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3D planning in revision total knee arthroplasty following periprosthetic joint infection. A pilot study

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Summary

Objective. Revision total knee arthroplasty (TKA) following a periprosthetic joint infection (PJI) represents a considerable challenge. The geometry of bony defects can be hard to assess on standard x-rays, thus requiring CT evaluation. CT data can be processed to create physical replicas by 3D printing. This model can be used as means of 3D planning through surgical simulation. This study aims to compare the ability to predict the need for augmentation to restore limb alignment between 2D and 3D planning.
Methods. Ten consecutive patients undergoing second-stage TKA revision following PJI were included. Pre-operative CT and standard x-rays were obtained in all patients. CT data were used to produce a model using a 3D printer. The surgical simulation was then conducted using TKA revision instrumentation. Standard 2D planning and 3D planning were independently performed by two investigators. Interclass correlation coefficient was used to evaluate agreement on the use of augment.
Results. For femoral augment, 3D and 2D accuracies were 80.8 and 37.5%, respectively. For tibial augment, 3D and 2D accuracies were 66.7 and 23.0%, respectively.
Conclusions. 3D planning with surgical simulation has shown to be a valuable method to predict the need of augment in revision TKA following PJI.

Key words: total knee arthroplasty, revision arthroplasty, periprosthetic joint infection, 3D planning, 3D printing

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Introduction

Currently, it is estimated that the number of primary total knee arthroplasties (TKA) in Italy will increase 45% by 2050 [1]. Similarly, we expect that revisions for aseptic and septic loosening will rise over time. Despite new clinical and technological advancements, periprosthetic joint infection (PJI) represents one of the most important causes of joint prosthesis failure, with an incidence estimated to range from 1-2% [2,3]. The current strategies for treating chronic PJI are one-stage and two-stage revisions. Although one-stage approach has shown promising results at certain institutions, the two-stage protocol remains the most widely applied [4]. The first stage consists of removing the infected hardware, thorough debridement, and implanting an antibiotic-laden spacer until infection eradication. In the second stage, the spacer is removed, a second debridement performed, and a revision TKA is implanted [5].

Revision TKA following PJI is still a challenge for the surgeon since the bone stock can be significantly reduced as a direct consequence of the infection or hardware removal [6], the soft tissues can be compromised as well [7]. These are among the reasons for a high percentage of aseptic loosening in patients affected by PJI [8]. Rigorous planning needs to be implemented for each patient to reduce the failure rate. A standard joint x-ray may be unhelpful to pre-operatively evaluate the best strategy to fulfill bone defects. A CT scan, providing high-quality imaging can help identify cavitary or segmentary defects, and may be more useful to overcome this issue [9]. Furthermore, a three-dimensional reconstruction can be created from a CT image to help understand the location and characteristics of the bone defects. Such models can be 3D printed to produce accurate physical replicas of the patient's anatomy [10], which can be used in a simulated TKA revision surgery, hence serving as a planning technique. The aim of our study was to compare standard 2D planning with 3D planning regarding the ability to predict the need for augmentation to correct the overall leg axis in the second stage (Fig. 1).

Materials and methods

We retrospectively analyzed 10 consecutive (2 men and 8 women) patients with a mean age of 73 ± 4 years who completed the two-stage approach following a PJI of a TKA at our institution from May 2020 to September 2020. After implant removal patients underwent two weeks of intravenous antibiotic therapy [13]. Drug choice was based on pre-operative synovial fluid culture when available. In case of negative cultures empiric therapy was used, selecting antibiotics active against gram-positive methicillin resistant bacteria. This regiment was then modified according to the results yield by the intra-operative cultures. In the present series all patients had at least one intra-operative positive culture. Following the first two weeks of parental therapy the patients were then switch to oral antibiotic therapy based on the microbiological evaluations. The median time between first and second stage was 8 weeks (6-12), and the therapeutic regiment was continued for 15 days after reimplantation [14]. No patients in our series discontinued antibiotic therapy because of side effects. According to our institution's standard protocol, all complex TKA revisions undergo a CT scan with 3D reconstruction. Due to the study's retrospective nature, no ethical committee approval was needed. Before reimplantation, all patients underwent a standard caliper x-ray and CT of the leg with MARS protocol [15] and a transverse slice thickness of 0.5 mm. All the data were gathered and anonymized by one of the experimenters who was not involved in the following phases. Each patient was assigned 2 codes, one for x-ray images and one for CT data. Two investigators independently planned the cases, one using the x-ray images and the other carried out 3D planning with surgical simulation. Patients' defects were categorized according to the Anderson Orthopaedic Research Institute (AORI) classification of bone defects [16]. Patient demographics and characteristics are summarized in Table I.

