4

INJURY BIOMECHANICS RESEARCH
Proceedings of the Thirty-Second International Workshop

Potential Applications (and Limitations) of 3D Imaging Data from Human Crash Subjects for Biomechanical Research

S. C. Wang, MD Ph.D, A. Lange, C. Poster, C. Brede, and D. Lange

This paper has not been screened for accuracy nor refereed by any body of scientific peers and should not be referenced in the open literature.

ABSTRACT

Most studies investigating the biomechanics of injury are limited by a paucity of data about the physical characteristics of the subject before the injury occurred. This is particularly the case with live human subjects from real-life cases, where little data except age, gender, height and weight have been available to date. With regard to the injuries themselves, previously available data has generally been descriptive and of insufficient granularity and anatomic specificity to provide insight into the path of force loading through the surrounding tissues or the mechanism of injury. Three-dimensional medical imaging has recently become part of the standard evaluation of injured subjects and a growing pool of this data is becoming available to the biomechanical research community. When reviewed in conjunction with detailed crash and vehicle information, this data can provide invaluable information regarding the baseline physical characteristics that may have affected the subject's injury tolerance as well as insight into injury mechanism. Taken out of the proper context or with improper image processing, portions of this imaging data can be misleading.

The objective of this study is to review changes in medical imaging technology over the past two decades as well as changes in its utilization for the standard evaluation of injured patients. Analysis of 3D medical imaging data for biomechanical studies requires image data processing beyond that used during interpretation for clinical purposes; these processes will be reviewed so that members of the biomechanical research community can better understand the potential uses and limitations of this data. The argument will be made for the research community to adopt common standards and procedures. Individual case studies will demonstrate the conditions under which pre-injury body composition data can be extracted from post-injury 3D medical imaging data. Pooled data will demonstrate the association that exists between these body composition data and observed injury tolerance. The implications of this data for the design and validation of finite element models capable of accurately predicting body tolerances to injury will be discussed.

INTRODUCTION

Blunt trauma is a major cause of injury and motor vehicle crashes are the primary cause of blunt trauma in the industrialized world. A major challenge that faces medical professionals who care for blunt trauma patients is that, unlike penetrating trauma, there are usually no external marks or evidence overlying the area of internal injury. At the same time, there is an urgent need to diagnose all internal injuries so that potentially life-saving treatments can be initiated. As a result, medical professionals in the United States have come to rely more and more on the use of CT scans that can rapidly assess large segments of a subject's body and identify internal injuries.

Several decades ago, CT scanning for evaluation of blunt trauma patients was used most often to evaluate for possible intracranial injuries. During the 1990s, CT scanning of the abdomen and pelvis became the standard of care for hemodynamically stable subjects with a significant mechanism for injury (motor vehicle crash with vehicle intrusion, fall from height, struck pedestrian, etc.). Over the past several years, CT scanning of the neck and chest has become widely used for the initial evaluation of blunt trauma subjects. This progressive increase in the extent to which CT scanning is used for trauma evaluations has been fueled by a number of factors including the realization that many internal visceral injuries can be managed non-operatively once their severity has been assessed by CT. The greatly improved speed and quality of CT scanners, as well as their increased availability, have also contributed to their increasing use for trauma evaluations.

While CT scans are obtained because they provide so much valuable information to the clinician caring for the subject, they also contain tremendous amounts of information, generally ignored by the clinicians in the acute setting of trauma, which is valuable to individuals interested in the biomechanics of injury. Medical professionals take care of a large population of patients affected by different disease processes and as such are well aware of the huge influence that the patient's baseline condition has on the disease process and outcome. Engineers and regulators generally have very little information regarding crash occupants besides, age, sex, height and weight. They tend to work with standardized human surrogates, whether crash dummies or models that have been developed to respond to specific crash conditions in a predictable and reproducible fashion. As a result, the engineering and regulatory literature tends to focus on vehicle or crash factors as the most important determinants of crash outcome. Currently, with the widespread application of CT for trauma evaluations, we have a tremendous body of data about crash occupants. In most trauma centers, CT scanning is done after the initial evaluation and stabilization of the potentially injured subject. In most urban regions, motor vehicle crash occupants are transported to a trauma center within 30 to 40 minutes of the crash. It is standard of care in most trauma centers to have the patient in the CT scanner within 30 minutes of arrival. As such, most CT scans (imaging a large portion of the patient's body) are performed within 1 hour of the crash. The short time between injury and CT scanning limits the non-injury-specific changes that may take place in the subject's body as a result of their body's systemic response to trauma. These scans are therefore representative (except in unusual circumstances) of the baseline pre-injury condition of the subject's body. In addition to this information regarding baseline condition, CT scans offer much more detailed information regarding the exact extent and anatomic location of the injury than previously available. Furthermore, the spatial relationship between multiple injuries can now be appreciated as never before.

3D Imaging Data for Determination of Injury Mechanism

While it is helpful to know that a subject sustained rib fractures, pulmonary contusion, splenic injury, and pelvic fractures from a crash, the ability to see the exact location and extent of those injuries and how they relate spatially to each other provides far greater insight into injury causation mechanisms. Figure 1 shows vehicle photos and transverse CT images of a driver involved in a side impact crash with a tree. There was significant intrusion into the vehicle compartment. Examination of the transverse CT images taken through the lower chest, upper abdomen and pelvis, shows injuries localized to the left posterior quadrants of the body at all three levels, consistent with all those injuries being caused by the intruding door and B-pillar.

