Effects of Driver Attributes on Lower Abdomen Contour

Matthew P. Reed, Byoung-Keon Park, Jason J. Hallman

Abstract Previous studies have documented increased injury risks for high-body mass index (BMI) and older drivers in frontal crashes. Laboratory studies have shown that age and particularly high BMI is associated with poorer lap belt fit. This study used three-dimensional body scan data to examine the contour of the lower abdomen in the area in front of the pelvis. Laser scan data from 89 men and 94 women in an automotive posture were used to calculate a contour spanning the area between the anterior-superior iliac spine landmarks. The analysis showed the contour length was strongly associated with BMI and weakly with age. High-BMI drivers had up to 3 times greater contour length. These results suggest that even with optimal lap belt routing high-BMI drivers will interact differently with the lap portion of the belt than lower BMI individuals.

Keywords safety belt fit, body shape

I. INTRODUCTION

Previous studies have documented that age and high BMI, calculated as body weight in kg divided by stature in meters squared, is associated with an increased risk of lower-extremity injuries in frontal crashes [1-5]. Some of the increase in risk may be due to the relatively poor belt fit experienced by drivers with high BMI [5,6]. A previous study documented that the length of lap belt webbing used by drivers with higher BMI was larger than for those with lower BMI, and the lap belt was routed higher and more forward for those with high BMI and increased age [7]. The current study used three-dimensional body shape data to examine the contour of the lower abdomen and to determine the extent to which the abdomen shape affects the amount of belt webbing required to span the pelvis.

II. METHODS

Three-Dimensional Body Shape Data

Laser scans of 89 men and 94 women wearing minimal clothing consisting of tight-fitting shirt and shorts in an automotive posture were captured using a VITUS XXL laser scanner. Their stature ranged from 1435 to 1965 mm, greater than the range from 5th-percentile female to 95th percentile male for the U.S. population [8]. BMI ranged from 17 to 49 kg/m^2, and age ranged from 20 to 95 years. A custom apparatus was used to support the posture that allowed maximum access for the scanner, which captured an average of about 500k surface points for each scan. Because the automotive posture extended beyond the scanning volume, the test seat was designed so that the subject could be moved without changing posture. The subject's posture was carefully controlled by fixing the seat back and seat pan angles and setting the limb postures using goniometers and a level. Two scans were taken, each requiring about 12 seconds, separated by about 20 seconds. Subjects breathed normally during the scans. The two scans were merged and holes were filled using Poisson reconstruction in Meshlab (meshlab.org). A total of 93 body landmarks were manually digitized in the scan data and the surface landmarks were used to estimate internal joint center locations [9]. A template mesh with 18271 vertices was fit to each scan using a two-step method [10]. First, a radial-basis-function morphing method was used to morph the template to match the scan at the landmark locations. Second, an implicit surface method was used to move the template vertices into the surface defined by the scan data.

Lower Abdomen Contour

Because previous work showed that lap belt fit was worse for older occupants and particularly for those with higher BMI [6, 7], the current analysis focused on the lower abdomen where the lap belt is routed. To quantify the differences in abdomen contour associated with driver attributes, the length of a contour extending across the lower abdomen was computed. The landmarks calculated for each scan included the anterior-superior iliac spine (ASIS) landmarks on the bone. The point on the surface lateral to each ASIS bone

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point was computed and a contour was generated across the anterior abdomen through the omphalion (navel) landmark. Figure 1 shows abdomen contours for a range of occupant sizes. The contour length was analyzed relative to gender, stature, BMI, and age.

