon must consider the magnification used in each LLPR. After manual planning, the evaluator would erase the strokes made on the printed LLPR and then proceed to the next planning phase through the application (Fig. 4). The application considered the magnification printed on the LLPR for positioning the bone cut lines (Fig. 5). The time spent and the AMFA calculated during conventional planning and during the use of the application were recorded. These two phases of action plans are shown in Fig. 6.

In the statistical analysis, the Kolmogorov–Smirnov normality test was applied to evaluate the parametrization of the sample. The Wilcoxon and Mann–Whitney tests were also used to assess the time of application use and AMFA accuracy. Fisher's exact test was used to cross-evaluate the questions in the application's usefulness questionnaire.

The basic principles of ethics in human research, such as autonomy, justice, beneficence, and nonmaleficence, guided

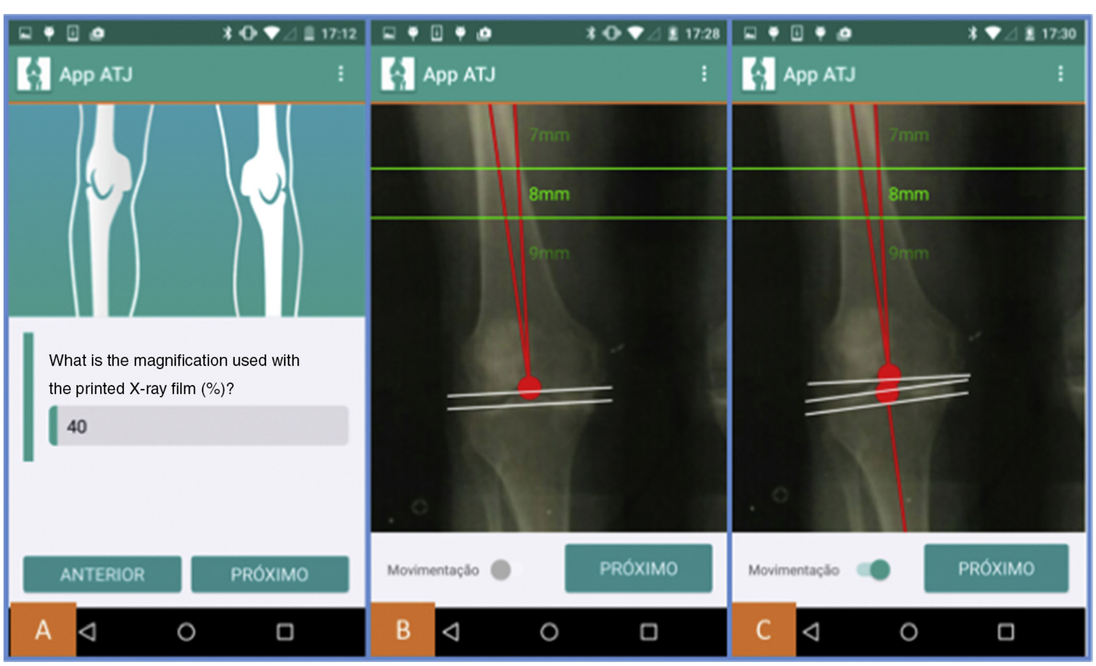

Fig. 5 – Recognition of magnification used in the LLPR exam. (A) Information to the application on the magnification adopted in the printed LLPR. (B) When informing the amount of bone to be resected, the application does the automatic calculation and positions the bone cut line at the height corresponding to the actual size. (C) Positioning of the tibial bone cut line based on the information provided by the user. The application is able to position the line automatically, not requiring mathematical conversions between the real height of the cut line and the magnified height.
***Source*: Prepared by the author.**

