Digital Two Dimensional (2D) Implant Design for Pre-operative Planning in Total Hip Arthroplasty

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Abstract: Pre-operative planning is very important in the process of a Total Hip Arthroplasty (THA) because it is a method for determining the size and optimal implant position. According to experts from Medical Center of Universiti Kebangsaan Malaysia (UKMMC), manual methods are still used to find a suitable implant size for the patient. By using the manual method, any error in template transformation such as rotating and scaling while recording the patient's hip bone radiographs prior to the surgery will lead to errors in determining the size of implant templates. Therefore, a digital method should be developed so that the implant size detection process can be effectively implemented. Manual implant template used by UKMMC is using as the basis for the hip joint implant design. This template is redesign using AutoCAD 2010 software. Template generated in AutoCAD format will be converting to JPEG format so that it can be used in Adobe Photoshop software for colouring and scaling. A total of ten X-ray patients were randomly selected to test the accuracy and effectiveness of the digital implant. Results showed this digital technique predicted stem component size well, with 80% within ±1 size and acetabular component was predicted slightly better with 90% within ±2 component size.

Keywords: Computer Aided Design (CAD), digital, templating, total hip arthroplasty (THA), implant.

1. Introduction

Over the past decade, computers have revolutionized medical imaging [1]. At present, the field of digital and computer technology has experienced a rapid development. It includes integrated technology to achieve, store and disseminate information in various forms such as text, sound, images, graphics, and animation. The use of computer technology is no longer limited to the professional sectors, but also to the health sector. Computer is used to help people move out tasks effectively and efficiently.

Design can be defined as new ideas developed in a painting such as drawing geometry, engineering and plans [2]. In product development, process design is the most critical process for any product to be produced should meet the specifications and in accordance with the requirements and demands of consumers. The design can be either a new process design or modifying the existing design. Design process using a computer is now simplified with extensive software which helps to improve design productivity and produces high quality design, as well as to reduce the development of a product. Among the software used in design work, are AutoCAD, MasterCAM, NX5, Solidworks and others.

Total hip arthroplasty (THA) or Total hip replacement (THR) is the most successful and most effective surgery in the world [3]. Success rate of this surgery in experienced medical

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centres were within 95%. The initial impact of this surgery is loss of joint pain as soon as leaving the surgery. Patients will be able to run again after two to three days and the patient can leave hospital within six to seven days after surgery. In THR, preoperative planning with overlying templates has become an indispensable part of modern THA, and numerous methods have been proposed for its implementation [4]. With better surgical techniques, aided by the use of computer and sophisticated equipment, THA at a later time will be complete within one day.

As digital technology improves and becomes more accessible to the health care industry, digital preoperative planning will be used by an increasing number of medical centers. More practices will become filmless and software will be necessary for successful templating. The digital implant design should be produced because it will benefit the medical sector, particularly in the orthopaedic field [5].

2. Objectives

- To produce a digital implant design for total hip arthroplasty using AutoCAD 2010 software.
- Implant design in two dimensions (2D).
- Implement digital implants produced on X-ray images digitally (DICOM data).

3. Research Background

The two important subjects that will be discussed are the designation of implants process and total hip arthroplasty procedure. These two things are extremely important as they play significant roles in the production of a good and effective digital implant design.

A. Computer Aided Design

Computer Aided Design or CAD can be defined as the usage of computer hardware and graphics software in assisting the production of product design from the first stage i.e the concept level through to the level of documentation [6]. CAD is a design activity that involves the use of computers to create, modify and document engineering design [7]. It is also a creation and manipulation activity of a drawing or computer engineering design. CAD produces more efficient design documentation and resulting in the creation of manufacturing database which can save time in product design development.

Skills in CAD area are very important in carrying out this study. Designing processes need to be done carefully so that the digital implants produced can be used effectively. In addition, the knowledge of the hip joint replacement should be prioritized. This is necessary because we need to know the type and size of the implants involved.

