Study of the Auricular Surface of Sacrum in Thais Using Geometric Morphometric Technique
ศึกษาผิวข้อต่อรูปใบหูของกระดูกใต้กระเบนเหน็บในคนไทยโดยใช้วิธีจีโอเมทริกมอร์โฟเมทริก

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ABSTRACT

To study sacral auricular surface in Thais cadaver in order to provide morphological information and better understanding in the mechanism of low back pain and pathologic change of joints of pelvic girdle. Total of 88 sacrum specimens were taken from 42 Thais cadaver and 46 dried bones. The auricular surface was studied by using outline-based geometric morphometric technique for analysis shape and size, then compared among sides, genders and ages. The result showed significant difference female mean shape is relatively broader than male ($P \leq 0.05$). On the other hand male mean size is larger than female ($P \leq 0.05$). The mean shape of female age over 60 years was broader than age group under 60 ($P \leq 0.05$). Articular surface of male age over 60 years was larger than under 60 ($P \leq 0.05$). Comparing between sides showed no significant difference in mean shape and size. It can be concluded that female shape has design for movement and pregnancy and larger size in male that design for transmit weight and absorb force. Moreover, the effect of repetitive force on activity of daily life may change shape and size.

บทคัดย่อ

ศึกษาผิวข้อต่อรูปใบหูใต้กระเบนเหน็บในคนไทยเพื่อเป็นข้อมูลทางสัณฐานวิทยาและเพื่อความรู้ ความเข้าใจกลไกและพยาธิวิทยาของอาการปวดหลังส่วนล่างและการเปลี่ยนแปลงของข้อต่ออุ้งเชิงกราน ศึกษาในกระดูกใต้กระเบนเหน็บของคนไทยจำนวน 88 ชิ้นโดย 42 ชิ้นจากร่างอาจารย์ใหญ่ และ46 ชิ้นจากโครงกระดูก ผิวข้อต่อถูกนำมาศึกษารูปร่างและขนาดด้วยวิธีจีโอเมทริกมอร์โฟเมทริก โดยเปรียบเทียบกันระหว่างข้าง เพศและอายุ ผลการวิเคราะห์พบว่า ผิวข้อต่อของเพศหญิงมีรูปร่างของกว้างกว่าเพศชาย และเพศชายมีขนาดของพื้นผิวใหญ่กว่าเพศหญิงอย่างมีนัยสำคัญที่ระดับ 0.05 เปรียบเทียบผิวข้อต่อในกลุ่มอายุพบว่า เพศหญิงกลุ่มอายุมากกว่า 60 ปีมีรูปร่างกว้างกว่ากลุ่มอายุน้อยกว่า 60 และเพศชายในกลุ่มอายุมากกว่า 60 ปีมีขนาดใหญ่กว่าเพศชายที่มีอายุต่ำกว่า 60 แต่เมื่อเปรียบเทียบระหว่างข้างพบว่าไม่มีความแตกต่าง จึงสรุปได้ว่ารูปร่างที่กว้างของเพศหญิงถูกออกแบบมาสำหรับการเคลื่อนไหวและการตั้งครรภ์และขนาดที่ใหญ่ของผิวข้อในเพศชายออกแบบมาเพื่อการส่งผ่านแรงและลดแรงกระทำต่อข้อต่อ ยิ่งไปกว่านั้นผลจากแรงที่กระทำซ้ำๆต่อผิวข้อต่อตลอดช่วงชีวิตอาจจะส่งผลต่อการเปลี่ยนแปลงของรูปร่างและขนาด

Keywords: Sacroiliac joint, Auricular surface, Geometric morphometric
คำสำคัญ: ข้อต่อเชิงกราน พื้นผิวข้อต่อรูปใบหู จีโอเมทริกมอร์โฟเมทริก

