ISSN No. 0976-5697

Volume 2, No. 1, Jan-Feb 2011

International Journal of Advanced Research in Computer Science

RESEARCH PAPER

Available Online at www.ijarcs.info

Digital Technique in Predicting Femoral Stem Size for Total Hip Replacement

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Abstract: Digital templating in total hip replacement (THR) is the preparation process of the pre-surgery scenario by using digital implant and x-ray. According to surgeons from Medical Center of Universiti Kebangsaan Malaysia (PPUKM), conventional identification methods are still used to find a suitable implant for the patient. Therefore, a digital technique should be developed so that the implant size identification process can be effectively implemented. This paper will show how the femoral stem implant designed for use in the digital environment. Manual implant template used by PPUKM is using as the basis for the stem implant design. This template is redesign using AutoCAD 2008 software. Template generated in AutoCAD format will be converting to JPEG format so that it can be used in Photoshop software for colouring and scaling. Results showed that the digital technique produced were suitable to predict the femoral stem size for total hip replacement (THR) process.

Keywords: Implant, total hip replacement, digital, technique, scaling, design, femoral stem

I. 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 medical field. Computer is used to help people move out tasks effectively and efficiently.

Total hip replacement (THR) is the most successful and most effective surgery in the world [2]. Success rate of this surgery in experienced medical 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 THR, and numerous methods have been proposed for its implementation [3]. With better surgical techniques, aided by the use of computer and sophisticated equipment, THR at a later time will be complete within one day.

Preoperative evaluation is essential in total hip replacement (THR) as it determines the size and position of the optimal implant before surgery. The accuracy of the results of preoperative enables to improve surgical procedures, save time and minimize damage to the implant after surgery [4]. Manual implant templating is quite difficult to perform due to x-ray film magnification factors that are constantly changing. In the process of digital templating, the templates and images can be automatically scaled to obtain the appropriate magnification scaling factor. Template preparation before surgery is crucial because it can determine the optimum size of the implant for the patient. For the conventional method, any scaling error in recording skeletal/skeleton radiographs before surgery will result in significant errors in determining the appropriate implant size [3]. Digital templating process is a pre-surgical process using a digital template image [5]. Preparation of a computerized planning allows surgeons to choose implant from the database and match it digitally.

The implant scaling can be done automatically and also can save time by using a computer and digital medical images [6]. However, in a scientific research by [3] entitled "Knee Joint Replacement Template Automation", there are still problems in digital implant scaling even aided by the use of computers. When the x-ray image is enlarge, the enlargement of digital implants is not according to the x-ray scale. This problem is caused by the x-ray images converted to a JPEG format. Each digital x-ray image has a different resolution depending on the value of compression image. The purpose of compression is to reduce the size of file in order to reduce the memory usage and to speed up file transfers [7]. Disadvantage of compression is that it can affect image quality. The usage of x-ray images in JPEG format has resulted in decreasing of image quality and causing the digital implants scaling to be less accurate. This problem can be solved with the use of medical images in DICOM format (*.DCM) and the appropriate scaling techniques.

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 centres. More practices will become filmless and software will be necessary for successful templating. The digital method should be produced because it will benefit the medical field, particularly in the orthopaedic field [8].

II. OBJECTIVES

The main objectives of this study are:

- To produce a digital implant design for total hip replacement using AutoCAD 2008 software.
- Implant design in two dimensions (2D).
- Implement digital implants produced on x-ray images digitally.
- Proposed and implement the algorithm for implant scaling with digital x-ray images.

III. RESEARCH BACKGROUND

In the surgical replacement of total hip joints, the damaged joints will be replaced with artificial joints or implant. Artificial joint consists of three parts, an acetabular, ball and stem. The outside of the acetabular is made of metal, while the inside is made of plastic. When the ball is connected to acetabular, it will provide smoother movement and without friction.

A. Hip Joints

Cartilage is the bone that allows joints to move freely and without pain. After some time and with the increasing in age, the cartilage can suffer wear or damage and this will cause the bones to rub against each other and can cause pain [8]. Normal cartilage is usually cream-colored and has a smooth, flat surface (figure 1). Meanwhile, the damaged and thinning cartilage caused by hip joints will be opaque yellowish in color with a rough surface or may not be there at all (figure 2). Example of damaged cartilage with total replacement hip joints is in figure 3.