B. Total Hip Arthroplasty (THA)

Total hip arthroplasty (THA) is a process in which the hip joints are replaced with artificial joints or implants. According to [8], THA is a surgical procedure that replaces the diseased cartilage and joint with artificial materials made of metal and plastic. The use of these implants is intended to help the patients lead a normal life without any interference or pain in the joints when walking and performing daily activities. Anatomically, the hip joint is comprised of a ball and socket joint. The socket is comprised of pelvic bones shaped like a cup, known as the acetabulum, which is connected to the end of the femur, which is shaped like a ball.

The three main components involved in THA are the stem, acetabular and ball. The corresponding artificial components are designed to ensure that the metal will always rub on the plastic and result in a gentle movement with minimum erosion [4]. In another words, an artificial hip joint (prosthesis) is made up of a ball and socket that fit together to form a joint very similar to patient's hip. Figure 1 shows the implants used in THA [9].

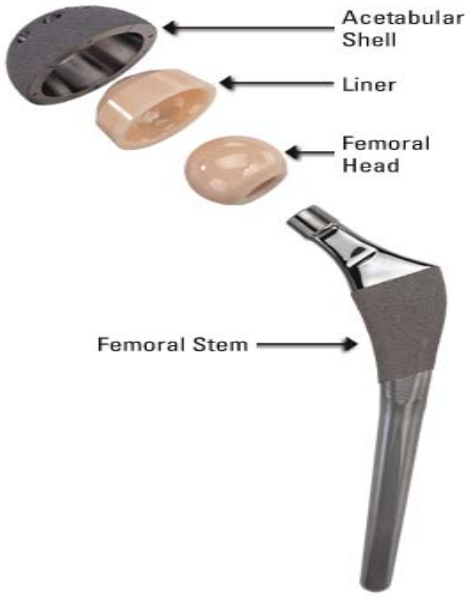

Figure 1. THA implant

A hip prosthesis or implant consists of the same basic parts as a human hip joint. The various types of implants are made up of metals or ceramics and plastics. The worn hip socket is replaced by a cup and the worn head of the thigh bone (femur) is replaced by a ball. The ball is attached to a stem that is inserted into the thigh bone for stability. While the prosthesis can restore hip movement, an artificial hip usually has a more limited range of motion than a healthy hip joint. Figure 2 shows the position of the implants after THA is performed [10].

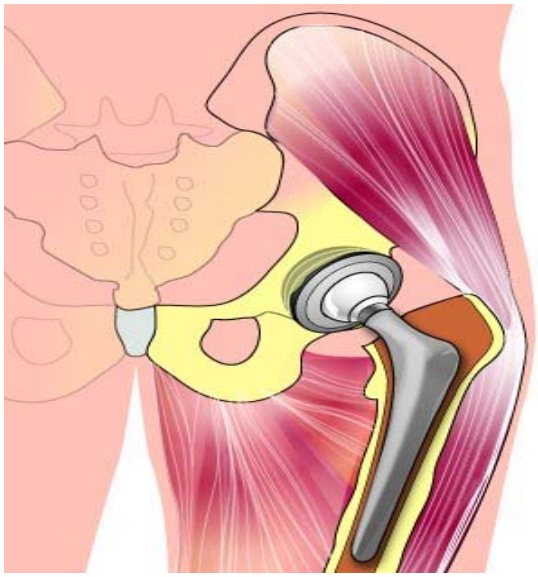

Figure 2. Position of the implants

C. Manual Pre-operative Templating

Pre-operative templating is an important part of a total hip arthroplasty [11]. The implant template preparation prior to surgery is important in the process of patient screening, in which the surgeon can determine the optimal implant size before surgery [4]. Normally the surgeon will perform the implant template customization and then bring the results to the operating room before making a final selection of the appropriate implant size. For the conventional method, any error in rotation and scaling during skeletal/skeleton radiograph recording before surgery will result in significant errors in determining the implant size [5]. Hopefully, the use of digital implant will help the surgeon to make more effective decisions. Figure 3 and figure 4 shows the manual implant template used in THA.