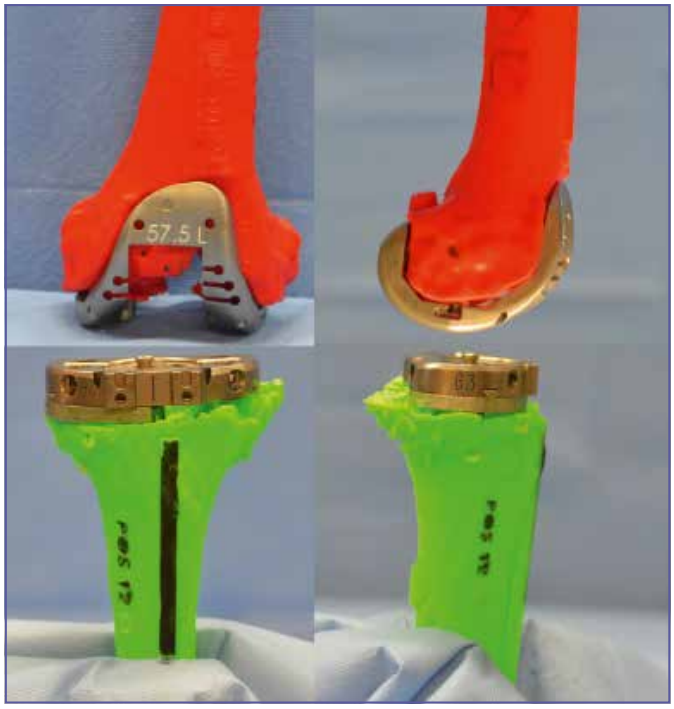

Figure 1. 3D printed model with the trail components for TKA revision in place.

CT data were then segmented using MIMICS Innovation Suite (Materialise Interactive Medical Image Control System Software, Materialise, Leuven, Belgium) to obtain a stereolithography (STL) file. The STL file was further manipulated; spacer components were removed, lines matching the femoral and tibial mechanical axis were drawn, and a code specific to the anonymization protocol was added. The file was then sliced using Ultimaker CURA (Ultimaker Cura 4.5, Ultimaker B.V., 4191 PN Geldermalsen, The Netherlands) and printed using polylactic acid (PLA) on a Creality Ender-3 FDM 3D printer. Models were then mounted on a support and carefully studied to assess the best strategy to obtain a mechanical alignment. Using revision TKA instrumentation, the appropriate cuts were made and augment selected. 2D planning was performed on the standard x-rays using Traumacad (Brainlab AG, Munich, Germany; Fig. 2) digital templating software. The necessity of prosthetic augments to fill the bone defect and restore the implant alignment in the two planning methods and collected intra-operatively.

Statistical analysis was performed using IBM SPSS statistics 27 (IBM Corp. in Armonk, NY) using intraclass correlation coefficients (ICCs) with a two-way random-effects model. This analysis measured the level of agreement between the final augment used in the implant and the planned ones from both the 2D and 3D evaluations. The accuracy of both planning methods was also measured by calculating the percentage of correct predictions. These were then compared using the chi-square test.

Table I. Patients' demographics and characteristics.

Patient	Sex-age	Implant removed	Time from TKA	Spacer type	Defect AORI (femoral/tibia)
1	F-70	Primary TKA	3 y	Articulated	2A/2A
2	F-66	Revision TKA	2 y	Articulated	1/2B
3	F-71	Primary TKA	2 y	Articulated	2A/1
4	F-73	Primary TKA	1 y	Articulated	1/3
5	M-74	Primary TKA	1 y	Static	2B/2A
6	F-67	Primary TKA	2 y	Static	2B/2B
7	F-72	Primary TKA	2 y	Articulated	1/2A
8	M-74	Primary TKA	1 y	Articulated	1/2A
9	F-71	Primary TKA	13 y	Articulated	1/2A
10	F-78	Primary TKA	5 y	Articulated	1/2A

AORI: Anderson Orthopaedic Research Institute classification

Results

The 3D planning successfully predicted the need for femoral and tibial augment in 80.8% and 66.7% of cases, respectively. Higher ICC values for the femoral augments were retrieved than tibial augments (0.808 [0.454-0.944] *vs* 0.667 [0.187- 0.896]). These results suggest an excellent level of agreement between the 3D planned and final use of augments for the femoral component. The results were highly significant (femoral: p = 0.001; tibial p = 0.007). The standard 2D planning predicted 23% of tibial augment and 37.5% of femoral ones. The difference in correct prediction between the two planning method was statistically significant for tibial (χ2: 6.6 p: 0.010) but not for femoral augment (χ2: 2.394 p: 0.127) (Fig. 3).