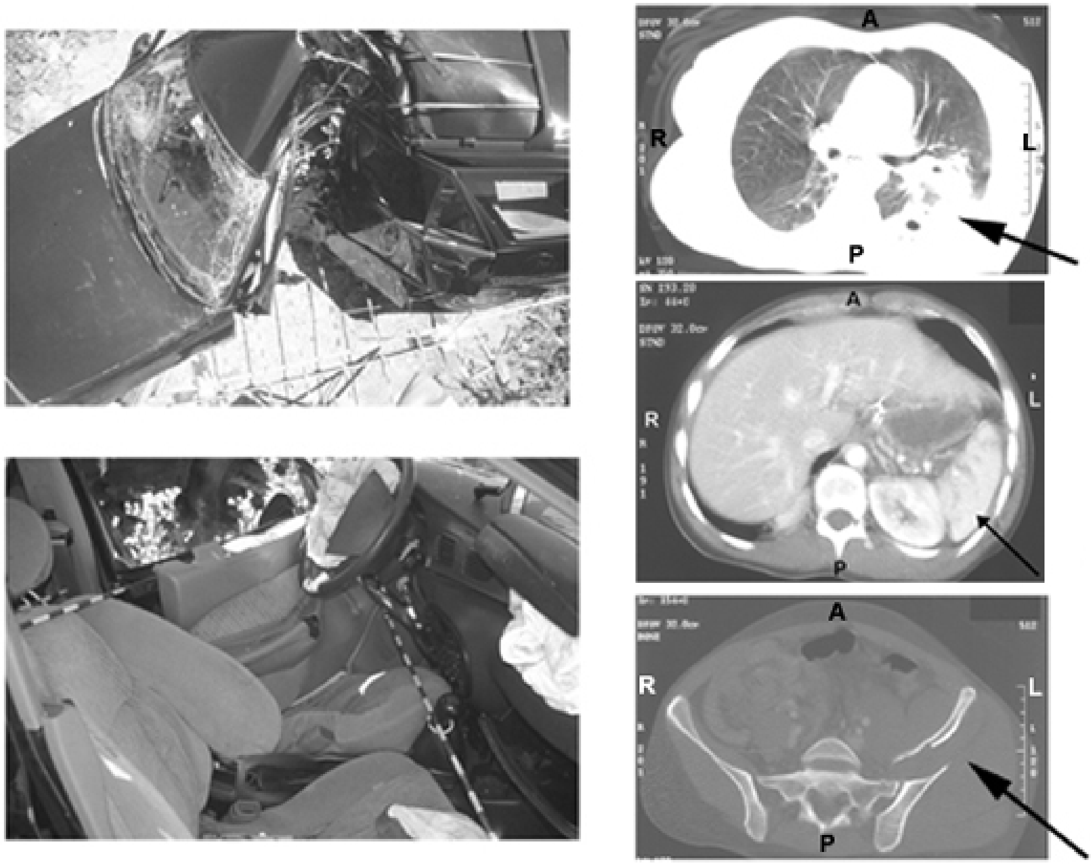

Figure 1: Lateral impact CIREN case. Photos on left show the exterior and interior vehicle damage. Case occupant CT scan image at the level of the lower chest (top right) shows a left posterior pulmonary contusion. CT scan image at level of the upper abdomen (mid right) shows injury to the spleen; image at the level of the pelvis (bottom right) shows an iliac wing fracture.

Figure 2 contains images of the vehicle, occupant and CT scans from a minor side swipe crash. There was minimal damage to the exterior of the vehicle and no measurable intrusion of the door into the passenger compartment. Nonetheless, the driver of the vehicle sustained a left posterior flank contusion, left posterior rib fractures, left pulmonary contusion and severe splenic injury. The contusion can be seen on the occupant photo and also in the edema and stranding within the subcutaneous fat seen over the splenic injury seen in the subjects left posterior quadrant on the abdominal CT image. The rib fracture and pulmonary contusions are also localized to that same left posterior quadrant of the lower thorax. The location of the side airbag which deployed in close proximity to the deduced location of the driver's left flank led to the conclusion that the airbag was the energy source for this subject's injuries.

