Predictive Model for Estimating Ovine Hip Joint Center

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Abstract—Measurements from CT imaging data of 9 Rambouillet sheep were used to create predictive models to estimate the location of the hip joint center (HJC) in sheep. The developed predictive model was evaluated to determine whether it could be used in the motion capture of ovine models. There is currently no predictive model for estimating HJC in sheep. The linear regression models found between the left hip joint center coordinates and the pelvic depth and width had \( R^2 \) values between 0.005 and 0.188.

I. INTRODUCTION

Animal models are tools that researchers use to study diseases and test treatments when human experimentation is not possible [2]. The most common animal models are laboratory animals or rodents. However, these animals do not provide a true replication of human diseases. This is due to their physiological differences in comparison to humans. These include their size and duration of life. Large animal models have more significant physiological similarities to humans. Sheep are large animal models used as biomechanical models to study diseases and devices due to their size, durability, reproducibility, and manageability [7]. Sheep’s composition, metabolism, bone remodelling, and body weight are like humans.

Motion capture is used to study the gait of the sheep. Quantification of ovine gait kinematics can help characterize these diseases and devices. Marker-based motion capture can be used to measure ovine joint kinematics and kinetics. The study of ovine kinematics and kinetics primarily focused on lower limb measurements [8]. Ovine pelvis and hip biomechanics have not been quantified in this research.

The HJC is not a protruding bony landmark; hence palpation cannot be used to locate the HJC. The location of the HJC must be calculated. Estimating the location of the HJC will help in quantifying the ovine pelvis and hip biomechanics and will affect the calculation of the hip loading, angles, and moments. Furthermore, gait analysis requires the HJC location to be found for complete quantification of the loading at the hip joint. The HJC will be the location about which hip moments are calculated.

There is currently no model for estimating the HJC in ovine.

There are two primary techniques to estimate HJCs: the predictive and the functional method. The predictive approach is used on subjects with a limited range of motion as it utilizes anatomical measurements and statistical methods to estimate the location of the HJC. Regression equations are used to estimate the location of the HJC (Figure 1). Different types of regression equations are used in predictive methods [4].

Functional methods utilize the dynamic motion of the femur relative to the pelvis to calculate the HJC [3]. Subjects are required to perform a star pattern with each leg (Figure 2). Increased range of motion (ROM) often helps with estimation accuracy. Estimation is less accurate for subjects with reduced hip joint range of motion [3].

![Figure 1 - The Range of motion required for functional HJC estimation.](image1)

Since the femur of the sheep does not have a full range of motion (Figure 2) [9], the predictive method is used to estimate the location of the HJC.

![Figure 2 – The range of motion of the femur in sheep.](image2)

This research aims to create predictive models to estimate the location of the HJC in sheep using measurements from CT imaging data. The created predictive models will be
evaluated to determine if they can be used in motion capture.

II. EXPERIMENTAL PROCEDURE

Full-body CT scans were performed on nine sheep in 2018. The CT scans were taken on 9 Rambouillet sheep (Ages: 1 year and two months, ender: 6 male, three female).

The CT scans were imported to 3D Slicer to segment the CT Data. The Pelvis and femur geometry were separated in 3D slicer (Figure 3). A CT scan has several 2-D slices that include bone and muscle tissue. Bone tissue in a CT scan appears as white, while soft tissue appears as shades of gray. A threshold is applied in 3D slicer on the CT scan, which identifies the bone tissue and separates it from the other tissues on the CT scan. Then, the slices of the CT scan were checked manually to ensure that the pelvis bone and femur were not joined by any pixels. The segmentation was completed for all nine CT scans before proceeding to the next step.

The segmented geometries were then imported to Meshmixer. It is necessary to check that each femur is separated from the pelvis. If they were not, then continue to separate them in Meshmixer.

Anatomical landmarks on the pelvis and femur were labeled in Meshmixer according to the anatomy of the sheep (Figure A1). Markers were placed on anatomical landmarks in Meshmixer. These landmarks are representative of motion capture markers. The prefixes R and L are used in labeling to denote right and left, respectively. Figure 5 shows the abbreviations used to label specific landmarks on the pelvis and femur geometries in Meshmixer.

Least squares sphere fitting was applied to the articulating surface of the femoral head by selecting the femoral head without the dent, where the ligament is (see in Figure 5 A). The center of the sphere was used as the location of the HJC. Figure 5 illustrates the steps of the sphere fitting the HJC.

The location of the markers relative to the global coordinate system (GCS) is available in Meshmixer. The coordinates of each marker in the GCS were extracted and tabulated (Table 1 in Appendix) for all nine sheep (a total of nine tables were made).

