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Morphometric study of the human sacrum by reverse engineering

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Abstract. With the help of advances in technology, bone imaging has become easier when compared to its initial stages. The purpose of this study is to analyse and interpret the morphometry of the human sacrum, through Reverse Engineering. Eight different sets of human sacra were obtained for which reverse engineered 3D CAD models were generated by employing a portable Coordinate Measuring Machine with a laser scanner. An appropriate software is used for the generation of the CAD model from the point cloud data obtained through the scanner. The study highlights the upper hand of reverse engineering to the conventional methods employed for bone imaging, which can be further used for surgical implications, design of sacral implants and other applications

1. Introduction

The recent medical bone imaging methods has enabled the recreation of bones in the form of images, for various medical studies and applications[1]. The creation of 3D models has also been easy and feasible with the rapid changes introduced into the field of biomedical engineering. Computed tomography (CT) have been used widely for generating 3D models for various parts of the human body[2][3][4] and need ethical concern. In previous studies dry cadaveric specimens were used for morphometric studies. The various parameters measured are Interfacet distance (IFD), facet depth (FD), Interauricular distance (IAD), body width (BW), mean auricular height (AHM), mean auricular surface area (ASA), mean facet surface area (FSA), Body Surface Area (BSA), mean sacral height (SH), Tripod index (IFD/FD), Transverse index (IAD/BW), Auricular index (SH/AHM), Sacraauricular index (IAD/SH) and Auriculofacet depth index (IAD/FD). All the parameters were measured manually by various instruments [5-10]. New methodology has been employed in the present work to study the morphology of human sacrum. The obtained cadaveric specimens are scanned to create a CAD model using reverse engineering. The obtained CAD model is used for measuring various dimensions. All the dimensions are measured as per the literature [5-10]. The benefit of reverse engineering over the manual measurements employed in the previous studies is that the level of accuracy involved is comparatively higher.
2. Materials and methods

The dry bones were obtained for morphometric study of the human sacrum. Eight specimens were selected for the morphometric study based on the similarities in structure. A portable coordinate measuring machine with a laser scanner was employed for scanning and point cloud data was generated simultaneously. The portable CMM has the ability to provide an accuracy of up to ±35μm with a scan rate of about 19,200 points/second. The dry bones (sacrum) are scanned one at a time using a suitable fixture that holds the specimen upright for proper generation of the point cloud data. The fixture is chosen in such a way that two separate scans for one single specimen, is taken with greater ease. Figure 1 shows the methodology followed in the present work.

![Diagram of process flow](image)

**Figure 1.** Process flow involved.

The laser probe used can be set to different modes according to the necessity so that the amount of point cloud data generated can be altered. The scanning process of each sacral specimen is done in two different views and the generated cloud points are imparted to the Geomagic software simultaneously.

![Scans of sacrum](image)

**Figure 2.** (a) First scanning view of the sacrum, (b) Second scanning view of the sacrum.
Figure 2 represents the two different orientation of sacrum for scanning. After scanning unwanted data points are removed and the required portion of the scan obtained in each view is combined to form a single entity. The generation of one single model by combining the scan data is done using an appropriate command in the software and the model is merged with respect to a coordinate system. Figure 3 represents the combined model of the sacrum from the two different scan data. Surface generation for the combined model is done so that various dimensions relating to the parameters of the sacrum can be studied and measured.

![Figure 3. Final merged surface model of the sacrum.](image)

The sacrum model can be changed with respect to the origin of the applied coordinate system for the change in orientation during the measurement of the different parameters. This enables parameters to be measured easily, avoiding the errors that are present when done manually. The surface area for the Facet of Superior Articular process (FSA), Articular Surface (ASA) and of the Body Surface (BSA), are measured using the property analyser present in the software. The horizontal center distance between each of the Posterior Sacral Foramina is measured along with each of their corresponding vertical distances, as it would be helpful in designing suitable implants for the sacral region.