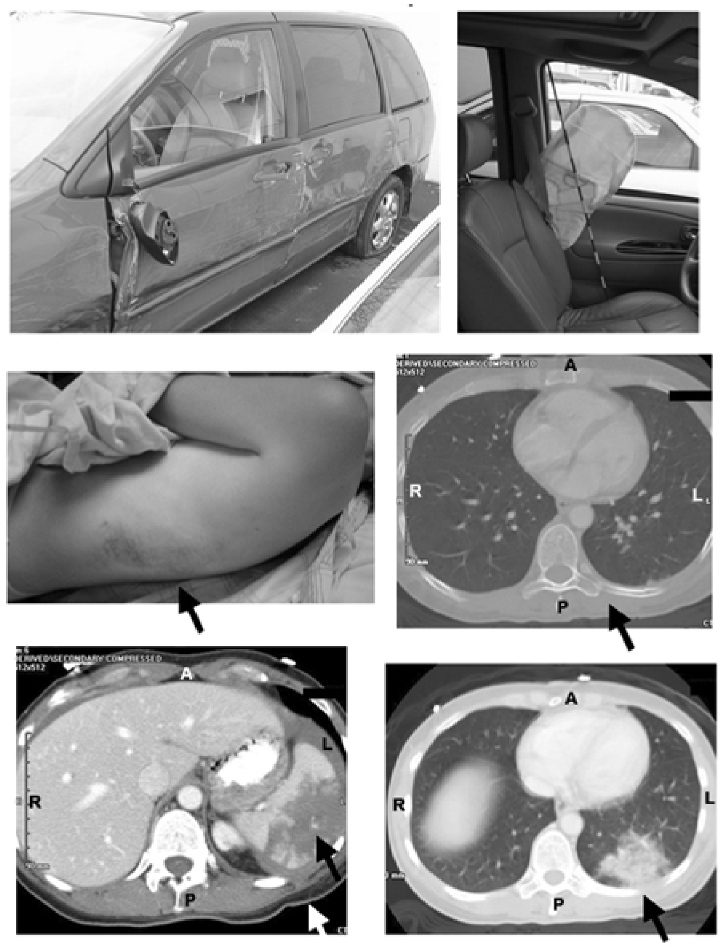

Figure 2: Minor, frontal side-swipe case from CIREN. Top photos show vehicle exterior and interior. The driver case occupant sustained a left flank contusion (mid left). CT scan image (mid right) at the level of the mid chest shows left posterior rib fracture. CT scan image (lower left) at the level of the upper abdomen shows a severe spleen injury (black arrow) as well as hemorrhage/edema within the subcutaneous fat (white arrow). CT scan image (lower right) through the lower chest shows a left posterior pulmonary contusion.

As a digital record of a crash subject frozen shortly after the time of the initial trauma, CT scans also provide a wealth of detail regarding minor injuries that can be of great assistance to biomechanical researchers attempting to determine injury causation mechanisms. One of the questions that frequently arises during CIREN case reviews at our institution is the issue of whether a subject's head injuries are due to contact with the vehicle interior or to crash forces alone without direct impact to the head. Contusions to the subcutaneous tissues overlying the skull are of minimal clinical significance and therefore ignored on radiographic interpretations, which focus on detection of clinically relevant injuries. Re-examination of head CT scans allows detection of even minor contusions that provide important information regarding the likelihood of significant direct contact of the head with the vehicle interior or another occupant during the crash. Even at our center, where we take care to document minor abrasions and contusions in the emergency room to assist with our CIREN crash case reviews, the initial medical examination may miss such injuries. Figure 3 shows the photograph and head CT image of a crash subject who sustained a loss of consciousness. The photograph of the subject in the emergency room showed no contusions or abrasions that would have provided evidence of a direct blow to the head. Physical examination also failed to reveal such evidence and none was initially noted on the detailed admission records or radiology report. Nonetheless, careful re-examination of the CT scan during a CIREN case review revealed a contusion to the left posterior parietal region of the head. This was taken as evidence of direct contact of the head with another solid structure. The location of the contusion on the posterior-lateral aspect of the head led to the conclusion that the head contact was with the B-pillar during the rebound portion of a frontal crash. There has been much confusion and controversy regarding the biomechanics of head injury in the past in part because the occupant detail has been insufficient. We believe that attempts to determine head injury causation without direct examination of the CT images is speculative and highly prone to error.

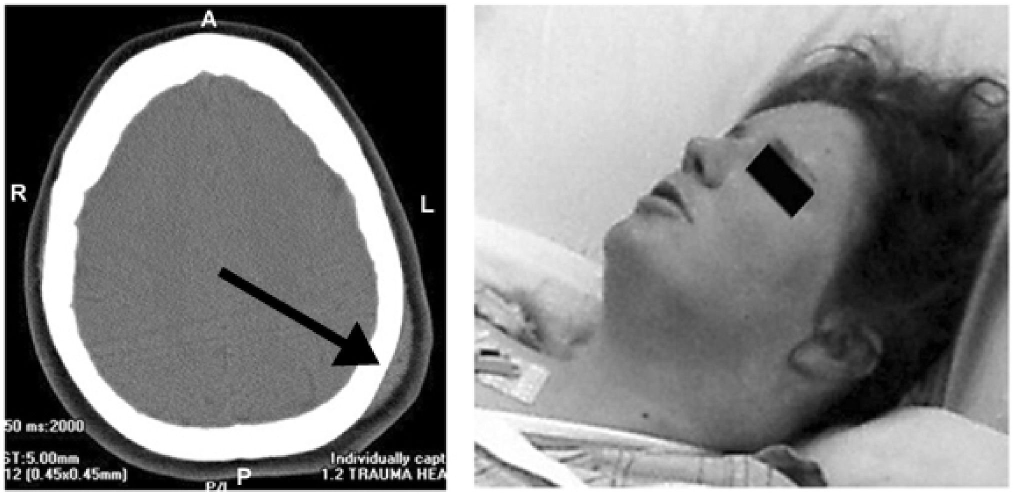

Figure 3: Transverse CT scan image of the subject's head shows a sizable contusion and hematoma over the left lateral posterior aspect of the skull. No corresponding abnormality was noted on physical examination or subject photograph.

