MORPHOMETRIC STUDY OF THE ACETABULUM ROOF FOR OPTIMUM IMPLANT PLACEMENT OF QUADRILATERAL PLATE FRACTURE

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MORPHOMETRIC STUDY OF THE ACETABULUM ROOF FOR OPTIMUM IMPLANT PLACEMENT OF QUADRILATERAL PLATE FRACTURE

FROM THE YEAR 2021 TO 2022

STUDY VENUE: HOSPITAL UNIVERSITI SAINS MALAYSIA

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ABSTRAK

Pengenalan

Kepatahan asetabulum yang melibatkan plat segi empat tepi adalah sangat rumit dan teknik pembedahanya sangat mencabar. Tambahan pula tiada implan yang sesuai untuk menstabilkan tulang plat segi empat tepi dengan selamat tanpa menjejaskan cawan sendi pinggul dan tiada kajian yang pernah dijalankan untuk mengkaji anatomi asetabulum di kalangan masyarakat Malaysia. Pembedahan pada plat segi empat tepi yang tidak sempurna menyebabkan morbiditi kepada pesakit. Kajian ini adalah bertujuan untuk menentukan profil asetabulum untuk kedudukan implan optimum di kalangan rakyat Malaysia.

Kaedah Kajian

Data di ambil dari rekod pesakit dan melalui system PACS di Hospital Universiti Sains Malaysia (HUSM). Pesakit berumur 18 tahun ke atas yang pernah melakukan Imbasan Tomografi Berkomputer di ambil untuk kajian ini. Pesakit yang pernah mengalami kepatahan atau instrumentasi pada kedua-dua belah asetabulum, keabnormalan kongenital pada tulang pelvis, tulang asetabulum yang tidak normal dan artifak pada imej dikecualikan daripada kajian ini. Perisian Materialise Interactive Medical Image Control System (MIMICS) versi 21.0 digunakan untuk menukar fail Digital Imaging and Communication in Medicine (DICOM) kepada model tiga dimensi (3D). Kemudian, pengukuran panjang dan sudut tulang asetabulum dikendalikan. Statistical Package for the Social Sciences (SPSS) versi 26 digunakan untuk menganalisa data. Pembolehubah selanjar dirumuskan dalam min dan sisihan piawai. Analisis ujian T-test dijalankan untuk mengkaji perbezaan yang signifikan antara jantina bagi jarak A-B (pubic tubercle ke had hadapan asetabulum), A-D (pubic

tubercle ke titik tengah asetabulum), A-C (pubic tubercle ke had belakang asetabulum) dan sudut selamat implant XY.

Keputusan

Jumlah pesakit yang dikumpul adalah 56 orang dan semuanya berketurnan melayu. Purata umur pesakit adalah 37 tahun dengan minimum 18 tahun dan maksimum adalah 86 tahun. 82.1% adalah lelaki, dan 17.9% adalah wanita. Semua ukuran adalah lebih besar bagi lelaki daripada wanita. Analisis T-test menunjukkan terdapat perbezaan signifikan antara ukuran panjang asetabulum dan jarak A-C antara jantina kecuali pada ukuran panjang antara A-B, A- D dan sudut X-Y. Kedudukan optimum implan adalah pada jarak 59.24-62.05mm dari pubic tubercle dan sudut selamat implan adalah lebih daripada 26.62 darjah.

Kesimpulan

Kajian ini memberi pengetahuan yang terperinci kepada pakar ortopedik mengenai anatomi asetabulum yang normal di kalangan masyarakat Malaysia untuk memudahkan operasi pada kepatahan plat segi empat tepi. Dengan ini, pengunaan implan dengan reka bentuk yang sesuai dapat dikenalpasti dan kedudukan implant yang optimum dan selamat dapat ditentukan untuk mencapai kestabilan plat segi empat tepi. Secara kesulurahanya komplikasi dan morbiditi kepada pesakit dapat dikurangkan.

Kata kunci: Plat segi empat tepi, asetabulum, normal morfologi, gambar 3D CT, perisian MIMICS 21.0

ABSTRACT

Introduction

Acetabular fracture involving quadrilateral plate (QLP) is complicated as the manoeuvre to reduce the fracture is challenging. Improper reduction of QLP fracture will cause significant morbidity to the patient. However, to date, there is no optimum implant to stabilize this fracture safely without compromising the hip joint and no study to measure the standard parameters of acetabulum among the Malaysian population. Thus, this study was conducted to determine the safety profile of the acetabulum for optimum implant placement among Malaysian population.