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Introduction

Sacrum is a key bony structure in the human locomotion system. It is a large triangular bone composes of five fused-segments of sacral vertebrae, connects to base of the last lumbar vertebra as lumbosacral joint and connects to left and right sides of pelvis to form sacroiliac joints (SIJ) (Alderink, 1991). The joint anatomically is linked between spine and hip bone of lower limb and functionally it plays an important role for stability and transferring load to lower limb (Vleeming et al., 2012). It is a reciprocal load transfer from body to lower extremities and ground reaction force upward to the pelvic ring. Stability of SIJ depends on the model of "force and form closure" (Vleeming et al., 1990). It supports the stability within the pelvic ring and decrease sacroiliac joint shearing force through the keystone-like which form closure were wedge shape of the sacrum and interfacing auricular surfaces while force closure were transferred load via tension of ligaments, fascia, muscles and ground reaction forces (Vleeming et al., 1990; Vleeming et al., 2012). Movements of SIJ are complex; they move correlatively together and combining rotation and translation along three axes (Goode et al., 2008). However, the main movements are nutation and counter nutation (Weisl, 1955). These motions depend on lumbosacral flexion and extension, respectively. In addition, gait cycle associated with pelvic complex whereby sacrum rotated posteriorly during swing phase and heel strike (Dontigny, 1985; Alderink, 1991). Structural variation of pelvis between genders have been reported particularly the sacroiliac joint region, which will affect movement pattern and loads bearing. The SIJ pain is predominantly found in female as well as in a person who has mechanical dysfunction (Schauberger et al., 1996; Sebastian, 2000; Vermani et al., 2010; Turgut et al., 1998). Previous studies revealed anatomical structure difference between surface area of male and female can be related to pelvic pain while only female joints shape was association of pain (Jesse et al., 2017), various studies focused on ligaments (Steinke et al. 2010), movement (Brunner et al., 1991), alignment (Braune, Fischer, 1892; Vleeming et al., 2012), significant differences of shape and size of auricular surfaces were advocated for different mobility and functional adaptation with major forces (Sebastian, 2000; Vleeming et al., 2012; Anastasiou and Chamberlain, 2013). The relaxin along with estrogen hormone changes affected ligamentous, fascia, and muscles in female lead to abnormal movement, which associated during menstruation and pregnancy (Maclennan, 1991; Facciolli et al., 2009). These differences may increased risk factor for SIJ dysfunction and shape morphology.

The SIJ has been implicated as cause of low back pain (LBP) and reported prevalence about 15% to 30% (Rashbaum et al., 2016; Cohen, 2005; Hansen, Helm, 2003). The morphological differences of the auricular surface led to degenerative changes in the SIJ (Nishi et al., 2018) and also had positive correlation with degenerative changes of hip, knee and zygapophyseal joints (Nishi et al., 2017). The morphological information of SIJ auricular surfaces are still missing in Thais.

Objective of the study

In order to lay a morphological foundation of SIJ articular surface, this study aims to verify the normal shape and size of sacral auricular surface in Thais by using geometric morphometrics and comparison between gender, sides, and age groups. These can provide better understanding of its biomechanical function and possible kinematic mechanism inducing pathologic changes and causing low back pain.

Materials and methods

This study has been approved by Siriraj Institutional Review Board (SIRB Protocol No. 167/2561). Total of 88 human sacrum bones with known age and sex were used, in which 42 were taken from formalin embalmed cadavers and 46 dried bones from the bone collection of Department of Anatomy, Faculty of Medicine Siriraj Hospital. The cadaveric specimens were dissected to remove all soft tissue out as well as cartilaginous covering on the articular surface. In order to get the clear surface area of the auricular and depression, the specimens were immersed in 40% potassium hydroxide solution for ten hours. The 42 cadaveric specimens were 16 male and 26 female while 46 dry bones were from 28 male and 18 female. Average age for male adult group was 43.45 years (range 26 to 58); male elderly group was 72.10 years (range 62 to 88); female adult group was 43.44 years (range 19 to 59) and female elderly group was 72.90 years (range 61 to 98). The specimens were categorized into 4 groups according to age and gender; male adult (age $\leq$ 59), male elderly (age $\geq$60), female adult (age $\leq$59) and female elderly (age $\geq$60). Exclusion criteria were bone breakage and pathologic changes on the auricular surface. After the cleaned specimens were collected, digital images for computerized analysis were taken. Specimens were place on the circular flat plate and mimic the anatomical position of sacrum with inverted 36º sacral slope (Figure1). Photograph was taken with a digital camera (Canon EOS 60 D; Canon, Surrey, UK) at constantly distance 47 cm between specimen and lens (Tamron SP 17-50mm F/2.8 XR Di II VC), focal length set at 50 mm. Another side of auricular surface was repeated again by rotating the circular plate. Digital images were filing in systemic manner and imported into CLIC (Collection of Landmark for Identification and Characterization, Version 99) program for shape and size analysis. The CLIC program was developed by Dr. Jean-Pierre Dujardin. The digitized images were examined using outline based geometric morphometrics and the obtained outline shapes were transformed and analyzed by Elliptic Fourier analysis. To quantify auricular surface and Procrustes superimposition of recomputed shapes only for graphic output. All the images of auricular surface were flipped vertically to anatomical position and their contour outline were plotted with regular interval. In order to compare shape difference by superimposition, the opposite auricular images need to be flipped horizontally. Later, equidistant radii were done by the program to get the centroid of each contour. Finally, the mean shape of configuration was yielded (Figure2) and then statistically analysis was carried out by multivariate method. Size variation was present by quantile box. Variable of shape was analyzed by permutation-based of mahalanobis distances and size (perimeter) with non-parametric analysis of variance (ANOVA) by using CLIC program. The significance level was set at *P*-value $\leq$ 0.05. Data were submitted to the repeatability to evaluate the measurements reliability.