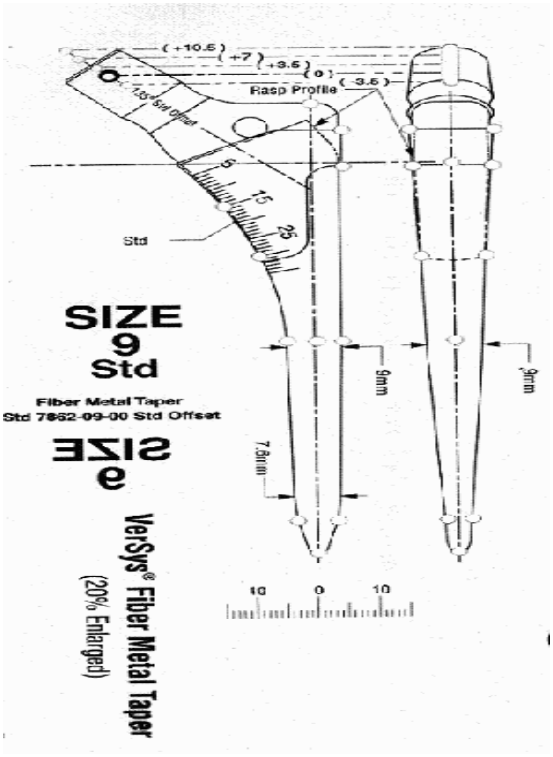

Figure 3. Stem implant template

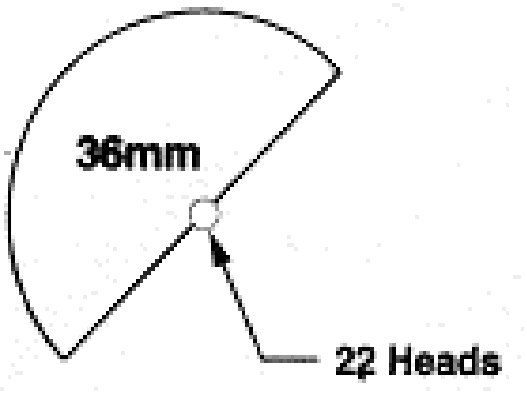

Figure 4. Acetabular implant template

4. Implant Design Methodology

To conduct this research, the methodology used is based on the approach of 'RAPID Application Development' (RAD). RAD life cycle includes four phases: planning, analysis, design and implementation. Figure 5 shows a simple flow chart of a sequence of steps needed to produce the digital hip joint implant

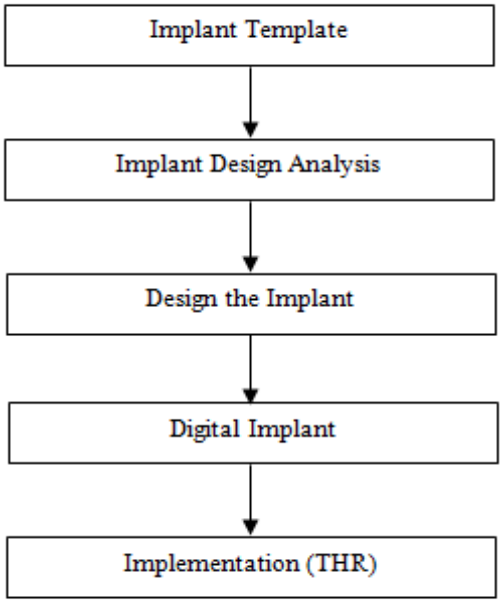

Figure 5. Design methodology for hip implant

The result of this research is the digital implant design for THA procedure. Important tool involved in the design is a two-dimensional (2D) sketch view using AutoCAD software. The environment and functions in AutoCAD 2010 software enables the 2D model to be produced easily and has a similar form with a real hip joint implant.

A. *Two Dimensional (2D) Implant Design*

The prerequisite of designing a stem is to model the shape of the stem implant [12]. The basic design of total hip's implant can be seen in figure 6 and figure 7.

