Computer Modelling of Rapid Prototyping Models for Hip Surgery

R. Dhakshyani, Ir. Dr. Senior Lecturer
School of Engineering
Asia Pacific University, Technology Park Malaysia,
Bukit Jalil, 57000, Kuala Lumpur Malaysia
dhakshyani@apu.edu.my

ABSTRACT

This research was done to show the usefulness of rapid prototyping (RP) models in dysplastic hip surgery. Since, there is lack of published information on the use of RP models in planning of dysplastic hip surgery; this research was done to provide such information. Computed tomography (CT) of patient with dysplastic hip was used. A special software was used to prepare the three dimensional model of the patient which was then used to produce the RP models. Then, these models were given to the surgeons to plan for the dysplastic hip surgeries. Measurements on the CT scan data were taken before surgery. Finally, surgeons’ comments on their experience of planning dysplastic hip surgery with the use of RP models were obtained. CT scan measurements taken before surgery indicated the severity of the dysplastic hip in each patient. Surgeons found the RP models very useful in planning of surgery which helped them make decisions, increased their confidence and also reduced surgery time. The result obtained shows the effectiveness of using RP models in planning of dysplastic hip surgery. This research provides an understanding on the use of RP models in planning of dysplastic hip surgery. Surgeons had new experience of using these models that greatly influenced the success of the surgery.

KEYWORDS

Computer Modelling, Rapid Prototyping, Mimics Software, Models, Measurements

1 INTRODUCTION

Hip joint surgeries are usually complex and time consuming. Therefore, minimizing the duration of the surgery should reduce the risk of complications during and after surgery. The main criteria involved while planning for the surgery is essential to reduce complication and smooth the execution of surgery. New surgical method not only focuses on diagnosis, operative techniques and patient management but also takes priority to code for care and operations [1]. This can be achieved using a technique called rapid prototyping (RP) modelling technique. RP technology in the medical field is one of the most interesting applications.

RP involves fabrication of prototype model precisely produced from three-dimensional medical image data [2, 3]. RP are used to produce physical models of anatomic structures and this are very useful as surgical aid, diagnosis, training, designing and also used to explain to patients on the surgery procedure. Models are accurate physical replicas of the human body parts created using medical scan data and RP processes. The advantages of using these models are good accuracy, quality, reduces risk which also improves patient rehabilitation and surgeon’s confidence during surgery. Moreover, surgeons prefer to have a physical model of their patient’s anatomy as it will enable them for better appreciation of the three dimensional object for planning of surgery [4]. In physical modelling the surgeon can hold, comprehend the object and manipulate it. Physical model gives better visualization compared to two-dimensional and three-dimensional data’s. RP produces complex features which are essential to help surgeons in making important decisions. Besides that, RP models can be used for designing of individual implants, prosthesis, as teaching tool for surgeons and also as communication tool between surgeons and patients. In custom fabrication of implants, the combination of computer-aided design (CAD), computer-aided engineering (CAE), computer-aided manufacturing (CAM), RP, rapid tooling (RT) and finite element method (FEM) enabled the researchers to study on the design and biomechanical strength which provides useful
information to surgeons prior to surgery [5, 6]. Overall, the use of RP models not only helps the surgeons to increase their surgery performance level but also leads to improved patient care. The use of RP models not only help the surgeons to increase their surgery performance level but also lead to improved patient care.

Diagnostic tools such as Computed Tomography (CT) are commonly used to describe, understand and diagnosis the patients [7]. CT provides detail information relating to the geometry and physical properties of skeletal structures [8]. CT is also an effective tool for understanding complex fracture patterns especially when combined with multi-planar reconstruction 2D reformatted images or 3D images [9]. This is an advantage as CT images can be effectively used for orthopaedic related cases. Related researches have been widely conducted on the use of RP in the medical field such as maxillofacial surgery and orthodontics [10, 11] but its contribution to orthopaedics is still limited which requires further exploration. The use of RP is invaluable as a tool to aid complex trauma and orthopaedic surgery. RP application can be used as means to quickly model the human bones for visualization and training, diagnostic, complex procedures for surgery planning and as reference model in the operation theater. Bone anatomy can be modeled effectively to understand the complexity of the case which also helps to diagnose the degree of injury [12, 13]. The use of RP model can help to reduce surgery time. Therefore, collaboration between engineers and surgeons are important to show the tremendous use of RP models in orthopaedic hip surgeries.