Materials and methods

This retrospective study used data from patient's record and PACS system in Hospital Universiti Sains Malaysia (HUSM). All patients aged 18 years and older were included. Those with bilateral acetabular fracture, prior pelvic instrumentation, congenital pelvic abnormality or pathology and image artefacts were excluded from this study. Materialise Interactive Medical Image Control System (MIMICS) version 21.0 software converted the Digital Imaging and Communication in Medicine (DICOM) data to three-dimension (3D) model. Subsequently, measurement of length and angle of acetabulum roof were made. Statistical Package for the Social Sciences (SPSS) version 26 was used for analysis. A continuous variable was summarized as mean and standard deviation (SD). An independent T-test was run to compare the mean difference between length A-B (pubic tubercle to anterior limit acetabulum), A-D (pubic tubercle to midpoint acetabulum), A-C (pubic tubercle to posterior limit acetabulum) and X-Y angle (safe angle of implant) among gender.

Results

Fifty-six patients were recruited in this study. The mean patient age was 37 years old, whereby minimum age was 18 years and the maximum age was 86 years. 82.1% were male, and 17.9% were female. All patients were Malay. All measurements were observed to be greater among males. T-test analysis revealed significant mean difference in measurement of acetabulum length and A-C distance between gender. Otherwise, there were no significant mean differences in measurements between A-B, A-D and X-Y angle among gender. Ideal placement of QLP is between 59.24-62.05mm from pubic tubercle and safe plate angle is more than 26.62 degree.

Conclusion

This study provides sufficient and reproducible knowledge to orthopaedic surgeons regarding normal acetabular anatomy among Malaysian population to facilitate internal fixation of QLP fracture. In addition, measurements obtained from this study can aid in developing a suitable implant design for optimum implant placement. This will eventually reduce complication rates and morbidity to patient.

Keywords: Quadrilateral plate, acetabulum, normal morphology, 3D CT imaging, MIMICS 21.0 software

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

Acetabular fracture is relatively an uncommon injury. The incidence of pelvic fractures in the USA and Western Europe have been reported to be 37 cases per 100,000 yearly with only 10% involving acetabulum[1] and Qatar reported incidence of 2 cases per 100000 annually[2]. This type of injury shows a bimodal age distribution where the first peak represents young patients sustaining high energy fractures and second peak involves elderly patients sustaining low energy fragility fractures[1].

Acetabular fractures are difficult injuries requiring special attention and expertise for its management[2]. It remains a challenge to orthopaedic surgeons due to its anatomical complexity, fracture morphology and intricate surgical exposure [3]. Restoration of stable hip joint by means of anatomic reduction and stable osteosynthesis are the primary principles in treating this fracture [4,5].

Quadrilateral plate (QLP) fracture, a subset of acetabular fracture is considered surgically demanding despite many surgical techniques that have been described with support of various biomechanical studies[6].QLP fracture require anatomical reduction and stable fixation to prevent medial displacement of femoral head [7]. Some of the concerns in addressing this fracture are attaining rigid internal fixation to counter displacement during post operative loading and safe screw placement intra operatively. In view of quadrilateral plate located medial to the articular surface of acetabulum, it is at high risk for intra articular screw penetration [5].

In our current practice, use of quadrilateral surface plate (De Puy Synthes,USA) provides adequate buttressing to quadrilateral surface area. It gives junctional support to the medial surface (by longitudinal portion of plate) and superior surface of pelvic brim (by suprapectineal portion of plate). Despite this, an alarming safety concern with this plate is intra articular screw penetration. The suprapectineal portion of this plate needs to be contoured prior to its application to prevent intra articular placement of screws Precontouring the plate to avoid such complication poses a risk of implant failure and loss of reduction. The ramification of this is post-traumatic hip arthritis, resulting in early hip replacement surgery.

Currently, prevention of intra-articular screw placement is dependent solely on intra-operative use of image intensifier, imagination capacity of the surgeon and essentially through trial and error [8]. Over the years, several studies have been published to report safe screw placement for quadrilateral plate fracture. These studies have attempted to outline safe and danger zones of quadrilateral surface, posterior acetabular wall, anterior and posterior acetabular column [9]. To date there is no study guide delineating the ‘danger zone’ over acetabular roof to avoid intra-articular screw penetration. Therefore, measurement of the acetabular roof will help surgeons to quickly and precisely identify ‘Danger Zone’ to facilitate safe screw placement along with assisting to design a proper implant to avoid complications perioperative and postoperatively. This will subsequently reduce the length of hospital stay and improve the patient’s quality of life.