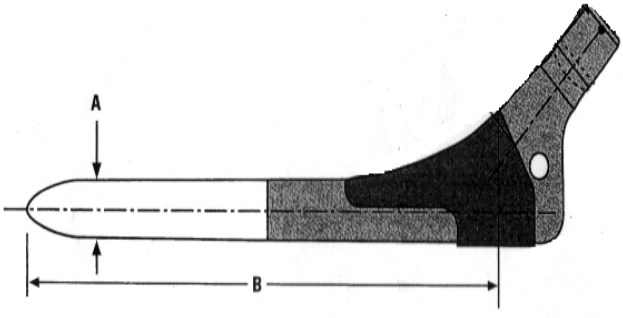

Figure 6. Stem basic design

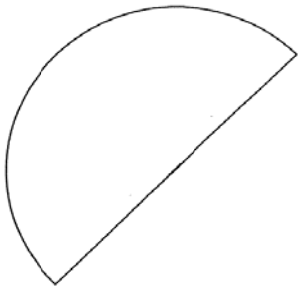

Figure 7. Acetabular basic design

The 2D implant sketch is produced using AutoCAD 2010 software. 2D views are as shown in figure 8 and figure 9. Three views shown in the 2D drawing using the viewport are Top View, Left View and SE Isometric View. Usage of viewport function helps in getting the views from various directions. Sketches are drawn with the aid of primitive entity in AutoCAD 2010 software such as Line, Polyline, Rectangle, Circle, Elipse Arc and others. The commands used to combine primitive entity to make a complex 2D view are Move, Rotate, Scale, Break, Join, Fillet and others.

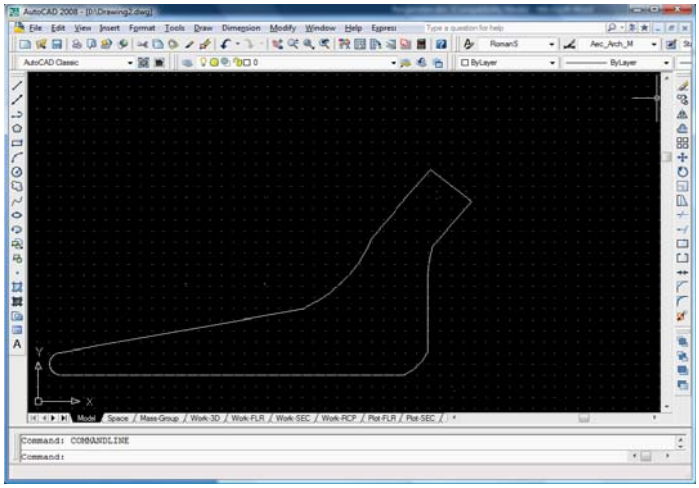

Figure 8. Stem implant design

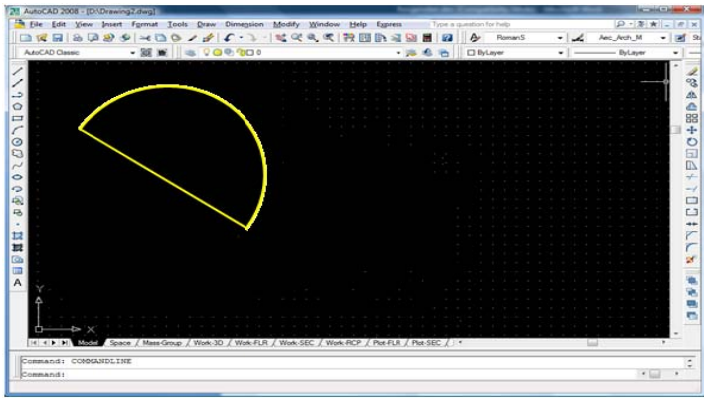

Figure 9. Acetabular implant design

The CAD file is then converted into JPEG format so that it can be used in Photoshop software to further beautify the implant. By using Photoshop, the digital implants can be coloured with any appropriate colours. Digital implants produced using Photoshop software can be seen in figure 10 and figure 11.

