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Dynamic Impacting of Unembalmed vs. Embalmed Human Cadaver Legs

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Abstract

Intact legs from 9 cadavers were collected for dynamic impacting to emulate motor vehicle trauma. Bequeathed cadavers arrived at the University of Louisville School of Medicine within 48 hours of expiration (all post-rigor mortis). Cadavers were screened for HIV and Hepatitis B virus. One leg was immediately removed and frozen at 0° C until thawed for testing. The other leg remained with the cadaver to be embalmed by standard femoral artery injection with 20% Isopropyl Alcohol, 20% Propylene Glycol, 4% Formalin (37% Formaldehyde Solution), 4% Phenol and 52% Warm Water. The embalmed legs were removed from the cadavers after a minimum of 7 weeks. Pre-test radiographs were made and the legs were transported to the University of Tennessee Engineering Institute for Trauma and Injury Prevention. Just prior to testing, a hole was drilled in the femur and a rod was inserted from side to side. The leg was placed upright in the test zone and a weight of over 50 kgs. was applied to the rod (simulating upper body mass). An athletic shoe was placed on the foot and the foot was set on a concrete block. Additionally, for most tests, there was an attempt to pressurize the vasculature by use of a crude embalming pump. The impacting apparatus consisted of a 50 kg. cart propelled by a pneumatic accelerator to approximately 7.7 m/s into the anterior of the leg midway between the knee and the ankle. The cart was headed by a steel pipe of nearly 4.75 cm. diameter. The pipe was coupled to a force transducer which relayed impact force data to a Hewlett Packard 3562A computer signal analyzer system. Testing was captured on VHS video, 35 mm still photos and 16 mm Color High Speed Film shot at 1,000 frames per second. Post-test analyses included radiographs and thorough dissection.

Introduction

Several test subjects are available to researchers in the study of human trauma biomechanics. These include animals, surrogates (crash dummies), cadavers and occasionally combinations thereof. Studies may be performed on live, anaesthetized animals but their anatomy, and the way in which it behaves dynamically, is often significantly different from humans. Although surrogate technology is progressing rapidly, the ability to directly infer the extent of injury (i.e. traumatized anatomy) is still insufficient.

Several issues must be considered when determining the proper experimental design. Will the subject be easy to instrument? Will results be consistent from test to test? Is the subject representative of human geometry? Is it sufficiently deformable or frangible, etc? Cost is also an important consideration but specimen biofidelity may be paramount. Is the subject going to yield an accurate picture of actual human trauma? In order to have valid trauma data, it is important to determine the **amount** of damage done by certain events. Cadaver use may be superior to the use of animals or surrogates in maintaining biofidelity but many drawbacks still exist:

1) Most bequeathed cadavers are the remains of persons who were of great age and of generally declining health. It can be argued, however, that safety designs that mitigate trauma for these specimens would likely be beneficial to almost any member of society (excluding some important different design challenges with regard to the small bodies of infants and children). In other words, if we can protect the most feeble members of our society then it stands to reason that the more stout persons will also be protected.

2) Cadaveric specimens lack the normal physiologic internal pressures of living persons including vascular pressure and normal turgor of the tissues, cells and the extracellular fluid. Shortly after death the decay process begins and cells quickly begin to deteriorate. This can be temporarily arrested to some degree by prompt freezing, but thawing brings about a return of the decay process.

3) Kinematics of a flaccid human cadaver may differ from those of a live person. However, this may be of little consequence during high speed dynamic experimentation. In such testing the velocities associated with the impact are high enough that human responses such as bracing, deflecting, and tensing have minimal effect on resultant injuries. So, the flaccid nature of the cadaver is not a major drawback as long as the mass/inertial effects of various body components are properly modelled or accounted for.

If the cadaver is deemed the appropriate model for experimentation, then the next consideration is whether to use unembalmed or embalmed tissue. Unembalmed or fresh tissue may be a pathogenic biohazard putting handlers at risk for AIDS, hepatitis, etc. Fixing the tissues as is done in the embalming process makes handling nearly risk free. Therefore, embalmed tissue has considerable advantages over unembalmed tissue in terms of its safety, ease of handling and storage. It is assumed, however, that the biofidelity of embalmed tissue is less than that of unembalmed.

