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**A THREE-DIMENSIONAL COMPUTER MODEL OF HUMAN BACK CONTOURS  
FOR AUTOMOTIVE SEAT DESIGN**

**By**

**Barry Lewis Frost III**

**A THESIS**

**Submitted to  
Michigan State University  
in partial fulfillment of the requirements  
for the degree of**

**MASTER OF SCIENCE**

**Department of Material Science and Mechanics**

**1999**

## **ABSTRACT**

### **A THREE-DIMENSIONAL COMPUTER MODEL OF HUMAN BACK CONTOURS FOR AUTOMOTIVE SEAT DESIGN**

**By**

**Barry Lewis Frost III**

**Driver and passenger comfort, as related to automotive seats, is a growing issue in the automotive industry. Seat designers are creating seats that need to support people in a larger variety of postures. By depicting human musculo-skeletal structures, three-dimensional contours representing the skin surfaces of a small female, average male and large male in a range of postures have been developed using the JOHN software program.**

**Contour development was based on studying cross-sectional photographs of humans and data from studies performed in seated automotive environments. Because rotations about spinal joint centers are modeled, contours are predicted for a wide range of postures by attaching skin points to different musculo-skeletal landmarks. The contours can be manipulated by changing the amount of spinal curvature and the recline angle. Using this anatomically-based model, seat designers will be able to create seats that fit and support humans in a larger array of postures.**

## **DEDICATION**

**To the Lord, who has blessed me beyond understanding. You have guided me, encouraged me, supported me, and has once again proven to me that anything is truly possible if I trust in you.**

## ACKNOWLEDGMENTS

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## 1. BACKGROUND AND OBJECTIVES

### 1.1 Background

Driver and passenger comfort in automotive seats is an issue that has increased in interest over the past decade. Seats are now being contoured to increase comfort by fitting the natural spinal curvature of humans. Seats are being designed with adjustable lumbar paddles and flexible mats in the seat backframe that promote movement and variation of spinal curvature and posture. In the past, seat designers created seats mainly with templates on paper. However, the use of templates has become increasingly difficult in the design of today's highly contoured seat. With the advent of computers and three-dimensional solid modeling programs, seat designers developed the ability to generate surface contours of seats. If human back contours can also be represented as solid models with computers, designers will then have the ability to create seats that fit people's contours. While not sufficient for comfort, the ability to fit seats to a human contour is one of the necessary steps for creating comfortable seats.

One of the original tools used by automotive seat designers is the Society of Automotive Engineers' two-dimensional drafting template [1]. The Society of Automotive Engineers, or SAE, originally developed the template, seen in Figure 1, to create a repeatable method of positioning the occupant in the automobile. The SAE also developed a three-dimensional seat testing device, shown in Figure 2, called the H-point

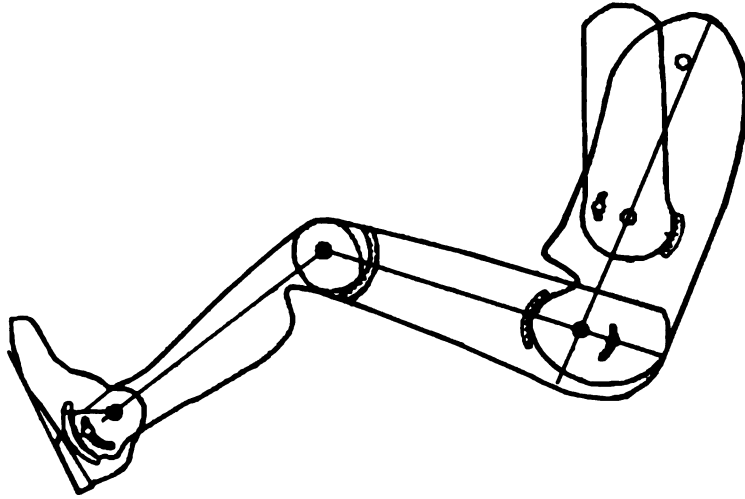


Figure 1 The SAE Drafting Template

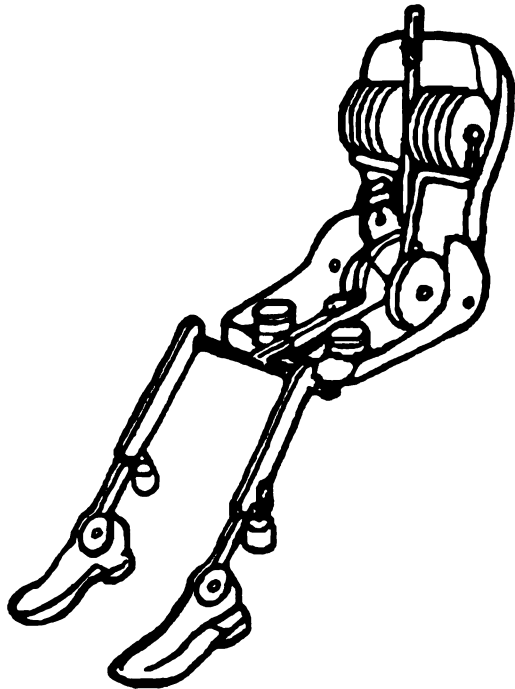


Figure 2 The SAE H-Point Machine

machine [1]. A computer model of the SAE H-point machine contour has also been created and used by designers to aid them in the design of new seats. While the SAE template, H-point machine and computer model were developed to be a guide in occupant positioning, these tools are sometimes used by seat designers to create the contours of the seat, a function for which they were never designed.

In the early 1980's, the University of Michigan Transportation Research Institute, or UMTRI, conducted an anthropometric study for crash dummy development by determining how an occupant is positioned within an automobile. In their study [2], UMTRI placed people in a simplified model of the driver's side of an automobile and used a combination of seat surface castings and photographs of anthropometric landmarks on the subjects to determine exterior skin contour points. Anthropometric data were collected for a wide variety of individuals and the individuals were classified and averaged into three categories: the mid-sized male [3], the small female and the large male [4]. An example of the data collected for the average adult male with external and internal landmarks is shown in Figure 3.

In the late 1980's researchers at Michigan State University, MSU, began developing computer models of the human musculo-skeletal system for seat design [5]. The first work at MSU was done by Haas [6], who developed a two-dimensional computer model, called JOHN, to determine the relative position of the head, thorax, and pelvis of an average male. JOHN was named in recognition of Johnson Controls, Inc. - Automotive Systems Group, who has continued to support the development of the model. The JOHN software program utilizes solid objects to represent the human skeleton in



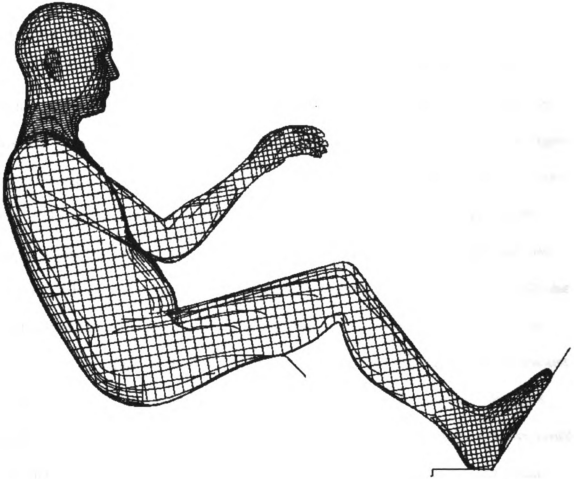


Figure 3 The UMTRI Average Male Contour

seated postures. The head, thorax, and pelvis segments in the Haas model were connected by a series of points depicting joint centers in both the cervical, thoracic, and lumbar spinal regions, as seen in Figure 4. During the course of his study, Haas examined the UMTRI data [3] and determined that the UMTRI pelvis was positioned incorrectly. In his model, Haas lowered the position of the pelvis relative to the thorax and head, resulting in a longer lumbar spine.

Two anthropometric variables were defined for the JOHN model [6]. Torso Recline Angle (TRA) was defined as the angle, measured from vertical, of the line that passes from the  $T_{12}/L_1$  spinal joint center to the  $L_5/S_1$  spinal joint center, as seen in Figure 5. The second was an internal anthropometric variable known as Total Lumbar Curvature (TLC). TLC is a measure of the total amount of curvature of the lumbar region in the sagittal plane. The sagittal plane, Figure 6, is the plane that cuts the body into right and left sides. A back with a flat lumbar section where all the spinal joint centers are collinear is defined as  $TLC=0^\circ$ , Figure 7. Given two reference lines, one on both the pelvis and ribcage, that are parallel to the  $TLC=0^\circ$  line, TLC can then be determined for any amount of lumbar curvature by measuring the angle between the two reference lines, Figure 8. Another method to measure TLC is to determine the angle between either of the reference lines and a line passing between the  $T_{12}/L_1$  and  $L_5/S_1$  spinal joint centers to determine half of the TLC, also seen in Figure 8. TLC is defined as positive when the back of the lumbar spine is concave.

The next study at MSU by Boughner [7] took the two-dimensional program of the adult male developed by Haas and created a three-dimensional solid model program. Boughner created models of the entire major skeletal structure on the computer, Figure 9,

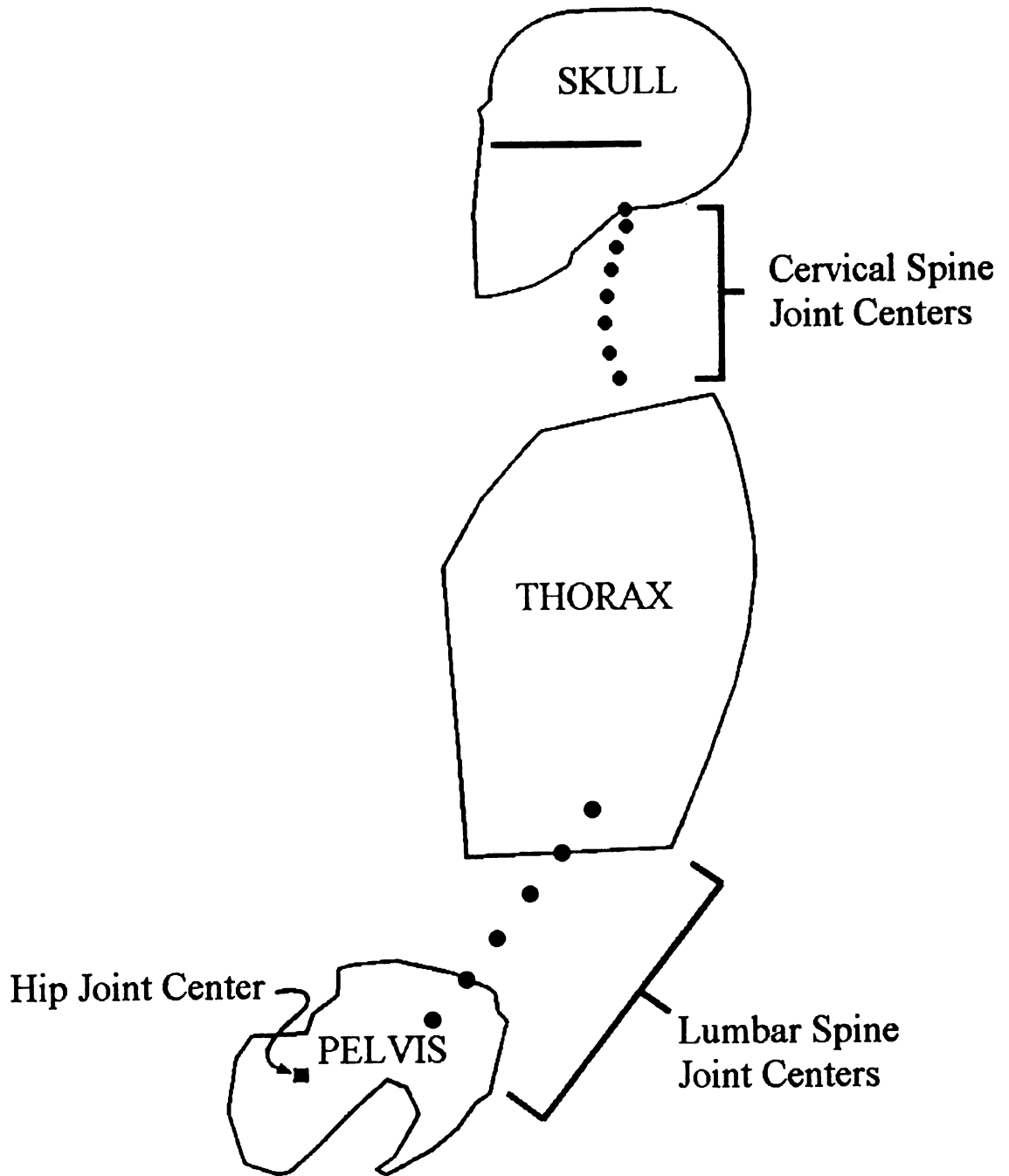


Figure 4 The Two-Dimensional JOHN Computer Model

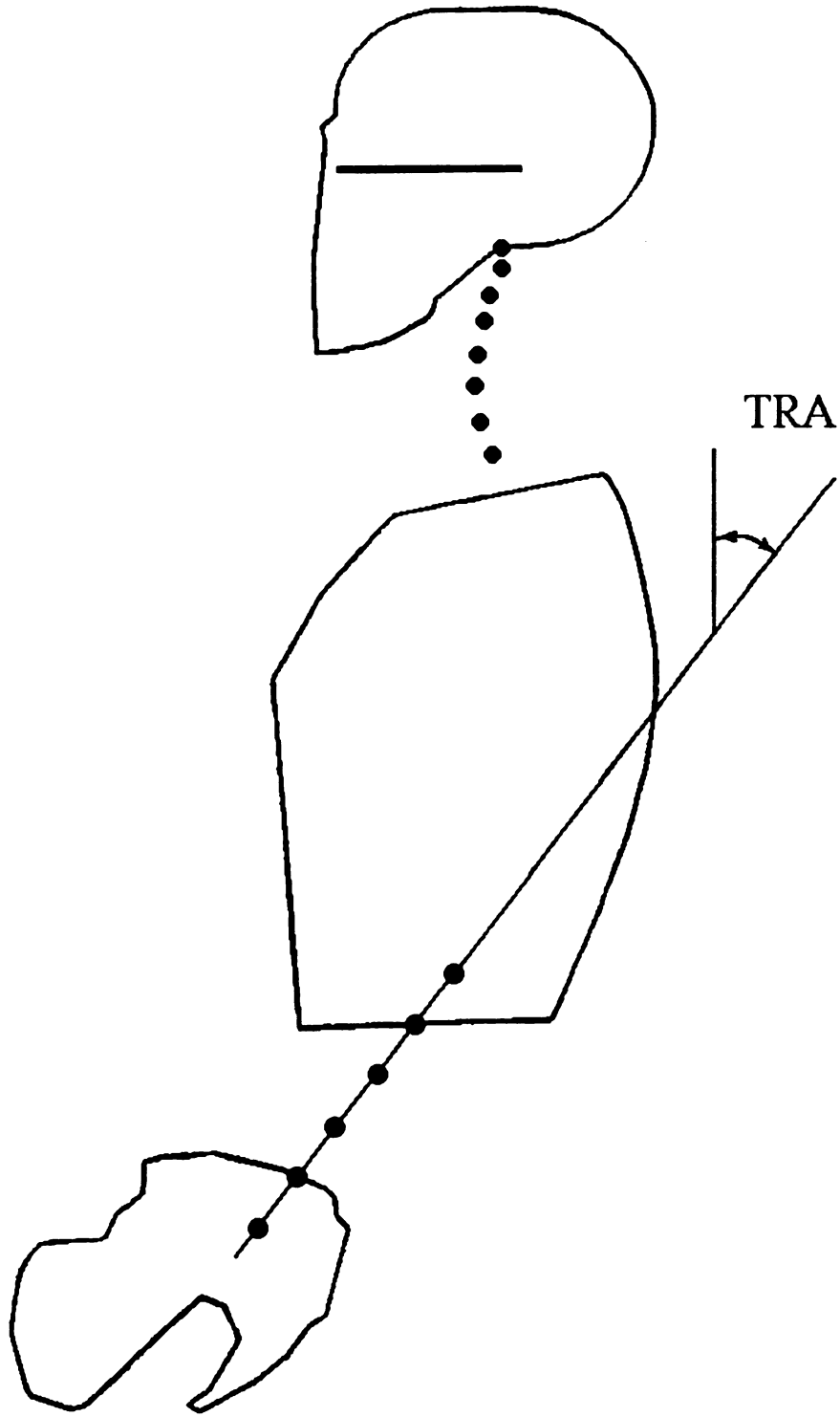


Figure 5 Torso Recline Angle (TRA)