Figure 4 shows the photograph and CT image of another crash occupant. The photograph shows minor facial abrasions with nothing of note over the right forehead. Examination of the CT scan, however, showed a large soft tissue contusion over the right forehead. In our experience, the presence of a significant contusion without overlying skin lacerations is consistent with the subject having contacted a padded surface such as the headliner rather than more solid structures such as the instrument panel or windshield. In other cases, we have used the presence of glass fragments within lacerations and contusions of the head as evidence of direct contact of the head with the windshield rather than other structures in the vehicle interior.

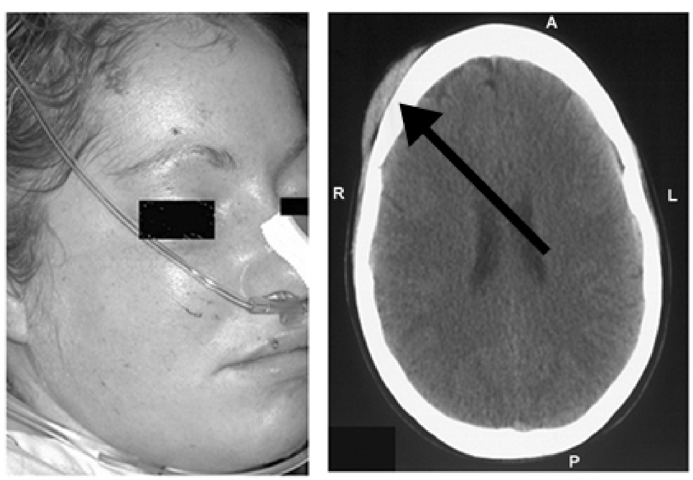

Figure 4: Crash occupant photograph shows only minor abrasions on skin of right forehead. Transverse CT scan image at the level of the forehead shows a sizable hematoma and soft tissue contusion on the right forehead.

Overall, we have found that the injury mechanisms (source of energy, contact and loading path) determined by consensus at our CIREN case reviews has been materially affected in 30% to 40% of cases as a result of the subject's 3D imaging data.

Occupant Variability: Differences Are Associated with Crash Injury Outcome

From the medical perspective, the subject always has significant influence on his or her outcome from any disease process or treatment. Because little occupant-specific data has been available to date from real-life crashes except age, sex, height and weight, it has been difficult to gain insight into how differences within the population affect the biomechanics of injury causation. CT and other 3-dimensional medical imaging data can provide valuable insights here as well. For instance, we had earlier found an increase in the rate of hip injuries, particularly to male occupants of frontal crashes (Sochor, 2003). The geometry of the bony pelvis differs significantly between males and females. We examined male and female pelvises using 3-D CT scans and found that they differed greatly in their presentation of the acetabulum (or hip socket) to the force transmitted along the femur in a frontal crash (Wang, 2004). Figure 5 shows that the acetabulum faces more laterally in males than females (lesser Open Angle), which would present less surface and structure to withstand a load directed along the femoral axis. This finding is consistent with the posterior wall acetabular fractures and posterior hip dislocations that we clinically see more often in males than females.

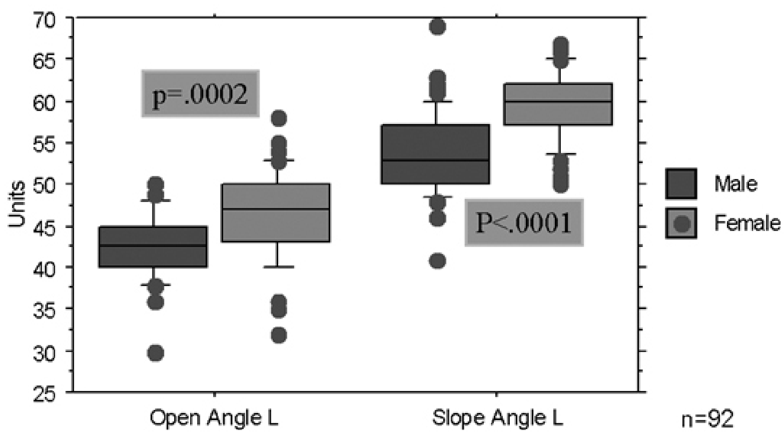

Figure 5: Comparison of open and slope angles of the acetabulum measured using CT scans of male and female pelvises.

We also found that the femoral heads in males were larger than in females although the depth of the acetabulum or hip socket was less (Figure 6). A larger femoral head sitting in a shallower socket would be more likely to dislocate, again consistent with the gender difference that we have observed in the crash population.

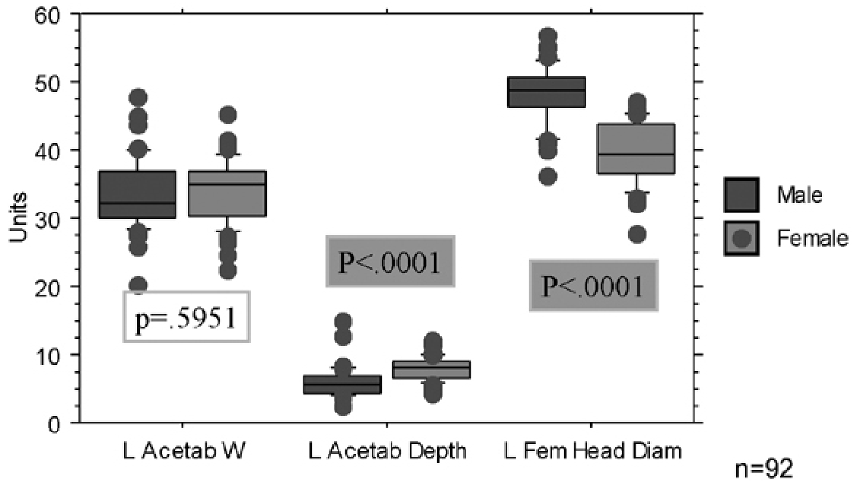

Figure 6: Comparison of acetabular width, acetabular depth and femoral head diameter measured using CT scans of male and female pelvises.