Objective

The objective of this study was to determine how the traumatized anatomy of embalmed human cadaver legs differs from that of unembalmed legs. The legs were impacted in experiments that simulate trauma due to motor vehicle accidents. Every effort was made to make the specimens as "life-like" as possible in hopes that the dynamic response would be similar to that of a live standing or walking human struck in the leg by an object of relatively large mass (automobile, motorcycle, etc.). Testing conditions accounted for: 1) the constraints of the upper body mass, 2) friction between the foot and the pavement, and 3) pressurization of the vasculature.

The extreme variability between human cadavera was accounted for by making the study self-controlled in that, for each cadaver, one leg was left unembalmed and the other was embalmed. Therefore, age, sex and overall physical condition could essentially be "factored out" allowing for a more meaningful comparison of the collected impact data.

Methodology

Cadavers are generously bequeathed to the University of Louisville Medical School for the expressed purpose of research and education. Many of the cadavers are preserved and dissected in a gross anatomy course for dental students. The lower limbs are not studied in this course, and therefore, the limbs are available for research pending committee and departmental approval. Approval was granted for ten such cadavers to be used in this study. The cadavers are usually received by the medical school within 48 hours of expiration (post-rigor mortis).

Upon arrival, cadavers were evaluated by a two-step screening process for inclusion in this study. First, an attempt was made to enter an equal number of males and females all of whom were ambulatory and did not appear to suffer a prolonged death. Ten suitable specimens were identified. The second phase of screening involved the collection of blood serum which was tested for the presence of hepatitis B surface antigens (HBV) and human immunodeficiency virus (HIV) antibody. Unfortunately, one of the ten tested positive for HBV and was immediately rejected and cremated. Thus nine pairs of legs were available for this study (see **Table 1**).

For each cadaver, one leg was sectioned from the body, bagged in plastic and securely placed in a freezer at 0° Celsius. The other leg remained with the body which was embalmed, bagged and stored for at least seven weeks. Embalming was achieved through femoral artery perfusion of a relatively standard preservative solution consisting of 20% isopropyl alcohol, 20% propylene glycol, 4% formalin (37% formaldehyde solution), 4% phenol and 52% warm water.

Just prior to departure for testing, the embalmed legs were removed from the cadavers and taken to a special radiology suite along with the frozen unembalmed mates. Pre-test radiographs were made in order to rule out recent fractures or the presence of prosthetic devices. After checking the X-ray films, the specimens were transported to a unique dynamic impactor facility at the University of Tennessee in Knoxville, TN, USA. The facility is housed within the Department of Industrial Engineering and operated by the Engineering Institute for Trauma and Injury Prevention. The unembalmed and embalmed legs were each subjected to the same test scenario.

Upon arrival at the test facility, the frozen specimens were allowed to thaw for at least twenty-four hours. Immediately prior to testing, the specimens were removed from their plastic bags and a hole was drilled from side-to-side in the distal femur at the level of the condyles. A rod was passed through the hole and the leg was placed upright in the impact zone of the test machine. A weight of over 50 kgs. was applied to the rod in an effort to simulate the upper body mass. The foot of the specimen was placed in an athletic shoe and set on a concrete surface. Additionally, for most tests, an attempt was made to pressurize the vasculature by using a crude embalming machine to infuse the vessels with a sugar water solution via cannulation of the popliteal or femoral artery (depending on where the specimens were sectioned at the thigh). The machine registered a pressure of between 2 and 3 psi (A resting systolic blood pressure of 120 mm Hg is equivalent to about 16 KPa which is roughly 2.3 psi). Two of the embalmed legs (301L and 314R) could not be adequately pressurized presumably due to the presence of fixed blood in the vessels. In one case (308L), an abnormal branching pattern of the femoral artery resulted in numerous small arteries, none of which would accept the pressurization cannula. Although the veins were of sufficient size, any attempt to pressurize them would have been futile due to the presence of natural one-way valves designed to prevent the flow of blood down the leg. **Figure 1** (on p.5) shows a specimen in the test set-up.

