



# Total Ankle Replacement Digital Templating Method

Azrulhizam Shapi'i, Mohammad Khatim Hasan, Riza Sulaiman

**Abstract:** Total ankle replacement (TAR) requires a step in the pre-surgery planning procedure that can help in determining the most suitable size for the implant. In recent years, digital implants of a size that is suitable for the patient have been widely used in the process of joint replacement surgery for hip and knee joints. Many patients have experienced traumatic damage to the ankle joint, and pre-surgery planning is currently still at the stage of using acetate templates and radiographs, which can cause errors in the surgical procedure. Therefore, a method of determining the implant size by trial and error needs to be developed so that pre-surgical planning can be implemented effectively. In this study, the Orthopaedic-TAR (OrthoAnkle) system is developed using Java software and is supported by Adobe Photoshop. This system allows a surgeon to determine the size of the implant effectively. The components involved in ankle joint replacement are Hintegra implants, designed using AutoCAD. In this way, the size of the Hintegra implant is determined based on the damage to the patient's ankle joint. DICOM X-ray images for several patients were randomly selected to test the accuracy and effectiveness of the size of the implant. A suitable size of implant can facilitate the surgical procedure and reduce damage to the implant after surgery. The results of this study, and particularly the model constructed here, contribute to the templating of digital implants for total ankle replacement. The results of the prototype test show a good response and a high level of effectiveness.

**Keywords:** Total Ankle Replacement, Digital, Design, Implant, Preoperative Planning, X-Ray

## I. INTRODUCTION

Computer graphics involve the representation of image data using a computer for the better understanding and interpretation of data [1]. Visualization is the branch of computer graphics which creates images to represent a particular set of data [2], while medical visualization requires the use of computers to create three-dimensional (3D) images from medical imaging data sets [3]. Modern medicine, and especially surgery and cancer treatment, relies on 3D imaging, made possible by magnetic resonance imaging scanners and computed tomography (CT) scanners, which create 3D images out of 2D 'slices'.

Manuscript published on November 30, 2019.

Azrulhizam Shapi'i \*, Faculty of Information Science & Technology, Universiti Kebangsaan Malaysia

Mohammad Khatim Hasan, Faculty of Information Science & Technology, Universiti Kebangsaan Malaysia

Riza Sulaiman, Faculty of Information Science & Technology, Universiti Kebangsaan Malaysia

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC-BY-NC-ND license <http://creativecommons.org/licenses/by-nc-nd/4.0/>

There are two types of data visualization: scientific and information visualization. Information visualization generally involves the visual representation of large-scale collections of non-numerical information, while scientific visualization is primarily concerned with the visualization of 3D phenomena to illustrate scientific data to allow a better understanding. Medical imaging is one of the major applications of scientific visualization that uses enhancement of images [4].

The use of scientific visualization within orthopaedics is becoming more prevalent, particularly in the preoperative digital templating of implants for total hip and knee replacements. Several digital templating software applications for hip and knee replacement have been developed, and comparisons with classical acetate templating in terms of accuracy have also been made. However, software for the digital templating of TAR is new, and our motivation is therefore to develop this.

## II. ANKLE ANATOMY AND BIOMECHANICS

### A. Anatomy

TAR is a surgical procedure that replaces the ankle joint with a false joint known as an implant. The ankle replacement (see Fig. 1) is a bone that connects the leg to the foot. These joints involve the bones of the lower leg called the tibia, fibula and talus, and can facilitate the foot in moving up and down. The bones are covered in cartilage known as articular cartilage.

The tibia is a form of the middle and superior. The fibula forms a slope in the lower part of the leg [4,5]. The superior talus articulates with the tibia and medial ceiling and lateral aspects that articulates with the malleolus.

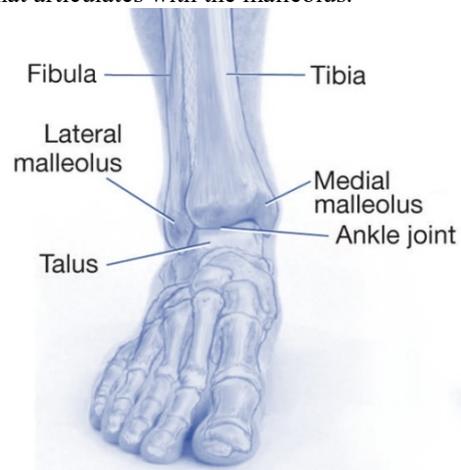


Fig.1. Anatomy of the ankle joint

## Total Ankle Replacement Digital Templating Method

The talus has a conical shape with a smaller medial side on the larger radius of curvature. When seen from the upper part of the articular, the talus is shaped like a narrow wedge from anterior to posterior. Including the soft tissue structures and ligaments syndesmotic collateral, the muscle, tendon and joint capsule configuration helps to stabilize the ankle bone.