1.2 OBJECTIVES

General Objective

To determine acetabular roof dimension for safe screw placement in QLP implant.

Specific Objectives

1. To measure anteroposterior length of Danger zone of acetabular roof and outline its territory using anatomical landmark identifiable during surgery.
2. To determine safe angle of suprapectineal portion of the QLP implant to avoid intra-articular screw placement.

CHAPTER 2: STUDY PROTOCOL

2.1 DISSERTATION PROPOSAL

TITLE:

MORPHOMETRIC STUDY OF THE ACETABULUM ROOF FOR OPTIMUM IMPLANT PLACEMENT OF QUADRILATERAL PLATE FRACTURE

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In our current practice use of quadrilateral surface plate (De Puy Synthes,USA) provides adequate buttressing to quadrilateral surface area. It gives junctional support to the medial surface (by longitudinal portion of plate) and superior surface of pelvic brim (by suprapectineal portion of plate). Despite this, an alarming safety concern with this plate is intra articular screw penetration. The suprapectineal portion of this plate needs to be contoured prior to its application to prevent intra articular placement of the screws. Precontouring the plate to avoid such complication poses a risk of implant failure and loss of reduction. The ramification of this is post-traumatic hip arthritis, resulting in early hip replacement surgery.

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Problem Statement

a) Limited morphological study on acetabular roof

Fracture involving quadrilateral plate is subset of complex acetabular fracture. There are lack of sufficient studies evaluating anatomic measurement of acetabular roof in literature. This is particularly important for surgeons as it determines the safe placement of implant intraoperatively.

b) Unavailability of proper implant for QLP fracture

Acetabular fracture involving quadrilateral plate is not uncommon. However the available implant in current market has high probability of intra-articular screw placement. The insertion of juxta-articular screws is done in a ‘trial and error’ manner, despite the use of image intensifier. With improper implant, principle of fixation which is achieving anatomical reduction with rigid fixation is compromised.

c) Malreduced QLP fracture has poor outcome

Difficulty in achieving reduction translates to longer operating time, higher blood loss and risk of infection. Contouring conventional plates is time consuming and inevitably leads to loss of reduction, weakening of implant and later failure of fixation. All these will add on to patient morbidity.

Research Justification

The surgical management of acetabular QLP fractures is indefinitely challenging for any orthopaedic surgeon. Therefore, precise anatomical measurements of the acetabulum will allow surgeon for proper planning preoperatively and guide them intraoperatively when managing these fractures surgically. Variation in acetabular morphology exists among population from different regions, hence exploring exact measurement within Malaysian population will provide better guidance to our surgeon.

Inevitably, non-anatomical reduction will lead to various complications and morbidity to the patient. Although there are several anatomical implants designed to accommodate fracture stabilisation, but none has been globally recognised due to varying anatomical morphometry among population worldwide. 3D CT pelvis will provide high accuracy compared to other imaging modalities as it provides better visualisation of patient's pelvis hence more precise measurement of the dimension and angle can be done. This will allow us to provide valuable data on morphological measurement of acetabulum among local population in Malaysia. Having this information is the keystone in developing a practical quadrilateral plate dimension information to propose implant design with safe screw placement.

Currently, there is no study conducted to measure the parameters of acetabular roof, hence this is the single study that is conducted to measure the normal anatomy among Malaysian population. With this data, occurrence of improper reduction of fracture will be reduced along with complications associated with it and indefinitely decrease patient morbidity.

Literature Review

Quadrilateral plate (QLP) anatomical surface marking is defined as a trapezoidal area in the pelvic region bounded by the greater sciatic foramen posteriorly , the obturator foramen anteriorly , and the pelvic brim superiorly with a horizontal line joining the ischial spine and the obturator foramen inferiorly [10] (Figure 1).Based on axial CT image quadrilateral plate is mapped as area corresponding to the medial surface of acetabulum ; from the level of anterior inferior iliac spine till the appearance of the obturator canal [10].

