PREGNANT FEMALE ANTHROPOMETRY FROM CT SCANS FOR FINITE ELEMENT MODEL DEVELOPMENT

Kathryn Loftis[1], Michael Halsey[1], Evelyn Anthony[2], Stefan M. Duma[1], Joel Stitzel[1]
[1]Virginia Tech – Wake Forest University Center for Injury Biomechanics
[2]Wake Forest University School of Medicine, Medical Center Blvd. Winston-Salem, NC 27157

Introduction

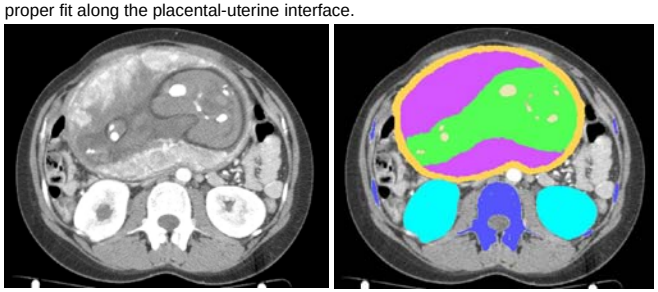
MVCs involving pregnant mothers are reported as causing an estimated 1500-5000 fetal losses each year in the United States [1]. In the latter stages of pregnancy, the gravid fetus causes the mother's abdomen to protrude from her body, and this makes the abdomen susceptible to trauma during a MVC. Common injuries to a pregnant female after a MVC include: excessive bleeding, placental abruption, uterine rupture, and premature delivery [2]. The most common fatal injury for the fetus when the mother survives blunt force trauma, such as that sometimes experienced in a MVC, is abruptio placentae [3]. This is caused by a shearing effect between the placenta and the uterus during rapid impact and deceleration. Often, this injury is not evident until it is too late to save the fetus [4].

Purpose

Changes during pregnancy drastically alter the abdominal anatomy of the pregnant female. In order to accurately predict maternal and fetal injury in a motor vehicle crash, an anthropometrically accurate pregnant female model is needed. This model would be helpful in determining the results of airbag deployment in MVCs involving pregnant females and also the effect of restraint systems. The inflation of the airbag has been hypothesized to result in higher abdominal pressures because the gravid uterus protrudes out to the steering wheel. [5] An accurate pregnant female model could test this theory in order to make public health recommendations on the best methods for travelling safely in a vehicle while pregnant. In this study, a CT scan from a 3rd trimester pregnant female is segmented using medical imaging software, and 3D models of the pregnant abdomen are created. This study investigates the anatomy of a pregnant female and seeks to determine gestational age by measuring 3D renderings of the fetus from CT scan data. Geometric measurements are also taken for each maternal organ in order to create a geometric blueprint of the abdomen for incorporation into a pregnant finite element model.

Methods

A scan most representative of a fifth percentile female in the early 3rd trimester with a healthy fetus and no abdominal injury was selected for analysis from available abdominal computed tomography (CT) scans taken over the past ten years at Wake Forest University Baptist Hospital. Scans were imported into Mimics (Materialise Software, Ann Arbor, MI) for image segmentation. Using Hounsfield unite threshold values and manual segmentation, the slices were segmented to create masks of each abdominal organ and the fetus. The uterus and placenta masks were created by also using Boolean operations, which subtracted one mask from another. This ensured a proper fit along the placental-uterine interface.

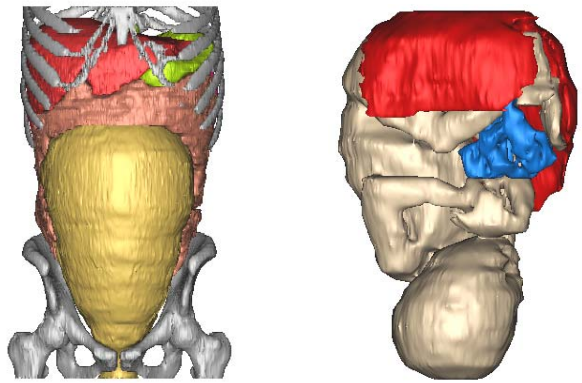


CT axial slice ***CT axial slice segmentation masks***

Figure 1 a) CT axial slice through the pregnant female abdomen with the spine, kidneys, uterus, placenta and fetus in view **b)** Segmentation of the same CT axial slice through the pregnant female abdomen with the spine, kidneys, uterus, placenta and fetus masks highlighted.

Methods, Cont.