The increasing use of CT scans for trauma evaluation of the chest over the past several years has provided information that has been unavailable in the past. Part of the reason for the increasing use of chest CT scans is the recent demonstration that such scans are quite sensitive and specific for detection of aortic injuries. CT scans of the chest are far less invasive and accompanied by fewer complications than the catheter-based aortograms used previously to detect aortic injuries. Three-dimensional reconstruction of the chest by CT has allowed us to get a far clearer picture of the exact location of rib fractures and therefore the direction of chest loading during a crash. We have noted in our examination of chest CT scans that there were significant difference in the angle of the ribs. Figure 7 shows the 3-D reconstructions of the rib cage from two individuals. Older individuals, particularly males, seem to have more horizontal ribs than younger individuals. This trend appears more pronounced with males than females. Differences in rib angle within the range that we observed would be sufficient to significantly alter the stiffness of the chest to frontal loading (Personal communication – Richard Kent, University of Virginia. Also see Discussion below).

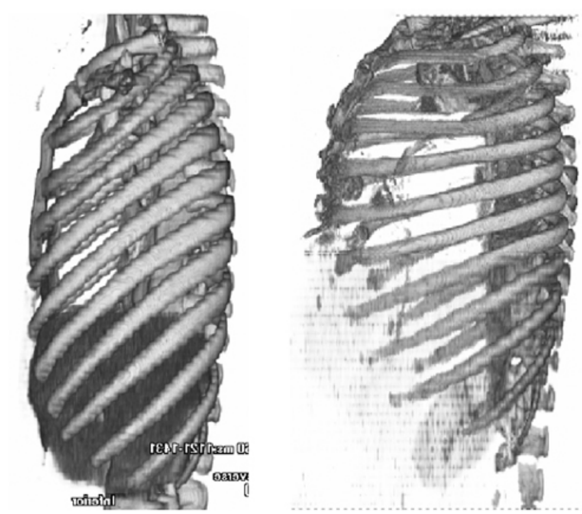

Figure 7: Three-dimensional CT reconstruction of the rib cage from two individuals shows a large difference in rib angulation.

The American population has become significantly heavier over the past several decades and as such differs greatly from the population several decades earlier that is taken as the reference for automotive safety design, testing and regulation. Among the crash subjects evaluated at our trauma center, we had clinically observed that abdominal visceral injuries seemed to be less common in heavier individuals compared to thinner individuals. We used the 3-D CT scans of CIREN crash subjects from our center to determine the effect of subcutaneous fat volume on abdominal injury severity. We found that increased subcutaneous fat depth had a tremendous protective influence on abdominal injury severity in frontal crashes (Wang, 2003). We subsequently measured the volume of both the subcutaneous fat and the visceral fat in a reference slice from the abdominal CT scans of CIREN crash subjects. Figure 8 shows that increasing subcutaneous fat volume had a very significant effect on the observed abdominal injury outcome. The effect of the fat volume was far greater than age, restraint use, or crash severity. It was interesting to note that this protective effect of increasing abdominal subcutaneous fat was not seen for side impact crashes.

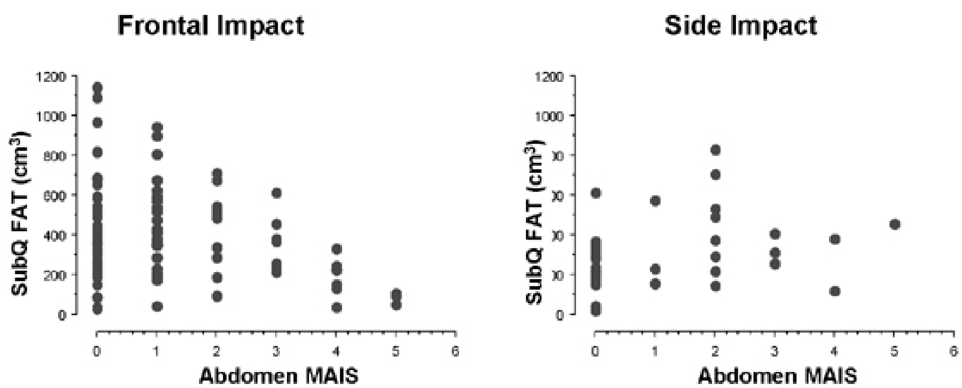

Figure 8: Effect of subcutaneous fat volume on observed occupant abdominal injury severity in frontal and side impact crashes.

Bone mineral density is known to have a significant influence on fracture tolerance in several regions of the body. We have noted on our evaluation of CT scans from CIREN crash subjects that there is a significant amount of variability in the density of bone at multiple locations in the body. Figure 9 shows the 3-D reconstruction of the same vertebral body from two females, young and old. The settings on the imaging analysis software were identical and the clear difference in bone density can be easily appreciated. Bone mineral density can be measured using a number of different techniques including DEXA scan and standardized plain radiographs. Recently, techniques to measure bone mineral density using CT have been developed. We are currently in the process of adapting those techniques for evaluation of bone mineral density in CT scans obtained for the purpose of trauma.