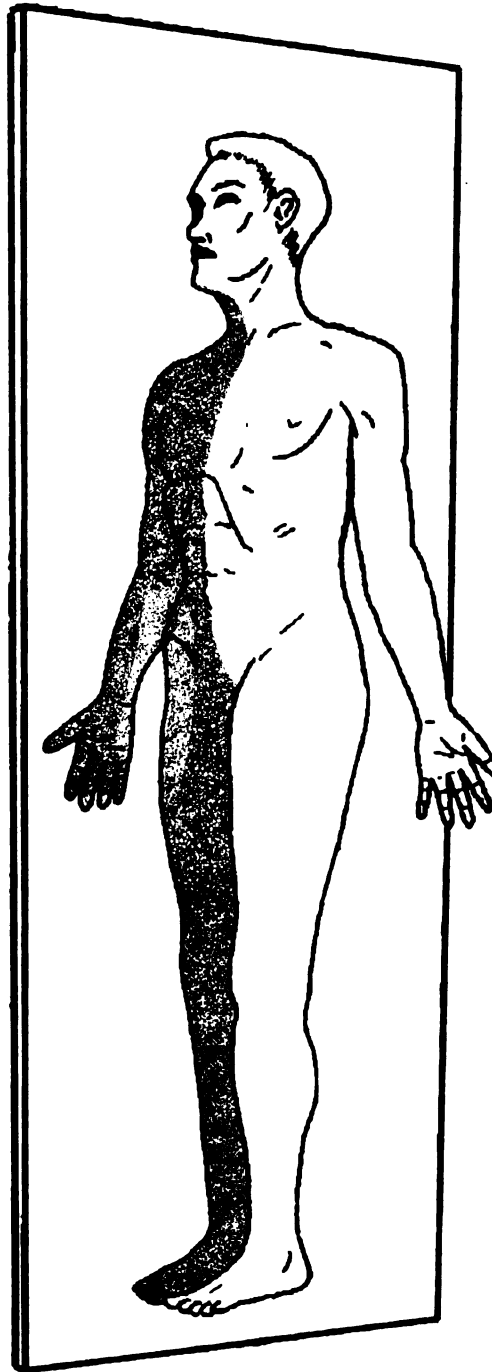


Figure 6 The Sagittal Plane [8]

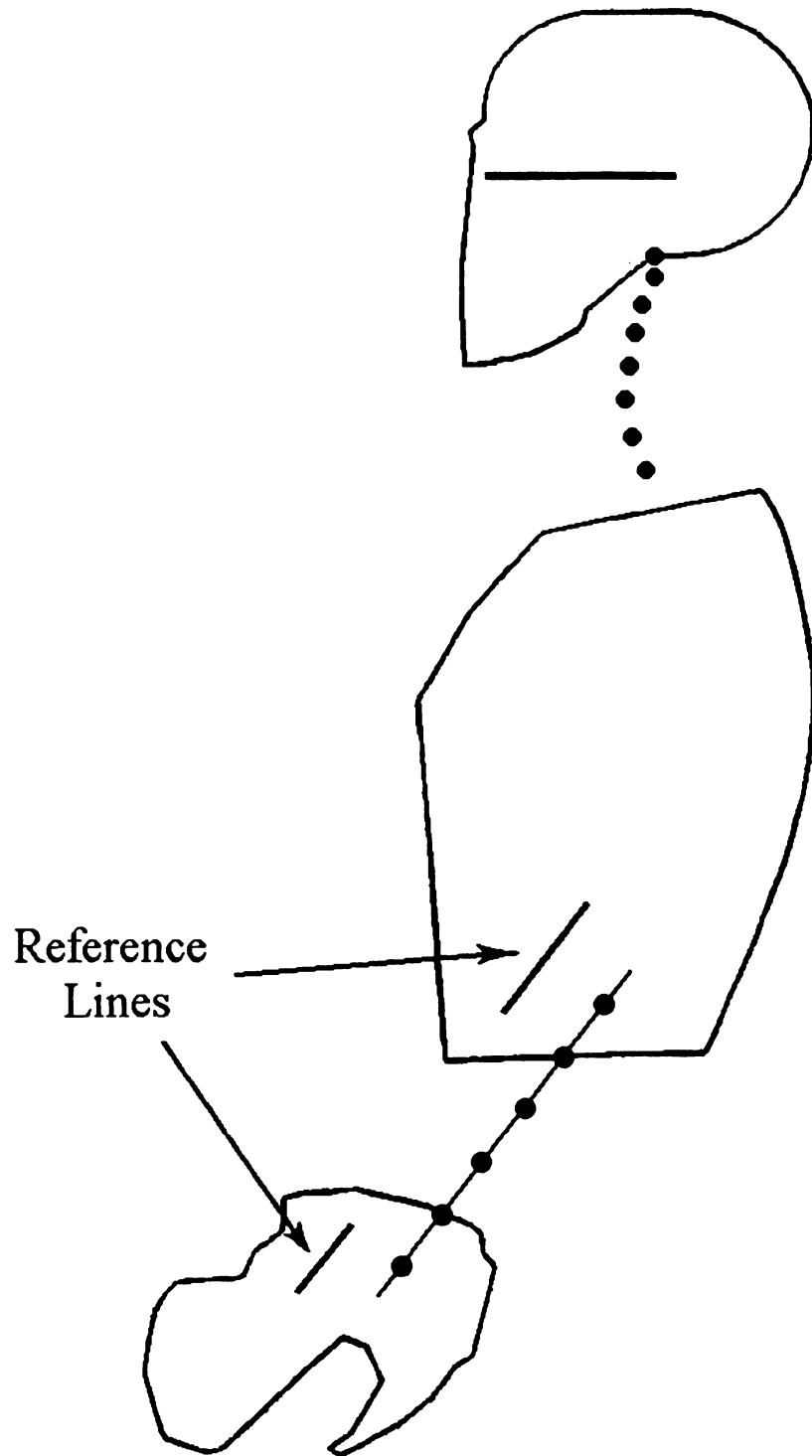


Figure 7 Total Lumbar Curvature (TLC) = 0°

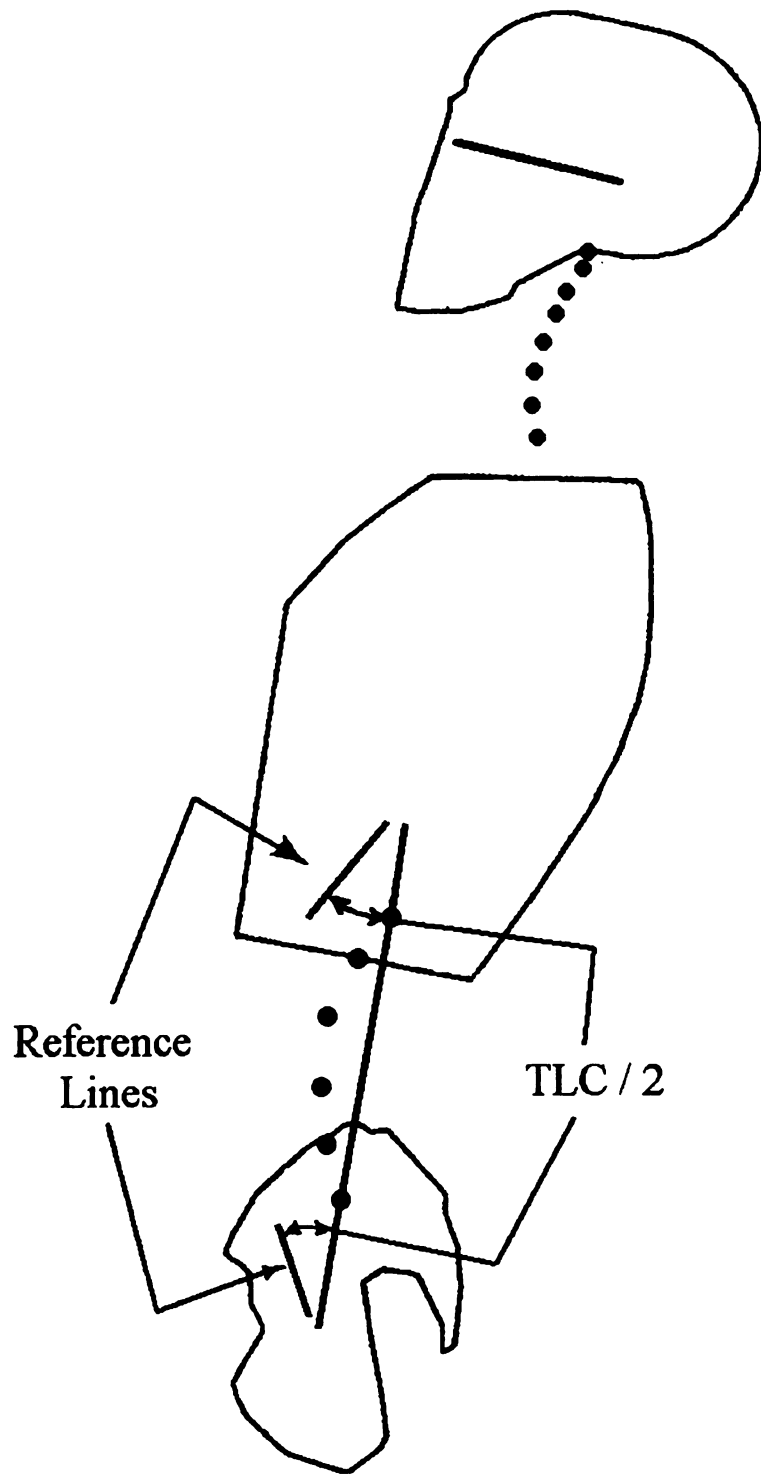


Figure 8  $TLC > 0^\circ$

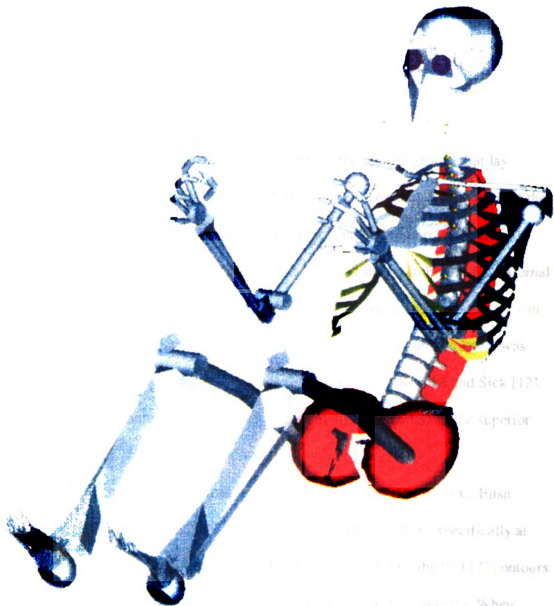


Figure 9 The Three-Dimensional JOHN Computer Model



using data from several anatomy texts [7,9,10] and data from the UMTRI study [3].

Boughner further refined his model by adding the ability to model leg muscle geometry and calculate hamstring length for the JOHN model.

In another investigation at MSU, Bush [11] developed models representing the shape and size of the *erector spinae* muscles, Figure 10, the muscle groups that lay directly to either side of the spinal column, and external skin contours for the back of the JOHN model, Figure 11. Bush created skin contours by generating horizontal cross-sections of the JOHN model spaced 50 millimeters apart, as shown in Figure 12. External contour lines were drawn by making an outline of JOHN's muscle and bone structure in each cross-section and adding an offset to that outline. The offset tissue thickness was determined by examining cross-sections of cadavers presented by Koritké and Sick [12]. An example of Bush's contour line generation, taken at 400 millimeters in the superior direction above the hip joint center of rotation, is shown in Figure 13.

Once he had the external contour lines for the JOHN model at 0° TLC, Bush developed skin contours for the JOHN model at discrete values of TLC, specifically at values of -10°, 0°, 10°, 20°, 30°, and 40° TLC. He did this by rotating the 0° TLC contours about the lumbar spinal joint centers to achieve the other TLC value contours. When Bush wrote of his findings, three-dimensional renderings of the UMTRI body contours were not available at that time, therefore he was not able to perform an in depth comparison between his contours and the UMTRI contours as had been done by Haas on the two-dimensional JOHN.

Besides the JOHN model, there are currently four other significant software packages for modeling humans in seating environments. These models are Safework,



Figure 10 The Erector Spinae Muscles

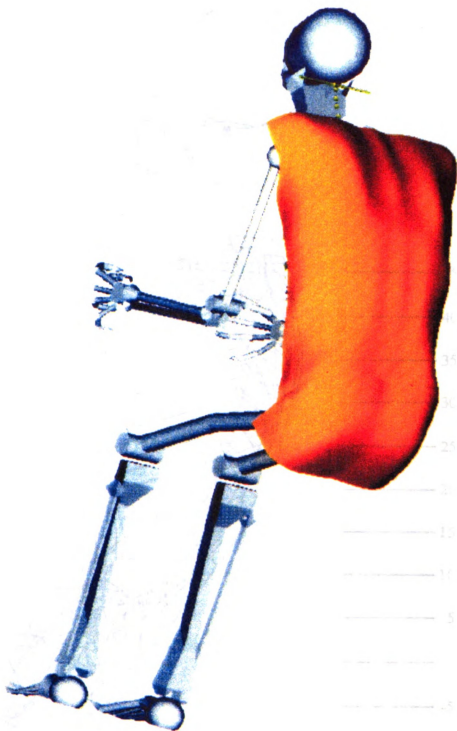


Figure 11 JOHN Model with Bush Contour

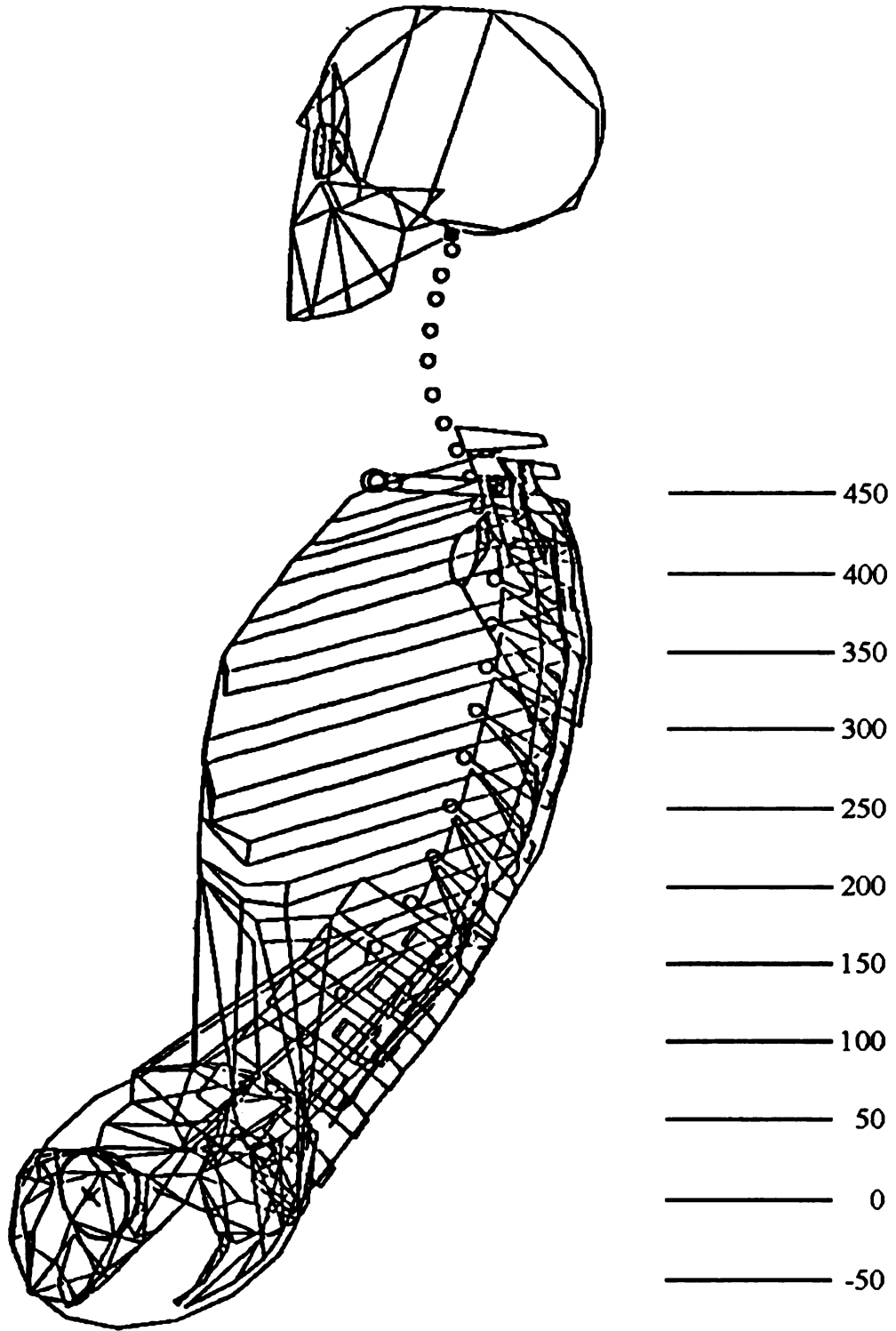


Figure 12 JOHN Model with Bush Cross-Section Locations

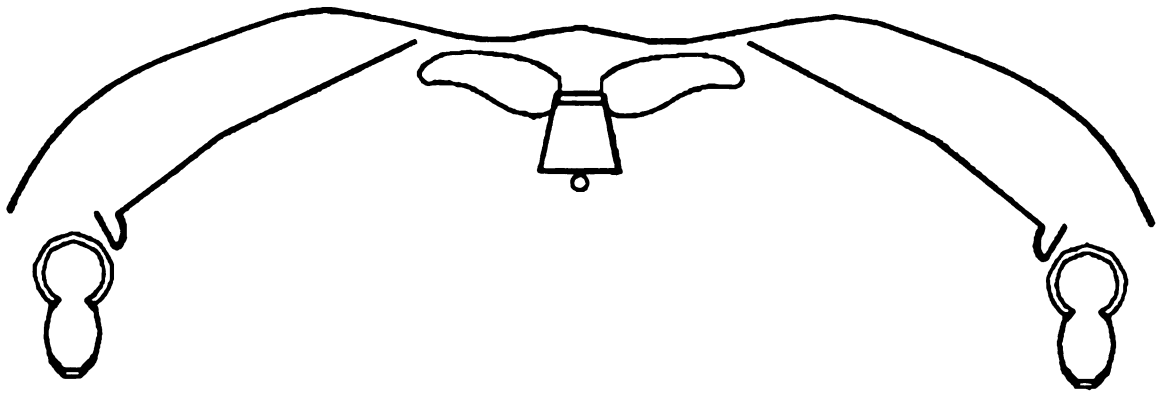


Figure 13 JOHN Model and Bush Contour at 400 mm

McDonnell Douglas Human Modeling System (MDHMS), JACK, and RAMSIS.]