### B. Biomechanics

According to [6], ankle biomechanics must be assessed when planning a TAR, and several factors must be considered in assessing ankle biomechanics. The important steps that need to be taken in the assessment of the biomechanics of the ankle include evaluating the limb and ankle alignment, the anatomy of the bones and ligaments of the ankle, and the leg movements in the sagittal, coronal and horizontal planes.

### III. INDICATIONS AND CONTRAINDICATIONS

Although the selection of patients is important for a successful and predictable outcome, the signs for the TAR is still defined [7]. TAR has evolved as an alternative for the treatment of end-stage ankle, and this procedure has indications and contraindications. Patient selection remains a very important factor in obtaining a good result in the replacement of ankle joints [8].

#### A. Indication

The ideal patient is one who is aged or elderly with anatomy parallel to the ankle and heel, has a good treatment to include a minimum of five degrees of dorsiflexion [7]. Diseases of the ankle joint often justify the performance of joint replacement, such as chronic inflammation in the ankle joint due to gout, psoriatic arthritis, inflammation due to hemophilia and hemochromatosis, which can cause excessive damage of the ankle joint. If patients with symptoms are excessive subtalar or arthrosis at the first assessment and fusion subtalar combined, TAR should not be performed until 45–60 days after the merger subtalar.

#### B. Contraindications

Contraindications for this procedure can be absolute or relative. As noted by [9], absolute contraindications include an active or recent infection, neuropathic arthropathy, avascular necrosis slope which affects more than 50% of the body, cover low-quality soft tissue, nerves shoot more limbs, severe misalignment and chronic ankle instability.

### IV. PROBLEMS REQUIRING TOTAL ANKLE REPLACEMENT

#### A. Osteoarthritis

Osteoarthritis (OA) of the ankle is a progressive, degenerative disease which often causes pain, a reduced range of motion, decreased quality of life and general disability [8]. Symptoms of OA have a much lower incidence in the ankle joint than in the other large joints of the lower body [10]. OA is usually caused by trauma, and can occur at a young age, causing this population to require surgery [7].

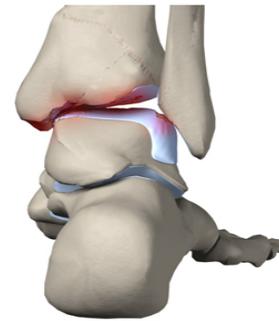


Fig. 2. Osteoarthritis

OA can arise from a single injury or the cumulative effects of multiple sprains, and is a degenerative ankle problem that continuously worsens. Currently, about 1% of the world's adult population is affected by OA of the ankle, causing significant mental and physical incapacity. OA can be divided into two types, namely primary and post-traumatic OA.

#### B. Rheumatoid Arthritis

Rheumatoid arthritis is one of several autoimmune disorders that cause inflammation of the joints [9]. The exact cause of RA is unknown, but several theories have been put forward (see Fig.3).



Fig. 3. Rheumatoid arthritis of the ankle

One characteristic of rheumatoid arthritis is the formation of a hyperplastic synovium that can destroy basic articular cartilage, subchondral bone and the musculotendinous and ligamentous support network [5,14,15,16].

### V. ANKLE REPLACEMENT IMPLANT

Hintegra is a system that involves three unconstrained components, consisting of the tibia component flush with the conical anatomy and the talar component density polyethylene. Figure 4 shows the implants used in TAR.



Fig. 4. TAR implant (Hintegra)

VI. MATERIALS AND METHODS

A. X-ray DICOM Imaging

DICOM (digital imaging and communications in medicine) is a file format that is widely used in medicine [11,13].

Use of the standard DICOM format allows the integration of scanners, printers, workstations, servers and network hardware from multiple manufacturers.

The properties of or information in the image can be interpreted, searched and carefully removed so that information is not lost during the integration process (NEMA, 2006).



Fig. 5. X-ray DICOM image

B. TAR Implant Template

Orthopedic specialists can use this template to match the patient's X-ray images to the implant, so that the optimum size can be determined. The template can be obtained from suppliers based on any false design. Hinteгра templates are available from University Kebangsaan Malaysia Medical Center (PPUKM). Templates are used to manually connect the implant to the AP radiograph, with the objective of determining the size of the talus and tibia. Figures 6 and 7 show the implant template used by surgeons in the TAR procedure.

