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A New Methodology for Investigating Airbag Induced Skin Abrasions

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ABSTRACT

Although airbags have been shown to reduce the incidence of life threatening injuries, they have increased the risk of minor injuries such as those to the skin. Based on the distribution of injuries that can be directly attributed to the airbag itself, it is believed that shear loading exists as a mechanism for these skin injuries. The purpose of this study was to develop a new methodology designed to assess the injury potential from different types of airbags with respect to shear loading. This new methodology utilized a high-speed impactor to accelerate the airbag fabric past a sample of skin. Contact normal forces were monitored by the use of pressure sensors, and fabric velocity was determined from high-speed video. The abraded skin samples were analyzed using light microscopic analysis and ultraviolet light source photography. A new abrasion rating method was developed called the Total Abrasion Score (TAS), which allows for quantifiable differentiation between the abrasions caused by different airbag fabric and seam types.

INTRODUCTION

Although airbags have been shown to reduce the incidence of life threatening injuries, they have increased the risk of minor injuries such as those to the skin (Dalmotas et al., 1995, Foley and Mallory, 1995, and Foley and Helm, 2000). A study of the National Automobile Sampling System (NASS) found that 66% of front seat occupants exposed to an airbag deployment incur a skin injury, 47 % of these injuries are attributed directly to the airbag itself (Jernigan, 2001). Of these injuries, 41% occur to the face (Cocke, 1992, Duma et al. 1996, Murphy et al., 2000, Rozner, 1996, Smally et al., 1992, and Smock and Nichols, 1995), 3% occur to the neck (Hansen et al., 1999, Morrison et al., 1998, and Steinmann et al., 1992). 11% occur to the chest and abdomen (Beckerman and Sama, 1995), 42% occur to the upper extremities (Freedman et al., 1995, Huelke et al., 1995, Burton, 1994, and Molia and Stroh, 1996), and 2% occur to the lower extremities

(Weinman, 1995). While these skin injuries may not be life threatening, nearly 300,000 occupants incur an airbag induced skin injury every year in the U.S. Because this number is so large, there is considerable motivation for investigating the possibility of airbag cushion modification in order to reduce the risk of skin injury.

Early research done by Kikuch showed that injury severity is directly proportional to the total pressure exerted onto the skin by an airbag (Kikuch et al., 1975). This was found by deploying airbags onto the shaved regions of rabbit heads; however, no specific injury criterion was recommended. Reed performed studies on human volunteers to elucidate the potential for skin abrasion caused by airbag deployment (Reed et al., 1992). The volunteers exposed the front of their lower leg to a deploying airbag. The magnitude of the pressure exerted onto the volunteers by the airbag was determined using an instrumented leg-form placed in the same position as the volunteer's leg to insure they would be exposed to similar pressures. The response time of the load cells used on the instrumented leg form were too slow to capture the event; therefore, Reed utilized Fuji pressure film to record the resulting pressure. Reed concluded that normal loading alone, as measured by the pressure film, induced enough pressure to cause skin abrasions. Two forms of skin abrasion injury criteria were presented: peak pressure from the Fuji film of 1.75 MPa (2490 psi), or a peak leading edge airbag velocity of 85 m/s (190 mph). Reed also established a method for utilizing these injury criteria by placing Fuji Pressure Film on the surface of a PVC pipe that was exposed to an airbag deployment in a test configuration that assumed a normal loading injury mechanism (Reed et al., 1993). Sugimoto utilized a similar test configuration, but recommended a slightly lower peak velocity criterion on 70 m/s (157 mph) (Sugimoto et al., 1994).

The purpose of the current study is to develop a new methodology for comparing skin abrasions caused by different airbag fabric and seam types due to shear loading. While the previous work by Reed presents an injury criterion for normal pressure alone, it does not characterize all types of airbag loading. In particular, the type of loading that would occur in the region of the airbag seam should be tested and evaluated. It is suggested that there are two general injury mechanisms for airbag induced skin injuries: normal pressure from perpendicular contact of the airbag with the face and thoracic areas, and shear loading as the airbag expands and interacts with the upper extremities (Figure 1). The purpose of this paper is to develop a new methodology for comparing abrasions caused by different airbag fabric and seam types with respect to shear loading.

