Morphometric Analysis of the Hip Bone as the Basis for Reverse Engineering

Miroslav TRAJANOVIĆ, Mišica TUFEGDŽIĆ, Stojanka ARSIĆ, Dragana ILIĆ
University of Nis, Faculty of Mechanical Engineering, Aleksandra Medvedeva 14, 18000 Niš, Serbia,
Machine-electrotechnical school, Cirila i Metodija 26, 37000 Krusevac, Serbia
University of Nis, Faculty of Medicine, Blvd. dr Zorana Djindjica 81, 18000 Niš, Serbia
Clinical Centre Niš, Center for Radiology, Blvd. dr Zorana Djindjica 48, 18000 Niš, Serbia
miroslav.trajanovic@masfak.ni.ac.rs, miltufegdzic@gmail.com,
stojanka@medfak.ni.ac.rs, draganailic.md@gmail.com

Abstract— One of the crucial steps in the process of reverse engineering of bone is the definition of anatomical landmarks that are best suited for process reengineering. Access is via the morphometric analysis of the given bone. This paper presents a morphometric analysis of the hip bone, so as the selection of anatomical landmarks. Input data were obtained with Toshiba MSCT scanner Aquillion 64, and then they were converted to a polygonal model, which is an initial model for remodeling in the CAD program, where a set of anatomical landmarks is defined. Defined set of anatomical landmarks is used to determine the reference geometric entities of higher order and can be used to obtain surface models of the hip bone.

Keywords— morphometric analysis, reverse engineering, hip bone, RGEs, CAD

I. INTRODUCTION

In everyday orthopedic praxis, many applications require the existence of high-quality 3D models of bones. Examples of such applications are: medical-diagnosis, therapy and treatments, rehabilitation (post-operative analysis), computer assisted surgical training and simulation - planning and explaining complex surgical operations (pre-operative researches), customized implant design (functional implants such as spine, hip and knee implants) and implant fabrication using rapid prototyping techniques (in the fields of prosthetics and implantation), design and development of medical devices and instrumentation, design and manufacturing biocompatible and bioactive implants and tissue engineering, teaching purposes [1,2,3,4,5]. For these applications, 3D models of bones are obtained by reverse engineering (RE) methods, [1].

Today RE and medical image-based modeling technologies allow construction of 3D virtual models of anatomical structures of human body based on anatomical information from scanning data such as CT, MRI, and laser (or structured light) scanning.

The paper presents a methodology of morphometric analysis of the hip bone (lat. os coxae) as the basis for reverse engineering, with the aim of defining anatomic landmarks and reference geometric entities (RGEs) that can be further used for generation of 3D surface model of the hip bone in CAD software.

The definition of accurate landmarks on hip bone has been a formidable task. The reason for this is complexity of the hip bone, which represents a very complex morphological entity resulting from the fusion of three separate bones: ilium, ischium and pubic bone. In order to accomplish this task we used the first steps of methodology which is already presented in [6,7,8,13]. This methodology was conducted through several steps:

• Data acquisition and pre-processing,
• Formation of polygonal model, healing and smoothing of bone,
• Separation of the three main parts of hip bone (three bones),
• Identification and selection of the anatomical-morphological landmarks needed to build RE model.

II. ANATOMICAL AND MORPHOLOGICAL CHARACTERISTICS OF THE HIP BONE

The hip bone (lat. os coxae) is a paired, massive bone, irregularly shaped, which resembles a plane propeller or windmill winch (Figure 1). It consists of three parts: 1. ilium (os illi); 2. pubis (os pubis); and 3. ischium (os ischii). On the outer side of its middle part (Figure 1) is a deep acetabulum. A large aperture, the obturator foramen is below acetabulum (foramen obturatum). The main parts of the hip bone and its anatomical landmarks are shown at Fig. 1.
The acetabulum consists of a central, non-articular part, acetabular fossa (fossa acetabuli) which is completely filled with adipose tissue and blood vessels of the hip joint. The articular part of acetabulum represents lunate articular surface (facies lunata).