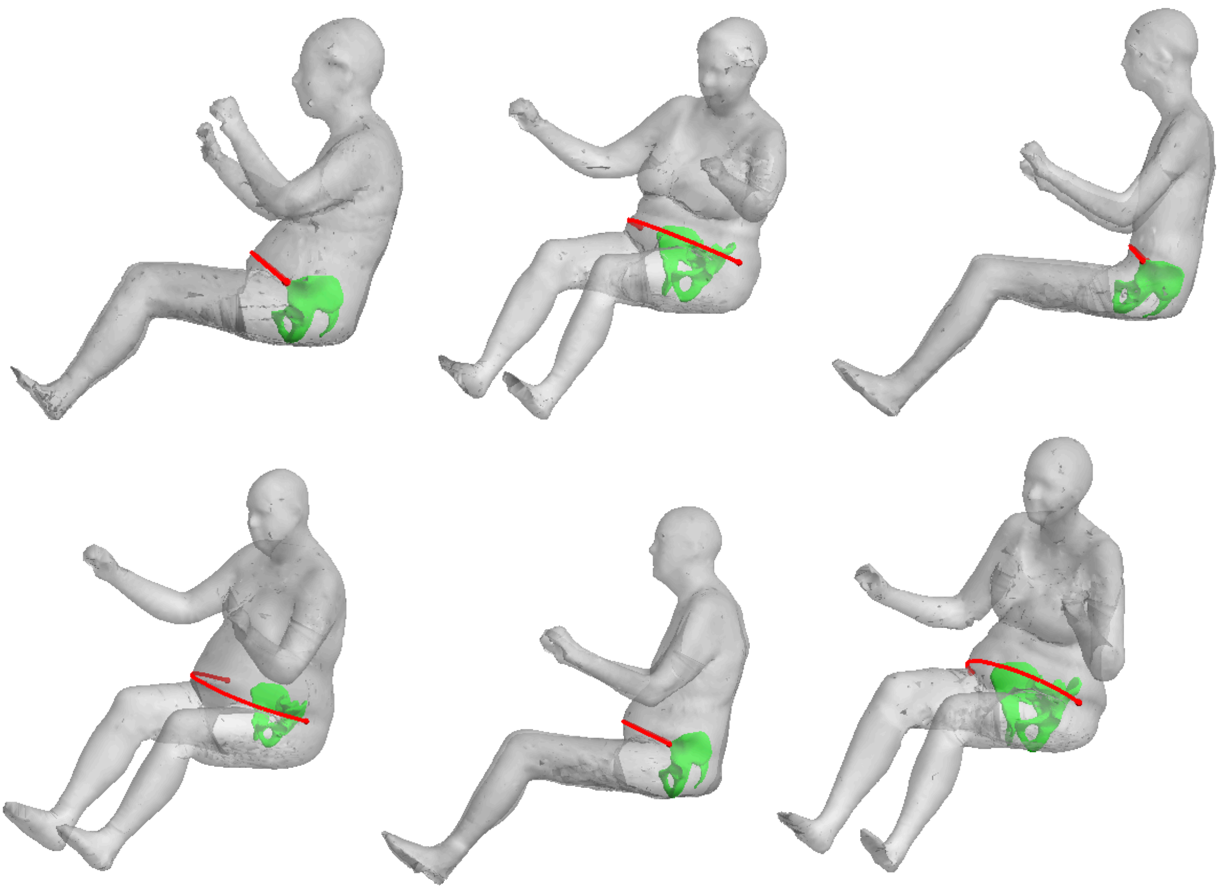

Figure 1. Abdomen contours with reconstructed pelvis estimates shown.

III. RESULTS

Stature had minimal effect on the abdomen contour length, but BMI had a strong effect that was similar for men and women. Figure 2 shows that men and women with approximately 5th percentile BMI have a contour length of about 250 mm. The contour length more than doubles to about 650 mm for drivers with a BMI of 40 kg/m^2, which is approximately the 95th percentile BMI for U.S. adults. For BMI > 30 there is considerable scatter in the data, reflecting differences in body shape. For example, young women with BMI near 30 tend to have much smaller abdomen contour lengths than elderly men with the same BMI. Figure 3 demonstrates that age has a smaller effect than BMI, but at age 80 the contour length is approximately 70 mm larger than at age 20 for people with BMI less than 30. Higher-BMI drivers do not show a trend with age. Figure 4 shows this trend with BMI on the horizontal axis, demonstrating that the effect of BMI is much larger than that of age.

A linear regression analysis was conducted with gender, stature, age, and BMI and their two-way interactions as potential predictors. Only the main effects of age and BMI were significant ($p<0.01$):

$$\text{Contour Length (mm)} = -149 + 1.27*\text{Age} + 20.5\ \text{BMI},\ R^2\text{adj} = 0.75,\ \text{RMSE} = 65.2\ \text{mm} \quad (1)$$

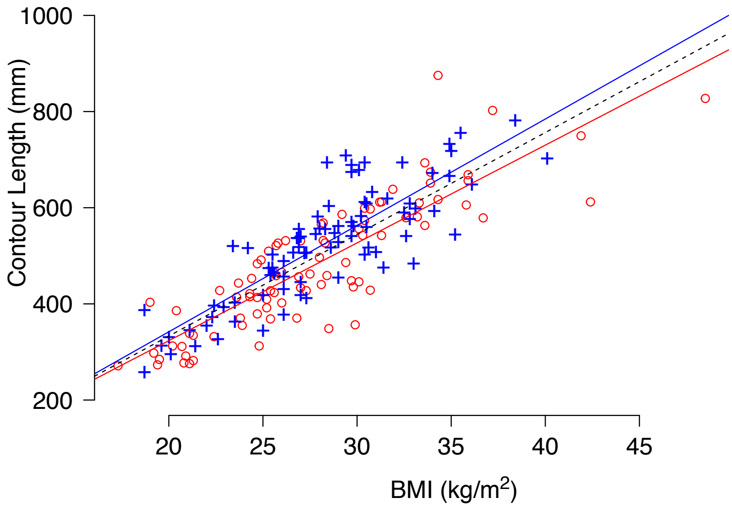

Figure 2. Abdomen contour length for men (+) and women (o) as a function of BMI.