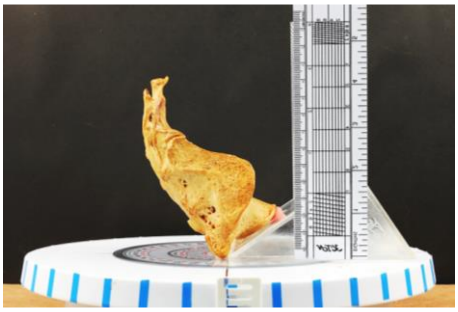

Figure 1 Setting of photos taking and positioning of the auricular surface

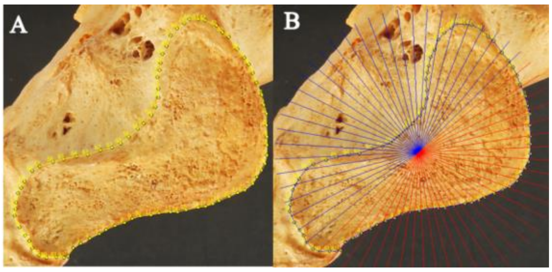

Figure 2 A. outline of auricular surface was plotted, B. radii for calculate centroid was presented

Results

The data obtaining method was verified for repeatability which was greater than 0.90 (0.94-0.98) represented excellent repeatability. The sacral auricular surface was situated at the levels of the first to the third sacral vertebrae (S1-S3) within these segments S1was the largest and S3 was the smallest. The second sacral vertebra coalesces into the superior and inferior limbs of sacral articular surfaces.

The mean shape of auricular surface of sacrum, comparison between genders both sides showed significant difference as mean shape in female was broader than male. The size variation showed male lager than female (Table 1) (Figure 3). Gender comparison on each side also showed significant difference of sides, whereby male mean shape was narrower and smaller than female in both left and right as well as significant size difference (Table 1) (Figure 4). Side comparison between within genders showed no significant difference both in mean shape and size (Table 1) (Figure5). Comparative study between age groups showed significant difference both age, genders comparison in age lesser than or equal to 59 group showed significant difference of mean shape and significant larger in male. The older group (age greater than or equal to 60) showed dramatically significant difference with *P*-value 0.004, male mean shape demonstrated narrow auricular surface but significant larger (Table 1) (Figure 6)**.** Age group comparison within each gender showed significant mean shape difference only in female but no size difference while mean shape between age in male was not different but showed the larger size in elder group (Table 1) (Figure 7). In summary, male sacrum generally demonstrated the larger auricular surface than female in both side and age group comparison. Within gender comparison, there was no significant difference between sides in shape and size, but in age group male sacrum showed significant larger in older group but not shape, while female sacrum showed no size difference but mean shape difference significant broader in older group. Genders comparison in side and age groups showed significant difference both in shape and size.

Table 1 showed P – value of the auricular surface attributed to side, gender and age.