Discussion

3D printing is becoming hugely popular in orthopedic [17] with its technology becoming cheaper and more available by the day. Images obtained from CT scans can be processed to accurately reconstruct the patient's anatomy.

In the present study, we explored the use of these models as a planning method and compared its accuracy with standard 2D planning. To our knowledge, this is the first study comparing 2D and 3D planning in revision total knee arthroplasty, especially following PJI. A physical model of the patient's anatomy is a valuable resource for the skilled surgeon and residents approaching the complexity of TKA revision. As a University Hospital, our focus has to be both on the patient and the trainee; therefore, offering the opportunity to simulate surgery beforehand helps the team revise surgery in a step-to-step fashion. TKA revision is typically planned using standard x-ray images. Interestingly the 3D planning showed a statistically significant higher accuracy for 3D planning when compared to standard 2D templating for tibial augment. As seen in a previous study [9] a cavitary defect might not be evident on x-ray and can only be revealed with CT. 3D printing technique presents more then few drawbacks among which we have the inability to evaluate soft tissue, which can require to modify the implant intra-operatively. Furthermore, the need for a CT scan greatly increases radiation exposure, even with Whole Body Low Dose CT scan [18]. 3D planning by surgical simulation requires times, expertise and resources that might undermine its wider application. On the other hand, standard calipered x-rays require minimal radiation exposure and are widely available. The present study has limitations due to the small sample, which did not allow further statistical analysis to be performed, therefore giving only an indication on the use of augment. No information could be extracted on implant size because of the risk of biasing the analysis. The current study focuses on the reliability of 3D planning, and no clinical data are yet available regarding patients' outcomes. Further studies are needed in order to investigate the utility of 3D planning by surgical simulation and its cost-effectiveness.

Conclusions

3D planning via simulated surgery has shown to be a valuable method to predict the need for augment in revision TKA following PJI.

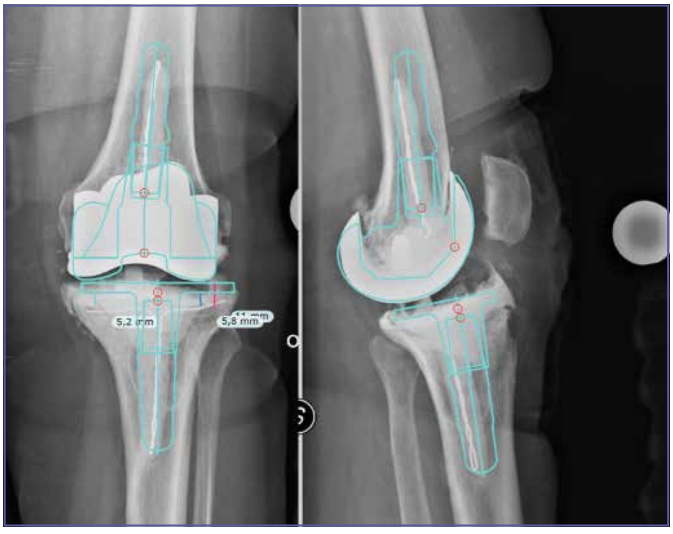

Figure 2. Digital 2D templating for the case showed in Figure 1.

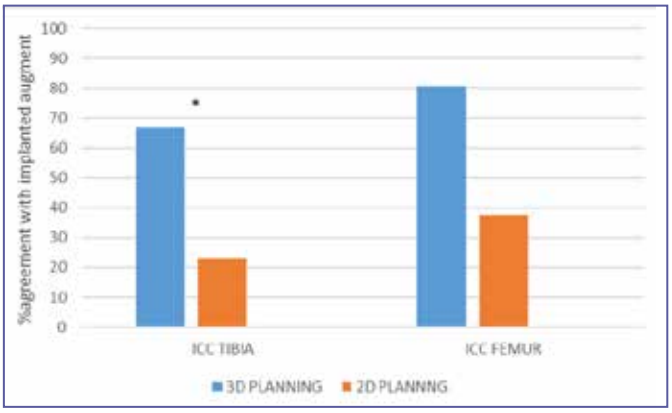

Figure 3. Graph displaying percentage of agreement for the two planning techniques.
*** indicates statistical significance with p < 0.05**

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Conflict of interest statement

The Authors declare no conflict of interest.

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Authors' contributions

GB, VDM: study design; GB, RV, RDG, DB,VDM: data curation; ML: statistical analysis; ML;RDG: writing-original draft preparation; GB: writing-review and editing; MM: supervision. All Authors have read and agreed to the published version of the manuscript.

Ethical consideration

No experimental procedures have been conducted. Due to the retrospective nature of the study ethical committee approval was not necessary. Patients were treated according to the ethical standards of the Helsinki Declaration, and were invited to read, understand, and sign the informed consent form.