Figure 1. The normal cartilage bone

Figure.2 Damaged cartilage

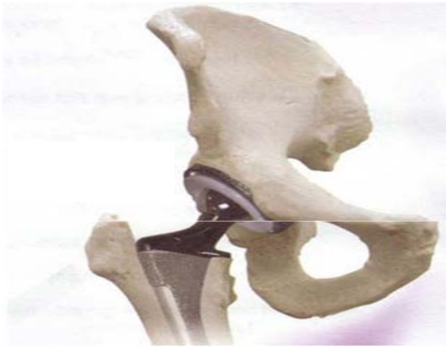

Figure 3. Bone cartilage damage joints replaced with implant

B. Femoral Stem Implant

To replace the damaged cartilage, a replacement hip joints process needs to be done. Appropriate implant is needed during the process. This implant is designed so as the metal always causes friction on the plastic resulting in soft movements and the erosion will be kept to the minimum [9]. Figure 4 shows the implant used in total hip replacement process.

Figure 4. Femoral stem implant for THR

C. Preoperative Templating

Preoperative templating is an important part of a total hip replacement (THR) [4]. 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 [3]. 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 or manual method, any error in rotation and scaling during skeletal/skeleton radiograph recording before surgery will result in significant errors in determining the implant size [8]. Hopefully, the use of digital implant will help the surgeon to make more effective decisions. Figure 5 shows the manual implant template used in total hip replacement.

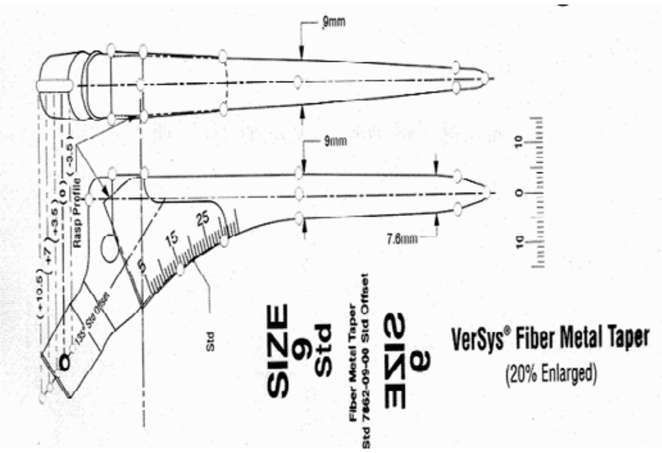

Figure 5. Manual template used in THR

IV. METHOD

To conduct this research, the methodology used is based on the approach of *'RAPID Application Development'* (RAD). RAD life cycle includes four phases: Design the implant, produced the digital implant, implementation and scaling the implant. Figure 6 below shows a simple flow chart of a sequence of steps needed to implement the digital technique for THR.

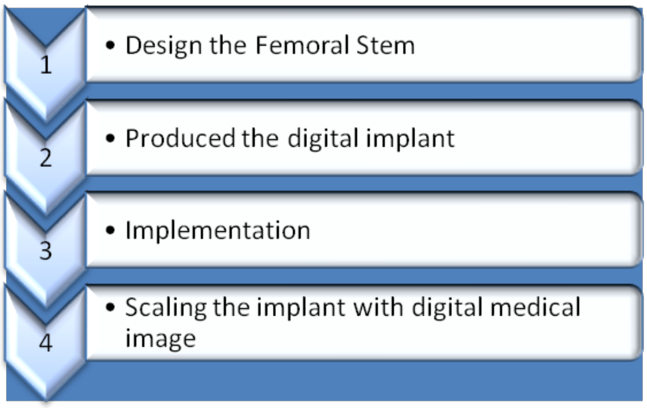

Figure 6. Steps to implement digital technique for THR

A. Design the Implant

The two dimensional (2D) implant sketch is produced using AutoCAD 2008 software. 2D views are as shown in figure 7. 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 2008 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.