FIGURE 1 : Anatomical landmark of Quadrilateral plate

Fracture involving QLP is commonly seen among younger patients from high velocity trauma usually in a road traffic accident, while elderly patients suffer similar injury from low energy trauma frequently from a fall at home [11,12]. Impact of femoral head to anteromedial weight bearing dome of the acetabulum results in QLP fracture which is located directly medial to articular surface of acetabulum [13]. This is usually accompanied by medial subluxation of femoral head from dome impaction [10,13]. Surgery is required in majority of the cases with primary aim to achieve anatomical reduction, decreasing rate of post traumatic hip arthritis and rigid osteosynthesis to counter the significant medializing displacement force of hip joint [13,14]. In order to achieve this, a displaced quadrilateral plate fracture requires infrapectineal buttressing to prevent femoral head subluxation [15]. In current practice, two commonly used surgical approaches in treating acetabular and pelvic ring fractures are Stoppa approach and Ilioinguinal approach. These approaches have different technique of exposure whereby ilioinguinal approach being the most technically challenging as it requires three exposure windows and increased difficulty for screw insertion over the quadrilateral surface as compared to Stoppa approach which is an intrapelvic extraperitoneal approach[9]. However, in my centre we prefer the ilioinguinal approach.

Several biomechanical studies have contributed to evolution of plate design and configuration for the buttressing effect on QLP surface with standard pelvic plate used as spring plate or other options like T-plate,H-plate,1/3rd tubular plate and reconstruction plate with different configurations [13,15] .The concern with these plates is contouring it to pelvic bone surface intra-operatively which is both time consuming and technically demanding [4,13]. Therefore in recent times, development of newer anatomical plate such as anatomical quadrilateral surface plate, acetabular fracture reduction internal fixator, acetabular wing plate, two anatomical pre shaped plate and anatomic quadrilateral plate have reduced the need for contouring but with expense to some loss of reduction in cases of imperfect fitting[13] (Figure 2). Apart from that, it has variable outcome based on clinical trials. In our current practice, universally utilized implant is the Quadrilateral Surface Plate (De Puy Synthes, USA). This implant provides adequate buttressing to quadrilateral surface area. It gives junctional support to the medial surface (by longitudinal portion of plate) and superior surface of pelvic brim (by suprapectineal portion of plate).

FIGURE 2: Variety of plate designed by different trauma centers.

Despite optimal plate design, an alarming safety concern with fracture fixation of quadrilateral plate is the intra articular screw penetration with usage of all plates including standard Synthes QLP implant. Anatomically being on the medial surface to acetabulum, its suprapectineal portion rests on acetabular roof predisposing to misplacement of screw into the hip joint. To overcome this, intraoperative bending of plate is often necessary (Figure 3).