2 DYSPLASTIC HIP

Dysplastic hip is referred to a range of development hip disorders. The range could be from a hip that is mildly dysplastic, concentrically located and stable to the hip which is severely dysplastic and dislocated [14]. Those suffering from osteoarthritis can also develop an idiopathic disease such as dysplastic hip. Dysplastic hip is a condition in which the acetabular roof is not developed properly and seen as shallow. This leads to smaller surface for weight-bearing that requires larger force per unit area during daily activities and early degeneration is expected [15]. Change in size, shape, orientation of the acetabular and femoral head are described as hip dysplasia which is a developmental abnormality also known commonly as dysplastic hip [16, 17]. There are differences that can be seen clearly to distinguish between the adults with normal hip and dysplastic hip as shown respectively in figures 1 and 2 [18].

In normal hip, the femoral head is covered well by the acetabular socket. The distance between the center of the hip and the attachment of the abductor muscles are equal to the lever arm of these muscles. This distance is known as femoral offset. Longer distance means less work is done by the muscle to push the limb to the side. The main difference in dysplastic hip is that the acetabular socket of the hip joint is shallow and oval [19]. The roof of the acetabular socket is oblique in shape which does not offer any resistance to the upward glide of the femoral head. The femoral head can be seen deformed but is retained within the acetabular socket with minimum coverage area. In other words, dysplasia of the human hip is characterized by insufficient anterolateral covering of the femoral head by the acetabulum [20]. The lever arm of the muscles is short meaning the femoral offset is short. This leads to the muscle being forced to work more to move the limb. As time goes by, this muscles will tend to fail due to overexert and becomes weak. Dysplastic hip if not treated will eventually lead to cartilage degeneration due to the increased stress in the joint. Therefore, the main goal in dysplastic hip surgery is to restore the contact between the femoral head and acetabular [21] which is achievable.
The most important morphological measurements for dysplastic hip are centre-edge angle, acetabular angle, depth-to-width ratio and femoral head coverage by acetabular [22]. These morphological measurements are very important to the surgeons to determine the severity of the dysplastic hip and to plan for surgery. CT scan of patients’ prior surgery can be used to determine these morphological measurements. The main problems faced by orthopaedic surgeons include making decisions in reduction of the hip in acetabular reconstruction, accurate placing of bone grafting and femoral shortening. It is important to secure the acetabular component stability and coverage, high hip centre and plan for the femoral shortening in order not to overstretch the neurovascular structures and to correct preoperative bony deformities. This is technically difficult and time consuming leading to increase of the surgical time. However, these problems can be solved by using the dysplastic hip RP models. Therefore, the main objectives of this research was to obtain the dysplastic hip morphological measurements of the patients before surgery to identify the severity of dysplastic hip, to assists the surgeons in planning and making decisions with the help of the RP models before conducting the actual dysplastic hip surgery.

3 METHODOLOGY

There are a few important procedures before obtaining the final output of the RP models as shown in figure 3.

3.1 Data Acquisition

3D digital image was obtained from CT scanner. Scanning was carried out at 78 mAs and 140 kV. CT data was acquired with a slice thickness of 1 mm. Patient scanning data was exported from the CT into the digital imaging and communication in medicine (DICOM) format and saved in a CD.