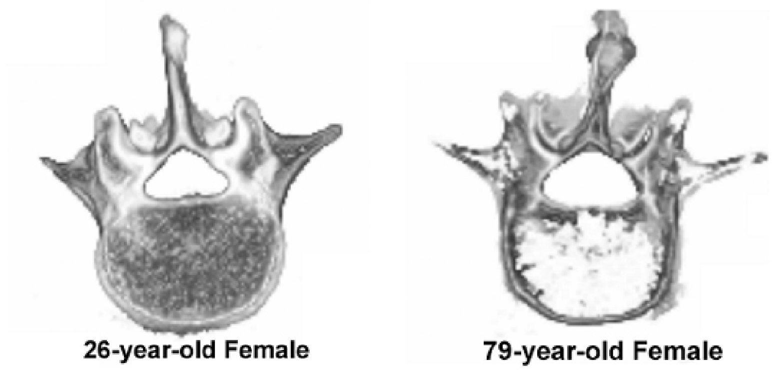

Figure 9: Three-dimensional reconstructions of the L4 vertebral body from two subjects show a clearly visible difference in bone mineralization.

The increasing use of CT scans for trauma evaluation also provides data from subjects where there has been exceedingly scarce data in the past. CT scans are used for the evaluation of infants and small children, providing a wealth of anatomic data from different stages of body development. CT scans are also used for the evaluation of pregnant subjects, particularly once they are past the first trimester, when the risk of radiation-induced fetal injuries has past. Figure 10 shows the exquisite detail of information that is captured about both the mother and fetus. The manner and extent to which internal organs are displaced by the enlarged fetus and uterus can be easily determined.

Figure 10: CT scan images of a 40-weeks-pregnant female. The top images show 3D reconstructions. The bottom images show coronal (left), sagittal (middle) and transverse (right) sections of the same subject.

Figure 11 is a graphical representation of the effect of 3D imaging data on the balance of information regarding motor vehicle crashes. We have found that the medical imaging data, in addition to providing previously unimaginable detail regarding the occupant's baseline state, injuries and injury mechanisms, also provides invaluable evidence for the determination of restraint usage, occupant position and occupant kinematics during the crash.

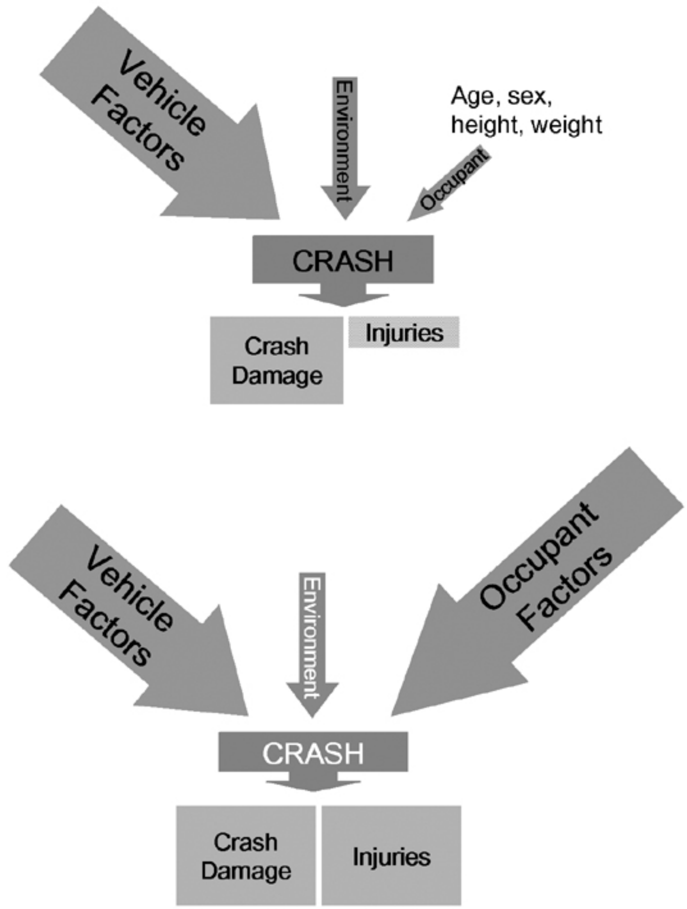

Figure 11. Graphical representations of the data available before (top) and after (bottom) the routine use of CT scanning for trauma subject evaluations.

POTENTIAL LIMITATIONS

As with any technique, however valuable, there are limitations that must be considered carefully. Injuries are, by definition, an induced abnormality in the subject and must be kept in mind whenever measurements meant to reflect the subject's baseline characteristics are being performed. For instance, a fractured rib may have a significantly altered angle. A subdural hematoma will significantly alter intracranial anatomy. Intubation and mechanical ventilation may alter chest expansion. In some instances, it may be possible to use the human body's symmetry to advantage if the other side is not injured. While such factors as bone mineralization will not change as a result of the crash, other factors such as soft tissue volumes and characteristics may change. Massive fluid resuscitation is often necessary for severely injured crash subjects and can increase their weight (and therefore soft tissue volume) by as much as 50 percent over the first several days following injury. Such non-specific artifact can be minimized by limiting analysis to medical imaging data obtained only within one or two hours of the initial injury event. Artifact can also be introduced by the use of different imaging equipment, technique or processing. All 3D scans are currently performed with the subject supine, usually in a cervical collar and on a backboard. Studies will need to be performed to determine how body anthropometry and internal organ location differs from the supine position and the automotive seated position.