The ilium is divisible into two parts, the body (corpus ossis ilii) and the ala (ala ossis ilii). The body builds the acetabular roof. The ala has two surfaces (external and internal) and three borders (superior, anterior and posterior). The external surface (facies glutea) is crossed in at three parts with three lines - the posterior (linea glutea posterior), anterior (linea glutea anterior), and inferior (linea glutea inferior) gluteal lines. The fields between these lines define the attachment sides to the gluteal (buttocks) muscles. The internal surface has two portions: the iliac fossa (fossa iliaca - Fol) and sacroiliac surface (facies sacropelvica), which includes articular surface - auricular surface (facies auricularis - FA), so called from its resemblance in shape to the ear and the lunate acetabular fossa (fossa acetabuli) which is completely posterior inferior iliac spine (spina iliaca posterior inferior - SIPS) and the border of ala there are noticed the posterior superior iliac is incisure (incisura iliaca anterior). At the posterior anterior superior - SIAS) which can be palpated under the ala are: the anterior superior iliac spine (spina iliaca anterior superior - SIPS) which can be palpated under the skin and the anterior inferior iliac spine (spina iliaca anterior inferior - SIAI). Between these iliac spines there is incisure (incisura iliaca anterior). At the posterior border of ala there are noticed the posterior superior iliac spine (spina iliaca posterior superior - SIPS) and the posterior inferior iliac spine (spina iliaca posterior inferior - SIP). There is incisure (incisura iliaca posterior) between these spines.

The pubis is divisible into three parts: a body (corpus ossis pubis), a superior (ramus superior ossis pubis) and an inferior ramus (ramus inferior ossis pubis). At the internal surface there is articular, symphysal surface (facies symphysialis - FS) which articulates with a similar surface of the pubis at the opposite side, forming pubic symphysis (symphysis pubica). The following anatomical landmarks are noticed at the superior ramus: the oblique groove (pecten ossis pubis), the obturator crest (crista orbiuratoria), the iliopectineal eminence (eminentia iliopubica - EI), which serves to indicate the point of junction of the ilium and pubis, and pubic tubercle (tuberculum pubicum - TP).

The ischium (os ischii) consists of a body (corpus ossis ischii) and ramus (ramus ossis ischii). The body constitutes a back third of the acetabulum, while the ramus joins the inferior ramus of the pubis. Together they build ramus iscooopubicus which limits large hole from the bottom side. This hole is called the obturator foramen (foramen orburatum - FO). At the posterior border of this bone are noticed the following landmarks: greater sciatic notch (incisura ishiadiaca major - IMa), lesser sciatic notch (incisura ishiadiaca minor- IMi), the tuberosity of the ischium (tuber ischiadicum - TI) and the ischial spine (spina ischiadicia).

The acetabulum consists of the acetabular fossa (fossa acetabuli - FA), the lunate articular surface (facies lunata - FL), the acetabular notch (incisura acetabuli - IA) and the acetabular rim (limbus s. margo acetabuli - LA), above which is a groove (sulcus supraacetabularis). The acetabulum is a significant part of the hip joint (art. coxae) and the head of the femur (caput femoris) enters inside it.

III. DATA ACQUISITION AND PREPROCESSING

Point of clouds are the input for RE data processing, so at the first stage of the modeling we have collected input data, from female pelvic bone, with Toshiba MSCT scanner Aquillion 64. CT scan was separated from the CT slices, performed in resolution of 0.5 mm and stored in the form of DICOM format. These 2D slice images were reconstructed in 3D polygonal model, written in STL (STereoLitography) format through two basic steps: image segmentation and region of interest segregation. This is the basic data structure for CAD modeling.