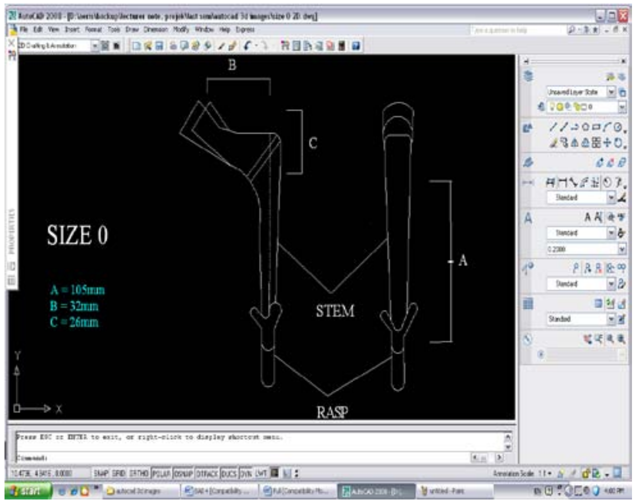

Figure 7. Implant designed by AutoCAD

B. Digital Implant

The CAD sketch 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 8.

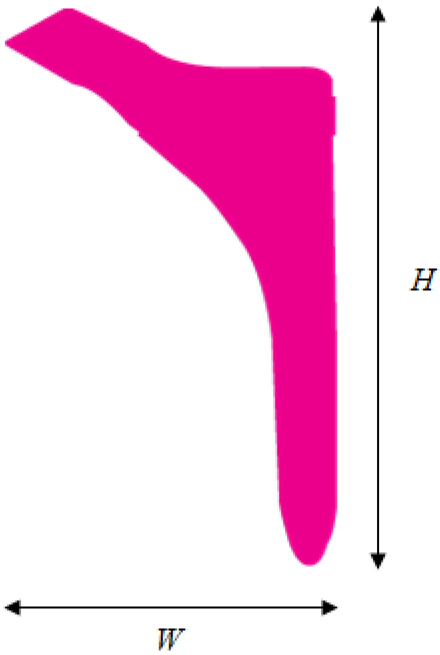

Figure 8. Digital stem implant for THR (W for width, H for height)

C. Implementation

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 [10]. 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 9 (a) and (b) shows the use of digital implant in THR.

Figure 9 (a). Digital implant used in THR (implant too small)

Figure 9 (b). Implant too big

Based on the figure 9 (a) and (b), we can see the size of digital implant not suitable for the x-ray images. Therefore, we have proposed a scaling method that can be used to match the implant size with digital x-ray and computer display.

D. *Scaling the Implant With Digital X-ray Image*

Scaling is a part of geometric transformation. Scaling transformation used to change the size of the object either to shrink or to enlarge. Object scaling typically used in computer graphics. This section discusses the techniques and algorithms that can solve the problem of scaling in the medical field that involves the use of medical images and digital implants. In the medical field, scaling techniques are used by the surgeon during the pre-surgery. For manual template method, the surgeon facing two different magnified image scales such as the x-ray scale and the implant (template) scale. To match the digital implant and x-ray images with the computer display, the ratio of digital implants with the x-ray images of patients generated using the resolution information and x-ray images pixel density. Figure 10 shows the method of scaling technique proposed in this research.