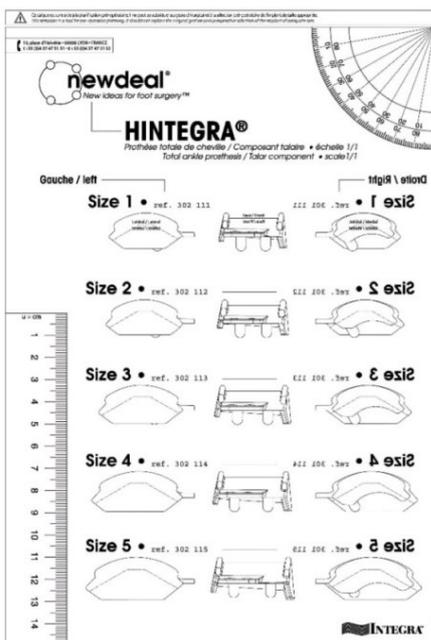


Fig. 6. Template for a Hinteгра talar implant

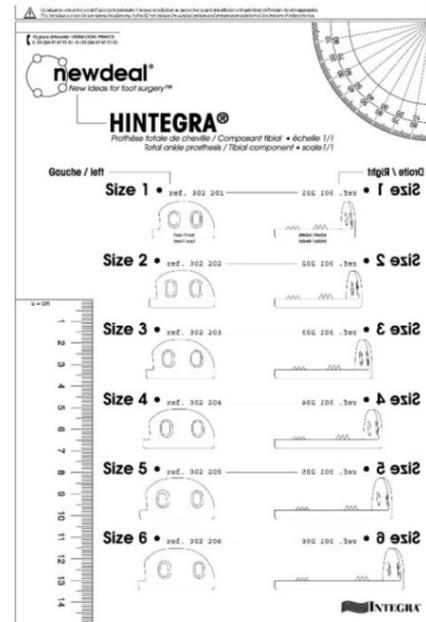


Fig. 7. Template for a Hinteгра tibia implant

VII. DESIGN

A. Digital Implant

Sketches of the implant are made using AutoCAD software to design templates for the tibia and talar implants. The purpose of these initial sketches is to obtain the basic design of the tibial implant and the talar template. After preparing the initial sketches, the model implant templates in AutoCAD format (.dwg) are then edited in Adobe Photoshop. Fig. 8 and 9 show sketches of a template image implant created using AutoCAD 2016 software.

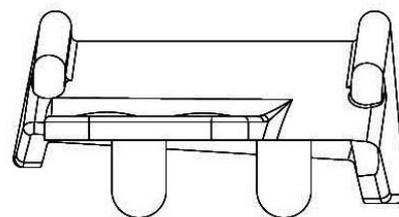


Fig. 8 The design of the talar implant model

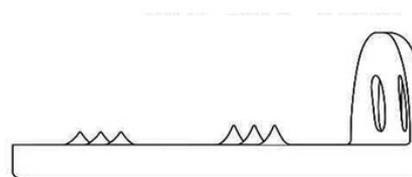


Fig.9 The design of the tibia implant model

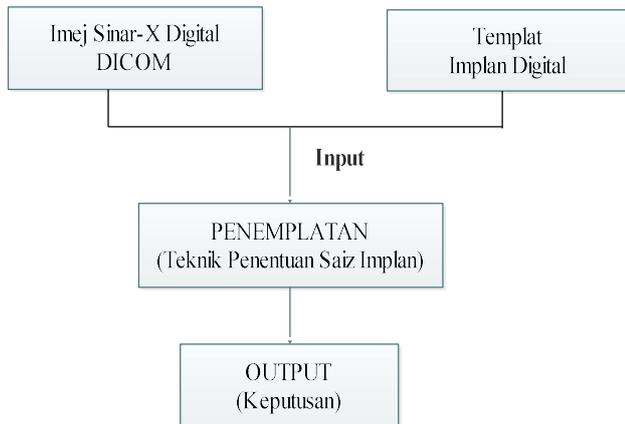
The next stage is to import the template model into Adobe Photoshop to color the implant.

B. System

The design of this system allows the implant to be successfully matched to the digital X-ray image.

# Total Ankle Replacement Digital Templating Method

Software design is the process of development of a product [11] and can involve either the process of producing new designs or the modification of existing designs. The design of the software system proposed here is shown in **Fig. 10**.