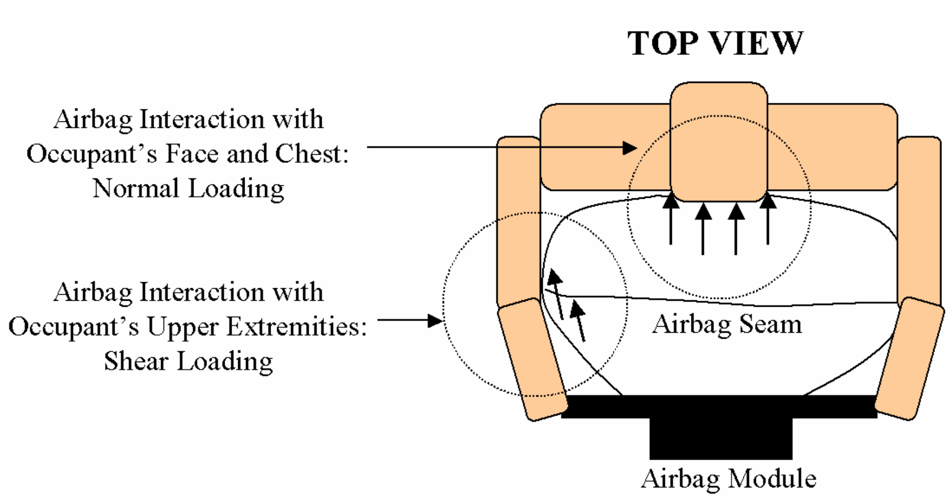


Figure 1: Two proposed injury mechanisms for airbag induced skin abrasions: normal loading of the face and chest versus shear loading of the upper extremities.

METHODS

Previous research done by Reed found that airbag velocities above 85 m/s (190 mph) resulted in skin abrasions for normal loading (Reed et al., 1992). Based on this criterion, the target fabric velocity for the current study was established at 89 m/s (200 mph). The experimental setup was designed to accelerate the airbag fabric to this velocity as it based below a tissue sample (Figure 2). The skin mount assembly held the skin in place and contained the necessary instrumentation to allow for contact pressure measurements. A pneumatic impactor fired an aluminum projectile that struck the airbag fabric mount in order to achieve the required velocity for the tests.

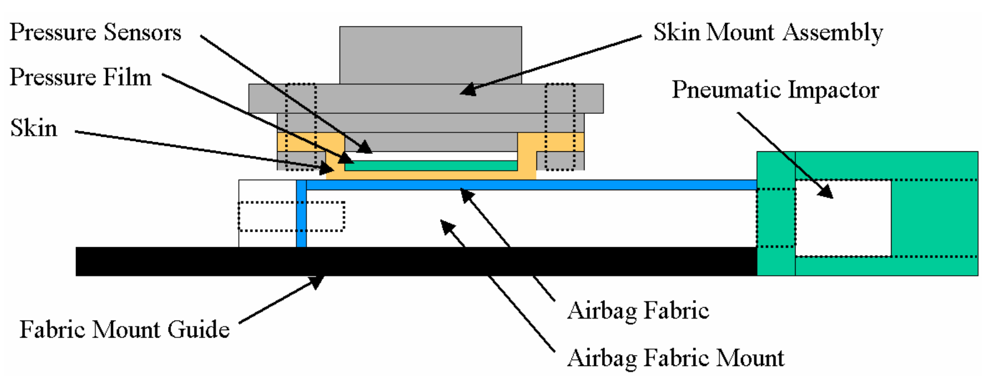


Figure 2: Orientation of skin and airbag material for abrasion testing.

A pneumatic impactor was used to accelerate the fabric mount up to the target velocity of 89 m/s (Figure 3). This was accomplished by accelerating an aluminum slug down the impactor barrel using compressed air stored in the air tank. The skin tester assembly was mounted on linear bearings, which allowed the skin tester to translate in order to absorb the recoil induced by the slug (Figure 2).