Following is a brief summary of each of these models and their differences to the JOHN model.

[ Safework [13], developed by Genicom Consultants, Inc. in Montreal, Canada, is a three-dimensional human modeling system for ergonomic analysis. While the program has several key features including vision analysis, to determine “blind spots”, and reach analysis, the placement of the internal skeletal structure within the shell of the model is not fully defined as it is for JOHN, therefore making placement of the model difficult in a seated environment.

MDHMS [14], developed by McDonnell Douglas, is a human modeling program used for seating of both passengers and crew-members in the airline industry. The program is also used to ensure safe and easy access for airline personnel, both baggage handlers while in the plane’s cargo area and maintenance personnel doing repair work.

As with Safework, McDonnell Douglas is more concerned with a person's overall seating and standing height and both arm and leg lengths and does not document whether linkages (joint centers) have been placed correctly within the human shape used by MDHMS.

JACK [15], a program developed by the University of Pennsylvania, has been used at John Deere as a virtual reality tool to help designers know if the operator would be able to see objects such as the mower blades from the seat. While the inside of JACK is being redesigned with a more refined vertebral column, the external structure does not appear to be based upon anatomical data. Unlike JOHN, which was developed for the automotive seating industry, neither Safework, MDHMS nor JACK have been used for automotive seat design to represent how well a person fits within their seat.

RAMSIS [16], developed by TechMath GmbH in Kaiserslautern, Germany, is an ergonomic, three-dimensional software program used for analysis and design of automotive interiors. With video images, the user can fit a mannequin, frame by frame, to the image of the subject to obtain force and moment analysis results, especially in ingress-egress studies. Because RAMSIS uses facets to represent the exterior of each of the segments of the human form, the contour shape is not an accurate representation of the actual human contour. As a result, RAMSIS has not been used to design seats for comfort.

## 1.2 Objectives

For the present study, the overall objective was to continue the development of the JOHN family of models, generating systems and protocols for the creation of

**anatomically representative software tools for automotive seat designers. More specifically, three main objectives were set for this thesis:**

- 1. Develop a more anatomically representative contour for the back of the torso and buttock region of the JOHN average adult male at 0° TLC based on previous contour designs and other related work.**
- 2. Design and implement a method to create contours at any value of TLC and TRA.**
- 3. Develop contours for the large adult male and the small adult female, based on the revised JOHN contour at 0° TLC, allowing for contour articulation.**

**The following sections of this thesis are devoted to each of the three individual objectives listed above. Each section will include an Introduction, Methods, and Results and Discussion. The thesis will end with an overall conclusion.**

## 2. REDEFINITION OF THE JOHN CONTOUR

### 2.1 Introduction

The first objective of this thesis was to evaluate the contours developed by Bush [11] and improve those contours for JOHN with data that have recently become available. Even though Bush had a limited amount of data with which to develop his contours, he developed a model that has been very useful but was not completely accurate. Bush developed the JOHN model contours from the inside out so that the skin contours on the back were based on an anatomically representative musculo-skeletal system, developed by Boughner [7]. Bush's skin contours were important because they were a significant first step in modeling the backs of humans for the purpose of fitting people comfortably into automotive seats.

In his research, Bush performed a rudimentary comparison between his contours and the contours developed by UMTRI [3]. Even though the body surface landmark data from the UMTRI study had been available for some time, they were not available in three-dimensional, computer form. Without computer models, Bush was limited to analyzing his data to UMTRI's data at only a few surface landmarks. More recently, complete three-dimensional UMTRI contours became available as wireframe models. With these new contour files, the differences between Bush's JOHN and the complete UMTRI contour data could be analyzed on a more detailed level.



## **2.2 Methods**

### **2.2.1 Comparing Bush Contour and UMTRI Contour**

To analyze most of the dimensional differences between the contour created by Bush, Figure 14, and the UMTRI contour, Figure 15, both contours were placed over the JOHN musculo-skeletal system. The UMTRI contour represents an average adult male in a single posture with a flat lower back, or straight lumbar spine ( $TLC = 0^\circ$ ). Therefore, the UMTRI contour was compared with Bush's contour for a  $TLC = 0^\circ$ .

Cross-sections of the contours in the back region were created through each of the vertebrae down the spinal column, seen in Figure 16. Each cross-sectional plane was defined by the mid-plane between the top and bottom of each vertebra. In the lower buttock region, the cross-sectional planes were defined as the y-z plane, also known as the vertical transverse plane, where y represents the width dimension and z is the vertical height dimension. The y-z planes were created at distances from the H-point in a range from 50 mm to -70 mm, at 20 mm increments from front to rear. In the upper buttock region the cross-sectional planes were defined by rotating the vertical transverse plane  $45^\circ$  about the y axis. Three sections were made at distances, measured perpendicular to the plane from the H-point, of 50, 70 and 90 mm in the rearward direction.

Once the new vertebral cross-sections were created, the Bush contour was compared to the UMTRI contour line at each cross-sectional level. The following comparisons can be viewed in Appendix A along with the new contours, which will be discussed in more detail in this section later. In the upper torso, sections of the back varied no more than 14 millimeters in the posterior direction and the differences between the contours in the lateral direction varied between 3 to 39 millimeters. In the buttock



Figure 14 The Bush Back Contour at  $TLC = 0^\circ$

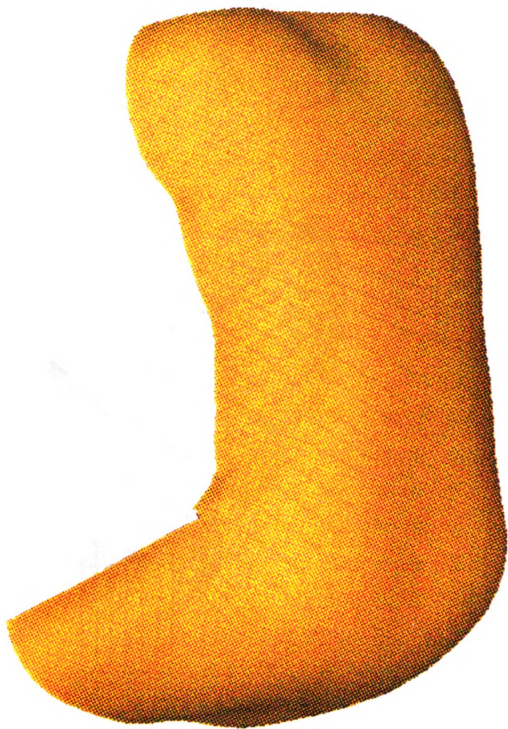


Figure 15 The UMTRI Average Male Back Contour

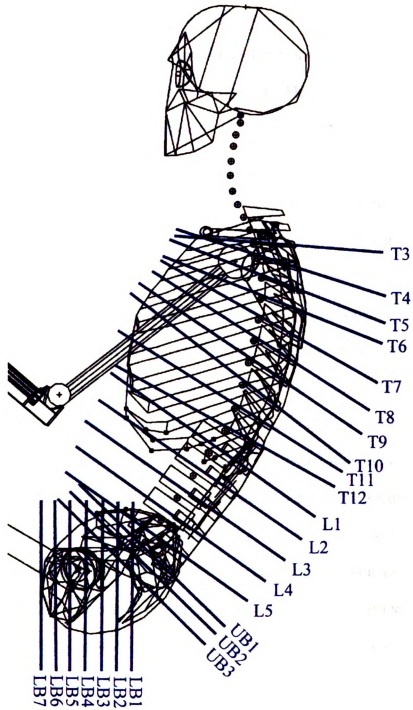


Figure 16 JOHN Model with Cross-Section Locations

region the Bush contour and the UMTRI contour had differences in the inferior direction ranging between 17 and 26 millimeters and lateral differences varying between 14 to 47 millimeters. The large differences between JOHN and UMTRI in the buttock region can be attributed to the fact that in the JOHN musculo-skeletal system developed by Boughner [7], the buttock region was modeled with the pelvis and two ellipsoids representing the gluteal musculature. While much detail went into the modeling of the pelvis, not much detail went into the gluteal muscles. When the Bush skin contour was added, a small offset layer of tissue representing fat and fascia was created between the muscles, represented by the small ellipsoids, and the skin. When compared to JOHN, the UMTRI contours show a larger amount of tissue in the buttocks of the average male.

New contour lines were then drawn at each vertebral level. Knowing that the UMTRI contours [3] were better representations of the overall shape of the average adult male, given their use of actual human subjects from which they took the skin point data, the new contour lines were based, or weighted, mainly upon UMTRI's data. The main problem with UMTRI's contours is that muscle and bone definition is lost due to their technique of averaging the data of all of their subjects and other techniques that they used to get the human-to-seat interface contour. Therefore, an attempt was made to keep the muscle and bone definition shown in Bush's contour [11], knowing that the JOHN skeletal model was very accurate and the muscle geometry, especially in the back region, were defined accurately. In sections where there was a very large difference between the positions of the Bush and UMTRI lines, like the buttock region, the new contour was positioned very close to the UMTRI contour.

The approach for representing body contours has been to model JOHN as if the model had no deformation of the skin surface, or zero forces acting upon the body. The goal of undeformable contours was difficult to obtain because every model examined in the development of JOHN was in a deformed, seated posture. Therefore, several approximations were used to move closer to the goal. Figure 17 shows a side view of the UMTRI model in the seat pan region. In order to remove obvious deflections caused by the frame and cushion of the seat, a curve was drawn from the UMTRI contour to represent an undeflected contour of the anterior thigh muscles.

By examining the Bush contour and UMTRI contour, new contour lines were drawn at each vertebral level using the weighing techniques described above. These new contour lines, as well as the Bush and UMTRI contours at each cross-section can be seen in Appendix A along with a guide to the labeling of each cross-section.

### 2.2.2 Determining the Number of Points for the New Contours

Once the new contours were drawn in for each vertebral level, coordinates of each point along each contour line were calculated according to the reference axes of the JOHN system. This was done so the contour could be manipulated and redrawn easily when the user wanted to create a contour at a TLC value other than  $0^\circ$ , described in more detail in the next section. A study was then performed on the minimum number of points needed to define each curve. This was done in an effort to ensure minimal calculation time. The minimal number of points needed to retain the shape of the curve was found to be 15. This was done by comparing a fully-defined contour line to splines created with varying numbers of points. Figure 18 shows two comparisons of the fully defined curve

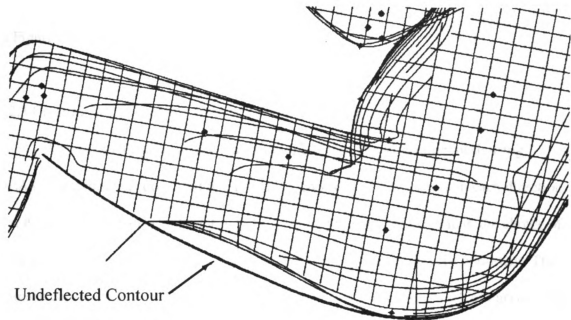


Figure 17 The UMTRI Contour Buttocks Region

to curves defined with 9 and 15 points. Curves defined with 15 or more points vary so slightly from the fully defined curve that these differences can be overlooked. When the number of points used to create the spline dropped below 15, the spline began to differ from the fully defined contour line. The 15 points defining each curve were chosen from the fully defined curve such that they were nearly equidistant from each other.

Each cross-section was then broken down into 15 equidistant points and the coordinates of the points were calculated and entered in to the JOHN model. The points were entered into I-DEAS [17], a solid modeling and meshing program, through the Construction Geometry task of the I-DEAS language. The points were saved as a separate wireframe geometry, Figure 19. Splines were then calculated by I-DEAS for each cross-

section and down each of the 15 vertical point lines to create a wireframe mesh as shown in Figure 20.

### 2.2.3 Creating Solid Contours from the Wireframe Mesh

A solid object skin surface was developed from the wireframe mesh using I-DEAS. The process is done within I-DEAS by choosing sets of curves in each direction that define the skin surface. In defining how the surface will be generated, the choice of direction of the first set of curves, known as the primary curves, is very important. The primary curves define the overall flow of the surface over the framework of curves. The secondary direction acts as the support structure for the primary curves. This can be best shown with an analogy of a ship hull. On the ship hull, the path from fore to aft is the primary direction, the direction that the planks are laid out to create the hull. The ribs of the ship form the secondary direction curves that define the hulls shape. Originally the horizontal, or cross-sectional, splines in the JOHN model were chosen as the primary curves but irregularities developed (including wrinkles and bumps along the contour surface), as shown in Figure 21. The vertical splines were then chosen as the primary curves and all of the irregularities disappeared, as shown in Figure 22. I-DEAS will only allow approximately 20 splines to be chosen at one time in the generation of skin contours. Not all of the splines could be chosen to create the solid. Therefore, all of the vertical splines were chosen in the primary (vertical) direction, secondary (horizontal) direction splines were only chosen at each of the following cross-sectional levels (shown in Appendix A):





———— Fully Defined Contour  
———— Contour Approximated with 9 Points

Fully defined versus 9 points



———— Fully Defined Contour  
———— Contour Approximated with 15 Points

Fully defined versus 15 points

Figure 18 Defining Curves with Minimal Points

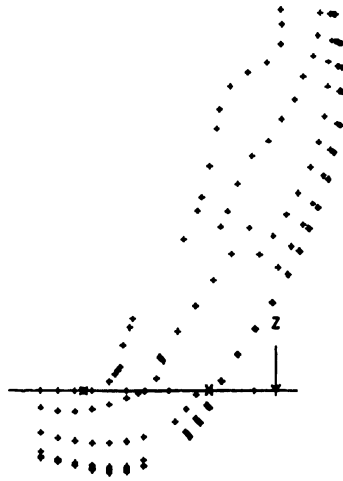


Figure 19 JOHN Contour Points

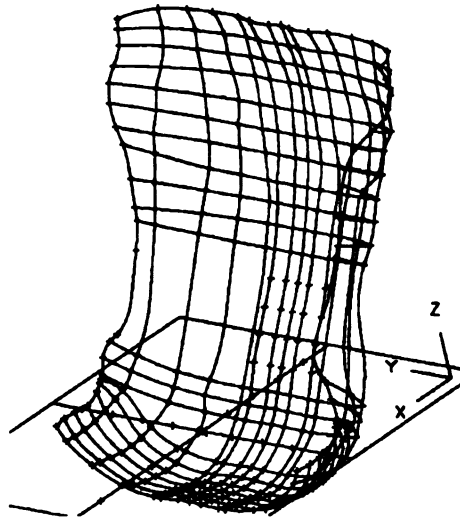


Figure 20 JOHN Contour Wireframe Mesh



Figure 21 The New Contour (First Generation)



Figure 22 The New Contour (Second Generation)

1. Third thoracic vertebra level ( $T_3$ )
2. Eleventh thoracic vertebra level ( $T_{11}$ )
3. Third contour line below the fifth lumbar vertebra level ( $UB_3$ )
4. Seventh or lowest contour line in the lower buttocks region ( $LB_7$ )

These four secondary splines were chosen as they are nearly equidistant along the length of the contour.

### **2.3 Results and Discussion**

The cross-sectional comparisons listed in Appendix A show that while the UMTRI contour was used as a guide to the overall size of the new contour, an attempt was also made to keep the muscle and bone definition shown in Bush's contour [11]. Figure 23 shows the new contour with the JOHN system at an oblique view. Compared to the Bush contour, the new contour now has a more representative size and shape, especially in the buttocks region, due to the much closer match to the UMTRI contour, which was developed from actual subjects.

Even though more information on human contours are being developed by current research at MSU, the new contour described above is the best contour possible with the currently available data for  $TLC = 0^\circ$ . Once new contour data becomes available from MSU and other sources, the JOHN contours can be further validated and refined. The importance of having highly representative contours can not be overstated. By using better contours, seat designers can design seats to have a better fit. The better a seat fits the occupant, the more comfortable the occupant will be in that seat.

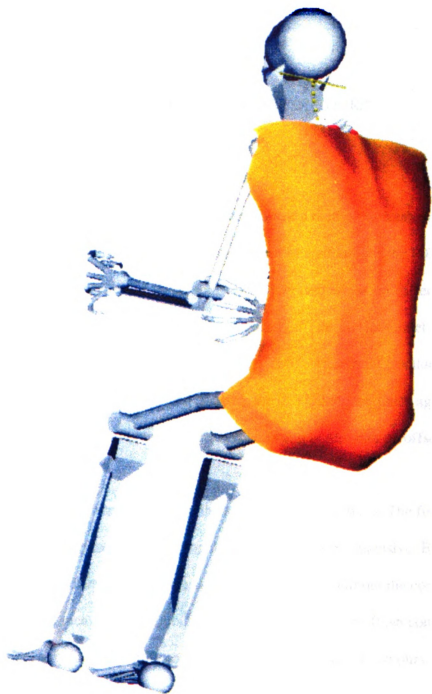


Figure 23 Oblique View of JOHN System and Contour

### 3. CREATION OF “VARIABLE” CONTOURS

#### 3.1 Introduction

The second objective was to design and implement a method to create contours at any value of TLC and TRA. In the original development of contours for the JOHN average adult male done by Bush [11], contours were only created for six different values of TLC. While keeping the amount of TRA at a constant  $35^\circ$ , the JOHN model was placed at angles of TLC equal to  $-10^\circ$ ,  $10^\circ$ ,  $20^\circ$ ,  $30^\circ$ , and  $40^\circ$ . At each TLC value, Bush created horizontal cross-sections as he had done for the  $0^\circ$  TLC model. Once again, contour lines had been drawn over the modeled muscles and bones with an offset thickness.