Comparison	***P* – value**	
	Shape	**Size**
Gender both side	0.005*	0.000*
Right side	0.045*	0.006*
Left side	0.050*	0.009 *
Male sides	0.936	0.888
Female sides	0.565	0.245
Gender $\geq$ 60	0.004*	0.003*
Gender $\leq$ 59	0.025*	0.018*
Male age	0.154	0.020*
Female age	0.001*	0.081

*p – value $\leq$ 0.05

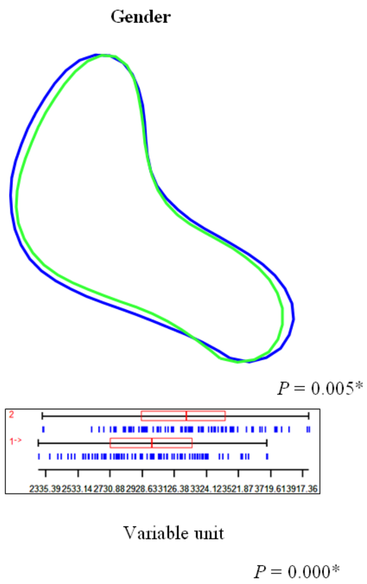

Figure 3 Illustration of gender comparison of mean shape of sacral auricular surface of sacrum both sides showed significant broader in female (● = Female, ● = Male). The below box-graph indicated the significant larger surface in male (1= Female, 2 = Male)

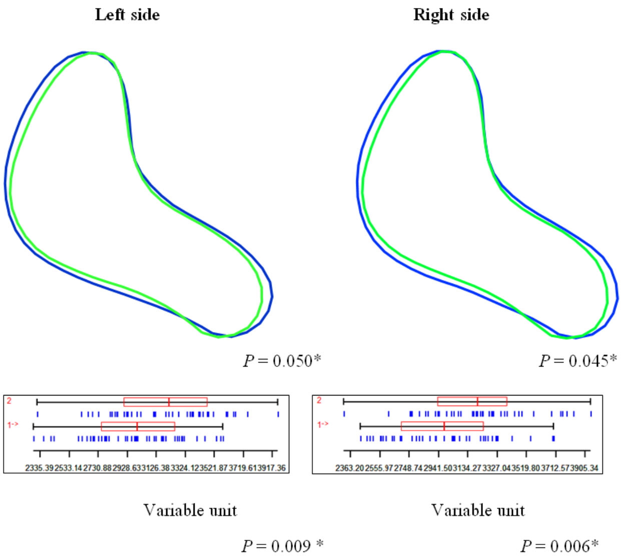

Figure 4 The sacral auricular mean shape comparison between genders showed significant difference both side, which the female mean shape is relatively broader than male (Lt.; ● = Female, ● = Male, Rt.; ● = Female, ● = Male). The box-graph showed significant larger in male both sides (1= Female, 2= Male).

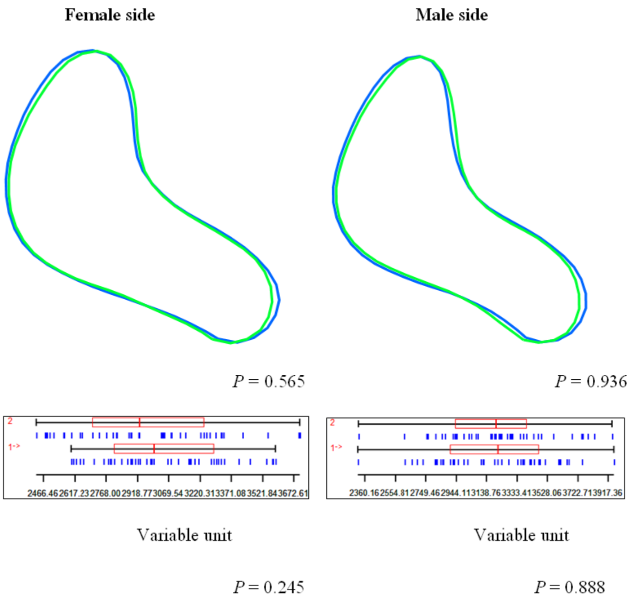

Figure 5 The side comparison of sacral auricular mean shape within gender showed no significant difference (Female ●=Lt., ●=Rt., Male; ●=Lt., ●=Rt.). The box-graph also showed no size difference (1=Lt., 2=Rt.).