3.2 Data Processing

This is an important computer modelling step that determines the quality of the RP models produced. Mimics software was used to convert the CT scanned image data from DICOM. CT images were imported into Mimics software. CT images were processed to filter the required data and the images file was extracted. Once loaded in the software, all images were registered accordingly and aligned for its orientation. Mimics software was used to perform segmentation of the anatomy through three dimensional selection and editing tools. Selection of the CT images was important as it represented the desired anatomical part of the body which is the pelvic, acetabular and femur displaying the dysplastic hip region clearly. Threshold was performed to create the first step of the segmentation mask. Threshold process enables to differentiate the bone from the surrounding tissue. This was then followed by region growing to split the segmentation object into separate masks. Manual segmentation was done due to the inconsistent density of the patient’s hard tissue. Skill is required in this step. Pixels are removed in order to separate the parts. CT scatters causing streaking, image noise and image distortion was manually removed. Selection of the parameters for 3D model was calculated and generated from the masks obtained. After that, digital model was remeshed to reduce the triangles and to smooth the model. Finally, the digital model was converted to a Standard Triangulation Language (STL) format. STL format is readable by the FDM machine.

3.3 CT scans Measurement

Important morphological measurements for dysplastic hip which are the centre-edge angle, acetabular angle, depth-to-width ratio and femoral head coverage by acetabular were measured for each patient. This was done in the Mimics Software. These morphological measurements are very important to the surgeons as it determines the severity of the dysplastic hip. It also...
helps the surgeon to classify the adult hip dysplastic based on Crowe classification.

3.4 Rapid Prototyping

The type of RP machine used for this research is Fused Deposition Modelling (FDM) machine type Dimension SST1200es. Warming up the machine took about 45 minutes. STL file was opened using CatalystEx software. Then the build parameters and build orientation of the model was set before sending to machine for model building. The medical model part was orientated in an optimum position for building. The machine process involved several steps. Firstly, the tip extrudes the filament of heated thermoplastic ABS plus which moves in the x-y plane direction on the build platform to form the first layer. The platform was maintained at a lower temperature which enables the ABS plus material to harden quickly. Support material was generated during build orientation of the RP model. Then, extrusion head deposits a second layer on the first layer after the platform lowers. This process continues until the medical model was finally built. The model was built by the machine based on layer by layer concept.

3.5 Post Processing

This step was necessary for removal of support material that was attached to the RP models. An ultrasonic bath contained Soluble Release solution was used for this purpose. RP models were immersed in the ultrasonic bath for 24 hours, rinsed in running water and dried.

3.6 Surgeons’ Feedback

The models were given to the surgeons for planning of dysplastic hip surgery. This is an important step as surgeons play crucial role in validating the fabricated RP models.

4 RESULT

Model precision on the planning of surgery takes into account of the CT scan accuracy and FDM machine accuracy. CT scan accuracy generally falls within 20% of the slice data. Therefore, CT data with a slice thickness of 1 mm gives accuracy equal of +/- 0.2 mm. FDM machine type Dimension SST 1200es a product by Stratasys of Eden Prairie produces models with good accuracy of +/- 0.254mm.

Dysplastic hip parameters for each patient were measured from the CT scan data. The obtained measurements indicated the severity of the disease in each patient. Patients 1 and 3 had right dysplastic hip while patient 2 had left dysplastic hip. The severity was classified based on Crowe classification. Patient 1 was classified as Crowe III, patient 2 as Crowe I and patient 3 as Crowe II. Table 1 shows the CT scans measurements obtained from the dysplastic hip patients.

<table>
<thead>
<tr>
<th>Dysplasia parameters</th>
<th>Normal Hip</th>
<th>Dysplastic Hip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre-edge angle (CE)</td>
<td>&gt; 25° is normal [12]</td>
<td>19.67°</td>
</tr>
<tr>
<td>Coverage of femoral head by acetabular</td>
<td>&lt; 75% is pathologic [19]</td>
<td>41.00%</td>
</tr>
<tr>
<td>Depth to width ratio</td>
<td>~ 60% is normal [19]</td>
<td>68.00%</td>
</tr>
<tr>
<td>Acetabular angle (Sharp’s)</td>
<td>&gt; 10° is abnormal [20]</td>
<td>35.83°</td>
</tr>
</tbody>
</table>

3D models generated in the Mimics software and FDM RP models produced for patients 1, 2 and 3 are respectively shown in figures 4, 5, 6, 7, 8 and 9. The build time taken to build the RP models for patients 1, 2 and 3 took 48 hours, 40 hours and 38 hours respectively.