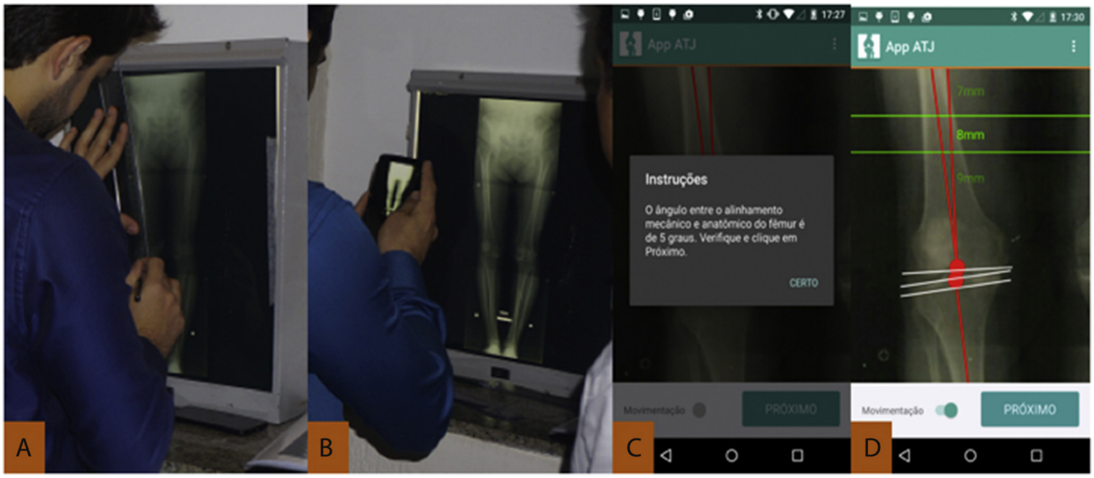

Fig. 6 – Photos showing the preoperative planning done in a traditional way and by the use of the application. (A) Conventional, manual planning. (B) Use of the application for image acquisition and planning. (C) Automatic measurement of the AMFA by the application, after the user marked the points. (D) Planning of bone cuts perpendicular to the mechanical axes of the femur and tibia.
***Source*: Prepared by the author.**

by Resolution 466/12, were followed. The study was submitted to the Human Research Ethics Committee (CEP), through the Plataforma Brasil, directed to the Christus University Center (Centro Universitário Christus) and accepted under protocol No. 1,764,812.

Results

The application was developed and the requirements defined during the flow of activities were met, which made it possible to evaluate the ATJ® application through a usefulness test.

The users agreed that the AMFA measurement and the tracing of bone cut lines perpendicular to the mechanical axis of the femoral and tibia bones could help surgeons in the preoperative planning.

The users also agreed that the planning proposed by the application could aid the learning process of orthopedic residents, knee surgery interns, and knee surgeons.

When asked whether the application appeared to be useful for TKA planning and would help to better understand the concepts related to surgical planning, the users responded favorably.

Table 1 presents a synoptic table of the answers to the questions of the usefulness assessment questionnaire.

A statistically significant correlation, evaluated by the Fisher's exact test, was observed between questions 6 and 7. This indicated that participants who understood that the technology was useful in TKA planning also agreed that the application helped to better understand the concepts related to said planning.

Regarding the AMFA measurement, it was observed that 17 participants (70.8%) achieved the same angle measurement through both the conventional form and the application. Six participants found a difference of one degree between the forms of measurement, and one participant observed a difference of two degrees. After the results were statistically analyzed using the Mann–Whitney and Wilcoxon tests, no statistically significant difference was observed between the two forms of measurement ($p = 0.240$). The analysis of this variable reinforces the benefits of the application, as it allowed a drastic

Table 1 – Data expressed as absolute frequency and percentage for answers to the questions of the usefulness evaluation questionnaire.

	n	%
The identification of bone cut lines can help decision-making		
It helps a lot	24	100.0
The angle measurements can help decision-making		
It helps a lot	24	100.0
The step-by-step procedure can help orthopedic residents		
It helps a lot	18	75.0
It helps	6	25.0
The step-by-step procedure can help orthopedic interns		
It helps a lot	18	75.0
It helps	6	25.0
The step-by-step procedure can help orthopedic surgeons		
It helps a lot	15	62.5
It helps	9	37.5
It appears to be a useful technology in TKA planning		
I disagree	1	4.2
I agree	10	41.7
I strongly agree	13	54.2
It has helped me to understand TKA planning concepts		
I am indifferent	2	8.3
I agree	10	41.7
I strongly agree	12	50.0

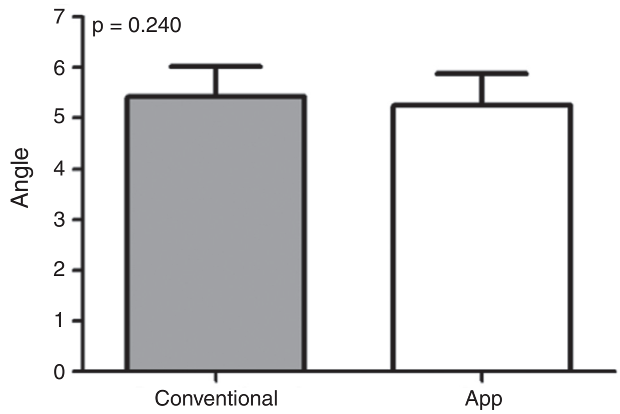

Fig. 7 – AMFA measurement by the conventional method and by the application. No statistically significant differences were observed between the two methods by the Mann–Whitney and Wilcoxon tests ($p = 0.240$).
***Source*: Prepared by the author.**

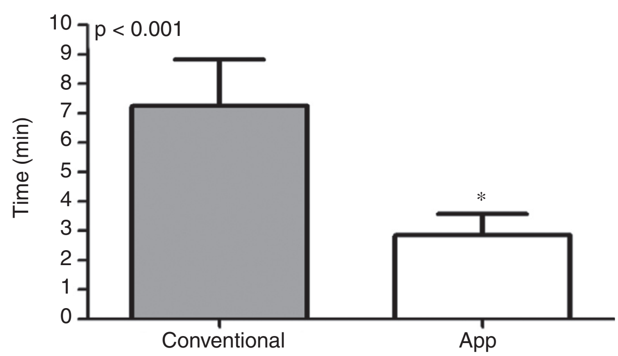

Fig. 8 – Time, in minutes, spent on TKA planning, using the manual method and the application. The results were plotted after the Mann–Whitney and Wilcoxon tests were applied ($p < 0.001$).
***Source*: Prepared by the author.**

reduction in the planning time, without losing effectiveness, at least regarding the AMFA measurement (Fig. 7).