Several limitations were found with the approach taken by Bush. The first limitation was that the method of developing the contours was time intensive. Bush also developed his contours from modeling the skeleton and muscles without the complete data from the UMTRI measured contours. Another limitation with the Bush contours was that seat designers only had the ability to evaluate seats with those six contours. If a designer wanted to create a seat for a person at  $17^\circ$  TLC, for instance, he or she would not be able to set JOHN's contour at that TLC value, but would rather have to use a contour at either  $10^\circ$  or, more than likely,  $20^\circ$  of TLC.

## **3.2 Methods**

### **3.2.1 Associating Contour Points to Objects in JOHN**

The method to vary the contours with TLC was developed at the same time the points were created to define the contour at  $0^\circ$  TLC. By examination of the posterior of the ribcage, it was assumed that points on the skin surface over the thoracic region tend not to move relative to the ribcage over a wide range of motions in the sagittal plane. In other words, the skin does not move in or out or slide over the surface of the ribcage hardly at all. The same assumption was made for skin points over the pelvis. For this reason, the contour points developed for JOHN in the last chapter were attached to the ribcage, pelvis, spine, and muscles of the JOHN musculo-skeletal model. Within the IDEAS program [17], these skin points were attached to musculo-skeletal objects that was closest to each point. The best way to visualize this is to imagine each point as the head of a pin and each of those pins are stuck into the JOHN model. Then as JOHN's parts move, the pin heads would move with the structure to which they were attached.

Now a designer can set the musculo-skeletal system in a preferred posture and have all associated skin points follow along as the model is orientated. Once that is done, the translated points can then be splined through and those splines can be used to create a new solid model of JOHN at that specific posture. The new contour splines would be created in the exact same manner as the  $0^\circ$  TLC contour had been created. This process allows for both a systematic and repeatable method for contour generation.



### 3.2.2 Development of Program Protocols

Due to a limitation within the I-DEAS program, the skin points could not be completely associated with the solid objects. To automate the contour process in I-DEAS, a protocol was developed to rotate the contour points about the lumbar joint centers and create the skin contour after the solid object manipulation program, developed by Boughner [7], finished moving the musculo-skeletal system into the desired posture. While the preferred method of articulation was to have both the skeletal system and the skin points articulate at the same time, I-DEAS does not allow points to be splined in the Assembly Modeling Task, where the JOHN system resides. Because the splining routine can only be accessed in the Construction Geometry Task within I-DEAS, the articulation of the system and the points had to be performed as a sequential process.

In order to obtain the correct articulation of the skin points that follow the JOHN skeletal articulation, six extra points depicting the centers of rotation for the  $T_{12}/L_1$  through  $L_5/S_1$  joints were added to the contour point model in the Construction Geometry Task in I-DEAS. Since all of the flexion of JOHN's spinal column is modeled around those six points, only these six joint centers were added to the contour point model.

### 3.2.3. Overview of Revised Articulation Program

The next step was to modify the articulation program developed for the JOHN model by Boughner [7]. The program was modified as follows. After the user selects the amount of TLC and TRA and chooses whether or not to implement the contour modeling option, the program articulates the musculo-skeletal objects about the lumbar spinal joints in the Assembly Modeling Task in I-DEAS. Once that step is complete, the program

switches to the Construction Geometry Task and retrieves the contour point model for 0° TLC. The points are rotated about the lumbar spinal joint centers just like the objects with which they are associated. Once this motion is complete, the points are splined and a solid contour is generated from the splines. The resulting contour is added to the assembly in the Assembly Modeling Task. The program then rotates the musculo-skeletal system, with the new contour, to the specified TRA and aligns the *ischial tuberosities*, shown in Figure 24, to their original position. Leg and arm motion is then manipulated at the request of the user.

### **3.3 Results and Discussion**

By allowing the contour points to articulate with the musculo-skeletal system, contours can be made for any degree of TLC. Figures 25 and 26 show side views and oblique views, respectively, of the JOHN contour at two different values of TLC and TRA. The seat designer is no longer limited to designing a seat for occupants only at TLC values of -10, 0, 10, 20, 30, and 40 degrees.

Even though the contour articulation is done as a separate process from the musculo-skeletal articulation, it is performed as if the points were associated with the musculo-skeletal objects. By separating the processes, each articulation can now be done as a stand-alone feature. By allowing the contour articulation to happen by itself, a shorter and faster program was created. This program, when run by itself, focuses solely on the contour manipulation without modeling the muscles or bones. This way, a designer is able to create any contour quickly without having to take the time to

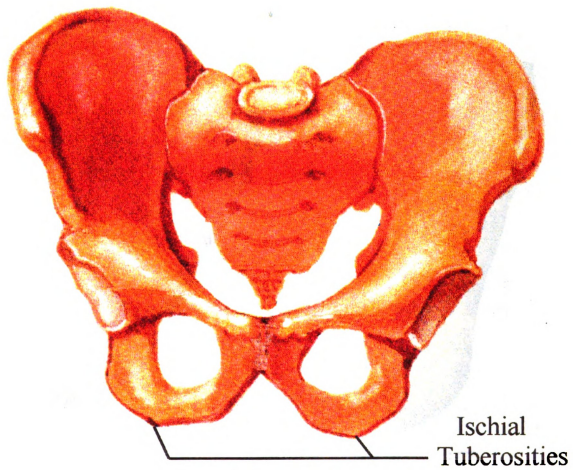


Figure 24 Ischial Tuberosities [18]



**TLC = 14°**  
**TRA = 35°**



**TLC = 37°**  
**TRA = 17°**

Figure 25 Side Views of Articulated JOHN Contours



TLC =  $14^{\circ}$   
TRA =  $35^{\circ}$



TLC =  $37^{\circ}$   
TRA =  $17^{\circ}$

Figure 26 Oblique Views of Articulated JOHN Contours

articulate the rest of the JOHN model, unless it is needed.

This process for contour generation can be used as a basis to articulate the external contours of other models besides the JOHN average adult male model. With the creation of contours for the large adult male and the small adult female, discussed in the next section, the JOHN contour articulation program can be added to the articulation programs of the small adult female and large adult male with only slight modification.

## 4. CONTOURS FOR SMALL FEMALE AND LARGE MALE

### 4.1 Introduction

Even though JOHN is a useful representation of the average man, designers need to determine if seats will also accommodate people that are tall or short in stature, or large or small in corpulence. Due to that need, two more models were developed at Michigan State University in addition to the JOHN model. In order to model tall, heavy men, the JERRY model was developed to represent the 95<sup>th</sup> percentile male in stature and weight. To represent small women, a 5<sup>th</sup> percentile (stature and weight) female model was developed called JANE. These models were based on studies by UMTRI [4] that establish skeletal landmark locations and body contours for tall, heavy men and short, light women.

Two different approaches were examined to create the contours. One approach was to follow the same development plan as the JOHN contours, creating each of the new contours for the large adult male and the small adult female by taking vertebral slices of the musculo-skeletal models down the length of the models and establishing skin contours at each level. A second approach was to develop scaling factors to change the size of the external contour of the JOHN model to create the new contours for JANE and JERRY.

The contours for both the large adult male and small adult female were created using the second approach by calculating scale factors to increase or decrease the size of

the average adult male contour. There were several reasons for pursuing this option. First, it was felt that the average male contour was well defined with the knowledge added by the UMTRI data. Second, by using the average adult male model as the reference, the small adult female contour and the large adult male contour would then be related to the average male contour, creating a basis for future models different from the 95th percentile male, 50th percentile male and 5th percentile female. Third, by having each of the three contours related to one another through the scaling process, a possible future plan would be to have the program create a contour for any possible human percentile. This process could be done by calculating a ratio of the scaling factors between the JOHN contour and the JANE or JERRY contours. For example, a 75th percentile male contour could be created by examining the JOHN (50th percentile) contour and the JERRY (95th percentile) contour with scaling factors and rotation values for the 75th percentile male being a function of JOHN and JERRY. ]

## **4.2 Methods**

### **4.2.1 Development of Thoracic and Pelvic Scaling Factors**

Scaling factors were developed by examining differences between the dimensions for the UMTRI average male contour [3] and the dimensions for the UMTRI small female and large male contours [4]. By examining the distances between different skeletal landmarks and comparing them between the three models, scaling factors were established. The torsos of the UMTRI contours were separated into three segments: thoracic, lumbar and pelvic and different scaling factors were chosen for each segment.



This was done because of differences in the relative proportions of these three body segments, especially between the male and female contours.

Scaling factors for the thoracic region were determined by examining the distances between the following anthropometric landmarks, seen in Figure 27, defined by UMTRI [2]:

1. *mesosternale* to the  $T_4$  spinous process,
2. Lowest (inferior) point on the right 10<sup>th</sup> Rib to the lowest (inferior) point on the left 10<sup>th</sup> Rib, and
3.  $C_7$  spinous process to the  $T_{12}$  spinous process.

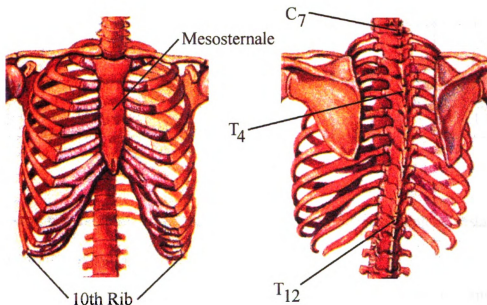


Figure 27 Thoracic Anthropometric Landmarks [18]

These distances were chosen because they were near the anatomical coordinate directions. The distances between each of the points were as shown below in Table 1. The scaling factors in each of the coordinate directions were calculated by dividing the distances for the small female and the large male by the related distance of the average male.

Table 1 Thoracic Distances and Scaling Factors

	JOHN Distance (mm)	JANE Distance (mm)	JANE Scaling Factor	JERRY Distance (mm)	JERRY Scaling Factor
Mesosternale - T <sub>4</sub> sp. Pro.	195.1	149.4	0.77	214.1	1.1
Right 10 <sup>th</sup> rib - left 10 <sup>th</sup> rib	312	258	0.83	388	1.24
C <sub>7</sub> sp. pro. - T <sub>12</sub> sp. pro.	343.6	325.2	0.95	376.4	1.1

Scaling factors for the pelvic region were determined by examining the distances between the following points:

1. L<sub>5</sub> spinous process to the center of the line between the right and left Anterior Superior Iliac Spine (ASIS),
2. Right ASIS to the left ASIS, and
3. iliocristale to the ischial tuberosity projection on the mid-sagittal plane.

Each of these anthropometric landmarks can be seen in Figure 28. Again, these dimensions were chosen due to their similarities in direction with the anatomical coordinate axes. Table 2 shows the distances and associated scaling factors for the pelvic region.

Table 2 Pelvic Distances and Scaling Factors

	JOHN Distance (mm)	JANE Distance (mm)	JANE Scaling Factor	JERRY Distance (mm)	JERRY Scaling Factor
<i>L<sub>5</sub> sp. pro.</i> - ASIS	164.6	148.4	0.89	187.4	1.15
Right ASIS - left ASIS	222	206	0.93	242	1.09
<i>Iliocristale</i> - Inf. tub. pro.	231.7	203.4	0.89	269.7	1.15

#### 4.2.2 Positioning the Thoracic and Pelvic Regions

Once the scaling factors had been established for both the thoracic and the pelvic regions, a systematic approach was developed to place the scaled regions in the proper orientation. It was apparent that there were postural differences between the UMTRI contours of the small female, the average male, and the large male. The differences in posture between the three UMTRI models were measured by scaling the torso segments of JOHN, scribing lines that are parallel to each other upon each segment and rotating those torso segments to match the UMTRI surface landmarks overlying skeletal features of the large male and small female. The angle between the scribed lines after rotation was

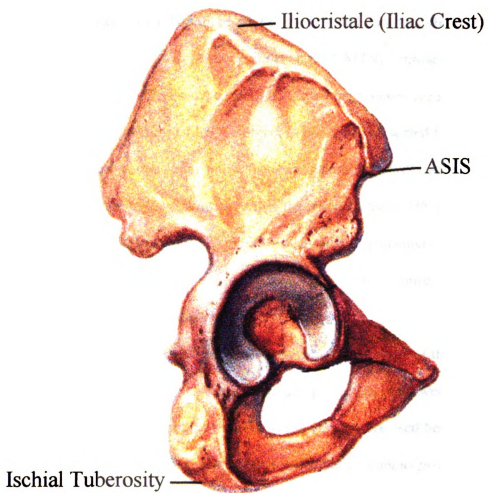


Figure 28 Pelvic Anthropometric Landmarks [18]

then measured and TLC was calculated from that angle as described in Figure 8. The UMTRI contours showed that large men tend to slouch more with a difference of  $-3^{\circ}$  TLC when compared to average-sized men. The small female contour showed a  $15^{\circ}$  more erect posture ( $+15^{\circ}$  TLC) relative to the average male. In order for JANE and JERRY's contours to be orientated correctly with respect to the UMTRI contours, the JOHN contour was first articulated and then scaled to match the UMTRI contours.

For an object or point to be scaled in I-DEAS, two parameters are required: the scaling factor and the point from which the object or point will be scaled from. When an object or point is scaled from a single point, the scaling procedure will cause all other points to move in relation to the first point. All of the points in the JOHN model were scaled from the origin, located at the H-point. This caused a displacement of the points from their original position. Therefore, each of the scaled regions required a translation to move them back into the correct position.

In order to realign the newly scaled pelvic regions, the x value of the *L<sub>5</sub> spinous process* point and the z value of the inferior tuberosity projection point were compared to their related values in each of the three models. These values were used because it was assumed that the height of the seat surface, indicated by the *L<sub>5</sub> spinous process* x value, and the depth of the seat back, indicated by the inferior tuberosity projection z value, were well defined due to the methods used in the UMTRI study [2]. The skin points were translated to align the *L<sub>5</sub> spinous process* and the inferior tuberosity projection using the translation values shown in Table 3. Translations were done only in the x and z directions. The x-axis points towards the anterior direction (behind the seat occupant). The z-axis points in the superior direction (above the seat occupant). Positive translations

indicate movement in the direction indicated. Negative translations indicate movement away from the direction indicated. In the case of the pelvic translations for both the JANE and JERRY contours listed below, some of the translations occur in the same direction due to differences in shape of the pelvic segments, especially relative to the H-point.

**Table 3 Pelvic Translation Values**

	JANE	JERRY
x (anterior) translation (mm)	-14.243	-21.415
z (superior) translation (mm)	-18.23	8.05

To position the newly scaled thoracic region, it was assumed that the *C<sub>7</sub> spinous process* is an easily palpated point, making it a location that UMTRI would be able to accurately measure. This point was then used as the guide to translate the scaled thoracic regions into position. The exact values of translation are listed in Table 4.

**Table 4 Thoracic Translation Values**

	JANE	JERRY
x (anterior) translation (mm)	-13.18	-7.40
z (superior) translation (mm)	-9.55	-6.90

The reason translations of the thoracic segments for both JANE and JERRY are in the same direction is due to the fact that the relative proportions of the thoracic and lumbar segments of the large male and small female, when compared to the average male, are very different. As will be seen in the next section, the length of the lumbar of the small female, when compared to the average male, is much smaller than the length of the lumbar of the average male, when compared to the large male.

#### 4.2.3 Scaling and Positioning the Lumbar Region

Scaling factors for the lumbar region were determined after both the thoracic and pelvic regions were scaled and positioned. By examining the distances between the newly positioned points on the thoracic and pelvic regions, scaling factors for the lumbar regions were established. It was assumed that a single scaling factor, in the direction of the lumbar spine, would be sufficient as the amount of curvature of the small female and large male lumbar segments would cause minimal change in the overall length of each lumbar segment. To determine the scaling factor, the distance was calculated from the newly placed  $T_{12}$  *spinous process* point to the center of the upper buttock ( $UB_1$ ) contour line. Table 5 shows the calculated distances and the resulting scaling factors. It should be noted that these scaling factors are smaller than those for the pelvic and the thoracic regions for both the large male and the small female. This may be explained by Boughner's three-dimensional model [7], which was based upon the two-dimensional model developed by Haas [6]. Even though Haas lowered the position of the pelvis relative to the thorax, creating a longer lumbar spine for the JOHN model, the positions of the large adult male and small adult female pelvic regions were never fully examined.

It is likely that pelvis in both the UMTRI small woman and large man are also positioned too high, as was discovered for the UMTRI average man.

Information about the y (lateral) direction in the lumbar region was not available from the UMTRI data because all of the points in that region lie on the mid-sagittal plane ( $y = 0$ ). In the JOHN model, the points defining the skin contour in the lumbar region cover only a narrow area down the center of the spine and over the *erector spinae*

Table 5 Lumbar Distances and Scaling Factors

	JOHN Distance (mm)	JANE Distance (mm)	JANE Scaling Factor	JERRY Distance (mm)	JERRY Scaling Factor
T <sub>12</sub> sp. pro. - UB <sub>1</sub> sp. point	206.4	162.3	0.78	212.2	1.02

muscles directly to each side of the vertebral column. Therefore, it was assumed that using the y scaling factor calculated for the thoracic region, Table 1, would suffice over the narrow width of the lumbar region for both the small female and the large male.

The placement of the lumbar region was determined by the final placement of both the pelvic and thoracic regions. The points associated with the lumbar region were translated into position so the point associated with the T<sub>12</sub> spinous process was placed back into its original position. Table 6 summarizes the amount of translation required to move the region into position for both the small female and the large male.