After the fetal skeletal mask and 3D rendering were created, the skeletal measurements of the fetus were taken using a 3D measurement tool provided by the software. The measurements were then compared with literature values to estimate gestational age [6-8].



Pregnant Female Abdominal Contents ***Pregnant Female Uterine Contents***

Figure 2. a) Anterior View of the pregnant female abdomen showing all of the abdominal organs, skeleton, and uterus. b) Posterior view of the fetus, umbilical cord, and placenta which are contained within the uterus.

From the volume renderings, measurements were taken for each region of the pregnant female using the 3D measurement tool. These measurements were exported to a mathematical program where the length, height, width, and depth in each plane were found for each region.

Results

The average gestational age predicted by fetal measurements using literature data is 32.2 weeks as seen in Figure 3.

Approximate Gestational Age		
Measurement	**Data (mm)**	**Age (weeks)**
Crown to Heel [12]	**360.91**	**29.5**
Avg. Foot Length [11]	**58.13**	**30.1**
Avg. Femur Length [10]	**63.87**	**32.5**
Avg. Humerus Length	**58.94**	**33.9**
Occipitofrontal Diameter	**101.84**	**32.0**
Biparietal Diameter	**87.83**	**34.9**
Head Circumference	**297.78**	**32.7**
Avg. Approximate Gestational Age		**32.2**

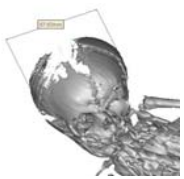


Figure 3. a) Gestational age estimation results comparing fetal skeletal measurements from 3D rendering and literature values for predicting gestational age. b) Fetal 3D rendering measurement using line tool

By measuring the height of T8-T12 on the CT scan and comparing it to literature data, the female is considered to be 5th percentile with an estimated height of 4' 11" and estimated weight of 104 lbs, The T8-T12 distance of 101.51 mm is in the literature range listed for a 5th percentile female[9]. Her size had to be estimated using T8-T12 height from the CT scan because her height and weight were not available in medical records.

Results, Cont

The computer program provided the volume, CT Hounsfield unit range, and average Hounsfield units for each mask created. Using these volume measurements, the 3rd trimester uterus and all its contents have a volume of 3377 cm^3.

Mask Name	Volume (cm^3)	Final Thresholds (HU)			Details
		Low	High	Avg.	
Uterine Volume	**2579.0**	**-150**	**1177**	**42**	**Interior to uterus and placenta**
Uterine Wall	**111.0**	**-1024**	**578**	**62**	**Uterus mask**
Placenta	**687.7**	**-69**	**271**	**102**	**Placenta mask**
Fetal Skeleton	**197.1**	**109**	**1177**	**250**	**Fetal skeleton mask**
Umbilical Cord	**95.0**	**-69**	**3071**	**33**	**Umbilical cord mask**

Figure 4. Table excerpt from pregnant female abdominal measurements

Discussion

Gestational age estimations are usually made from the brain and skull anatomy using ultrasound [10]. Using CT, it was difficult to locate the specific brain landmarks where these skull measurements were to be taken because of slice spacing and resolution of scans. The measurements were compared with data found in the literature values and estimated the fetus to be approximately 32 weeks gestation which agrees with the emergency department reported medical record listing the female to be 32 weeks pregnant. At this stage of gestation, clinicians estimate that all gestational approximations are ±3 weeks accuracy.

While the skin, fat, and maternal skeletal volumes and measurements will differ for all females, the organ size and uterus, placenta, and fetus sizes are relatively consistent for pregnant females. The size of the uterus in the 3rd trimester is determined by the size of the fetus, not the size of the mother. This makes these organ volumes applicable for primarily all pregnant females, independent of body size. There are, however, some limitations to this study because it only utilized one pregnant female. While it is common for the placental attachment point to be at the fundus, other placental locations and individual anatomical differences will create different results. Additional studies at different gestational times would also be useful in creating multiple pregnant models for testing, but the 3rd trimester pregnant female was chosen to obtain geometry in a more distended state.

In the future, further studies using a larger study group could validate the results of this study. The average uterus area for each slice could be calculated and used to create an accurate representation of the amount of amniotic fluid that is present. This could then be incorporated into the pregnant female model to predict how the amount of incompressible fluid within the uterus affects the fetus during blunt force trauma. After creating an accurate model of the uterus-placenta attachment, it may be possible to predict where abruption will occur by looking at thin points in the uterine wall and thick areas of the placenta. This prediction technique would also be helpful in formulating fetal injury criteria independent of maternal injuries.

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VIRGINIA TECH WAKE FOREST UNIVERSITY
School of Biomedical Engineering and Sciences

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