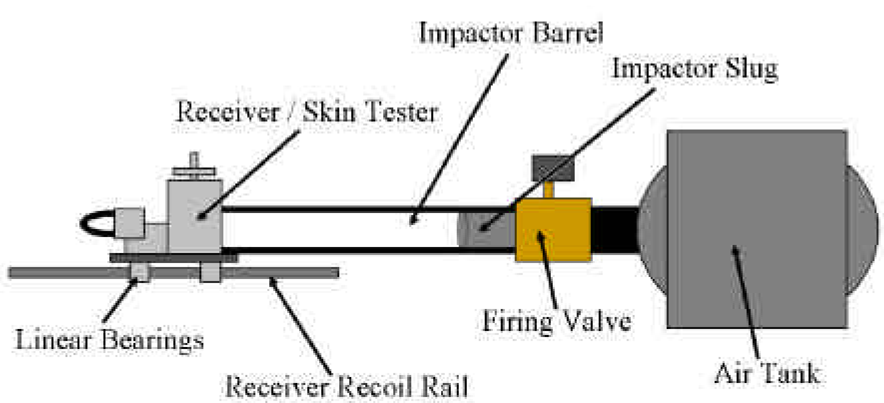


Figure 3: Pneumatic impactor used to achieve a relative velocity between the skin and airbag fabric of 200 mph.

Eight different airbag fabric and seam types were obtained and prepared by cutting into a rectangular shape and mounting to a polycarbonate plate, or fabric mount (Figure 3). The mounting was such that the fabric was held in tension along all four directions. The airbag fabric was attached to the fabric mount and positioned for testing. A control test was also performed using the fabric mount without fabric attached to it.

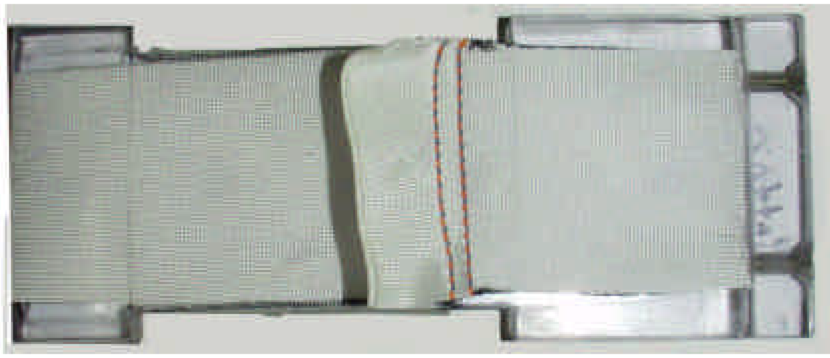
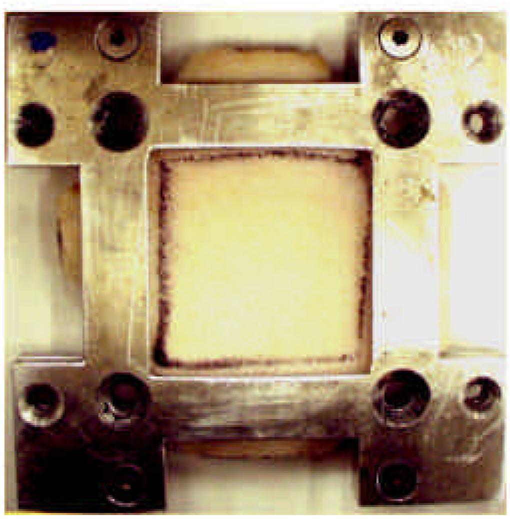
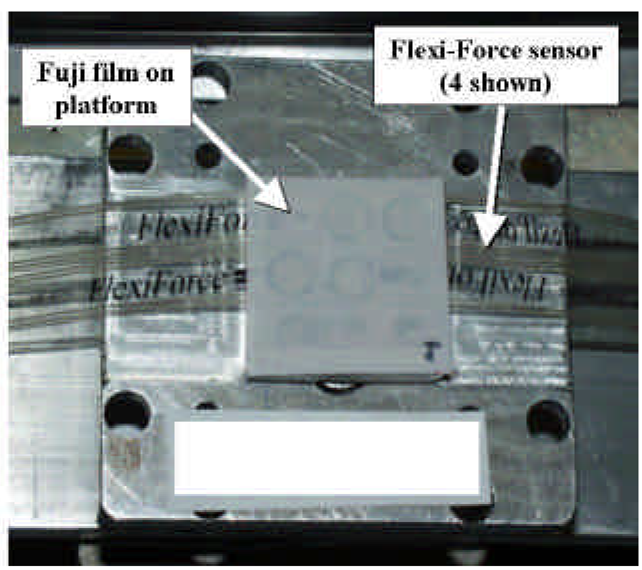