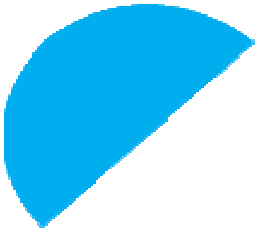

Figure 10. Digital acetabular implant for THA

Figure 11. Digital stem implant for THA

5. Result and Discussion

Digital templating is the preparation process of the pre-surgery scenario by using digital implant that designed in this study. Digital implant can be manipulated as a tool for measurement and artificial templates for orthopaedic surgery [13]. Digital implant usage enables surgeons to select implant and do the computerized pairing. The surgeon performs the necessary measurements on the template and executes surgical planning in the digital environment. Figure 12 and figure 13 shows the use of digital implant in total hip arthroplasty pre-operative planning.

To test the effectiveness of the digital implants, testing with actual cases has been carried out in cooperation with orthopaedic specialists from the Universiti Kebangsaan Malaysia Medical Centre (PPUKM). A total number of 10 actual cases of patients who had undergone THA are used for testing purposes. Testing with actual cases has been implemented because it plays an important role in determining the effectiveness of the digital implant. Results of the implant size produced by the digital technique are compared to the implant size used in actual cases. Figure 14 shows the example of an X-ray image of a patient who has undergone total hip arthroplasty surgery.

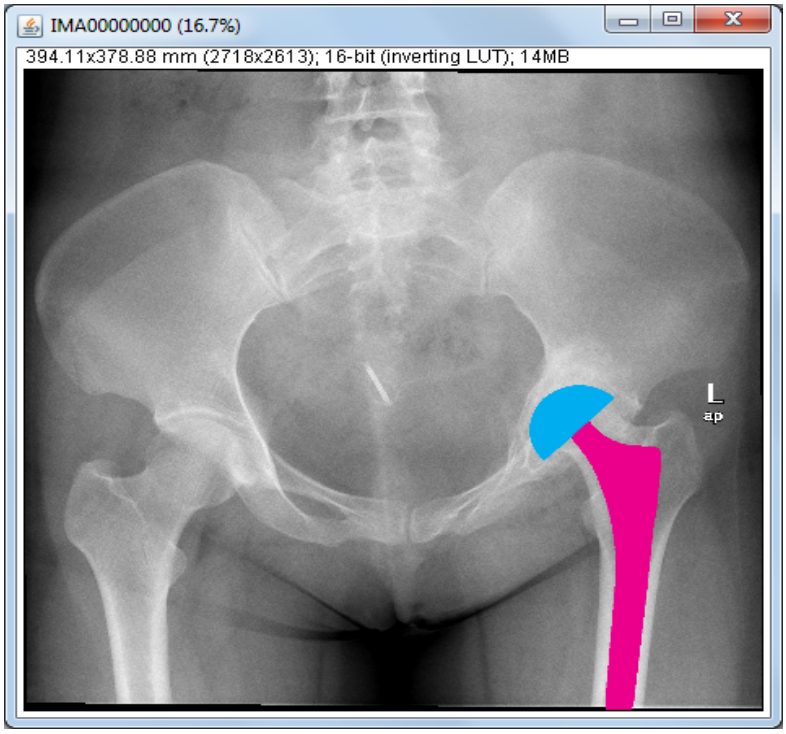

Figure 12. The use of digital implant in THA (left hip)