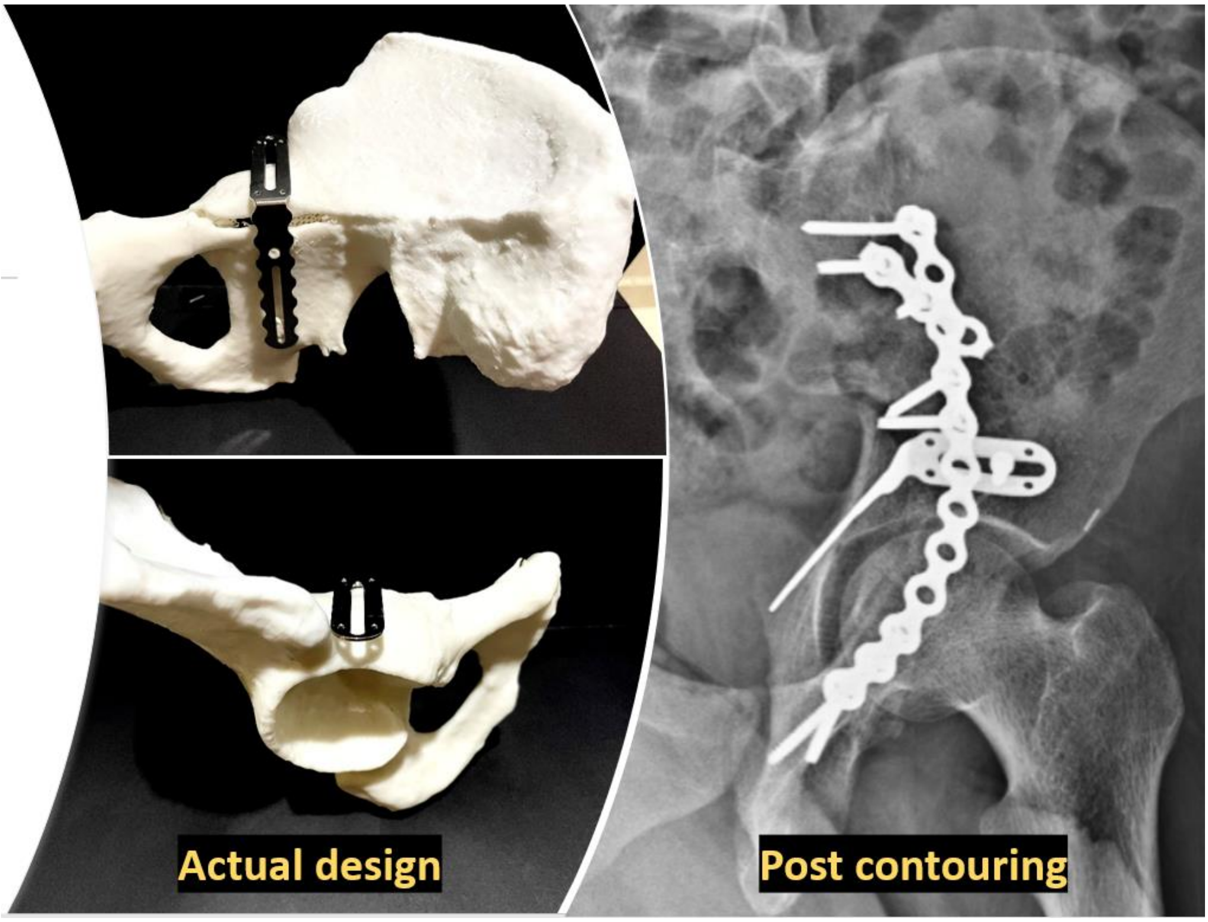


FIGURE 3:Actual position of 'Synthes' Quadrilateral surface plate prior to contouring showing risk of articular penetration (left), and post contouring of implant to avoid intra articular penetration of screw (right)

Previous studies have evaluated boundaries of safe and danger zone to avoid screw misplacement on posterior acetabular wall, quadrilateral surface, anterior and posterior column[9], but the danger zone of acetabular roof has not been explored as to our knowledge. Methods utilized by previous researchers to determine secure screw placement include sectioning cadaveric hemipelvis [15], computational 3D pelvic model [9], fixation simulation on virtual and 3D printed acetabular model [4].

Hence the purpose of my study is to define the 'Danger Zone' of acetabular roof which indicates the region within which a screw inserted is at risk of intra articular penetration and measure safe plate angle to facilitate safe screw placement away from acetabular roof. This study will be conducted based on distinct radiological landmark and reproducible surgical reference point.

Research Questions

1) What is the territory of Danger zone of acetabular roof ?
2) What is the optimum angle of suprapectineal part of the implant required to avoid intra articular screw penetration ?

Research Objectives

General Objective

To determine acetabular roof dimension for safe screw placement in QLP implant.

Specific Objectives

1. To measure anteroposterior length of Danger zone of acetabular roof and outline its territory using anatomical landmark identifiable during surgery.
2. To determine safe angle of suprapectineal portion of the QLP implant to avoid intra-articular screw placement.

Study Period

This study was carried out from 24th November 2021 until 23rd November 2022

Study Location

This study was conducted in the Radiology Department and Orthopaedic Department Hospital Universiti Sains Malaysia (HUSM) Healthcare Campus in Kubang Kerian, Kelantan. HUSM is a trauma centre, tertiary referral centre and a teaching hospital in Kelantan, which cover states in east coast region of Peninsular Malaysia.

Study Design

This study is a univariate descriptive study to evaluate the danger territory for screw placement over acetabular roof and the safe angle of QLP implant among subjects treated in Hospital Universiti Sains Malaysia from 1st January 2016 to 31st December 2021.

Study Population

The study population is patients who had CT scan pelvis done in Hospital Universiti Sains Malaysia (HUSM), Kubang Kerian, Kelantan. These patients were not specially recruited for this study, but imaging was done based on other medical reasons.