A total of 42 parameters were measured in one sacrum and eight sets of measurements were taken for the study. The average of each parameter along with the Standard Deviation was calculated for assigning the standard limit for such parameter. The various parameters are measured based on the following region of the sacrum Posterior Sacral Foramina (PSA), body side, facet side, auricular side, Sacral Height and Tip width. The parameters measured based on PSA is depicted in figure 4 and the corresponding measurements are listed in table 1.
**Table 1.** Posterior Sacral Foramina parameter measurements.

| Parameter | Average measured value (mm) | Range of the parameter measured (mm) |
|-----------|-----------------------------|-------------------------------------|
| PSFH-A    | 41.88                       | 41.88±2.51                          |
| PSFH-B    | 37.89                       | 37.89±3.18                          |
| PSFH-C    | 33.59                       | 33.59±1.91                          |
| PSFH-D    | 31.95                       | 31.95±1.87                          |
| PSFRV-1   | 23.21                       | 23.21±2.40                          |
| PSFRV-2   | 17.58                       | 17.58±2.98                          |
| PSFRV-3   | 17.25                       | 17.25±1.78                          |
| PSFLV-1   | 23.10                       | 23.10±3.51                          |
| PSFLV-2   | 18.00                       | 18.00±3.87                          |
| PSFLV-3   | 16.54                       | 16.54±2.45                          |

The parameters measured based on body side is depicted in figure 5 and the dimensional values are listed in table 2.
Figure 5. Body side parameters of the sacrum. Body Depth and Body Width are measured along with the Facet Depth, FD. IAD, Interauricular Distance; IFD, Interfacet Distance.

Table 2. Body side parameters.

| Parameter | Average measured value (mm) | Range of the parameter measured (mm) |
|-----------|-----------------------------|-------------------------------------|
| BW        | 46.22                       | 46.22±3.00                          |
| BD        | 28.83                       | 28.83±2.64                          |
| BSA       | 12.044                      | 12.044±1.7786                       |
| FD        | 12.99                       | 12.99±2.05                          |
| IFD       | 54.50                       | 54.50±2.84                          |
| IAD       | 98.18                       | 98.18±7.98                          |

The Facet parameters measured are depicted in figure 6 and the corresponding measurements are listed in table 3. Facet parameters were measured for both left and right sided of the sacrum.

Figure 6. FH, Facet Height; FW, Facet Width; FSA, Facet Surface Area. R symbolises right side of the sacrum.

Table 3. Facet parameters for right and left sides of the sacrum.

| Parameter | Average measured value (mm) | Range of the parameter measured (mm) |
|-----------|-----------------------------|-------------------------------------|
| FH-R      | 16.18                       | 16.18±3.12                          |
The Auricular parameters measured are depicted in figure 7 and the corresponding measurements are listed in table 4. Auricular parameter were measured for both left and right sided of the sacrum.

**Figure 7.** Auricular parameter measurements along with the area. AH, Auricular Height; AW, Auricular Width; ASA, Auricular Surface Area; L symbolises left side of the sacrum.

**Table 4.** Auricular side parameters for right and left sides of the sacrum.

| Parameter | Average measured value (mm) | Range of the parameter measured (mm) |
|-----------|-----------------------------|-------------------------------------|
| AH-R      | 55.39                       | 55.39±5.12                          |
| AW-R      | 33.65                       | 33.65±3.37                          |
| AH-L      | 54.56                       | 54.56±5.24                          |
| AW-L      | 31.43                       | 31.43±3.34                          |
| AH MEAN   | 54.98                       | 54.98±4.95                          |
| ASA-R     | 10.701                      | 10.701±1.4166                       |
| ASA-L     | 10.892                      | 10.892±1.5221                       |
| ASA MEAN  | 10.796                      | 10.796±1.4458                       |
Figure 8. SH, Sacral Height; TW, Tip width.

Table 5. Measured values of SH and TW along with the various indices in the parameters.

| Parameter | Average measured value (mm) | Range of the parameter measured (mm) |
|-----------|----------------------------|-------------------------------------|
| SH        | 101.21                     | 101.21±9.38                         |
| TW        | 17.55                      | 17.55±5.29                          |
| ASA/BSA   | 0.90                       | 0.90±0.12                           |
| ASA/FSA   | 5.34                       | 5.34±1.32                           |
| BSA/FSA   | 5.88                       | 5.88±1.12                           |
| IAD/FD    | 7.77                       | 7.77±1.66                           |
| IAD/SH    | 0.97                       | 0.97±0.09                           |
| IFD/FD    | 4.30                       | 4.30±0.77                           |
| IAD/BW    | 2.13                       | 2.13±0.14                           |
| SH/AH     | 1.84                       | 1.84±0.09                           |

3. Result and Discussion

The various dimensional parameters of eight sets of sacrum were measured in the software through reverse engineering by creating CAD models of the specimens. The measured values were compared with the previous studies conducted on the morphometry of sacrum and were compared with the results obtained through reverse engineering technique and the same has been shown in table 6.