Figure 4: Polycarbonate block with fabric ready for testing.

Porcine skin tissue was used because of its scheduled post-mortem availability. A comparative study was performed between human cadaveric tissues and the porcine specimens to compare the thickness of the different layers of the skin. Before the skin tissue was removed from the porcine subjects, square outlines were made on the skin with the inside dimensions of the clamping bracket. This made it possible to apply pretension to the skin back into its original biaxial state of stress once inside the aluminum bracket (Figure 5a). Once the tissue was secured in the aluminum bracket, the assembly was mounted to the tissue stage. The tissue stage was prepared with Fuji film sheets (Medium Fujifilm Prescale Mono Sheet Type, Fuji Photo Film, Tokyo, Japan) and Flexi-Force pressure sensors (FlexiForce A101 100lb, Tekscan, South Boston, MA)(Figure 5b). A total of four sensors were used, each with a sensing diameter of 9.5 mm.





a) b)

Figure 5: a) Skin mount bracket with tissue sample in place. b) Tissue stage with sensors installed.

During testing, data acquisition and high speed video was used to capture the event. The data acquisition system was configured to record the pressure exerted on the skin by the airbag seam and sampled at a frequency of 28.4 kHz. High-speed digital video (Phantom IV, Vision Research, Wayne, NJ) was used to capture the motion of the fabric mount at 7,100 frames per second. This frame rate allowed sufficient resolution of the fabric block in motion to facilitate velocity calculations and track the event.

After each test the tissue was removed and post-test photos were taken. Visual examination of the skin and fabric was facilitated using an ultraviolet light source and orange filters. The black light caused the dermis to fluoresce. The appearance of this fluorescence was more apparent in the skin samples with a higher degree of abrasion. In cases where the abrasion was significant, the use of an orange filter increased the contrast between the exposed dermis and the remaining skin. Based on visually determining which section received the highest degree of abrasion, three sections of skin were removed for histology purposes.

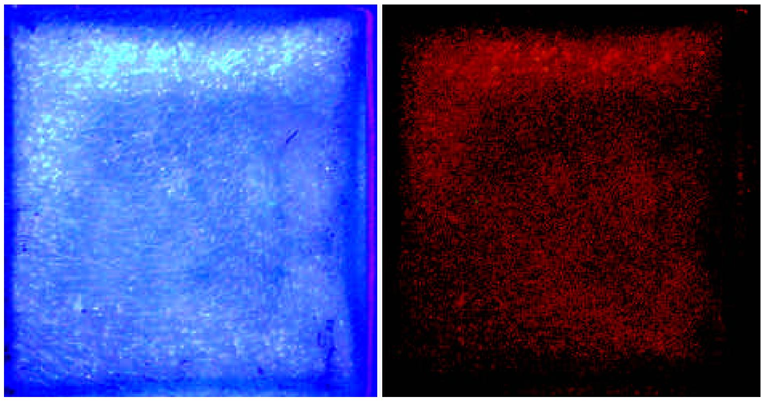
RESULTS

The data gathered during the experiments were used to investigate the effects of normal pressure and velocity on skin abrasions in the shear loading condition. The maximum average velocity observed during the tests was 95 m/s (213 mph), with an overall average velocity of 84.8 m/s (190 mph). The maximum peak pressure observed was 2.95 MPa (427 psi), with an average peak pressure of 1.83 MPa (265 psi). The histology analysis showed that all tests resulted in abrasions with the exception of the control tests. The abrasions varied from a slight removal of the epidermis, to a partial removal of the dermis. In no instance did the abrasion remove the full thickness of the dermis (Table 1).