Sampling Method

In this study, patients had CT scan pelvis done as part of evaluation for their clinical condition and not specially for this study. Non-probability sampling method is used to select patients from the PACS database which encompass all the age group, gender and ethnicity. They are then subjectively selected in accordance with inclusion and exclusion criteria. The keywords used to browse the data from PACS database are ‘pelvic’, ’pelvis’, ‘abdomen’ and ‘abdominopelvic’.

Subject Criteria

The inclusion criteria include :

- Adult (18years and older)
- CT pelvis performed in HUSM
- Subjects with at least an unfractured hemipelvis
- Both genders
- Malaysian

The exclusion criteria is as follows:

- Presence of bilateral acetabular region fracture (new or old)
- Presence of congenital abnormalities of pelvis
- Presence of pathology of the pelvis (infection or tumour)
- Presence of prior instrumentation to the pelvis
- CT pelvis images with artefacts

Sample Size Estimation

Sample size estimation was determined using single mean sample size calculator (web based) by Dr Wan Nor Arifin from Unit of Biostatistics & Research Methodology, School of Medical Sciences, Universiti Sains Malaysia. This calculator is licensed under Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License.

The sample size was calculated based on the specific objectives.

Obj 1: To measure anteroposterior length of Danger Zone of acetabular roof and outline its territory using anatomical landmark identifiable during surgery.

Using single mean estimation calculator by Arifin, W. N. (2020):

Standard deviation (σ) : 3.8 (Khobragade et al 2017) [16]

Precision (± mean) : 1.0

Confidence level 100(1 - α): 95%

Sample size, n = **56**

Obj 2: To determine safe angle of suprapectineal portion of the QLP implant to avoid intra-articular screw placement.

Using single mean estimation calculator Arifin, W. N. (2020):

Mean : 36 (14-55) (Egli et al 2017) [5]

Standard deviation (σ) : 10.25

Precision (± mean) : 3.0

Confidence level 100(1 - α) : 95%

Sample size, n = **45**

Therefore, the highest number of sample size required for this study is 56.

Research Instrument

The research tools used in this study are as follows:

a. Patients' record was obtained from the record office.

b. CT scanner used to perform scans were either Toshiba Scanner Aquilion PRIME TSX-303A or Siemens Somatom Definition AS+ 128-Slice.

c. CT scan of pelvis images were obtained from PACS Picture Archiving Communications System.

d. PACS data were converted to Data Imaging and Communication in Medicine (DICOM).

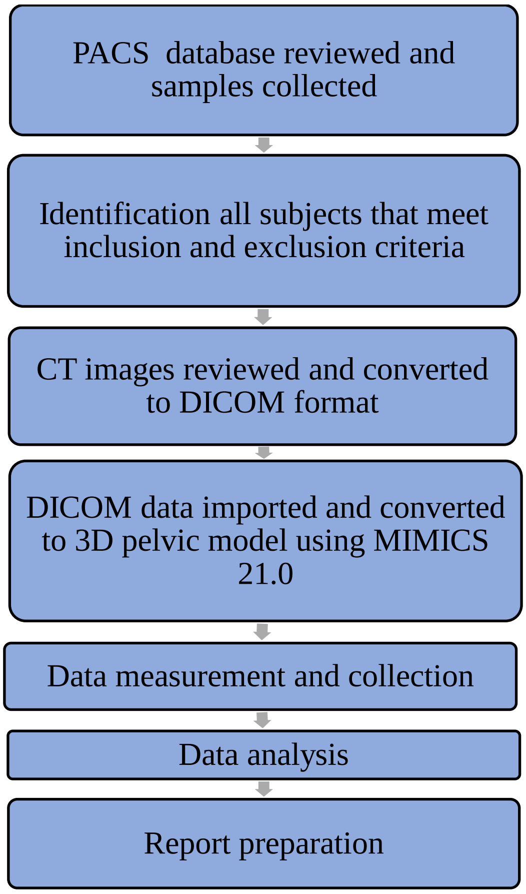
e. Materialise's Interactive Medical Image Control System (MIMIC) 21.0 software used to convert the DICOM data to 3D model pelvis for measurement.

Data Collection Method

Firstly,approval from hospital director, head of record office and head of radiology department were obtained to conduct and retrieve data for this study. Searching of study's participants were carried out from Picture Archiving Communications System (PACS) using key word 'pelvis', 'pelvic', 'abdomen' and 'abdominopelvic' in the CT slot, dated between 2016 until 2021.