Reference

1 Romanini E, Decarolis F, Luzi I, et al. Total knee arthroplasty in Italy: reflections from the last fifteen years and projections for the next thirty. International Orthopaedics (SICOT) 2019;43:133-138. https://doi.org/10.1007/s00264-018-4165-7

2 Tande, Aaron J, Patel R. Prosthetic joint infection. Clin Microbiol Rev 2014;27:302-345. https://doi.org/10.1128/CMR.00111-13

3 Koh CK, Zeng I, Ravi S, et al. Periprosthetic joint infection is the main cause of failure for modern knee arthroplasty: an analysis of 11,134 knees. Clin Orthop Relat Res 2017;475:2194-2201. https://doi.org/10.1007/s11999-017-5396-4

4 Lum ZC, Holland CT, Meehan JP. Systematic review of single stage revision for prosthetic joint infection. World J Orthop 2020;11:559-572. https://doi.org/10.5312/wjo.v11.i12.559

5 Karczewski D, Winkler T, Renz N, et al. A standardized interdisciplinary algorithm for the treatment of prosthetic joint infections. Bone Joint J 2019;101-B:132-139. https://doi.org/10.1302/0301-620X.101B2.BJJ-2018-1056.R1

6 Calton TF, Fehring TK, Griffin WL. Bone loss associated with the use of spacer blocks in infected total knee arthroplasty. Clin Orthop Relat Res 1997;345:148-54. PMID: 9418632.

7 Osei DA, Rebehn KA, Boyer MI. Soft-tissue defects after total knee arthroplasty: management and reconstruction. J Am Acad Orthop Surg 2016;24:769-779. https://doi.org/10.5435/JAAOS-D-15-00241

8 Kienzle A, Walter S, von Roth P, et al. High rates of aseptic loosening after revision total knee arthroplasty for periprosthetic joint infection. JBJS 2020;5:e20.00026. https://doi.org/10.2106/JBJS.OA.20.00026

9 Solomon LB, Stamenkov RB, MacDonald AJ, et al. Imaging periprosthetic osteolysis around total knee arthroplasties using a human cadaver model. J Arthroplasty 2012;27:1069-1074. https://doi.org/10.1016/j.arth.2011.09.012

10 Punyaratabandhu T, Liacouras PC, Pairojboriboon S. Using 3D models in orthopedic oncology: presenting personalized advantages in surgical planning and intraoperative outcomes. 3D printing in medicine 2018;4:12. https://doi.org/10.1186/s41205-018-0035-6

11 Parvizi J, Tan TL, Goswami K, et al. The 2018 definition of periprosthetic hip and knee infection: an evidence-based and validated criteria. J Arthroplasty 2018;33:1309-1314.e2. https://doi.org/10.1016/j.arth.2018.02.078

12 Ascione T, Balato G, Mariconda M, et al. Synovial cell count before reimplantation can predict the outcome of patients with periprosthetic knee infections undergoing two-stage exchange. Clin Orthop Relat Res 2021;479:2061-2068. https://doi.org/10.1097/CORR.0000000000001788

13 Esposito S, Leone S, Bassetti M, et al.; Bone Joint Infections Committee for the Italian Society of Infectious Tropical Diseases (SIMIT). Italian guidelines for the diagnosis and infectious disease management of osteomyelitis and prosthetic joint infections in adults. Infection 2009;37:478-496. https://doi.org/10.1007/s15010-009-8269-2

14 Ascione T, Balato G, Mariconda M et al. Continuous antibiotic therapy can reduce recurrence of prosthetic joint infection in patients undergoing 2-stage exchange. J Arthroplasty 2019;34:704-709. https://doi.org/10.1016/j.arth.2018.12.017

15 Olsen RV, Munk PL, Lee MJ, et al. Metal artifact reduction sequence: early clinical applications. Radiographics 2000;20:699-712. https://doi.org/10.1148/radiographics.20.3.g00ma10699

16 Mancuso F, Beltrame A, Colombo E, et al. Management of metaphyseal bone loss in revision knee arthroplasty. Acta Biomed 2017;88:98-111.https://doi.org/10.23750/abm.v88i2-S.6520

17 Wong RMY, Wong PY, Liu C, et al. 3D printing in orthopaedic surgery: a scoping review of randomized controlled trials. Bone Joint Res 2021;10:807-819. https://doi.org/10.1302/2046-3758.1012.BJR-2021-0288.R2

18 Baldi D, Tramontano L, Alfano V, et al. Whole Body Low Dose Computed Tomography Using Third-Generation dual-source multidetector with spectral shaping: protocol optimization and literature review. Dose Response 2020;18:1559325820973131. https://doi.org/10.1177/1559325820973131