In summary, the increasing use of CT scans and other 3D imaging techniques for evaluation of crash occupants has markedly increased the amount, granularity and accuracy of data available about crash injuries. This includes data for especially vulnerable subpopulations where there has previously been scarce data, including infants, small children, and pregnant females. The newly available imaging data has one especially valuable feature. The digital nature of the information does not decay with time or analysis. Unlike cadavers, the data can be dissected electronically time and time again to measure specific items of interest without affecting the original data. A better understanding of how differences in body composition affect the human body's tolerance to high-energy trauma will enhance the biofidelity of the human surrogates, whether real or virtual, that are for crash testing and regulation. Given the magnitude of the increase in occupant information which is now available as a result of 3D medical imaging, it will be essential to develop common protocols and terminology so that work being conducted by interested parties in both the medical and engineering communities can be compared, contrasted and built-upon in a scientifically rigorous manner.

ACKNOWLEDGEMENTS

This research has been supported by the U.S. Department of Transportation/National Highway Traffic Safety Administration (DOT/NHTSA) and is based on research conducted under the Crash Injury Research and Engineering Network (CIREN) project funded by DOT/NHTSA. This material represents the position of the author(s) and not necessarily that of DOT/NHTSA. The document is disseminated under the auspices of the Crash Injury Research and Engineering Network (CIREN). The United States Government assumes no responsibility for the contents or use thereof.

REFERENCES

SOCHOR, M.R., FAUST, D.P., SCHNEIDER, L.W., and WANG, S.C. (2003). "Knee, Thigh and Hip Injury Patterns For Drivers and Right Front Passengers In Frontal Impacts". Society of Automotive Engineers paper # 2003-01-0164.

WANG, S.C., BEDNARSKI, B., PATEL, S., YAN, A., KENNEDY, T., LINK, E., ROWE, S., SOCHOR, M., and ARBABI, S. (2003). "Increased Depth of Subcutaneous Fat is Protective Against Abdominal Injuries in Motor Vehicle Collisions" Annu Proc Assoc Adv Automot Med. 2003;47:545-59.

WANG, S.C., BREDE, C., LANGE, D., POSTER, C.S., LANGE, A.W., KOHOYDA-INGLIS, C., SOCHOR, M.R., IPAKTCHI, K., ROWE, S.A., PATEL, S., and GARTON, H. (2004). Gender Differences in Hip Anatomy: Possible Implications for Injury Tolerance in Frontal Collisions. 48th Annual Proceedings, Association for the Advancement of Automotive Medicine; In Press.

DISCUSSION

PAPER: **Potential Applications (and Limitations) of 3D Imaging Data from Human Crash Subjects for Biomechanical Research**

PRESENTER: ***Stewart C. Wang, University of Michigan Program for Injury Research and Education***

COMMENT: *Richard Kent, University of Virginia*

I just want to highlight the point you made because you made it quickly. That rib angle factor that we looked at - we basically did a finite element model and re-meshed the model with the ribs up slightly at 7^{o} and looked at the effect of going from a young person's bone marrow properties to an older person's bone marrow properties versus going from a young person's rib angle to an old person rib angle. And by far, the structural responses, structural characteristic of simply loading those ribs—more like a barrel (older people) as opposed to a rib that rotates, (younger people)—was much more important in terms of dictating the overall response than the change in material properties. So this morning, we've talked a lot about material characterization and how it is different from structural characterization. I think this is extremely important data to help us understand because a lot of times what you see is a structural effect, not a material effect. So thanks, Stewart. This is great work.

QUESTION: *Guy Nusholtz, DaimlerChrylser*

I have two questions: First, do you think the fat content is important enough that NHTSA should regulate it for the driving public?

ANSWER: It's very important. Actually, a number of other governmental agencies are trying to regulate or alter the population profile with regards to the amount of fat.

Q: But I think it sounds like it's going in the wrong direction.

A: Clearly, it is.

Q: Second question: Did you do any verification or validation for your injury mechanisms that you were discussing where you identified it was an airbag or was that just based on perceptions from the accident data?

A: The only way that we can do that is by utilizing, in particular, the CIREN case analyses. As you know, our case analyses are run with 40 or 50 people in the room, including not only surgeons, but quite a few engineers from the automotive companies as well as the restraint companies. So we come to consensus, typically, on the mechanism of the injury. I would argue that we go through the most rigorous process in the world right now in terms of determining injury mechanisms. And remember, these are live subjects. We can't go and test them again. We don't have the camera in the car. But for real live subjects, I think we go through the most rigorous analysis in terms of the mechanism.

Q: But it's basically a Delphi port of analysis. You're just talking about opinions of the people in the room when you do that consensus. You're not doing anything like any finite element models against the mechanisms or any testing.