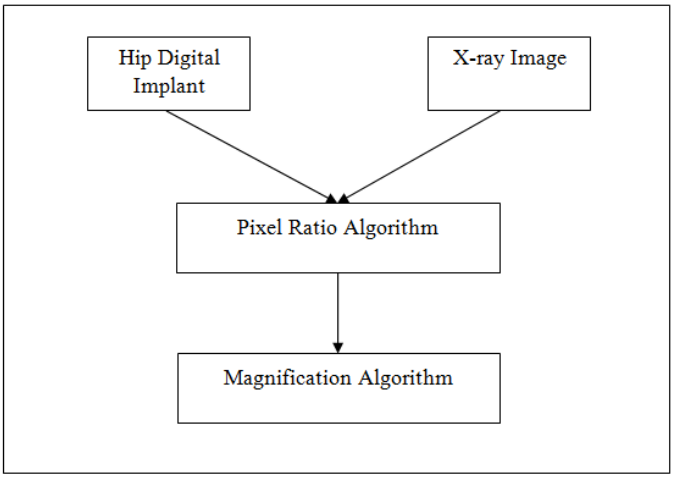

Figure 10. Scaling technique

1) Pixel Ratio Algorithm (Pr): Digital hip implant need to be scaled with a digital x-ray image in advance so that no problems arise when matching the digital implant with the x-ray medical images. Algorithm for digital implant scaling with x-ray image shown as below. The propose algorithm develop to find the ratio of digital implant pixel and x-ray image.

```
public void scaleImplantAndDICOM() {
DICOM tempDICOM = new DICOM();         //Dicom Object
tempDICOM.open(this.varDICOM.getFileInfo().fileName);
 Info info = new Info();      //DICOM new information
IJ.write(getTag(info.getImageInfo(this.varDICOM,this.varDICOM.getProcessor()),"0028,0030")); //Get the image pixel density
String str_pixel_mm = getTag(info.getImageInfo(this.varDICOM,
this.varDICOM.getProcessor()), "Resolution");    // Get the
resolution information
int indexPixelPerMM = str_pixel_mm.indexOf("pixels per mm") //
Get the "pixel per mm" from DICOM file
double double_pixel_mm =
Double.parseDouble(str_pixel_mm.substring(0,
indexPixelPerMM));     // parse the info to type double
 this.pixel_mm_ratio = (double_pixel_mm) / this.pixel_mm; // Pixel
ratio for scaling                                            (1)
```

Pixel ratio (*Pr*) produced (1) in the above algorithm will be using in algorithm magnification for digital implant.

2) Magnification Algorithm: Magnification (*M*) algorithm is extremely important because it will be using to scale digital implant (see fig. 8), to enlarge or reduce size according to the resolution and medical images magnification. These algorithms use the ratio pixel produced in the implant scaling algorithm with images [11]. The equation for this algorithm is:

$$Wd = W \times M \times Pr$$
$$Hd = H \times M \times Pr$$
$$Wd, Hd, W,H, M, Pr > 0$$

With this algorithm, the digital implant can be scaled accurately. Magnification algorithms coding used is as follows:

```
a public void drawStem(Graphics g) {
if (this.varImageIconStem != null) {int posSrcX1 = (int)
(this.varImageIconStem.getIconWidth() * magnification *
this.pixel_mm_ratio);  // scaling implant width
int posSrcY1 = (int) (this.varImageIconStem.getIconHeight() *
magnification * this.pixel_mm_ratio); // scaling implant height
int dstX1 = (int) ((stemImgPosX -
this.imp.getCanvas().getSrcRect().x) * magnification);
int dstY1 = (int) ((stemImgPosY -
this.imp.getCanvas().getSrcRect().y) * magnification);
```

Output for the two algorithms above will be discuss in subsequent section.

V. RESULTS AND DISCUSSION

Output of algorithm (1) shown in figure 11 (default size). In figure 11, the x-ray image size is 50% of the actual size. Figure 12 shows the x-ray medical image zooming at 75%, whereas figure 13 shows the size of medical images zooming to the level of 100%. Here, it can be seen that when the size of the digital medical images is enlarging, digital implant will also grow in scale as determined by the magnification algorithm. Therefore, the use of digital implants with 600 dpi pixel density is appropriate. As we can see in the figure, the implant image does not jagged even when the medical images is zooming to the level of 100%.