Table 1
Specimen Data

Specimen Number	Age and Sex	Cause of Death[2]	Left or Right	Embalmed or Unembalmed	Time (months) Embalmed or Frozen
295	74-♀	Lung Cancer and Pulmonary Disease	R	E	4½
			L	U	4
300[1]	92-♂	Cardiac Arrest and Diabetes Mellitus	R	E	4
			L	U	3½
301	94-♀	Pneumonia and Dehydration	L	E	4
			R	U	3½
306	75-♂	Small Cell Lung Cancer	L	E	3½
			R	U	3
308	79-♂	Acute Myocardial Infarction	L	E	3
			R	U	2½
310	91-♀	Urosepsis and Dehydration	R	E	3
			L	U	2½
312	43-♀	Liver Failure and Cervical Cancer	L	E	2½
			R	U	2
314	76-♂	Myocardial Infarction and old Stroke	R	E	2¼
			L	U	1¾
316	91-♂	Adenocarcinoma and Colon Cancer	R	E	2¼
			L	U	1¾

[1] All specimens were Caucasian except for 300 which was African-American.
[2] Causes of death are listed as noted on the death certificate.

The specimens were impacted on the anterior mid-leg by a 50 kg impact cart. The cart is propelled by a pneumatic-based accelerator to a velocity of approximately 7.7 m/s (range = 7.15 to 7.94). The accelerator consists of a pressurized cylinder with a piston and ram system. The ram pushes the rail-guided cart through a stroke of approximately 1.5 m, then the cart travels freely for about 0.5 m before impacting the specimen.

The leading or striking edge of the cart consists of a steel pipe measuring 4.75 cm in diameter. The pipe is mounted to the cart transversely by two slide pins that enable the pipe to freely impinge on a piezoelectric quartz force transducer (PCB Series 208A). The signal from the force transducer is transmitted through an amplifier and on to a Hewlett Packard 3562A signal analyzer. A record of force versus time is stored for each test (system error led to no trigger of the analyzer on test 295R). Testing was also recorded with 35 mm still photography and on standard VHS video at 30 frames/s. Most of the tests were filmed with a 16 mm rotating prism high speed camera at 1,000 frames/s on color 400 ASA film for tungsten lighting.

After testing, the legs were x-rayed again and then carefully dissected. All damage was noted and photographed. Vessel integrity was determined by pressurization with a syringe. Remains were returned to the University of Louisville School of Medicine for proper cremation and burial.

Figure 1
Test Set-up

Fig. 1 - Every effort was made to insure that the set-up conditions for each specimen remained consistent. This was a difficult task due to the soft and highly flexible nature of the unembalmed specimens. In this photo a stack of weights is seen at center top. The bar supporting those weights is connected to a harness that straddles the leg and is connected from side-to-side by a rod through the femoral condyles. The various riggings seen restrict movement of the weights after impact. The foot was placed in a shoe on one or two concrete blocks depending on specimen length. Note the plastic tubing on the left leading to the top of the specimen. This is the tube used in an attempt to pressurize the vasculature with a sugar water solution. The impact cart will strike the specimen as it runs from right to left in this photo. The small up-turned lamp in the center of the photo is part of the timing mechanism for cart velocity determination.

Results

Mid-shaft tibial cortex thickness, peak force and cart velocity data are listed for each test in **Table 2**. Dissection results indicating damage to the skin, muscles, vessels and bone are summarized in **Table 3**.

Table 2
Test Data

Specimen[1]	Avg. / Smallest Cortex Thickness (mm)	Peak Force (kN)	Cart Velocity (m/s)
295Re	4.33 / 1.97	No Trigger	7.08
295Lu	4.93 / 2.10	5.95	7.94
300Re	6.74 / 4.33	6.80	7.15
300Lu	6.56 / 3.53	7.80	7.62
301Le	6.24 / 3.36	4.78	7.30
301Ru	4.13 / 2.90	4.18	7.87
306Le	7.79 / 4.61	8.46	7.30
306Ru	7.49 / 4.81	6.21	7.84
308Le	7.89 / 4.25	8.46	7.71
308Ru	7.74 / 4.79	7.43	7.69
310Re	4.15 / 2.48	5.03	7.48
310Lu	5.34 / 3.05	3.75	7.84
312Le	6.29 / 4.11	5.32	7.51
312Ru*	8.41 / 5.27	5.69	7.76
314Re	7.85 / 5.13	7.56	7.59
314Lu*	7.02 / 4.29	6.29	7.41
316Re	6.56 / 4.41	7.51	7.50
316Lu*	8.31 / 7.38	8.16	7.3[illegible]

[1] The specimen number is listed followed by designations for left (L) or right (R) and embalmed (e) or unembalmed (u).