IV. MORPHOMETRIC ANALYSIS OF THE HIP BONE

Importing STL data in CAD system represents the next step in modeling process. After cleaning and removing all unnecessary additional entities, polygonal model is created. This model must be healed, tessellated, optimized and smoothed with the aim to meet the requirements from the end-use model. Model is suitable for further processing, so the next step is determination of Referential Geometrical Entities (RGEs) on initial model at all three bones, which correspond to the anatomical landmarks, according to anatomical and morphological characteristics

A. Determination of Referential Geometrical Entities (RGEs) on initial model

The procedure of identification and definition of anatomical landmarks is based on result of morphometric analysis. Anatomical landmarks are defined for a given bone only once, and are important as references for other geometrical features.

1) Acetabulum

At the acetabular rim (limbus acetabuli - LA) twenty-two points are selected. Connecting these points gives the approximation for the LA. Based on the measured distance from the surface which limits the LA to selected points in LA, we have chosen the farthest three points and one nearest point at the LA, which are used to determine the two planes. By setting the plane though three the most distant points, where the projection of the center at the given plane is selected for the center of the circle, is obtained the first approximation for LA (represented by the yellow circle at Figure 2). The mean value of the projection distance between the points and the center projection on that plane gives the radius of 26.583 mm.

By setting the plane though three points - the farthest, the nearest and center of the area that covers acetabulum, when the projection of the center of the area is chosen for the center of the circle, the second approximation for LA is obtained (represented by the pink circle at Figure 2). The mean value of the projection distance between the points and the projection center to the given plane now gives the radius of 26.855 mm. By comparing these values with the distance from the surface that limits FA to the selected points in 3D (mean value from 26.962mm), we have concluded that the second approximation is better because it shows significantly lower deviations.
In the acetabular fossa is made the approximation of the articular area in the acetabulum floor (facies lunata - FL), shown at Figure 3. The center of this area will be used later for defining the axis of rotation for the planes of intersection at the hip bone.

2) Pubis

At the pubic bone we have defined points which determine articular symphysial surface of pubis (facades symphysialis - FS). Area bounded by curve obtained by connecting these points represents an approximation for FS. The approximations for FS and FL are presented at Figure 3.

3) Ischium

At the ischium body is defined the area that represents ischial tuberosity (tuber ischiadicum TI), by constructing the boundary line through border points on TI. After measuring the distance of these points on this boundary line that limits the TI surface, the farthest and the nearest point were chosen (Figure 4). These two points and the center of TI determine a plane which can be used for the intersections on the upper part of ischium body.

4) The ilium

At this bone are defined the following anatomical landmarks: anterior superior iliac spine (spina ilica anterior superior - SIAS), anterior inferior iliac spine (spina ilica anterior inferior - SIAI), posterior superior iliac spine (spina ilica posterior superior - SIPS) and posterior inferior iliac spine (spina ilica posterior inferior - SIPI). The coordinates of these anatomical landmarks on the left and right hip bone may be used to determine pelvic measurements, e.g. pelvic width, pelvic height and pelvic depth, end for the estimation of hip center in frontal, sagittal and transverse planes, [10], as well as for determination of the anatomical and technical frames [11], and pelvic anatomical coordinate system, [12].

V. CONCLUSIONS

Morphometric analysis which is presented here includes the definition and determination of anatomical landmarks which represent RGEs and are essential for reverse engineering process of bones. The results that are generated by this method directly depend on the quality of landmarks which are chosen with the aim to provide an optimal and adequate coverage of anatomical and morphological characteristics of the hip bone and have the same locations on each bone. These, so called, true landmarks can be also used for definition of pseudo-landmarks (constructive points) or mathematical landmarks (extreme points), for determination of RGEs of higher order (curves, surfaces and solids) and their sub entities (vertices, faces and edges).

ACKNOWLEDGMENT

This paper is part of project III41017 Virtual human osteoarticular system and its application in preclinical and clinical practice, funded by the Ministry of Education, Science and Technological development of Republic of Serbia, for the period of 2011-2014.

REFERENCES

Tech Products Development, MECAHITECH’10, Bucharest, 23-24 September 2010,


ECCOMAS Special Interest Conference M. Papadrakakis, M. Kojic, V. Papadopoulos (eds.) Rhodes, Greece, 22–24 June 2009