**Table 6 Lumbar Translation Values**

	JANE	JERRY
x (anterior) translation (mm)	-22.5	-31.155
z (superior) translation (mm)	16.6	5.924

### **4.3 Results and Discussion**

Oblique views of the JANE and JERRY contours at a value of 0° TLC are shown in Figures 29 and 30, respectively. To compare each of the new contours to the UMTRI small female and the large male contours, the new contours were articulated back to TLC values of +15° and -3°, respectively. The respective large male and small female contours match to within several millimeters of one another. Figure 31 is a side view of JANE's contour, cut at the mid-sagittal plane, overlaid onto the UMTRI small female contour. Figure 32 is the same overlay, viewed from the back. The side view overlay of JERRY's contour, cut at the mid-sagittal plane, with the UMTRI large male is seen in Figure 33 with the back view overlay in Figure 34. Select cross-sections of the JANE contour compared to the 5th percentile female UMTRI contour are shown in Appendix B. Cross-sections of the JERRY contours compared to the 95th percentile male UMTRI contour are shown in Appendix C.

Each of the new contours of JANE and JERRY are representative of the size and shape of the small adult female and the large adult male, while maintaining muscle and bone representation throughout the contour. The JANE and JERRY contours can also be

articulated into any degree of TLC and TRA, in exactly the same manner in which the JOHN contour was articulated. By scaling the contours of JANE and JERRY from the JOHN contour, each contour is now related to the other. The seat designer now has the ability to model not just the average male, but can design seats that fit a larger array of occupant sizes.

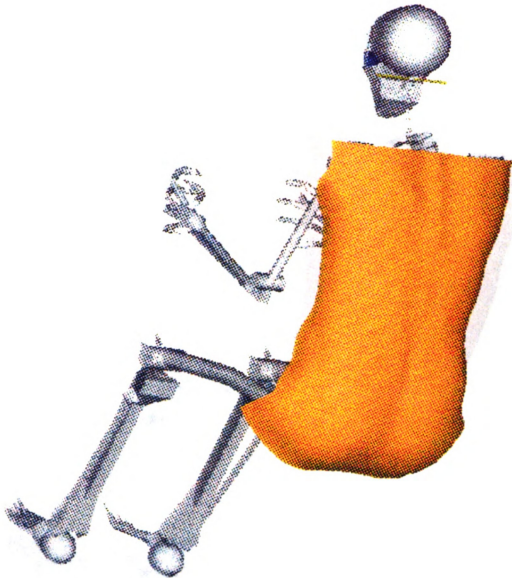


Figure 29 Oblique View of JANE System and Contour

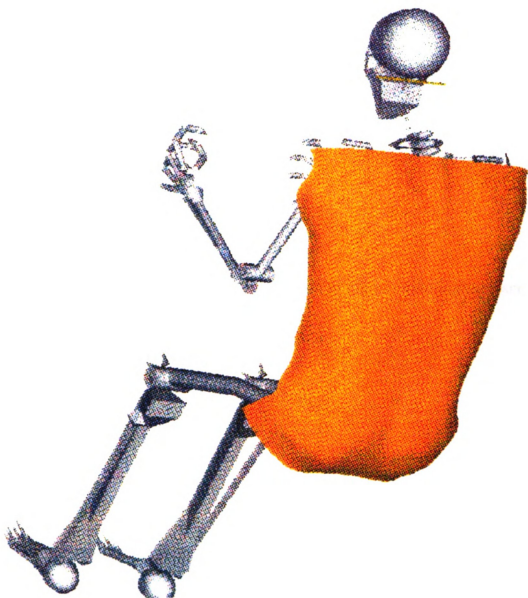


Figure 30 Oblique View of JERRY System and Contour

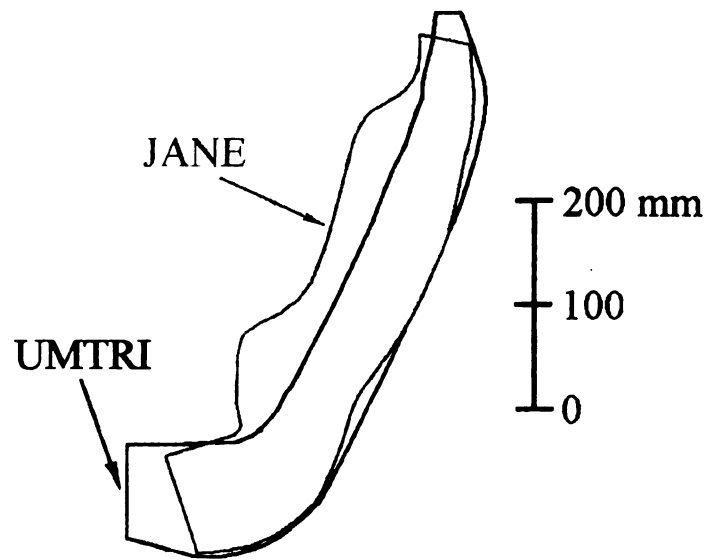


Figure 31 Side View Comparison of JANE to UMTRI Contour (mid-sagittal plane)

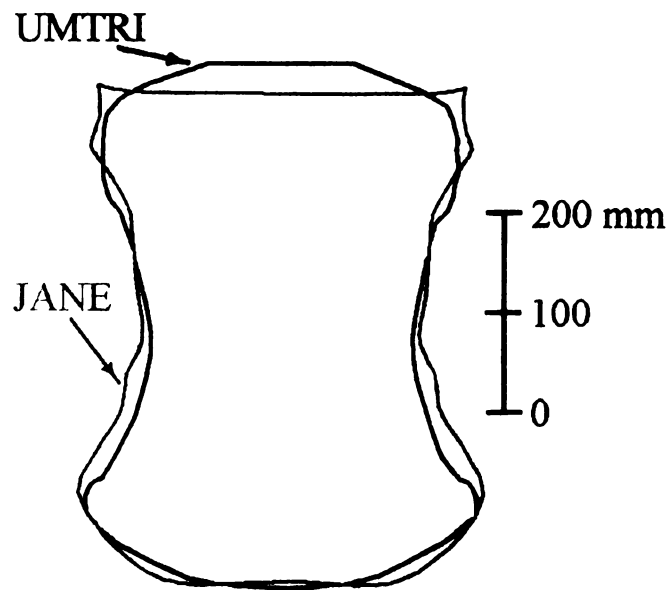


Figure 32 Back View Comparison of JANE to UMTRI Contour

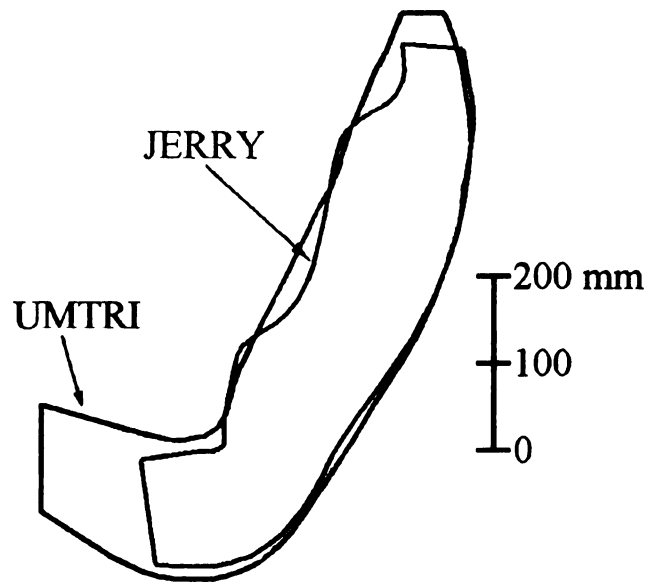


Figure 33 Side View Comparison of JERRY to UMTRI Contour (mid sagittal plane)

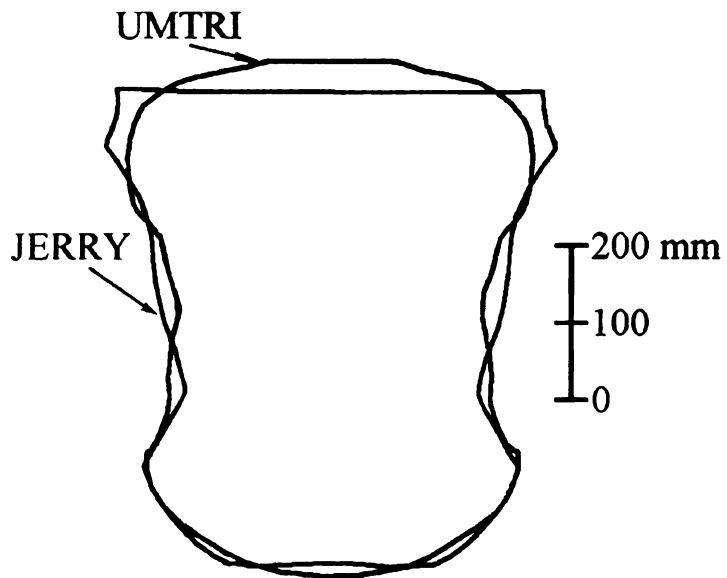


Figure 34 Back View Comparison of JERRY to UMTRI Contour

## 5. CONCLUSION

The three objectives for this thesis have been accomplished. The external contour of the JOHN model was reconfigured to be a more anatomically representative model of an undeflected average adult male skin surface as compared to the UMTRI [3] subjects whose soft tissues were deformed by seat contact. The new contour was developed using both the original contour created by Bush [11] and the data generated by UMTRI [2,3]. This new contour is also more representative of the back and buttock regions, compared to the Bush contour, because it is partially based on the UMTRI average male, which was compiled by studying a large population of average adult male subjects. The new contour also retains the muscle and bone definition noted in Bush's model.

Once the average adult male contour was improved, a contour articulation program for the average adult male was created. The external contour of the average male can now be articulated in the sagittal plane to the same amount of TLC and TRA as its underlying musculo-skeletal systems. The articulation program was later expanded to include the external contours of both the small adult female and the large adult male.

External contours for both the small adult female and the large adult male were developed based on the JOHN average adult male contours. Each of these new contours can be used with the same ease as the JOHN contour. Both of the JANE and the JERRY contours are based on the JOHN contour, thus making all of the contours related to each other.

Since these models have improved contours, designers will be able to use them to create seats that fit people better. With contours for any value of TLC and TRA, the designer will be able to fit occupants in seats in a larger variety of postures. By allowing designers to model not only the average male but also the small female and the large male, designers can create a seat that will fit a larger segment of the population. Fit, while it is by no means the sole component, is one of the most important elements to designing comfortable seats. If seat design tools like the JOHN family of models can better represent how a large variety of people fit into seats using different positions, seats designed with those tools should be more comfortable.