Figure 11. X-ray image zooming at the level of 50%

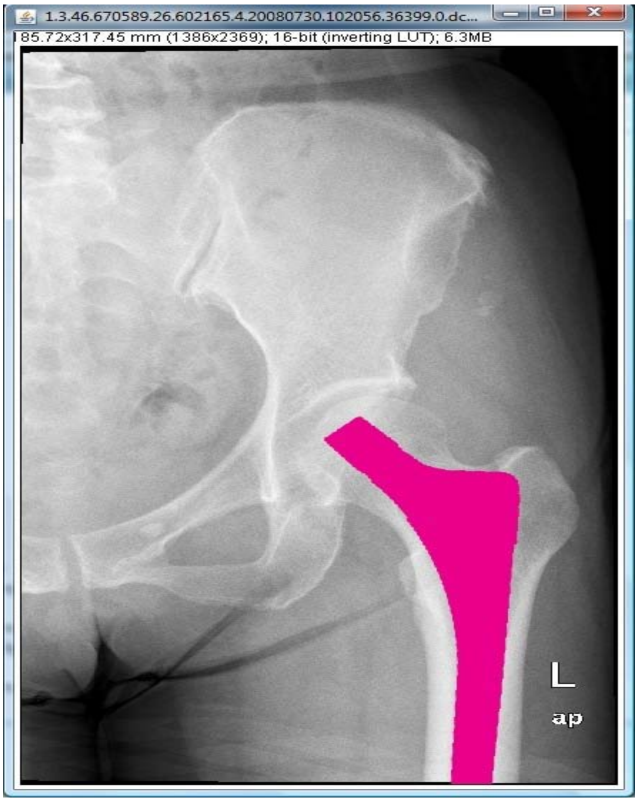

Figure 12. X-ray image zooming at level 75%

Figure 13. X-ray image zooming at level 100%

To prove the accuracy of the technique that was developed, an experiment was conducted with the assistance of the surgeon from PPUKM based on conventional methods for predicting the appropriate implan t size. Results of conventional methods compared with the results obtained using digital technique to test the accuracy of the technique developed. Table 1 shows the sample of patients who were tested.

Table 1. Conventional vs Digital

Bil	Conventional Stem Size	Digital Stem Size	Difference
1	12	12	√
2	11	11	√
3	12	11	±1
4	13	13	√
5	15	15	√
6	12	12	√
7	16	15	±1
8	13	13	√
9	11	11	√
10	15	15	√

Results for each sample and stem implant size by both met hods were recorded. Eight out of ten samples showed clearly that the size is determined by using the digital method is similar to the size of which is determined using conventional method. The difference between the size of the acceptable range of clinical value is approximately the size of a (± 1) for which this value was determined by the surgeons from Medical Centre of Universiti Kebangsaan (PPUKM).

Based on the table above, the digital technique developed in this research is suitable to predict the femoral stem size for THR. The technique developed enables for accurate implant scaling and suitable to be used in medical images because of the ability of the algorithm to read the resolution information and medical images pixel density.

VI. CONCLUSIONS

Preoperative template planning is an important step in achieving a successful outcome in total hip replacement (THR). With classical tracing paper now obsolete, we have developed specific technique and algorithm designed to undertake the templating procedure with digital implant and x-ray. Scaling is one of the geometric transformation that can be used to shrink or enlarge an object according to the specifications or the scale ratio specified by the user. In this research, the scaling technique is use to scale digital hip joint implant with x-ray medical images. X-ray images scale conversion to the actual size of the bone is the basis for the provision of digital templating process. The use of x-ray images, which converted to JPEG format may cause an error scaling implants. In addition, the provision of digital implants with high dpi is highly recommended. The higher the value of dpi, the higher the quality of the resulting digital implants produced. Based on the output generated from the techniques in this research, it can be said that the technique is capable of accurate implant scaling. Implant size will reduce or enlarge according to x-ray images size. With greater emphasis on the resolution and pixel density images, this technique enables to reduce errors during preoperative evaluation. Besides that, the use of quality x-ray images can also create a strong impact in the production of digital technique with high accuracy.

The limitations of our study include the relatively small number of sample that were evaluated. In summary, multiple options exist for predicting implant size using digital technique in total hip replacement. The surgeon can rapidly template and perform preoperative planning in a digital environment [1].

VII. ACKNOWLEDGEMENT

This research project conducted in collaboration with Dr. Abdul Yazid Mohd Kassim, Dr. Hamzaini Abd Hamid and Dr. Nor Hazla Haflah from the Department of Orthopedics and Traumalogy, Medical Centre of Universiti Kebangsaan Malaysia (PPUKM). This research also funded by University Grant UKM-OUP-ICT-34-171/2009 and UKM-GUP-TMK-07-01-035.

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