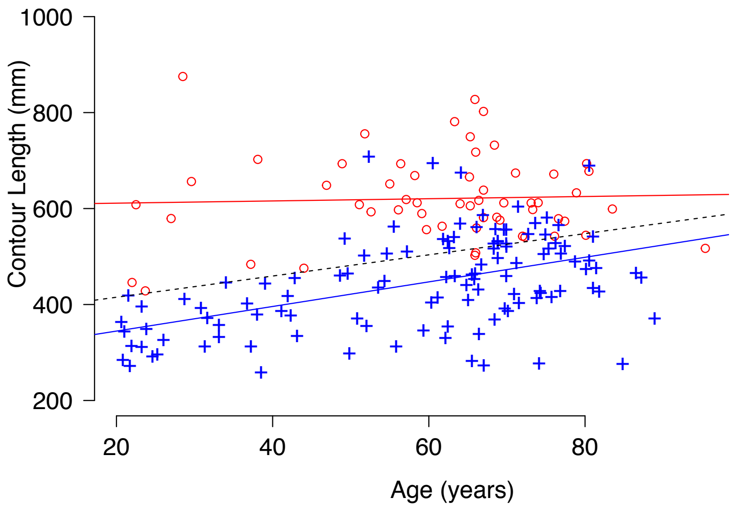

Figure 3. Abdomen contour length for BMI ≤ 30 (+) and BMI >30 (o) as a function of age.

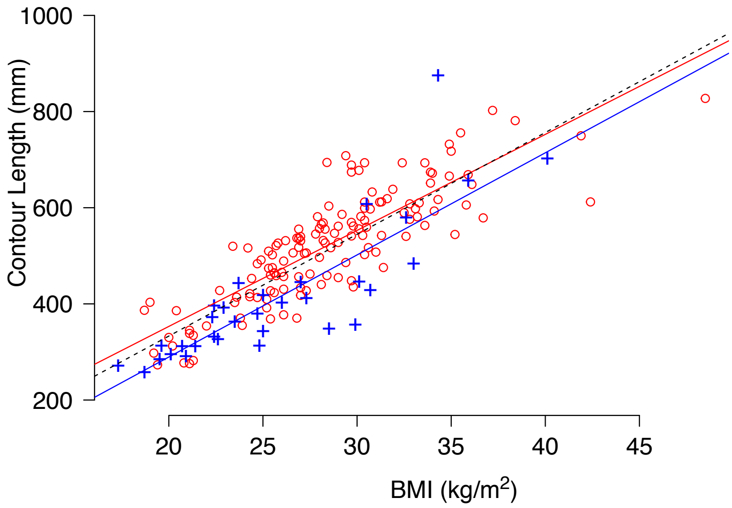

Figure 4. Abdomen contour length for age ≤ 40 years (+) and age >40 years (o) as a function of BMI.

IV. Discussion

This analysis demonstrated that increased age and BMI are associated with a larger lower abdomen contour across the front of the pelvis. Even with ideal belt routing at the thigh/abdomen junction, this greater volume of soft tissue means that there is additional belt slack that must be taken up by a pretensioner or by occupant translation before substantial restraint force can be applied to the pelvis.

The analysis is believed to be the first to use 3D body shape data to consider the belt interaction in this area. However, the findings are limited by several issues. The posture measured in the scanner is similar but not identical to any individual's driving posture. Posture differences could change the shape of the lower abdomen. The determination of the contour length is affected by the calculated pelvis locations. Because high BMI makes locating the pelvis difficult [7] the uncertainty in contour length is greater for individuals with high BMI. The actual belt placement relative to the abdomen is variable [7], so these contour lengths are probably close to a best-case scenario for a belt placed low on the pelvis, just above the thighs. However, an individual could choose to tighten the belt, displacing some tissue and reducing the additional belt length spanning the pelvis. The contour chosen programmatically in this analysis might not follow the belt path. In particular, because the contour starts at the height of the ASIS, the contour is generally flatter than an ideal belt path, which would pass more vertically over the proximal thighs rather than more horizontally over the lower abdomen. However, the analysis quantifies the challenge posed by protuberant lower abdomens.

Clothing can be expected to affect the belt routing. The thin shorts worn for this study minimized clothing bulk, but elastic in the material may have changed the shape of the soft tissue. Clothing effects should be studied further, including the effects of outer garments such as coats worn in cold weather.

Further work is needed to assess the consequences of belt routing for high-BMI individuals. Studies with post-mortem human subjects [3] and finite-element models [11, 12] suggest that the displacement of the lap belt path away from the bony pelvis creates adverse kinematics in frontal crashes and increases the risk of belt loading of the abdomen and lower extremity injury due to more forceful interaction with the knee bolster. Countermeasures might include improved belt systems and knee bolsters capable of managing greater energy. Computational modeling of obese occupants will be aided by accurate belt routing based on laboratory and in-vehicle measurements. The current analyses show that lower abdomen volume and contour will be a critical determinant of belt webbing length.

V. Conclusions

Increased BMI is associated with a larger lower abdomen that can greatly increase the length of the belt path across the front of the pelvis. Because the underlying tissue must be displaced before substantial restraint forces can be applied to the pelvis, the extra belt webbing required to span the abdomen represents slack that must be taken up by the pretensioner and occupant translation. For some high-BMI men, an additional 350 mm of slack must be removed by displacing soft tissue to allow the belt to engage the pelvis.

VI. ACKNOWLEDGEMENT

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