**Fig. 10. System design**

## VIII. SOFTWARE DEVELOPMENT METHOD

OrthoAnkle™ software was developed in NetBeans using the Java programming language. This software consists of three modules: input, templating and output. This software was designed for TAR preoperative planning, to enable the digitalization of the talar and tibial template.

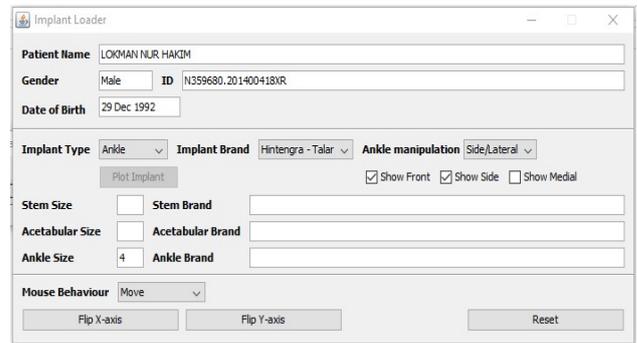
### A. Input

Two-dimensional (2D) X-ray images are used as the input for the software. Figure 11 shows an example of a 2D digital X-ray used in this study. Ankle replacement only involves the AP view (frontal view) of X-ray images, although other data contained in the X-ray images is also used. Figure 12 shows the other information corresponding to the digital X-ray shown in **Fig. 11**.



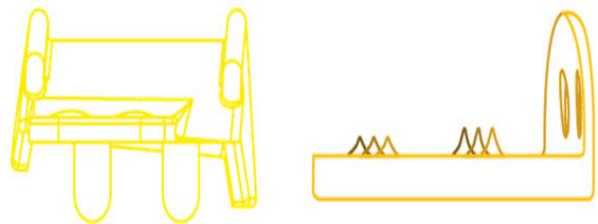
**Fig. 11 Digital X-ray of a patient**

The digital X-ray DICOM image contains patient information (see **Fig. 12**) that is used to determine the size of the implant required for ankle replacement.



**Fig. 12. Patient information**

In this module, the template images for the implants designed by the software using AutoCAD and Adobe Photoshop are used as input for the coloring stage. Figure 13 shows the Hintegra implant after coloring.



**Fig. 13. Implant after coloring**

### B. Templating

In this module, the digital implant template is shown on the X-ray image. The size of the implant can be input, and implant templates are matched with the X-ray image. The templates representing the talar and tibia components in the AP view are selected based on the trial and error technique to determine the size of the implant. Figure 14 and 15 show the talar implant at this stage.



**Fig. 14. After talar input**



Fig. 15. After tibia input

### C. Output

In this module, the display shows the implant matched to the X-ray DICOM image, where the size has been determined and the implant moved into position. Fig. 16 shows the implant at this stage.



Fig. 16. Implant after being moved

The size of the implant, as determined by the surgeon using this system, is output. Figure 17 shows a report of a successful implant template.

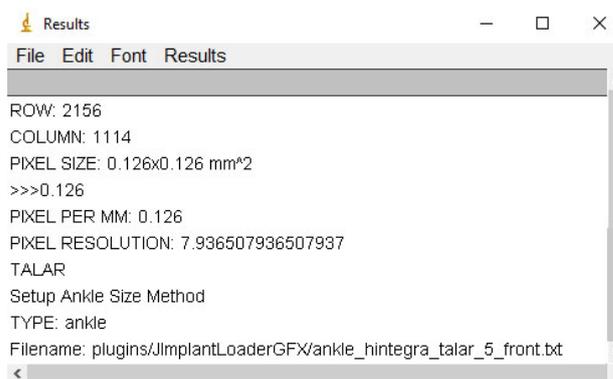


Fig. 18. Report generated for an implant template

### IX. CONCLUSIONS

TAR has been developed over a period of four decades, and template implants, surgery equipment and surgical techniques have also been modified to reduce complications and improve clinical outcomes. Various software applications and digital templates for hip and knee replacements have been developed, and comparisons with these templates in terms of their accuracy have also been carried out. However, software for digital templating of the ankle joint is new. OrthoAnkle™ offers a simple solution to this problem, using conventional methods involved in TAR. The problem is addressed here by digitizing implant templates for use in the software program. The software application allows the user to choose an implant using a computer prior to surgery. Our proposed software provides a user-friendly interface and an accurate solution for surgical planning. The limitations of this study include the relatively small number of patients evaluated. In future research, we plan to test the software using data from 10 patients. Further clinical studies are also planned to confirm both the qualitative value of the software and the quantitative precision of the results.