A: Not typically. We have modeled occupant kinematics, which helps us to determine the mechanism. When I say mechanism, we don't typically take it to the point of saying there's this much strain, there's this much tension, etc. We consider the loading and the physical component within the vehicle, which causes the loading. That's typically far more granular than is done in most other case analyses. So we consider where the occupant is, where they moved, what part of the body contacts what part of the car and where any vehicle deformation occurred. We go through the cases, I think, in a more rigorous fashion than any other case analyses out there.

Q: Yeah, but it's basically all done through consensus, right?

A: Yes.

Q: Okay. Thank you.

A: But there is representation clearly of not only the physicians, but also of the restraint makers and the suppliers and OEMs in the room. You might be surprised generally, how quickly we come to consensus. For those cases where we don't, we write minority opinions and we have that available.

Q: Yeah. It's still basically opinion though. Thank you.

QUESTION: *Frank Pintar, Medical College of Wisconsin*
This is interesting stuff. In terms of regulating fat, I just heard that the 50th percentile male numbers coming out now are 191 pounds. And so, I think it does influence or it should influence our idea of what the 50th percentile male is now because now our dummy is no longer representative of that. So, the reality is that the CIREN Centers are seeing real crashes to real people and I think that really should be taken into consideration at some time. Perhaps, it's a good time to redo our anthropometry studies again. My question was really centered around the 3D CT and I think a lot of times you do spiral CT's and they're often 5 mm. Do you have an idea of what the accuracy is? I mean, do you use it more for a qualitative analysis or qualitative understanding of your mechanism of injury or do you really go back and look at measuring off those CT's? Because we've noticed when we do 3D CT's, often even some of these minor fractures, we miss stuff because of the way that the CT was done. So you can—you actually see some fractures better in the 2D plane than you would in the 3D reconstruction.

ANSWER: Yes**.** We do both. We do both 2D and 3D reconstructions. In terms of fusing together the loading and the mechanism, although Guy would take exception with that, we find that the 3D tends to be helpful in giving us a better global loading pattern, but we do both. In terms of accuracy, there are certain things to consider. For instance: dimensional measurements I think are extremely accurate because that's been well calibrated. In terms of bone marrow density, I just showed you rough marrow density based on the CT using a standardized technique. I would say that that's +/- 10%. It could be affected by whether you have a backboard on board, whether you change your CT scan, whether you change your technique, and the mass of the patient. We're fortunate in that we do all of our CTs using a standard technique in a single CT scanner, which is located 10 feet away from the trauma bay. So, we have very consistent technique in that way. It's also important to go back and look at your scanner's daily calibration logs; that will give you an idea of how much variability the scanner might add. So we're pretty comfortable about the bone marrow density. We can adjust for it using a couple of equations with fat, but we think that the phantom will help significantly further with that.

Q: Is your standard spiral, is that a 5 mm spiral or it varies?

A: It really depends on which part of the body we are scanning. We actually do 1 mm slides in certain portions.

Q: Oh, do you?

A: We do 1 mm in the neck. In the pelvis, we do 1 mm slices for anybody that we suspect has an injury. The degree of detail that we're getting is pretty phenomenal.

Q: Do you have any regulation in terms of how much radiation these patients receive because obviously, CT of the whole chest is a significant amount of radiation?

A: I don't have that slide with me. Surprisingly, it's not a tremendous amount of radiation. I know there are representatives here from the international community, and I think in many of the other countries they're much more concerned about the amount of radiation. In the US, this has really evolved over the last seven or eight years as the standard of care. I don't know if it's because of the number of lawyers that are floating around looking for missed injuries or not, but we and I think in most Level I advanced trauma centers around the country are scanning everything because you have to. It's cost-effective medical care. Therefore the amount of radiation is not generally a factor we consider in making a decision of whether or not to scan. Pregnant women and infants are obvious exceptions. One good thing is that the technique is reasonably similar. Nonetheless, I would like for the centers that are going to be doing this, to come to agreement. We should then negotiate with our radiology departments to accept those protocols and conditions.

QUESTION: *Barry Myers, Duke University*

I just want to come back and punctuate Guy Nusholtz's point regarding the consensus driven analysis. It's great work; it's detailed; it's interesting; and, it makes a lot of people much more savvy about injuries. By contrast, we've had the opportunity to go back and look at specific neck injuries in some of our data and come to very different conclusions about what we believe happened. Now, it's not to say that we're right and whoever did them is wrong, but rather that these aren't—I don't think we can treat these analyses as gold standard but take the whole experience and learn from it collectively.

A: I would agree with you on that although I would say that there are differences of opinions and also differences in levels of expertise between the CIREN Centers. I agree that neck injury mechanisms are very complex. But there are far more instances of injury mechanisms that are not so complex - such as chest loading or pelvis loading. Between a combination of EDR data, the vehicle deformation data, the belt load data, etc., we end up with a pretty good picture of what happened. Until we have video in every car, this is the best we have.

COMMENT: *Stephen Rouhana, Ford Motor Company*

To follow up on Barry's comment. I have actually sat in on the CIREN meetings at University of Michigan with many other physicians, many well qualified people from suppliers and OEMs who have a lot of crash test experience who go through this data meticulously, with all of the imagery that you've shown, and I would like to say that in my opinion—and, this is an opinion, Guy—the conclusions that are reached are more than just an opinion. They're very well educated opinions. Yes, in some cases, the crash scenario is very complicated and the injuries may be very difficult to diagnose. Very often, I think we come to very solid conclusions and I think the CIREN program is really quite effective in that regard.