Table 1. Summary of Testing Results

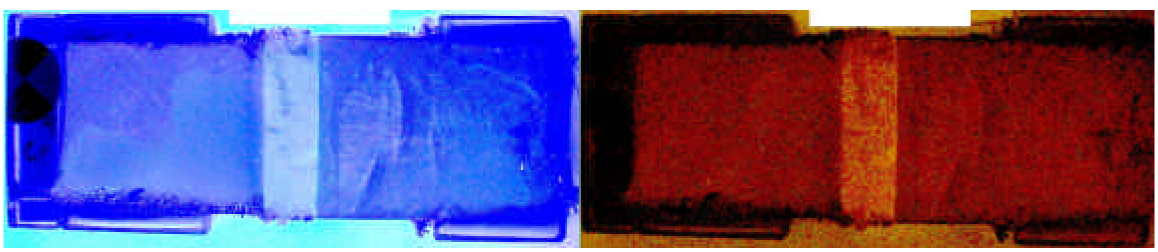
Airbag Fabric / Seam Type	Average Velocity (m/s)	Peak Pressure (MPa)	Average ARS score	Average Max WARS Score	TAS
0 – control	89.0	1.51	0	0	0
1	95.0	2.95	1.17	2.33	18.0
2	76.0	0.80	1.67	2.00	14.5
3	84.0	1.88	2.50	2.00	27.0
4	86.0	1.50	3.00	2.50	33.5
5	82.0	1.62	2.00	3.00	18.0
6	79.0	1.80	3.83	1.33	32.5
7	89.0	1.89	1.83	1.00	9.00
8	83.0	2.56	2.00	2.00	16.0

The ultraviolet light digital images were examined for exposed areas of the dermis (Figure 6a). The same technique was used for the fabric samples to determine the areas where the dermis transferred to the material (Figure 7a). An orange filter was also used on both the skin samples and the fabric samples to increase the contrast of the dermis for further evaluation (Figure 6b and Figure 7b).



a) b)

Figure 6: a) Ultraviolet light image of an abraded skin sample.
b) Orange-filtered ultraviolet light image of the same sample.



a) b)

Figure 7: a) Ultraviolet light image of a mounted fabric sample.
b) Orange-filtered ultraviolet light image of the same sample.

Abrasion Scoring Methodology

To facilitate the analysis of the histology slides, an abrasion scoring method was developed. This scoring criterion incorporates both the depth of abrasion and the width of abrasion. Reed developed the Abrasion Rating System (ARS) that was used to indicate the severity of skin abrasion as a function of depth (Reed et al., 1992). The system breaks the depth of injury into five categories ranging from partially through the epidermis (ARS = 1), to completely though the dermis (ARS = 5). These values were obtained by light microscopic analysis of the histological samples. The Width of Abrasion Rating System (WARS) was employed to relay the severity of the width of abrasion, as a percent of the total width of the skin specimen. This system breaks the width injury into three categories: WARS = 1 for less than 25%, WARS = 2 for 25% to 75%, and WARS = 3 for greater than 75%. The Combined Abrasion Rating System (CARS) score combines both rating systems to give a score that is representative of the area of tissue removed (Figure 8).