Table 6. Comparison of dimensional parameters of sacrum with reported literature.

| Dimensions | Present study     | Mahato N K (2010) |
|------------|-------------------|-------------------|
| IAD        | 98.18±7.98        | 102.79±10.09      |
| BSA        | 12.044±1.7786     | 10.02±2.35        |
| BW         | 46.22±3.00        | 46.34±6.62        |
|       | Mean       | Standard Deviation |
|-------|------------|--------------------|
| SH    | 101.21±9.38| 105.05±10.24       |
| AH-R  | 55.39±5.12 | 60.82±8.51         |
| AH-L  | 54.56±5.24 | 61.49±8.44         |
| AH MEAN | 54.98±4.95  | 61.15±8.16        |
| ASA-R | 10.70±1.4166 | 10.47±1.92    |
| ASA-L | 10.89±1.5221 | 10.24±2.00    |
| ASA MEAN | 10.796±1.4458 | 10.36±1.86  |
| IFD   | 54.50±2.84  | 52.12±4.34         |
| FH-R  | 16.18±3.12  | 16.36±2.28         |
| FW-R  | 13.94±2.25  | 16.82±2.75         |
| FH-L  | 16.10±3.53  | 15.79±.78          |
| FW-L  | 13.46±2.34  | 17.03±2.86         |
| FSA-R | 2.113±0.5050 | 1.73±0.52       |
| FSA-L | 2.125±0.5802 | 1.68±0.58       |
| FSA MEAN | 2.119±0.5355 | 1.71±0.51     |
| FD    | 12.99±2.05  | 15.24±2.90         |
| ASA/BSA | 0.90±0.12    | 1.01±0.24         |
| ASA/FSA | 5.34±1.32    | 6.27±2.24         |
| BSA/FSA | 5.88±1.12    | 6.17±1.91         |
| IAD/FD | 7.77±1.66    | 6.92±1.25         |
| IAD/SH | 0.97±0.09    | 0.98±0.08         |
| IFD/FD | 4.30±0.77    | 3.53±0.70         |
| IAD/BW | 2.13±0.14    | 2.24±0.34         |
| SH/AH  | 1.84±0.09    | 1.74±0.22         |

**Figure 9.** Comparison of Facet dimensions (a) mean (b) standard deviation.
The comparison of the facet dimensions was done and it was noticed that the width of the right and the left facet had some variation for the mean values. All the other dimensions of the facet had comparatively very small variations. The comparison for the standard deviations of the facet dimensions was also conducted and almost all the dimensional values had some significant variations, because the number of specimens used for the study was lesser than that used for the previous studies. Only eight sacral specimens were used for this study due to the lack of availability of specimens available.

![Figure 10. Comparison of Indices (a) mean (b) standard deviation.](image1)

The comparison for the indices was also done and it was noticed that almost all the values were closer to the values acquired from the previous studies. The variations in standard deviations is because of the difference in number of specimens used for this study.

![Figure 11. Comparison of auricular dimensions (a) mean (b) standard deviation.](image2)
Figure 11(a), 11(b) and 12(a), 12(b) indicate the comparison of auricular dimensions and body side dimensions respectively. There is significantly less variation in the mean values for both auricular and the body side dimensions, but the variation in the values can be noticed for the standard deviations because of the number of specimens used in current study compared with the previous study.

4. Conclusion

The process of reverse engineering has a very high advantage over the conventional digital vernier caliper and the tracing method employed with the previous studies relating to the sacrum. The accuracy of the scanning method used for this study is much higher and the errors relating to a vernier caliper were avoided. The different sacral parameters measured from eight different specimens were taken into account and they were compared with the previous study. Though the standard deviation values obtained through the present study show a variation with the previous study, the mean values are more or less similar. The unavailability of specimens limited the number of dimensional measurements obtained. The study also highlights the ease of generation of CAD models with which the morphometry of the sacrums were analysed. The CAD models generated can also be used for further studies relating to the human sacrum and also the same measurement technique will be extended for other regions in the spine.

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