## APPENDIX A

APPENDIX A

Cross-Sections of JOHN

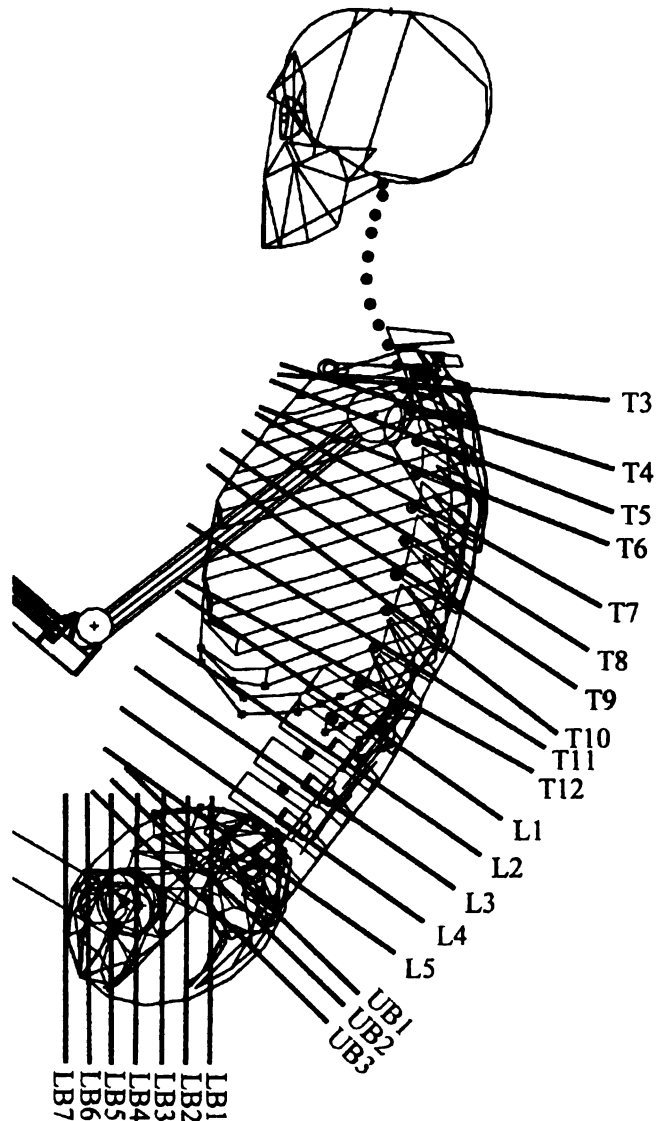


Figure A1 Cross-Sections of JOHN

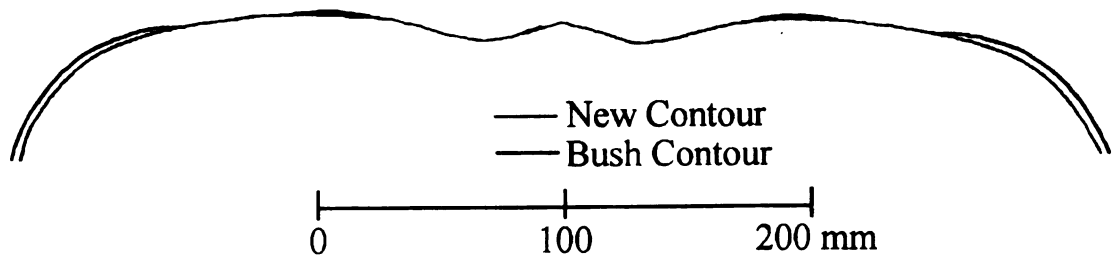


Figure A2 Third Thoracic (T3) Cross-Section

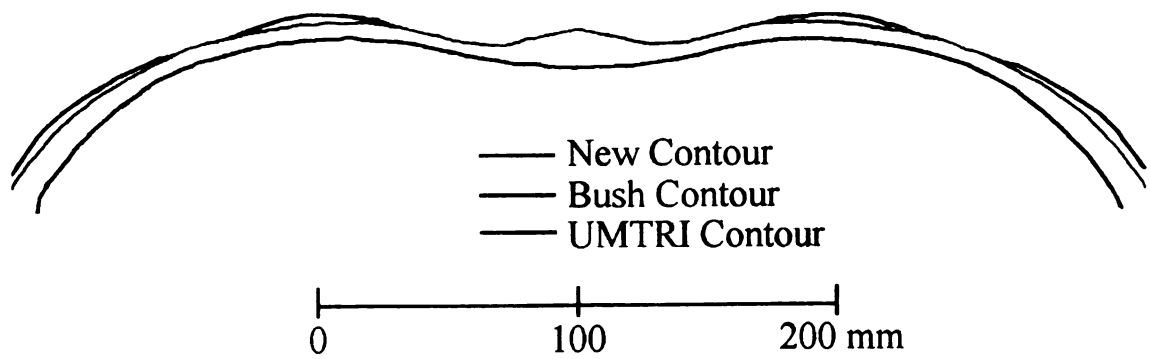


Figure A3 Fourth Thoracic (T4) Cross-Section

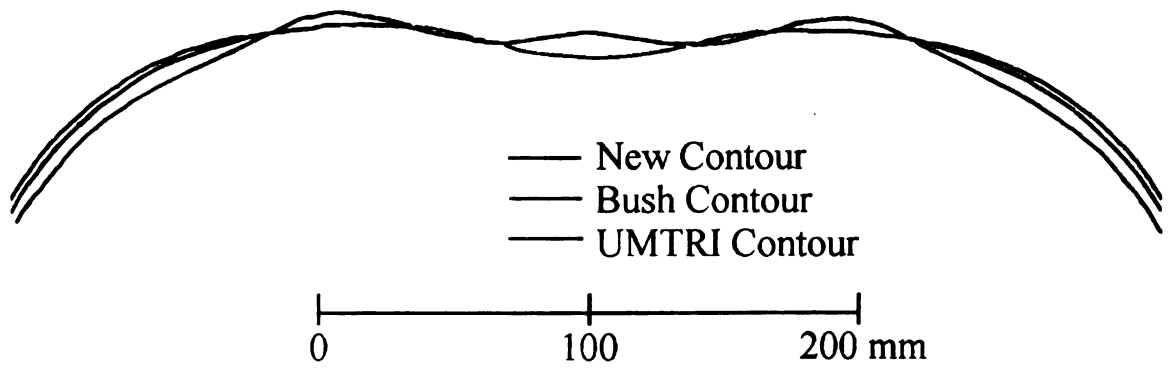


Figure A4 Fifth Thoracic (T5) Cross-Section

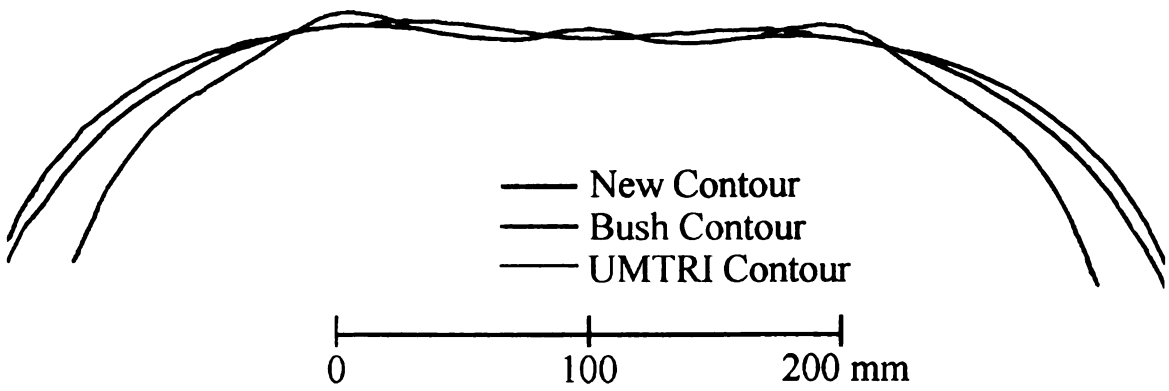


Figure A5 Sixth Thoracic (T6) Cross-Section

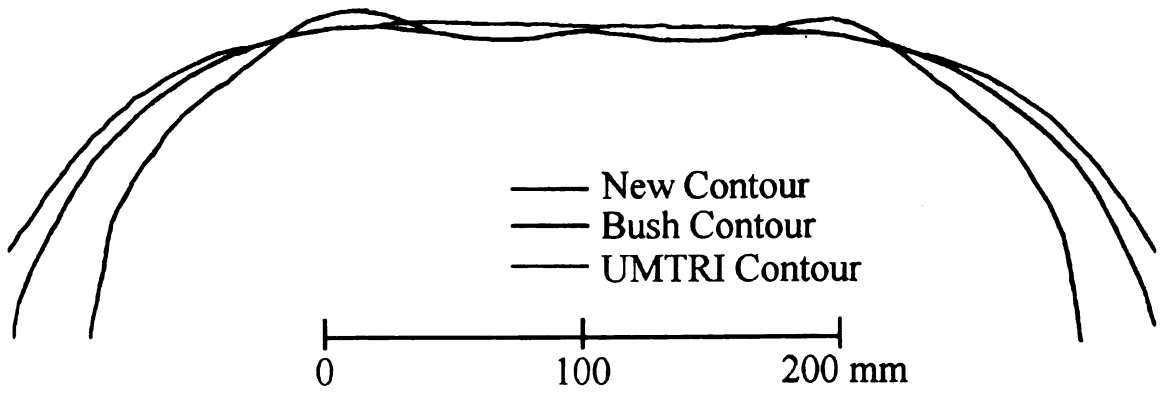


Figure A6 Seventh Thoracic (T7) Cross-Section

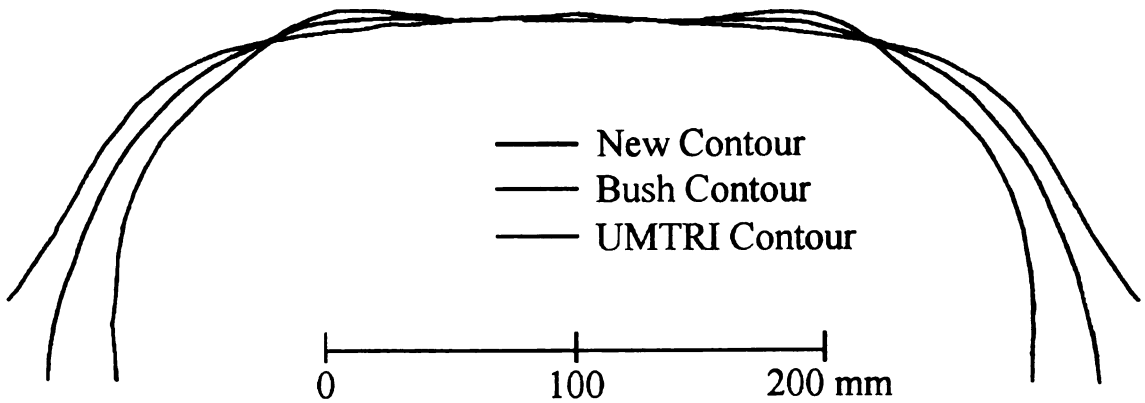


Figure A7 Eighth Thoracic (T8) Cross-Section

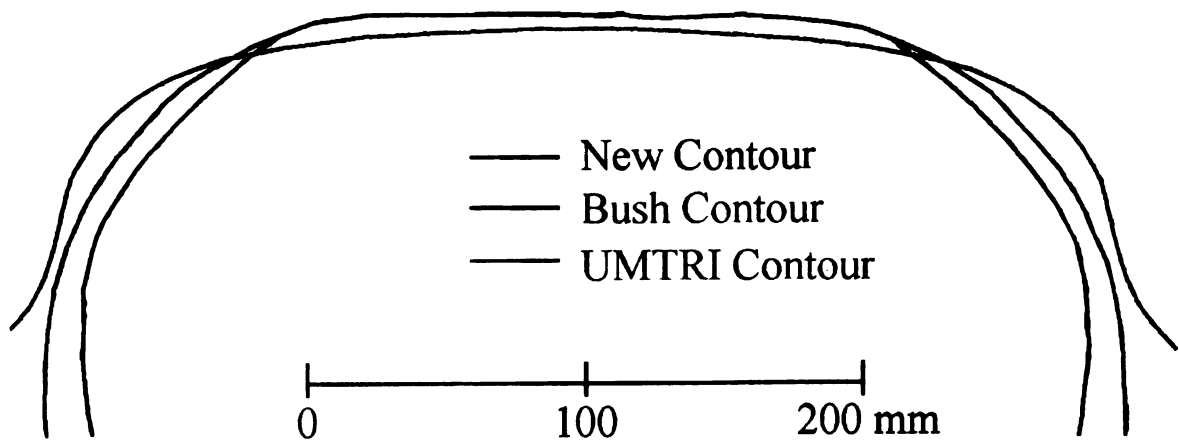


Figure A8 Ninth Thoracic (T9) Cross-Section

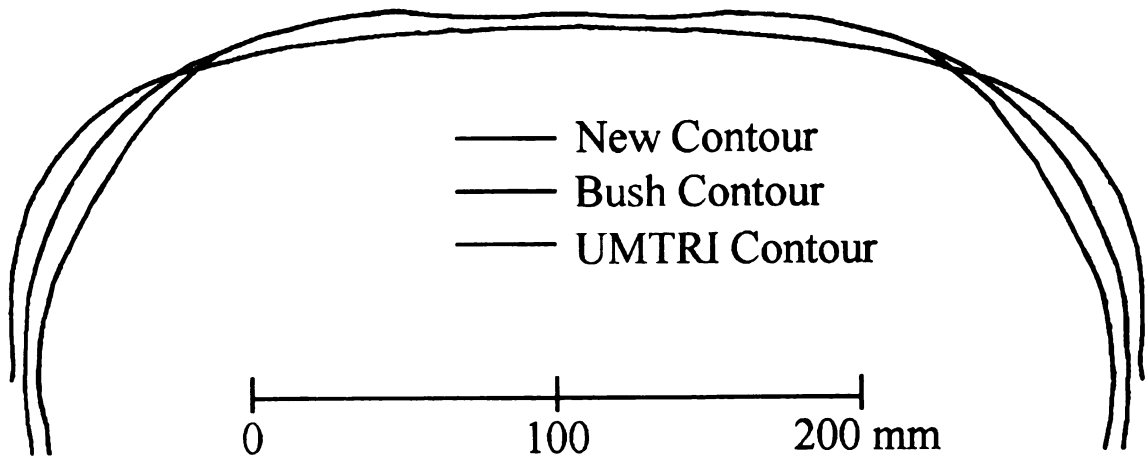


Figure A9 Tenth Thoracic (T10) Cross-Section

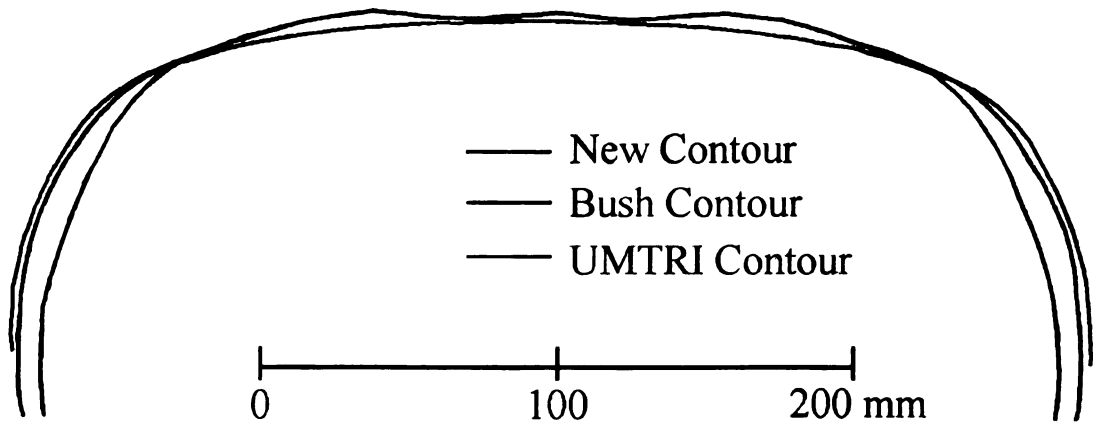


Figure A10 Eleventh Thoracic (T11) Cross-Section

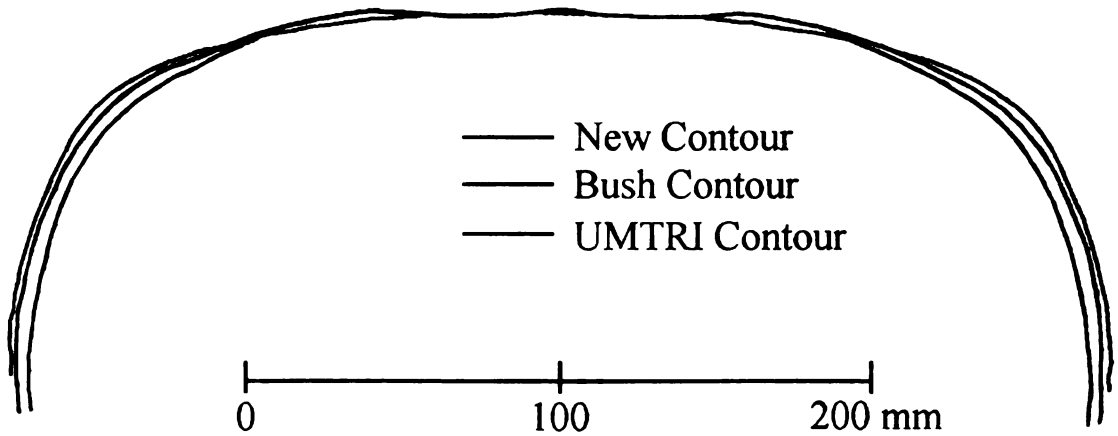


Figure A11 Twelfth Thoracic (T12) Cross-Section

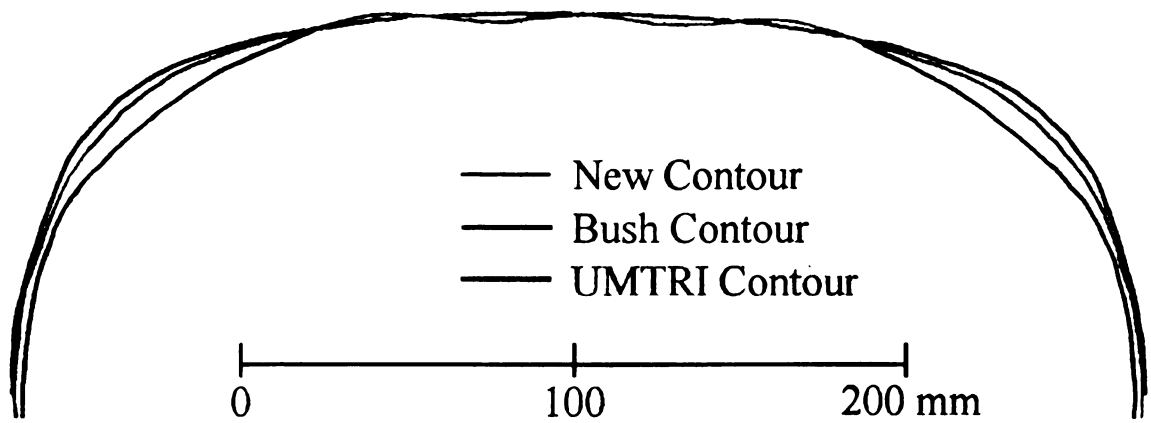


Figure A12 First Lumbar (L1) Cross-Section

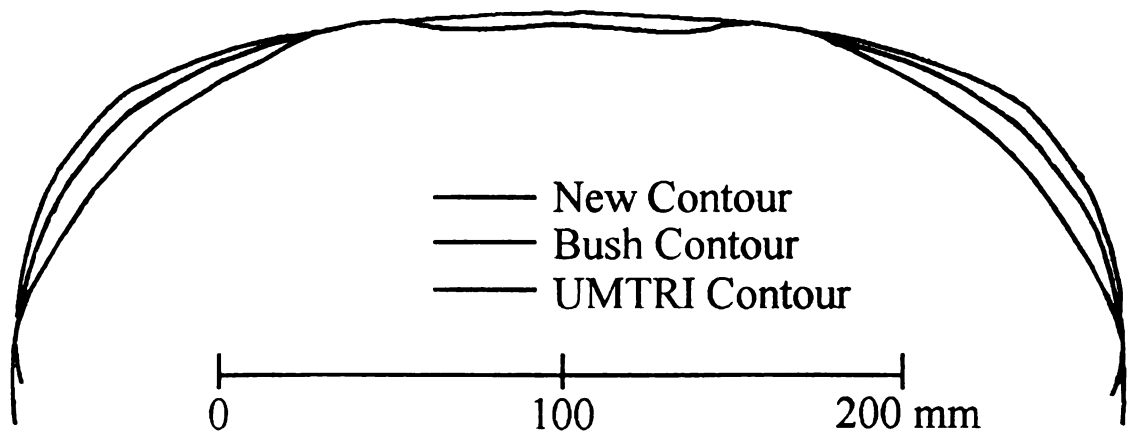