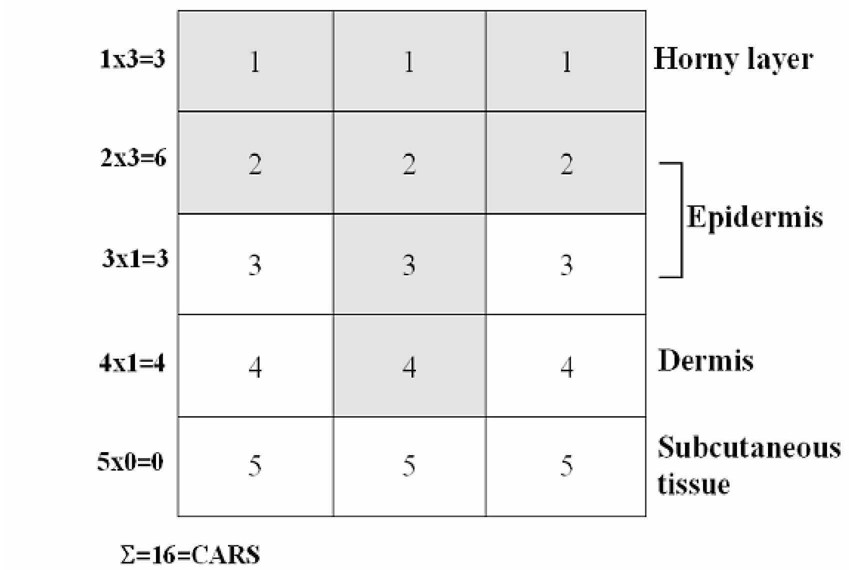
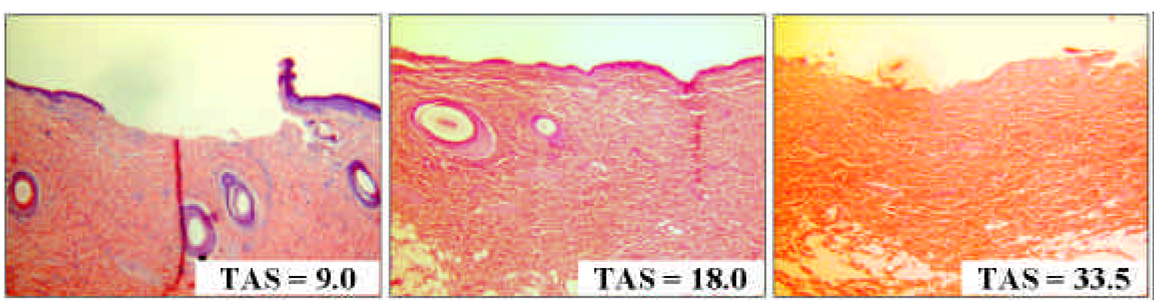


Figure 8: Example of a CARS score for a skin section. The number in each box represents the ARS score for that particular section. Each section represents a WARS score of 1.

After averaging the two scores from each section, the resulting three scores were added to produce the Total Abrasion Score (TAS) for that test (Figure 9). The TAS score is a relation to the volume of skin that was removed for a particular test. However, this volume relation is weighted on the depth of the abrasion. This yielded a more precise indication of the severity of the abrasion caused during that test. This is more realistic due to the effect of depth on pain and time required for the wound to heal.



a) b) c)

Figure 9: Histological comparison between three different tests using the Total Abrasion Score (TAS).

a) TAS = 9.0, Average Maximum ARS = 1.83, Average Maximum WARS = 1.
b) TAS = 18.0, Average Maximum ARS = 2, Average Maximum WARS = 3.
c) TAS = 33.5, Average Maximum ARS = 3, Average Maximum WARS = 2.5.

CONCLUSIONS

The analysis of the results obtained from these tests show that it is possible to measure the effects of different airbag fabric and seam designs on the level of skin abrasion with respect to shear loading. The variety of airbag fabric designs used during these tests indicate that any type of airbag fabric is capable of producing some type of abrasion, although in some cases this is limited to a partial removal of the epidermis. The most severe abrasions induced during these test were limited to the dermal layer, while no abrasion removed the full thickness of the dermis.

The development of the Abrasion Rating System (ARS), the Width Abrasion Rating System (WARS), and Total Abrasion Score (TAS) proved beneficial in the quantification of the overall severity of skin abrasions caused by different airbag fabric and seam types. The TAS score yields a volume relation to the abraded region that is weighted on depth of the abrasion. Weighing the TAS score more heavily on depth provides a better description of abrasion severity on a human subject.

This new methodology utilizes active pressure sensors for monitoring contact normal pressure in real time. By using ultraviolet light photographic techniques, abrasions, which expose the dermis, may be located on the skin sample as well as the airbag fabric. The combination of these techniques allows for the direct comparison of airbag construction types on the risk of skin abrasion.