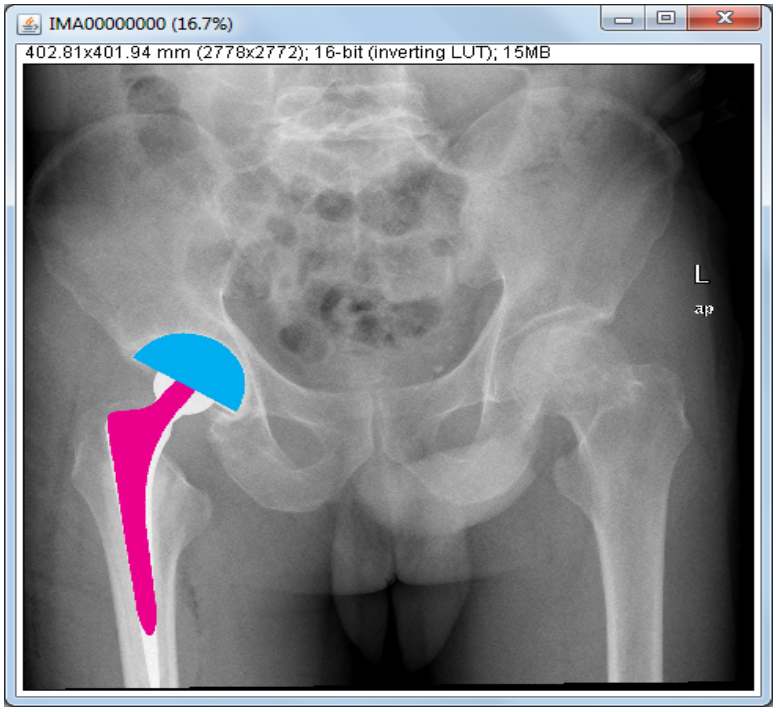

Figure 13. The use of digital implant in THA (right hip)

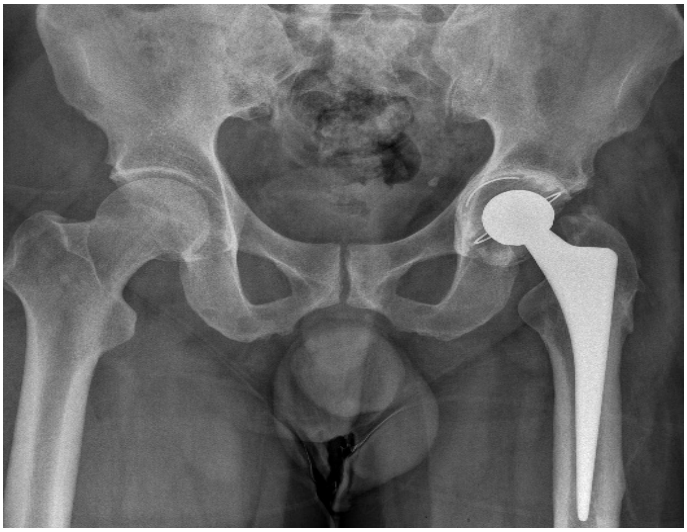

Figure 14. Total hip arthroplasty actual case

For each X-ray sample, the optimal implant sizes determined by both manual and digital methods were recorded. The difference between the two sizes was calculated and shown in Table 1. It is evident that the digital technique yields very close results to those obtained through the conventional method in all ten studies. The difference, if any, is also within the error of clinically acceptable range (±1 mm size for stem, ±2 mm for acetabular) obtained through the manual templating method. In addition, the study also demonstrated that the average time taken for implant templating in THA pre-operative planning using the digital technique was much less than when using the manual method.

Table 1. Manual vs digital

Cases	Stem (Conventional)	Stem (Digital)	Diff.	Acetabular (Conventional)	Acetabular (Digital)	Diff.
1	12	10	±2	48	48	0
2	11	11	0	54	52	±2
3	12	11	±1	50	50	0
4	13	13	0	52	52	0
5	15	17	±2	46	46	0
6	12	12	0	48	46	±2
7	16	15	±1	52	56	±4
8	13	13	0	58	56	±2
9	11	11	0	56	56	±2
10	15	15	0	54	54	0

6. CONCLUSIONS

AutoCAD is highly skilled software in performing drawing works. AutoCAD usage is extremely useful in designing digital implant for the hip joint. The research shows that the AutoCAD 2010 software is highly potential in producing a detailed and complex product design. At present, the AutoCAD usage is not only limited to the field of manufacturing and architecture, but it can also be used in the medical field. The production of this implant allows it to be used in the digital environment.

The digital implant provides several advantages for THA surgery. Compared to the manual method in which the surgeon uses a template manually and place it on the patient's X-ray , the use of digital implant not only saves time, but it also can reduce the error due to consistency difference when making adjustments to patient's implant size [14-16]. In addition, by using digital implant, it can be manipulated easily such as doing rotation and scaling. The digital method, if being use properly will enable to help surgeons to make decisions accurately and effectively. Based on the testing results, the digital implants produced were suitable and can be used in the digital environment.

Acknowledgment
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