Subsequently, inclusion and exclusion criteria advocated to filter participants either from CT scan report or from patient's record file. Raw data obtained were stored in Data Imaging and Communication in Medicine (DICOM) format. 3D pelvic model was then reconstructed from the raw data using MIMICS (Materialise Interactive Medical Image Control System) version 21.0 software (Materialise, Belgium).

Then the 3D pelvic model was edited to only display hemipelvis for easier measurement. Measurement of 'Danger Zone' of acetabular roof and safe plate angle was done by principal investigator followed by tabulation of raw data in Excel spreadsheet. The process of data management in the software is illustrated in flow chart below.



Definition of measurement

1. **Measurement of anteroposterior (AP) length of Danger Zone of acetabular roof and outline its territory using anatomical landmark identifiable during surgery.**

- STEP 1

  In order to practically be able to identify danger zone intraoperatively, it is imperative to use a reproducible anatomical landmark as a surgical reference point. For this research we use pubic tubercle, labelled as ***Point A*** as shown in Figure 4. This point is easily identified during ilio-inguinal and Stoppa approach.

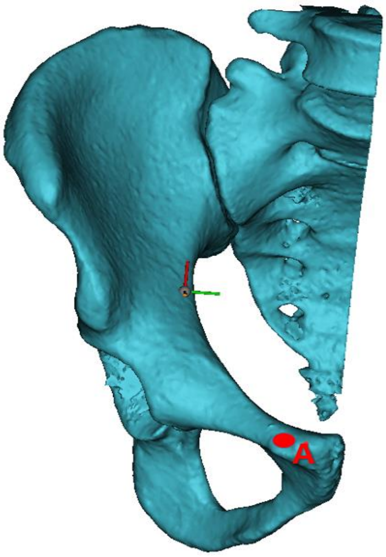


FIGURE 4 : The marking of pubic tubercle (Point A).

- STEP 2

  Pelvis is positioned such that acetabular roof is parallel to Y-axis. Acetabulum is then outlined and its largest anteroposterior diameter is measured (red line) as shown in Figure 5.

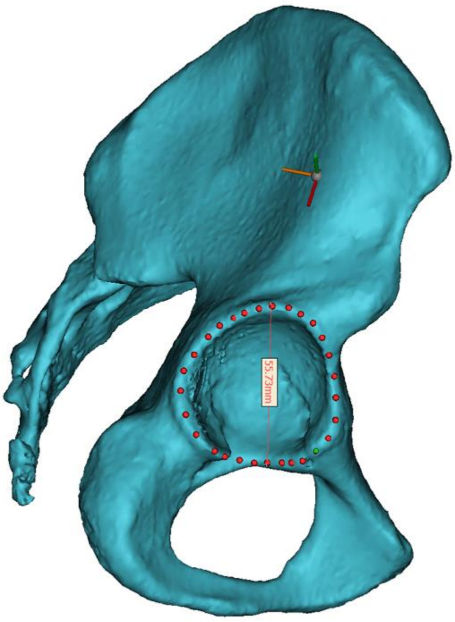


FIGURE 5: Illustration of acetabular outline and measurement of its largest anterior posterior diameter

- STEP 3

  Pelvis is then rotated along Y-axis to reflect this line over pelvic brim. Pelvic brim is defined as a line formed by upper margin of the pubic symphysis anteriorly, onto the pectineal line of the pubis, the arcuate line of ilium and reaching to the sacral promontory (anterior margin of superior sacrum) posteriorly [13]. Area within these reflected lines represent 'Danger Zone' of acetabular roof. In other words, screw placed within this area risks penetration to hip joint. The point at which these lines intersect the pelvic brim is marked; ***Point B*** (represents the anterior limit of acetabulum) and ***Point C*** (represents the posterior limit of acetabulum) (Figure 6). Intra operatively, surgeons will be able draw an imaginary 'Danger Zone' territory based on the distance of these two points from previously labelled Point A (pubic tubercle). Then distance between point '**A-B'**, '**A-C**' and '**B-C**' are measured respectively. ‘B-C’ distance represents the largest AP diameter of the acetabulum reflected on the pelvic brim (Figure 7) .