Fig. 4 3D Dysplastic Hip Computer Model of Patient 1
RP models were given to the surgeons before the surgeries. The surgeons found the models very useful towards planning of the hip surgeries. The model precision effect on the planning of surgery is high as the measurements taken using the RP models was used to determine the implant sizes used in surgery and helped to decide on bone grafting and length of for femoral shortening. The surgeons found the differences minimal which was about +/- 0.2 mm. The acetabular cup and implant sizes was determined exactly. Acetabular cup size 46 mm and implant stem with femoral offset ~35mm was used during the dysplastic hip surgery for the patients.

The surgeons used different surgery approach for each patient which was planned using the RP models. Surgery method for patient 1 and patient 3 was based on the removal of the femoral head which was inserted with the cobalt chromium stem implant and acetabular cup made of Ultra High Molecular Weight Polyethylene that was placed at the acetabular region for hip stability while patient 2 was inserted with cobalt chromium stem implant and an acetabular cup.
made of cobalt chromium. These implants were used to improve the patients’ hip stability.

The outcome of the three hip surgeries was successful. The surgeons were very amazed and satisfied with the RP models. They found that decisions made just from the radiographs do not provide that much of information compared to holding and rehearsing the surgery with the existence of the RP models. They also commented on the increase in their confidence level as they were able to prepare and plan prior the actual surgeries are to be conducted.

5 DISCUSSION

The precision of the RP is driving towards the refinement of the algorithms for identifying surfaces and features from the CT scan data. A CT scan machine gives good precision with high resolution. Based on this advantage, RP can be integrated for medical applications. From the surgeons’ point of view, requirement of the model precision about 0.2 +/- 0.5% is acceptable in medical applications. Model precision in medical applications is required in prior fabrication of prostheses, templates, implants which are used in joint replacement surgeries and revision surgeries.

Dysplastic hip is a developmental abnormality which requires the attention of the orthopaedic surgeons to plan for successful surgery. CT scan measurements provided the information on the important parameters of the dysplastic hip and also on the Crowe classification which is a useful tool to classify the severity of the dysplastic hip. CT scan was used to measure the parameters as the measurements are more accurate than on X-rays which also give limited information [23-25].

Planning towards a dysplastic hip surgery involves various surgical techniques to secure the hip stability such as selection of implant sizes, bone grafting, femoral shortening, high hip center and leg length discrepancy [26]. RP model enabled the orthopaedic surgeons to determine the surgical approach and to rehearse on the model before performing the actual surgery.

RP models allow rapid manufacture of accurate three dimensional models of dysplastic hip [27]. These models were very helpful in preoperative assessment, severity classification and preoperative planning of dysplastic hip surgery. The RP model produced using FDM is made of acrylonitrile butadiene styrene thermoplastic material is robust and has good strength but can be cut using the operating theatre tools [28].

A surgeon gets to view, handle and practice on the physical model which is an actual anatomical replica of the dysplastic hip. They also stated that decision which they made using the radiographs to plan for surgery was different compared to when they were given with the RP models. The reason was due to the fact that they can view the dysplastic hip region clearly that is exactly the same as when they operate on the patient in the operation theatre. Besides this, they also found that the use of RP models in planning of dysplastic hip surgery improved their understanding on the respective case and helped to reduced surgery time. Additionally, using RP model enabled better communication between surgeons to study and exchange views on the suitable surgical technique.

This research clearly shows the advantages of the RP models in planning of hip surgeries which also provided the surgeons with a new experience to further enhance their skills.

6 CONCLUSION

Preoperative surgical planning is a very important step which is made easier with technique of computer modelling. RP models are an important tool to aid in the orthopaedic surgery. The use of RP models improves quality of the preoperative planning; increases surgeons’ confidence, reduces complexity of the surgery, reduces surgery time, ensures successful surgery outcome and faster patient recovery can be expected. Surgeons can choose proper operative approach prior to actual surgery which also reduces the risk of the surgery. The many advantages and potential of computer modelling and RP models give very good reasons to explore more in orthopaedic surgeries.

7 REFERENCES