Figure A13 Second Lumbar (L2) Cross-Section



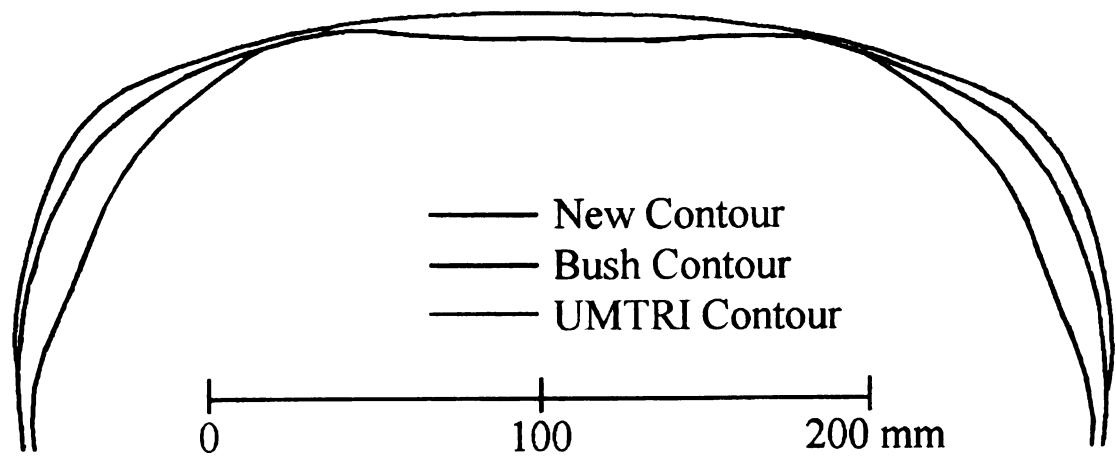


Figure A14 Third Lumbar (L3) Cross-Section

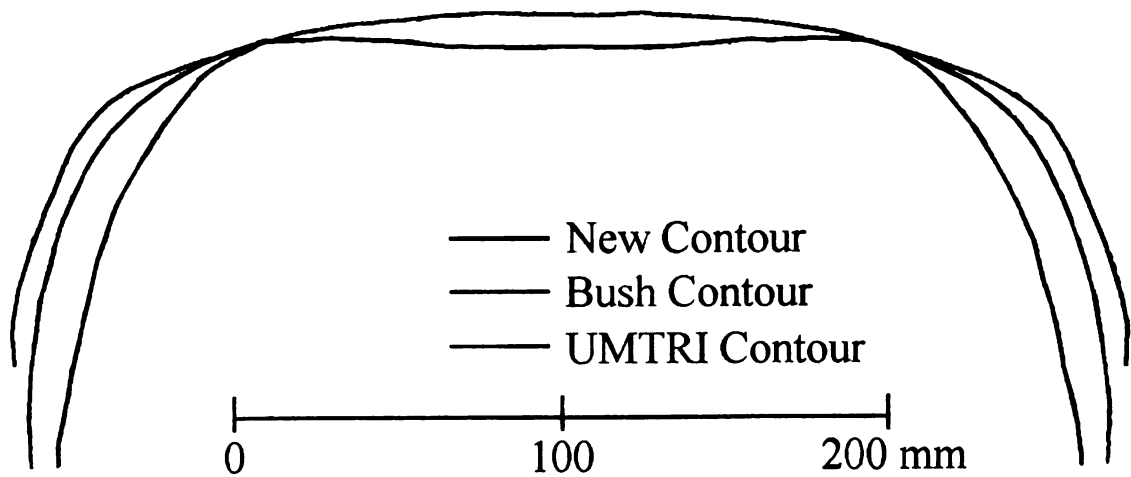


Figure A15 Fourth Lumbar (L4) Cross-Section

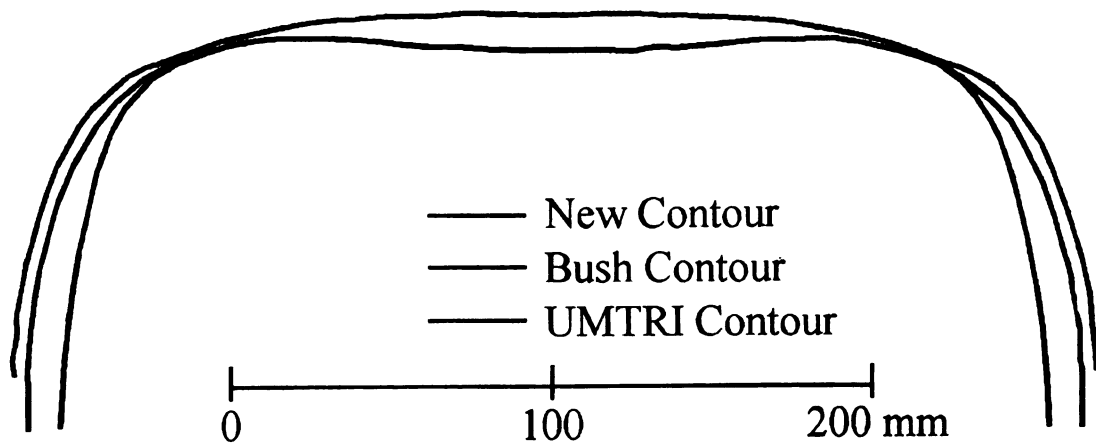


Figure A16 Fifth Lumbar (L5) Cross-Section

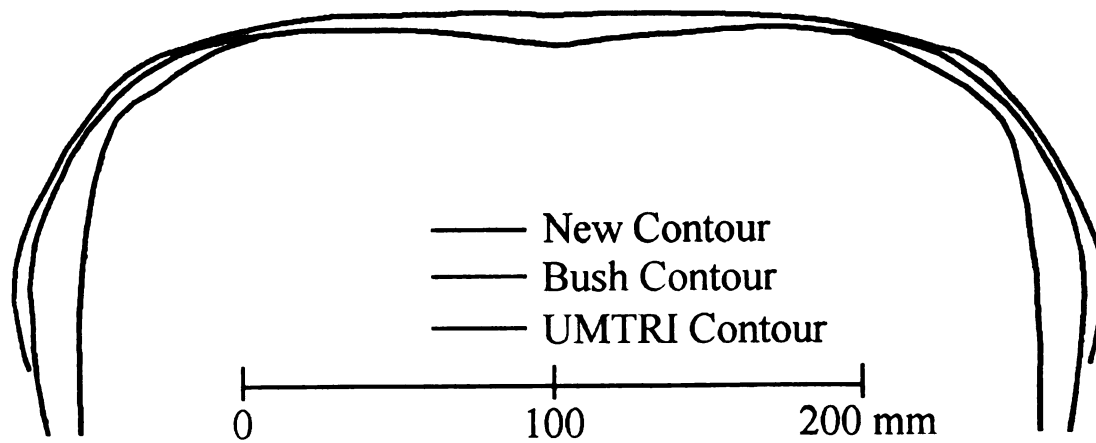


Figure A17 First Upper Buttock (UB1) Cross-Section

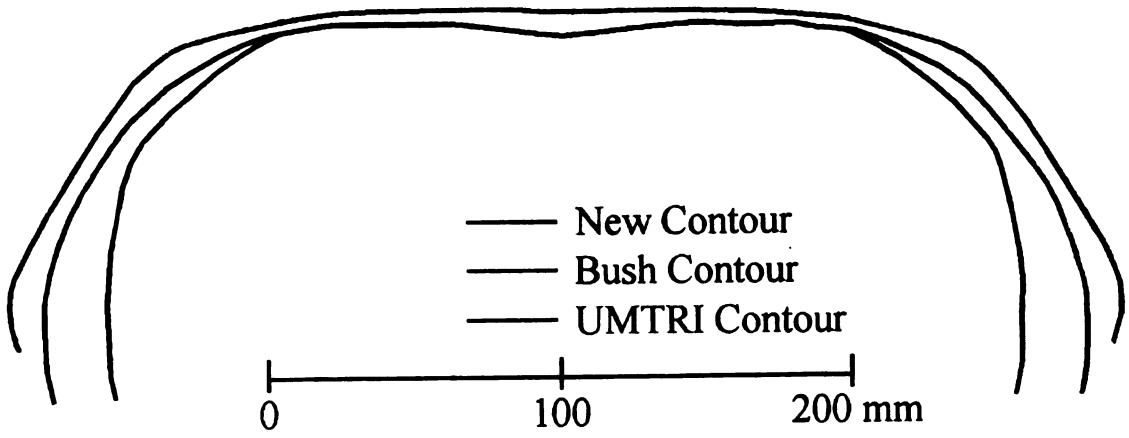


Figure A18 Second Upper Buttock (UB2) Cross-Section

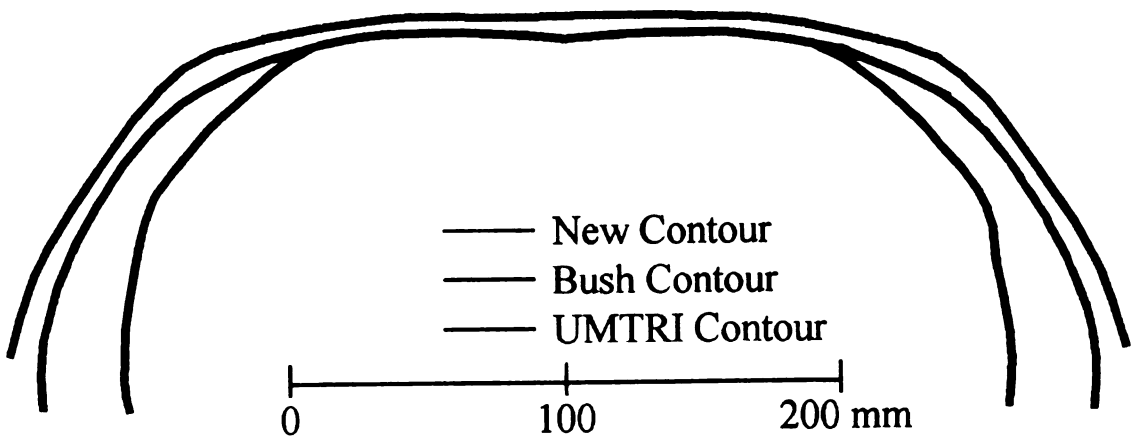


Figure A19 Third Upper Buttock (UB3) Cross-Section

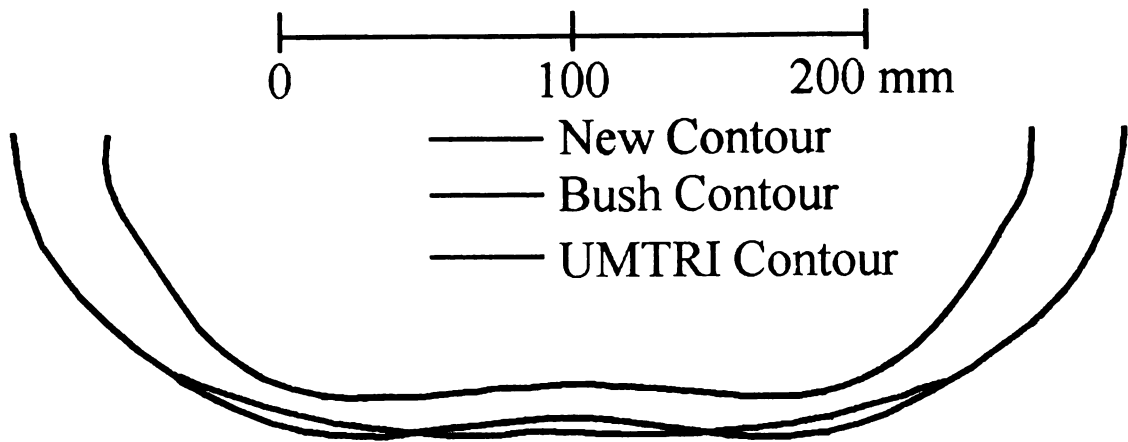


Figure A20 First Lower Buttock (LB1) Cross-Section

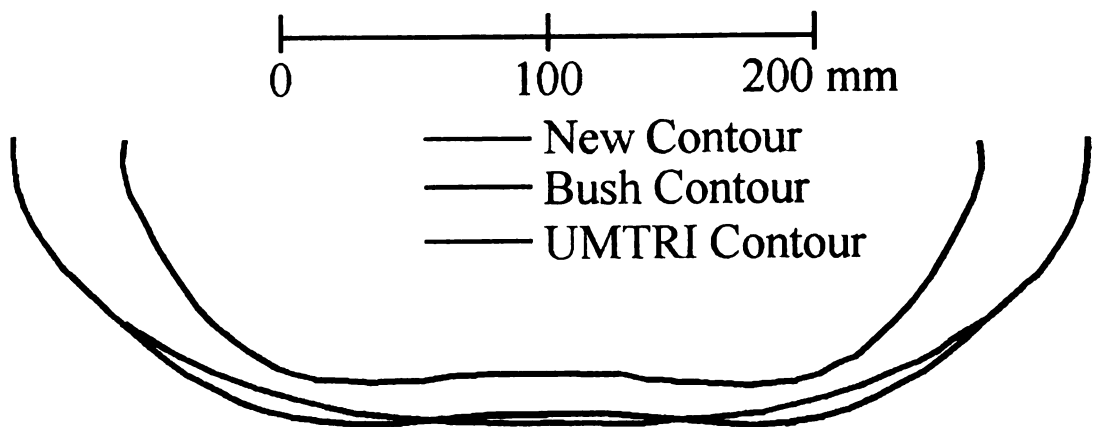


Figure A21 Second Lower Buttock (LB2) Cross-Section

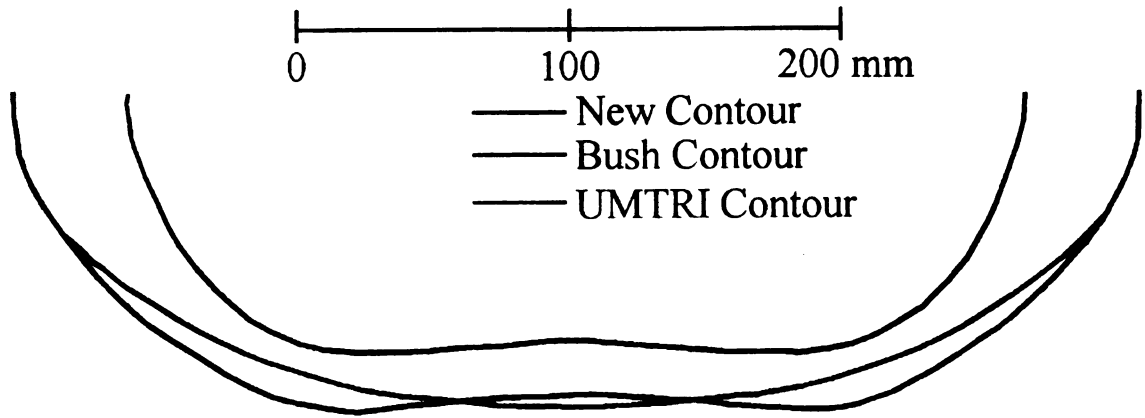


Figure A22 Third Lower Buttock (LB3) Cross-Section

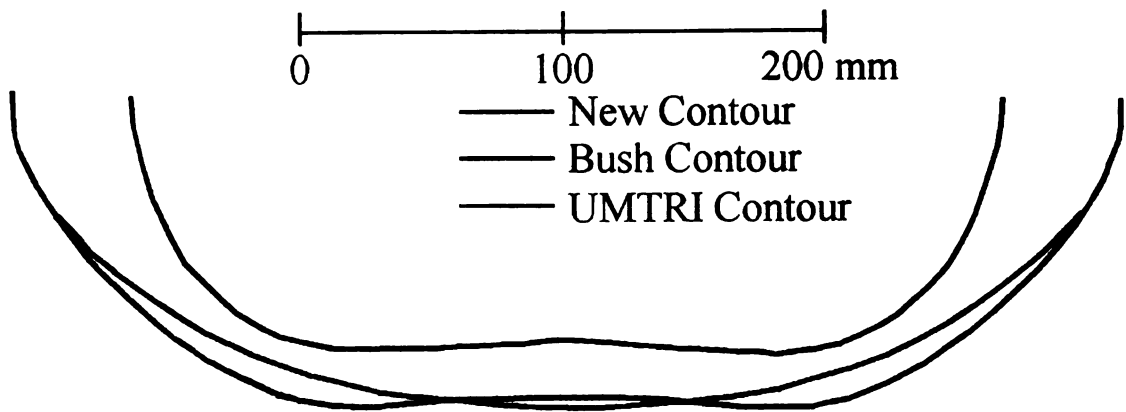


Figure A23 Fourth Lower Buttock (LB4) Cross-Section

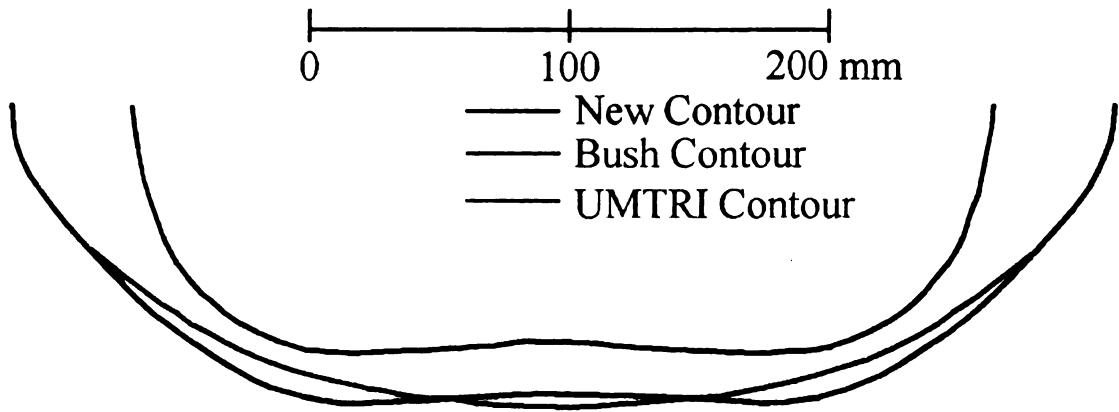


Figure A24 Fifth Lower Buttock (LB5) Cross-Section

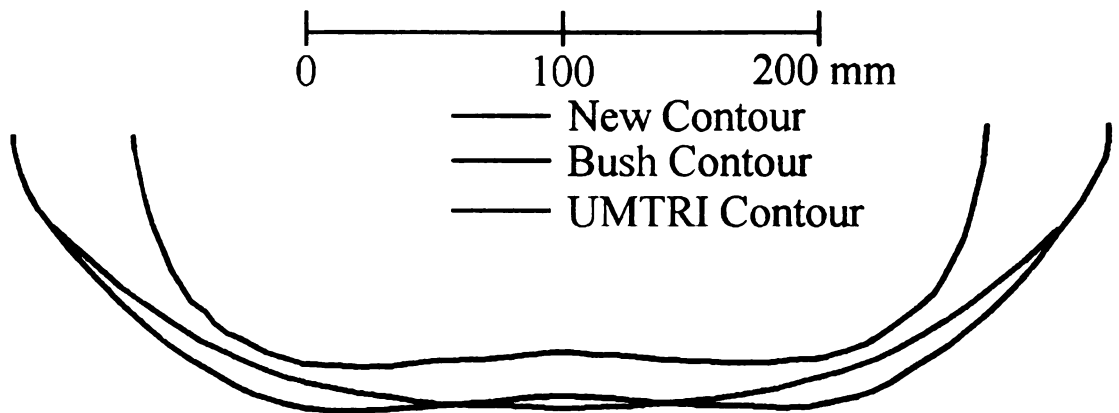


Figure A25 Sixth Lower Buttock (LB6) Cross-Section