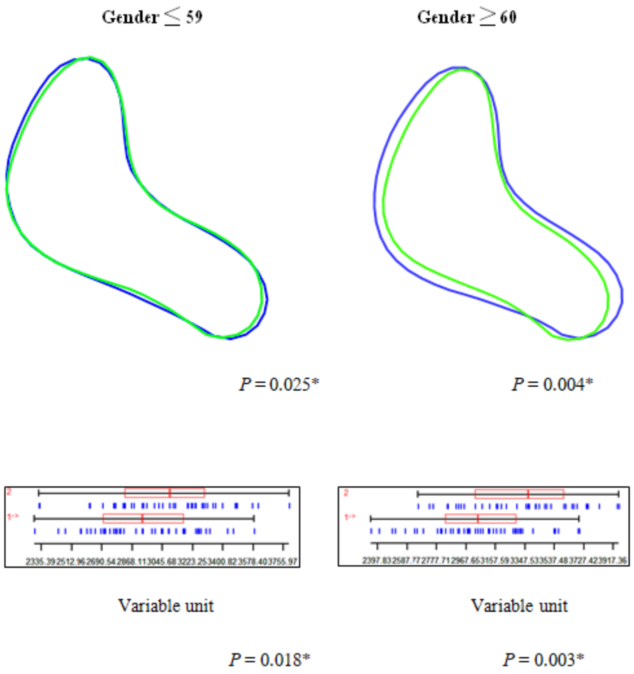

Figure 6 The genders comparison of sacral auricular mean shape in different age groups showed significant difference both in shape and size in both age groups (Age ≤ 59; ●= Female, ●= Male, Age ≥ 60; ●= Female, ●= Male). The box-graph indicated significant larger in male both groups (1= Female, 2= Male)

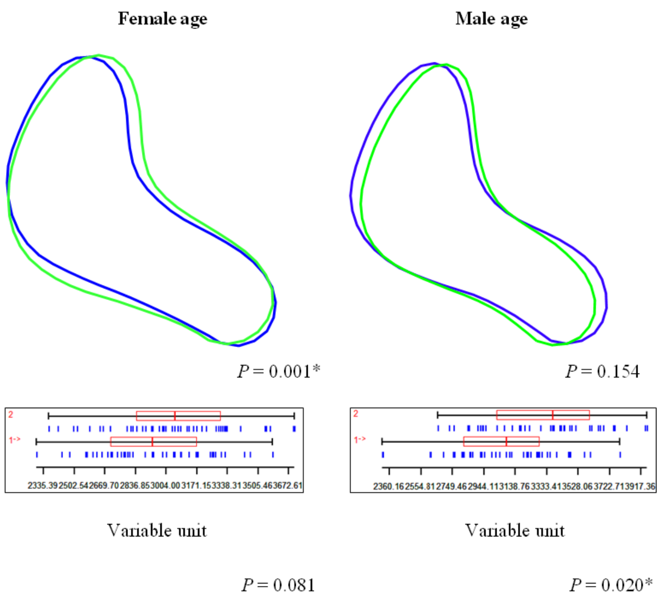

Figure 7 The age groups comparison of sacral auricular with in gender showed significant broader in female older group but no difference in male. (Female; ●= ≤ 59, ●= Age ≥ 60, Male; ●= ≤ 59, ●= Age ≥ 60). The box-graph indicate significant larger in male older age group but no size difference in female (1= Age ≤ 59, 2= Age ≥ 60).

Discussion

Sacrum, a middle piece of pelvis, plays an important role in weight transfer and locomotion. It is a large triangular bone composes of five fused segments of sacral bone and articulated with ilium. Especially, auricular surface is important for connect to ilium sides to form SIJ. It is the largest axial joint, which plays a crucial role in maintain stability, weight transferring and absorption while it has to sacrifice mobility. The sacral auricular surface has relatively less movement but receives great stresses on its joint surface as well as load distributing to surrounding ligaments and muscles (Vleeming et al., 1990; Vleeming et al., 2012). Thus, morphology of the articular surface can reflect the joint function or malfunction. Most of previous studies on the auricular facet morphology were carried out using traditional method as linear measurement. This method still has limitation in excluding size from shape (allometry) which has a great influence on shape. As follows, the recent method for studying shape is geometric morphometrics which can eliminate the size effect on shape. The present study of auricular shape in Thais using geometric morphometrics revealed significant gender difference in shape. It indicated that female was relative broader than male while male auricular surface was significant larger than female. The result corresponded with the work of Anastasiou and Chamberlain, they used landmark-based geometric morphometric techniques and showed significant difference auricular shape between genders and male was larger (Anastasiou, Chamberlain, 2013). In general, male skeleton was larger than female which related to functional designed for greater force absorption. The prior studies also reported the larger size of auricular surfaces in male (Wagner et al., 2017; Basaloglu et al., 2005). Brunner and coworkers reported the correlation of morphology, histopathology finding of auricular surface and mobility of the joint, they concluded that movement of SIJ was limited in male and the main motion was translation, while active force was most likely to induce rotational movements in female (Brunner et al., 1991). These leaded to gender specific morphology of the auricular surface.