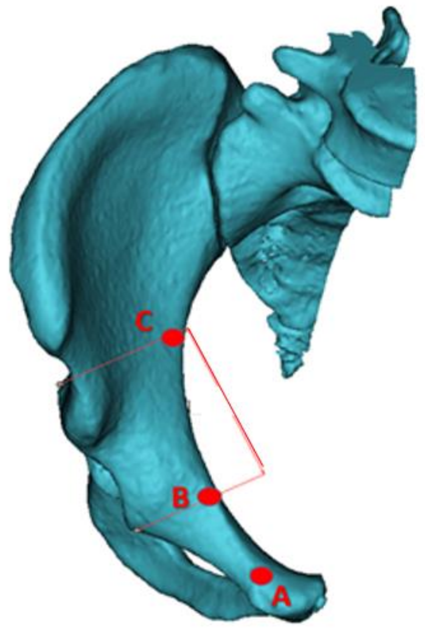


FIGURE 6: The reflected line of acetabular diameter onto acetabular roof which represents the Danger Zone.

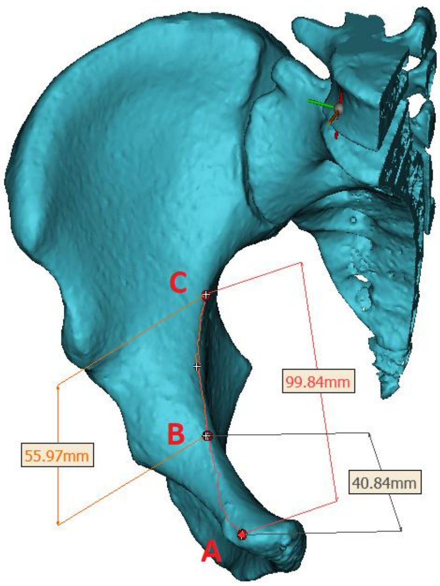


FIGURE 7 : Measurement of ‘A-B’, ‘A-C’ and ‘B-C’ distance . B-C corresponds to largest anteroposterior diameter of acetabulum.

2. **To determine safe angle of suprapectineal portion of the QLP implant to avoid intra-articular screw placement.**

- STEP 1

  Midpoint of B-C is identified and labelled as ***Point D***. This denotes the central point of acetabulum which is the ideal position of QLP implant. **A-D** distance is then measured (Figure 8)

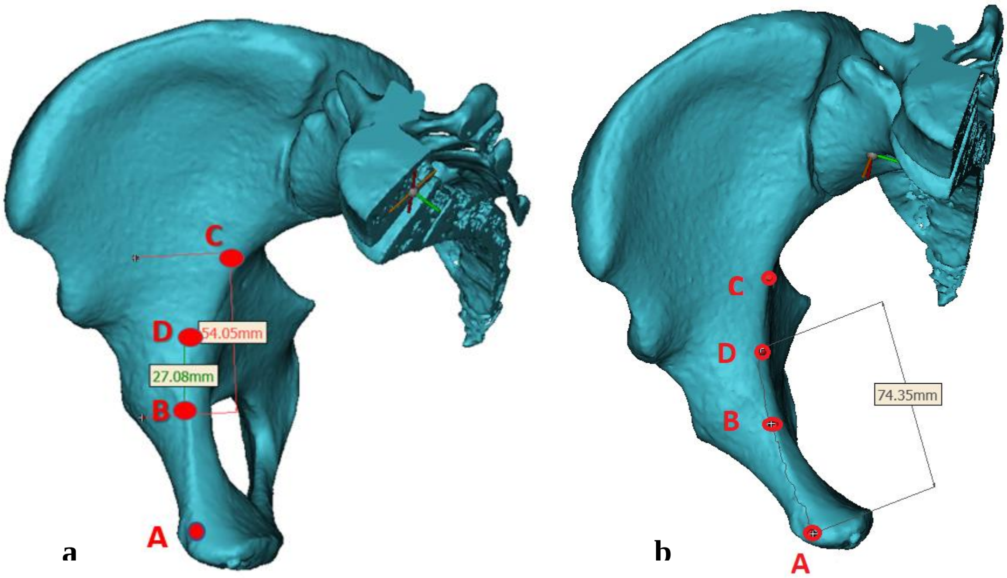


FIGURE 8: Identification of point D by measuring the midpoint between B-C (a). Measurement of A-D distance (b).

- STEP 2

  A line perpendicular to pelvic brim is drawn from point D towards acetabular roof. This line is labelled ***X*** (Figure 9). This represents the original position of suprapectineal portion of QLP implant which falls within the 'Danger Zone '.