When comparing the manual planning with that performed using the application, a reduction in preoperative planning time was observed. The mean time the 24 participants spent in manual planning was 7.2 ± 1.6 min, *versus* 2.9 ± 0.7 min in planning using the application. From the analysis of the planning times of the 24 participants of the usefulness test, it was observed that the use of the application reduced the planning time by 4.4 ± 1.8 min, approximately 39% of the time spent in the manual procedure. This difference was considered statistically significant ($p < 0.001$). Fig. 8 represents the difference in planning time using the conventional method and through the application.

Table 2 complements this analysis, stratifying the values measured in seconds into: upper limit, third quartile, median, mean, first quartile, and lower limit. It was observed that the values of the medians were lower than those of the means, but the 39% proportion of reduction was maintained. This finding is important because it reinforces the results of the study as, unlike the mean, the median is a measure of central tendency and is not so influenced by erratic and non-significant individual values.

Table 2 – Planning time, measured in seconds, by the manual method and by the application ($n = 24$).

	Traditional planning	Planning with the ATJ App
Upper limit	10.5	3.7
3rd quartile	8.5	3.4
Median	6.6	26
Mean	7.2	2.9
1st quartile	6.2	2.3
Lower limit	4.1	1.9

Discussion

Manual planning continues to be a standard in TKA. To do so, the surgeon needs a printed radiography and a negatoscope in the room in which the surgery is planned. The surgeon must also carry some tools, such as pencils, rulers, protractors, goniometers, and eraser. With a planning strategy in mind, the surgeon needs to mark points, trace lines, and, through these parameters, estimate the alignment and plan the bone cuts. This type of planning has as a main advantage its low cost. In turn, it requires knowledge of a pre-defined rational methodology and has as a limiting factor the fact that manual planning tools are not always available in all the environments in which surgical planning occurs. This could have a damaging consequence, to the extent that a surgeon may decide not to plan given the lack of necessary material. In addition, the surgeon should note that most of the radiographs are modified in their size range, and this mathematical adjustment between actual size and print should be considered when positioning the bone cut lines.

Some studies have compared manual and digital preoperative planning in TKA. When estimating the size of the prosthetic component, both manual and digital planning have good reliability[7]; however, when estimating AMFA, manual planning is more accurate than digital.[8] The authors of this study developed an application that does not require the use of manual planning tools, in addition to considering the magnification used in each exam; the application prevents surgeons from having to perform conversions, through calculations, by automatically measuring the AMFA and positioning the bone cuts lines in a millimeter bar, which considerably reduces the planning time.

The influence of technology on medical learning is a trend that has gained space with the emergence of m-learning. Using mobile devices, such as tablets and smartphones, physicians have at their disposal a number of potential learning benefits.[9] Applications provide the practitioner with hands-on learning tools and aid in medical decision-making. The most commonly used applications in this context are medication guides and medical calculators. Users easily notice the advantages of these tools, including their convenience, efficiency, and potential to accelerate learning. However, disadvantages such as distraction, dependence, and poor regulation of knowledge can hinder the learning process and cast doubts on the use of mobile applications.[10]

A systematic review of applications in the surgical medical field demonstrated the usefulness of these applications in pre, intra, and transoperative contexts. Although most studies point to numerous benefits of using smartphone and tablet applications, more evidence-intensive studies need to be conducted to further analyze the impact of the widespread adoption of such tools.[11]

In the orthopedic setting, a study has assessed the reliability of the use of a previously existing smartphone application that simulates a goniometer. The application was shown to be reliable when considering the measurement of range of motion angles. However, in that study an application was only tested, not developed.[12]

In the TKA area, the ATJ App® application increases the possibilities of preoperative planning. Most of the applications developed in orthopedics aim to measure angles and estimate the size of prosthetic components; to date, no application has offered a standardized step-by-step that allows the user to trigger "shortcut" help, with a theoretical insight into each step in question, supported by reliable literature. In addition to these factors, the ATJ App® application anticipates possible situations that can be encountered in the face of each deformity and offers a tutorial in the shape of "tips." These features can direct the user to a safe preoperative planning methodology and assist in understanding wholly the TKA surgery.

This study had some limitations, since some features could have made the application more robust, such as the possibility of remote loading an image from a database. Regarding the application of the usefulness test, the bias of the authors knowing part of the participants is noteworthy, as it may have inhibited a critical posture of some participants. In addition, by initiating manual planning, participants may have raised doubts and questions about the methodology at this stage, which may have contributed to a longer duration of this step. In this phase of the study, intra and interobserver agreement tests were not applied.

Conclusion

The developed application was shown to be useful in the context of TKA planning. It is a safe way to measure AMFA, and it is able to reduce the preoperative planning time while still being accurate regarding the AMFA measurement.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgments

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