The mean shape of auricular surface in this study demonstrated L-shape or crescent shape in both gender but broader in female specimens which corresponded to ancient work of Brooke (Brooke, 1924). Various features of sacral auricular surface can lead to SIJ problem. It has been reported that SIJ pain was associated with shape that predominantly found in female. Jesse MK et al. carried out a retrospective cohort study and reported the SIJ pain associate with the shape of auricular surface in female which 32% of joint pain allied with crescent shape and 17.5% with auricle shape but not significant in male, and surfaces area in male are larger than female (Jesse et al., 2017). Thus, the broad shape and small size in female may associate with SIJ pain more than male by influence on force distribution which male surfaces are narrow shape but large size, the greater the area the larger force dissipation and greater decrease of stress (Vleeming et al., 2012). In addition, numerous patients with low back pain were reported pain associated with the SIJ problems (Rashbaum et al., 2016; Cohen, 2005; Hansen, Helm, 2003). The wider shape of female auricular surface must be related to the greater mobility of the SIJ in female (Sebastian, 2000). Recent idea of hormonal effect on musculoskeletal system, particularly on SIJ because of the high incidence of low back pain in women and during pregnancy has been reported. The influence of relaxin hormone can be found in the puberty, during the menstruation (Rashbaum et al., 2016). The hormone stimulates structural change of connective tissue by activating collagenolytic effect (Qin et al., 1997; Granstrom et al., 1992) and causing joints laxity (Lubahn et al., 2006; Dragoo et al., 2011), which can promote joints injury (Dehghan et al., 2014; Wojtys et al., 2002). Moreover, the relaxin can increase pelvic width and height (Perezgrovas and Anderson, 1982; Musah et al., 1986). The relaxin along with estrogen and growth factors promotes bone remodeling (Dehghan et al., 2014). The higher level of estrogen in women supported the occurrence of wider auricular facet in female and significant difference of auricular shape in female aged groups (Inklebarger et al., 2017). In addition, it can affect bone growth by stimulating osteoclast-activating factors to increase bone resorption (Facciolli et al., 2009). Therefore, a direct force through joint with a weak ligament can cause abnormal movement and contribute to atypical distribution of mechanical loading. Furthermore, the nutritional influence on bone development has been hypothesized by a few researchers, which it also affected bone formation (Angel, 1982; Angel et al.,1987).

Comparison between age group showed broader in female and large size in male older group. In older age has been decreasing SIJ mobility (Vleeming et al., 2012), stiffness is frequently observed in older (Walker, 1992; Cassidy, 1992; Bowen, Cassidy, 1981; Vleeming et al., 1992) and decrease space in aging over 40 years (Demir et al., 2007). These lead to changing of joint surfaces together with the direction of compressive force reacts to the joint can cause alteration of the joint surface (Kampen, Tillmann, 1998). In addition, variation of physical activity causes various force distribution on auricular surface, for instance man is more agile and vigorous than female and decline during aging (Azevedo et al., 2007). The shape and size of SIJ during development may be a result of mechanical stress from body weight and advocates to stimulate bone growth. The octahedral shear stress promotes endochondral ossification while compressive dilatation stress inhibits ossification, thus these local tissue histories play role in controlling bone formation (Carter, 1987; Carter, Wong, 1988). In summary, the female shape and male size in older may be consequence of pertinent factor of degenerative changes in SIJ collaborate with zygapophyseal joint, hip joint, and have been reported positive correlate with pathological changes on lumbar facet joint and hip joint both side (Nishi et al., 2017).

Limitation of this study was not having the information of height and weight of the cadavers as well as daily activities health problem related to SIJ during life.

Conclusion

This study demonstrated anatomic information of sacrum in Thais. Morphometric information showed that sacrum is difference in shape, which revealed relative broad shape in female and large size in male. These results provided beneficial anatomical background for clinicians and scientists for better understanding gender variation of anatomy of SIJ which can be related to low back pain and pathologic changes.

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