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DISCUSSION

PAPER: **A New Methodology for Investigating Airbag-Induced Skin Abrasions**

PRESENTER: ***William Hurst, Virginia Tech***

QUESTION: *John*
Just one question on maybe the difference in your--differences in pressure. Fuji film is notoriously inaccurate when subjected to sheer. Did you do anything to try and isolate it so that it didn't get tractions because it'll just burst if there's any sheer?

ANSWER: Well, that was one of the reasons why–We had to the Fuji film on there, and primarily the reason we had that was more for a map. The values that we got from the Fuji film were comparable to the ones that we got from the pressure sensors, but those values that I indicated were actually from the pressure sensors, not from the Fuji film.

Q: How much pressure was behind the fabric when it made contact with the skin?

A: I'm not sure right off the top of my mind.

Q: Because you're–It would seem to me that this would be much different than the type of pressures that are behind in an airbag. You might have either higher velocities with lower pressures.

A: True.

Q: Or lower pressures and higher velocities depending on who it was which would have some, would definitely have difference on how well–how much it penetrates into the skin.

A: Well, the reason why we did this research was primarily looking at differences in seam and fabric designs. So if we were actually going to state–"This particular of airbag gives this type of injury," that is something that we would have to verify. We would have to make sure that we had the amount of contact pressure that we should expect. Basically, looking at the results that we got from our testing, we were able to differentiate between the different fabric and seam types, and that was the real goal of this research. But, you're right. We would have to look into that further to actually come up with an actual quantity that tells us how much the skin injury would actually be.

Q: And you need some sort of equivalence because this may show you, under these conditions, what the different materials do. Under different conditions, you could end up with a different result.

A: Yes, I agree with that.

Q: Thank you.

Q: *Larry Schneider, University of Michigan*
Just to clarify: The Reed Study. When we did this, we started out thinking this must be sheer abrasion type of activity that would cause these injuries. And in fact, what we found out was deploying airbags of various types of folds into the legs of humans and some, of course, some subjects, that it wasn't sheer and that we couldn't–Sheer–Or, abrasion was not sufficient, but it was a normally-directed force. That was sufficient, and you could have some sheering action going on to remove the skin cells that were knocked off by the normally-directed force. But, the scraping action of the fabric was not sufficient under these deployment conditions to cause

the abrasions. So, in fact, you get a lot of abrasion or abrasion action on a lot of the skin that isn't–that doesn't experience any, any injury. So, we turned the Fuji film inside out, of course, and, to eliminate that problem of the Fuji film being sensitive to the sheering action. So, we were simply measuring the normally-directed force.

But you know, we looked at the real world, too, and saw these injuries and thought, "Well, they must be scraping type of action." So, I don't think the assumption that you're seeing them on the arms means that they must be scraping. I think you have to see what your laboratory tests show in terms of, you know, what is actually causing these; and, we only saw these where the hot–where they were high-peak pressures where the seams were contacting, and we got very repeatable, you know, comparable patterns in our Fuji film, high-peak pressures to the injuries that we produced.

So, in fact, we found that there was no difference in the abrasions that we could produce in humans or in pigs with different denier fabrics–840 or 420 denier. In fact, the 420 denier sometimes would produce more significant abrasions because it was, had a higher velocity and had a higher normally-directed force.

A: Well, the one thing that we looked at in our results was the fact that we did have pressures that were so low. And basically, the, because of the fabric and the seams that we're looking at, we just felt by looking at it–because we did look quite extensively to the work that Reed did. And basically, we just felt that for the seam design, it seemed like we would want to look at the sheer component more while still having normal component. But, that's one thing. If we actually did want to develop–as was stated earlier–If we did actually want to truly quantify it, saying how much injury there would be, yes. We would have to take into account the normal component more. But since we're just doing a comparative study between different types, we felt that the set-up that we used was adequate.

Q: What were the fabrics that you were using, the deniers? What was your?

A: I don't remember specifically because I actually only worked on part of this, but I kind of worked on this off-shoot. So–As far as–I just focused more on the methodology for this.

Q: So, you're obviously showing you can produce these abrasions under these velocities, but the question is: Is that what's really causing them, even though it's the arm or the face or the neck? I'm not sure that's what's going on with the deployments of airbags. Thank you.