### ACKNOWLEDGMENT

This research project was conducted in collaboration with Associate Prof Dr Yazid Bajuri from the Department of Orthopedic and Traumatology, Medical Centre of University Kebangsaan Malaysia. This research was also funded by the University Grants PP-FTSM-2019.

### REFERENCES

1. Tan, J. A., Bajuri, M. Y., Leong, J. F., Levin, K. B., & Alias, A. (2018). Total ankle replacement for treatment of avascular necrosis of the talus. *Asian Journal of Pharmaceutical and Clinical Research*, 11(8), 1-2.
2. Mazli, N., Bajuri, M. Y., Ali, A. M., & Das, S. (2018). Use of a locking compression plate in the management of congenital pseudarthrosis of the tibia. *Journal of Clinical and Diagnostic Research*, 12(12), RD01-RD03.
3. Ibrahim, N. F. I., Daud, R., Hassan, M. K. A., Zain, N. A. M., Kamaruddin, N. S., Azizan, A. F., & Bajuri, M. Y. (2018). Effect of ring material and diameter on orthopedic implant stability: External fixation in Femur bone. *International Journal of Engineering and Technology(UAE)*, 7(4), 190-193.
4. Mansor, N., Abd Rashid, A. H., & Ibrahim, S. (2018). Paediatric femur fractures: A plea for minimally invasive surgery to prevent osteomyelitis. *Malaysian Orthopaedic Journal*, 12(2), 73-74.
5. Sadoghi P, Roush G, Kastner N, Leithner A, Sommitsch C, Goswami T. Failure modes for total ankle arthroplasty: a statistical analysis of the Norwegian Arthroplasty Register. *Arch Orthop Trauma Surg*. 2014;134(10):1361-1368.

## Total Ankle Replacement Digital Templating Method

6. Norazimah A., Azrulhizam S., Riza S., Abdul H., Mohd Fahmi M.A., Salyani O. A Comparative Study on Computer Aided System Preoperative Planning for High Tibial Osteotomy. Lecture Notes in Computer Science 9429: Advances in Visual Informatics - 4th International Visual Informatics Conference, IVIC 2015 Bangi, Malaysia.
7. Tomlinson M, Harrison M. The New Zealand Joint Registry: report of 11-year data for ankle arthroplasty. *Foot Ankle Clin.* 2012;17(4):719–723.
8. Seaworth CM, Do HT, Vulcano E, Mani SB, Lyman SL, Ellis SJ. Epidemiology of total ankle arthroplasty: trends in New York State. *Orthopedics.* 2016;39(3):170–176.
9. Singh JA, Ramachandran R. Time trends in total ankle arthroplasty in the USA: a study of the National Inpatient Sample. *Clin Rheumatol.* 2016;35(1):239–245.
10. Zhou H, Yakavonis M, Shaw JJ, Patel A, Li X. In-patient trends and complications after total ankle arthroplasty in the United States. *Orthopedics.* 2016;39(1):e74–e79.
11. Saima AL, Rosziati I, Nik Shahidah AMT, Norhalina S, Suhaila S. Thresholding And Quantization Algorithms For Image Compression Techniques: A Review. *Asia-Pacific Journal of Information Technology and Multimedia.* 2018; 7(1):83-89.
12. Guyer AJ, Richardson G. Current concepts review: total ankle arthroplasty. *Foot Ankle Int.* 2008;29(2):256–264.
13. Norhasliza, K. Active Contour Model Using Fractional Sinc Wave Function For Medical Image Segmentation. *Asia-Pacific Journal of Information Technology and Multimedia.* 2016; 5(2):47-61.
14. Shanmugam, L. & Nadesan, G. 2019. An Innovative Module for Learning Computational Thinking Skills among Undergraduate Students An Innovative Module for Learning Computational Thinking Skills among Undergraduate Students. *International Journal of Academic Research in Progressive Education & Development* 8(4): 116–129. doi:10.6007/IJARPEd/v8-i4/6440
15. Shanmugam, L., Yassin, S. F. & Khalid, F. 2019a. Incorporating the Elements of Computational Thinking into the Mobile Application Development Life Cycle ( MADLC ) Model (5): 815–824.
16. Shanmugam, L., Yassin, S. F. & Khalid, F. 2019b. Enhancing Students' Motivation to Learn Computational Thinking through Mobile Application Development Module ( M-CT ) (5): 1293–1303.