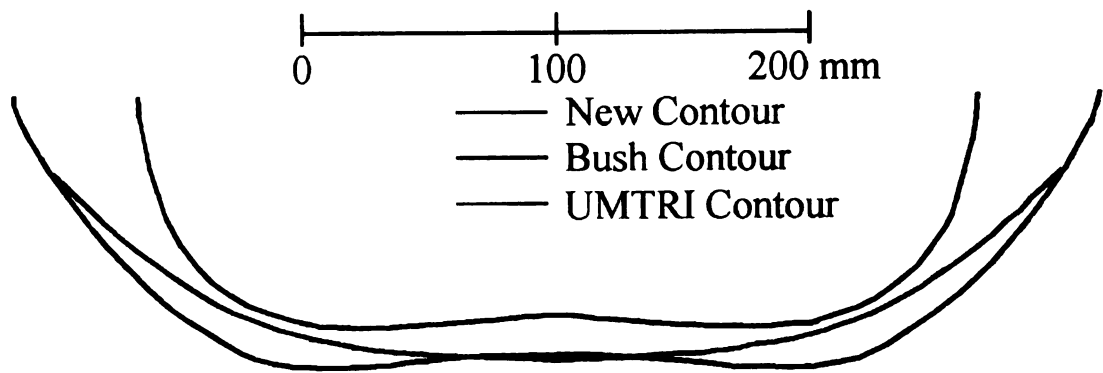


Figure A26 Seventh Lower Buttock (LB7) Cross-Section

## **APPENDIX B**



APPENDIX B

Cross-Sections of JANE

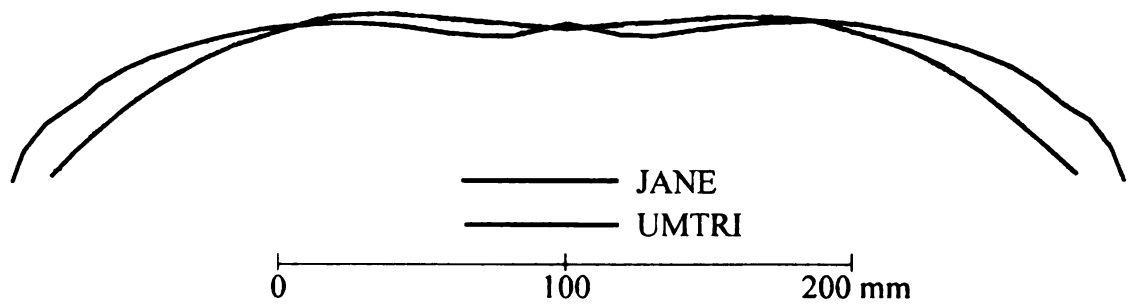


Figure B1 Fourth Thoracic (T4) Cross-Section

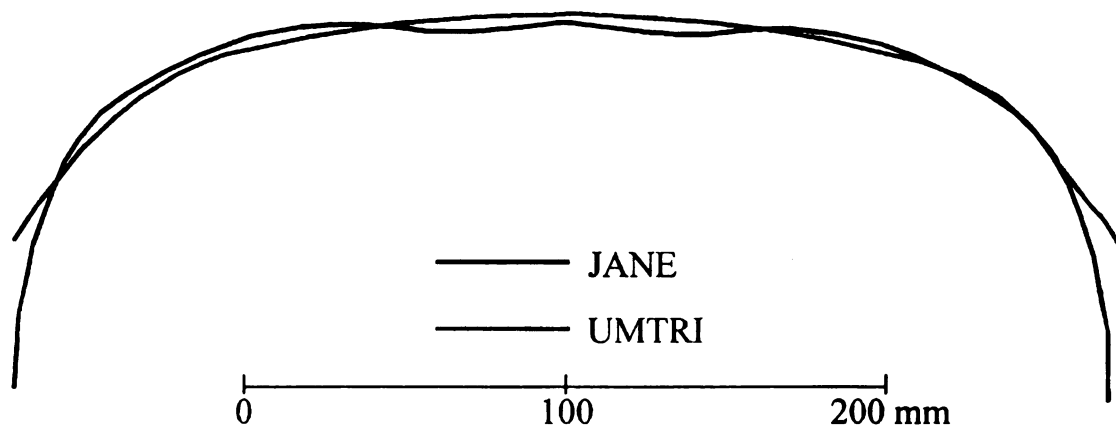


Figure B2 Eighth Thoracic (T8) Cross-Section

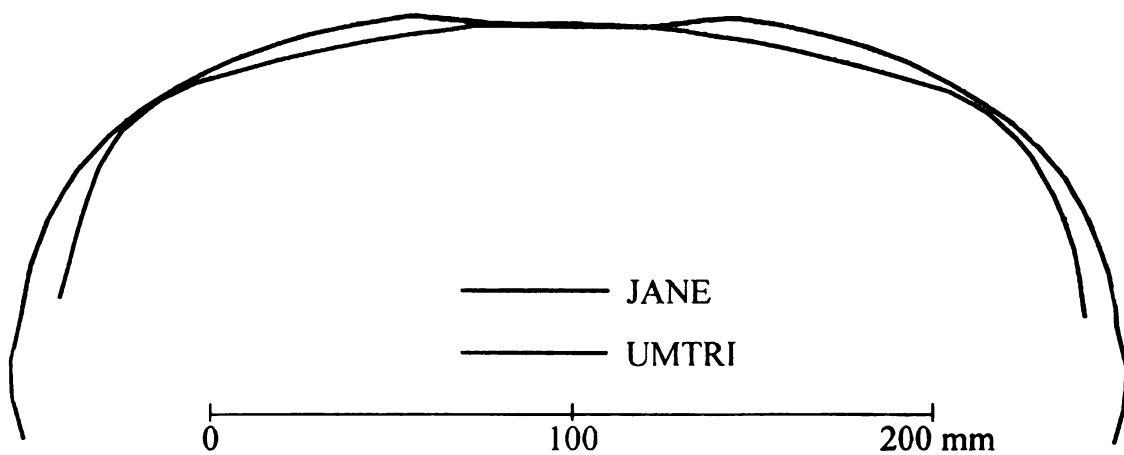


Figure B3 Twelfth Thoracic (T12) Cross-Section

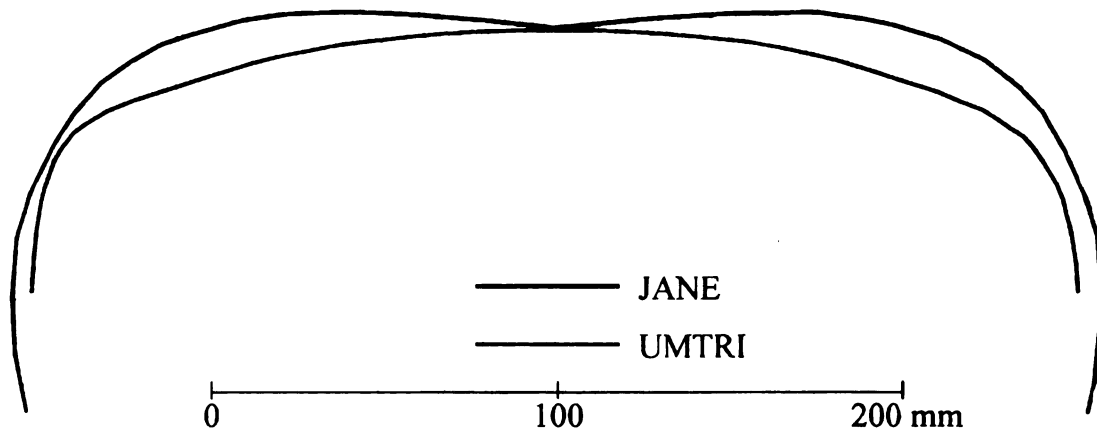


Figure B4 Fifth Lumbar (L5) Cross-Section

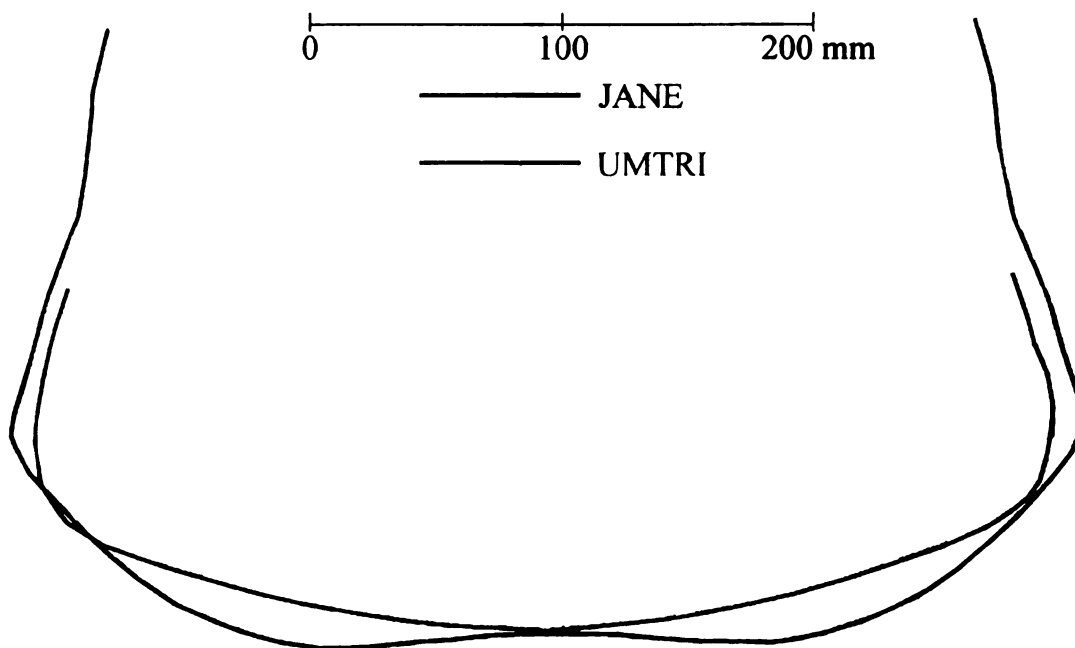


Figure B5 Second Lower Buttock (LB2) Cross-Section

## **APPENDIX C**

APPENDIX C

Cross-Sections of JERRY

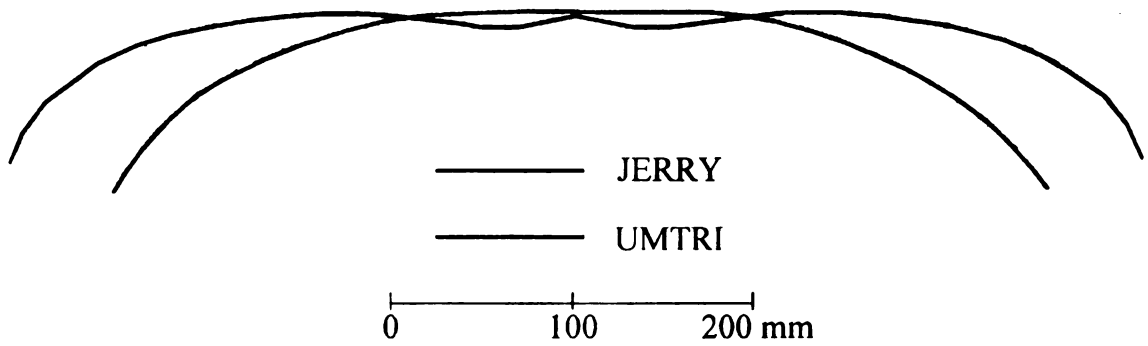


Figure C1 Fourth Thoracic (T4) Cross-Section

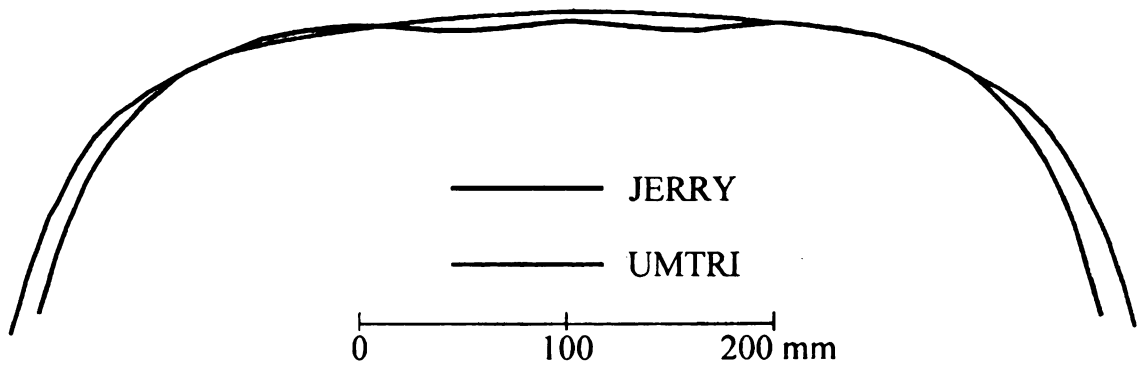


Figure C2 Eighth Thoracic (T8) Cross-Section

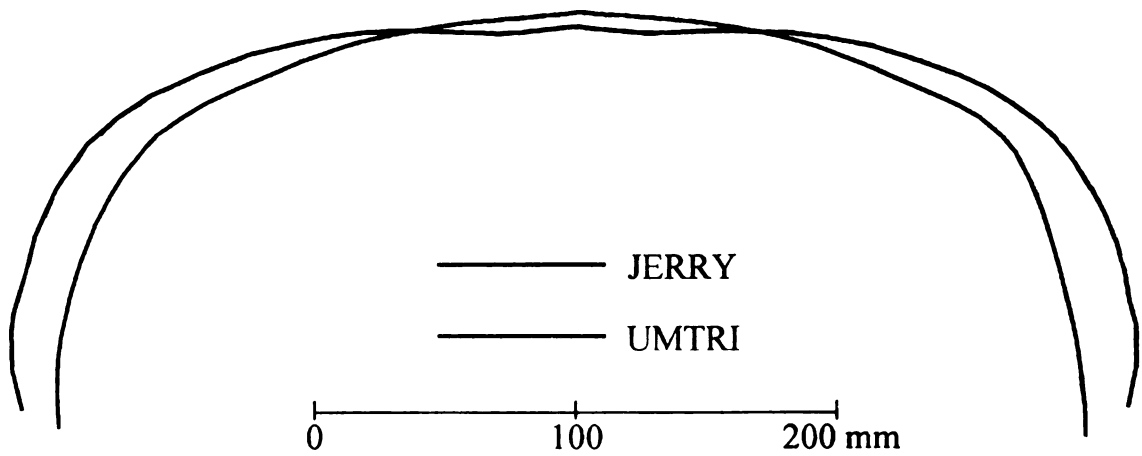


Figure C3 Twelfth Thoracic (T12) Cross-Section

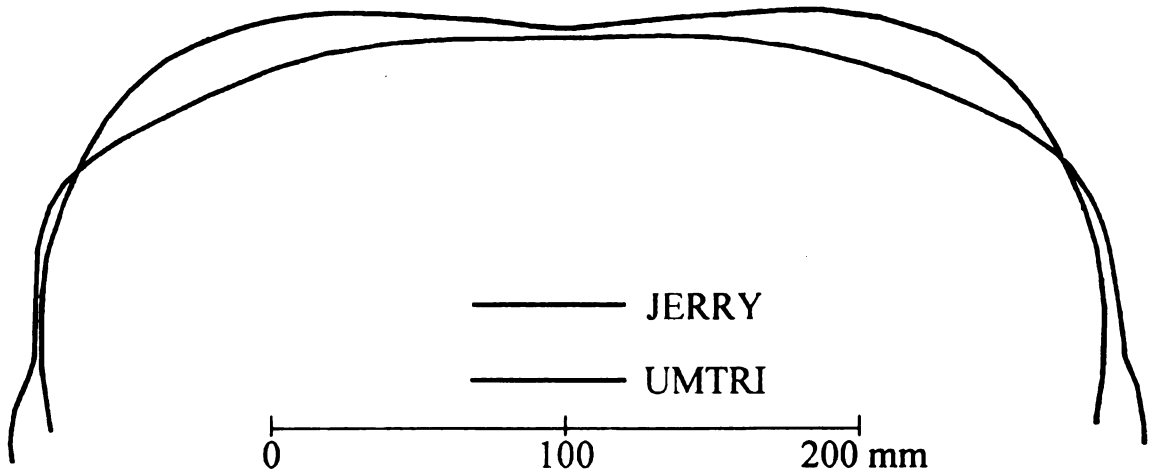


Figure C4 Fifth Lumbar (L5) Cross-Section

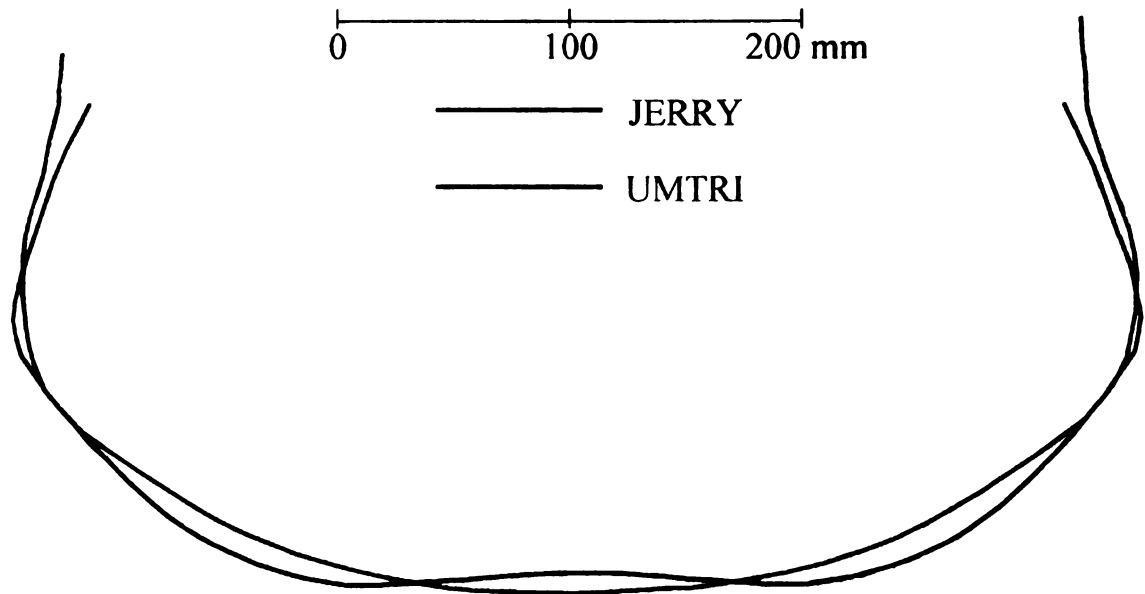


Figure C5 Second Lower Buttock (LB2) Cross-Section

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