A pelvic coordinate system (PCS) was defined (Figure 6). The PCS's origin was defined as at the midpoint of the LTC, RTC, LISC, and RISC markers (at the center of the pelvis). A PCS was defined for each of the nine sheep. The global HJC coordinates are then converted to the HJC coordinates in the PCS. The HJCs were now located within the PCS. Similarly, the rest of the markers were located with the PCS.
The final step is to create regression models. The pelvic width (PW) and depth (PD) measurements were made using the markers (LTC, RTC, LISC, and RISC) in Figure 4. The PW is measured from the LTC to the RTC (Figure 7).

The midpoint of the LTC and RTC was calculated and recorded as midTC. The midpoint of the LISC and RISC was calculated and recorded as midISC. The PD is measured from midTC to midISC (Figure 7).

For each of the nine sheep, the hip joint center coordinates and measurements of their pelvic depth and width were recorded. Linear regression models were created between the left coordinates of the HJC (LHJC) and the PW and PD.

III. METHODOLOGY

In this experiment, the least squares or linear regression method was used to calculate the best fit line through the data. The correlation coefficient, denoted by R, is a quantitative measure of how good the linear relationship is. The square root of the coefficient of determination, denoted by R², equals the correlation coefficient (R). The closer the absolute value of R is to 1, the higher the linear correlation between the data points and the better the fit is.

IV. RESULTS AND DISCUSSION

Figure 8 - The left hip joint center coordinates are plotted against the pelvic depth. The plots show the straight line of best fit and the coefficient of determination.
The HJC in humans was found to have a sufficient linear correlation with pelvic dimensions [5]. It is predicted that the HJC will correlate with the PD and PW in sheep because the sheep's femur and pelvis are connected similarly to humans.

Figures 8 and 9 show the left hip joint center coordinates plotted against the pelvic depth and width. Linear fits of the graphs were made. The R^2 of the linear fits had values between 0.005 and 0.188. Thus, the correlation coefficient ranged between 0.071 and 0.434. Since the values of the correlation coefficients of the linear regression are closer to zero than 1, the linear model found is insufficient for the relation between the LHJC and the PD and PW.

A small sample size will result in a small range for the independent variable; hence, higher precision in measurements will be required to view a sufficient correlation. Human error while manually segmenting the CT scans and adding the markers in Meshmixer would have led to an uncertainty in the coordinates extracted from Meshmixer. Additionally, a mistake that could have led to an insufficient predictive model could be associated with the position of the sheep in the CT scanner. Positioning the sheep in the CT scanner in approximately the same place may result in a higher correlation.

V. CONCLUSIONS

The correlation coefficient ranged between 0.071 and 0.434, which means that the linear regression models created are insufficient to estimate the HJC location. There was not enough linear dependency between the two parameters used.

Many factors could have led to the low correlation. Information on the gender of the sheep should have been provided. In the future, the measurements used in finding the linear fit should come from sheep of the same gender. In this experiment, the sheep were all around two years old. Consequently, the range of the x coordinate on the plots was small (only 10 mm). Therefore, in the future, the sheep should be of different ages to achieve a larger range for the independent variables (pelvic depth and width). The sample size was nine in this experiment. A larger sample size should be considered.
VI. REFERENCES


VII. APPENDIX I

Table 1 – The tabulated coordinates of the labelled landmarks in the global coordinate system extracted from meshmixer.

<table>
<thead>
<tr>
<th>Marker</th>
<th>X Global (mm)</th>
<th>Y Global (mm)</th>
<th>Z Global (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHJC</td>
<td>62.871</td>
<td>-593</td>
<td>-191</td>
</tr>
<tr>
<td>RHJC</td>
<td>-42.58</td>
<td>-619.1</td>
<td>-178.4</td>
</tr>
<tr>
<td>LTC</td>
<td>66.457</td>
<td>-466.7</td>
<td>-214.7</td>
</tr>
<tr>
<td>RTC</td>
<td>-108.8</td>
<td>-511.3</td>
<td>-199.6</td>
</tr>
<tr>
<td>LIC</td>
<td>53.341</td>
<td>-539.1</td>
<td>-208.2</td>
</tr>
<tr>
<td>RIC</td>
<td>-61.89</td>
<td>-564.7</td>
<td>-196.8</td>
</tr>
<tr>
<td>LISC</td>
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<td>-653.6</td>
<td>-203.5</td>
</tr>
<tr>
<td>RISC</td>
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<td>-193.7</td>
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<tr>
<td>LRGT</td>
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<td>-603.8</td>
<td>-205.4</td>
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<tr>
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<td>-211.2</td>
</tr>
<tr>
<td>LRCT</td>
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<td>-746.1</td>
<td>-77.92</td>
</tr>
<tr>
<td>RRCT</td>
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<td>-773.6</td>
<td>-99.48</td>
</tr>
</tbody>
</table>

"On my honor, as an Aggie, I have neither given nor received unauthorized aid on this academic work." Menna Fawzy