* These specimens did not fracture.

Table 3 - Damage Summary (Dissection Results)

Leg[1]	Laceration[2]		Muscles & Ligaments Damaged[3]	Vessels[4]	Bone Fractures[5]
295Re	4	20.5	5% TA	Fib V	Bad Comm >15 pcs
295Lu	2	34.0	60% Gas & Sol, 100% EHL & TP, 50% FDL & FHL, 10% FiB	None	Bad Comm >6 pcs w. Protrusion
300Re	1	1.5	10% FDL	None	Mild Comm Trans
300Lu	1	7.5	50% FDL, 20% TA, 20% Gas, 30% Sol, 50% FHL, 5% FiB	P. Tib A & Vs	Mild Comm Obl
301Le	6	13.5	50% Gas, 40% Sol, 33% FHL, 50% FDL,	Part of Saph V	Comm >15 pcs w. Protrusion
301Ru	2	19.5	50% Gas, 50% Sol, 30% FHL, 90% TP	Fib A & Vs	Mild Comm Trans
306Le	0	0	<5% TA	A. Tib. A	Mild Comm Trans
306Ru	1	1.5	10% TA, 10% Gas,, 10% FHL, 5% TP	Fib Vs	Mild Comm Trans
308Le	2	3.5	2 cm vertical tear in Gas	None	Mild Comm Trans
308Ru	1	1.5	10% Gas & Sol, 30% FHL, 50% FDL, 5% FiB	P. Tib A	Mild Comm Trans = Large Segs
310Re	1	13.0	10% FDL, 10% TP, 75% FHL, 5% TA	None	Comm >6 pcs w. Protrusion
310Lu	2	13.5	30% FDL, 10% TP, 75% FHL, 30% Gas & Sol	Fib A & Vs	Mild Comm Obl w. Protrusion
312Le	0	0	50% Gas, 50% Sol, 5% FHL	None	Comm w. Tension Wedges
312Ru	0	0	Knee ligaments & all muscles were OK	None	None
314Re	1	1.5	<5% TA	None	Mild Comm
314Lu	0	0	Knee ligaments & all muscles were OK	None	None
316Re	1	1.5	10% Sol, 10% FDL	Fib A & V	Mild Comm Trans
316Lu	0	0	Knee ligaments & all muscles were OK	None	None

[1] The specimen number is listed followed by a designation for left (L) or right (R) and embalmed (e) or unembalmed (u).
[2] The number of skin lacerations is listed, followed by the total linear distance those cuts travel (cm).
[3] Note: The percent values represent an estimate of the horizontal tear length as it relates to total width of the particular muscles listed.
Muscle key: Gas= Gastrocnemius, Sol= Soleus, T= Tibialis, Fi= Fibularis, A= Anterior, P= Posterior, F= Flexor, E= Extensor, D= Digitorum, H=Hallucis, L=Longus, B= Brevis.
[4] Artery (A) and Vein (V) damage key: P.= Posterior, A.= Anterior, Tib= Tibial, Fib= Fibular, Saph= Saphenous.
[5] Fracture descriptions: Comm = Comminuted, Trans= Transverse, Obl= Oblique, Seg= Segmental.

Three of the unembalmed legs did not fracture. For the purposes of the discussion in the following paragraph, these and their respective matches will be excluded in order to generalize findings with respect to the six pairs that fractured.

The fractured **unembalmed** specimens showed considerably more soft tissue damage than their fractured embalmed match (see **Figure 2**). Lacerations to the skin and superficial fascia were judged to be greater in five of the six pairs. Muscle damage was greater for the unembalmed leg in all six cases and vessel damage was greater in four of the six. Oddly enough, the nervous system appeared to escape serious injury as there was virtually no gross damage to any of the nerves. It is important to note that no microscopic analysis was performed; since nerve components are often injured by "stretching" or "pinching," it is quite probable that damage was present but went undetected. The comparison of the osteologic data is more complex. The damage was similar in half of the matched pairs, but the other half appeared to show greater comminution of the embalmed legs. Further review of the post-test radiographs may lead to a more clear picture regarding bone damage.

Figure 2
Impact Comparison

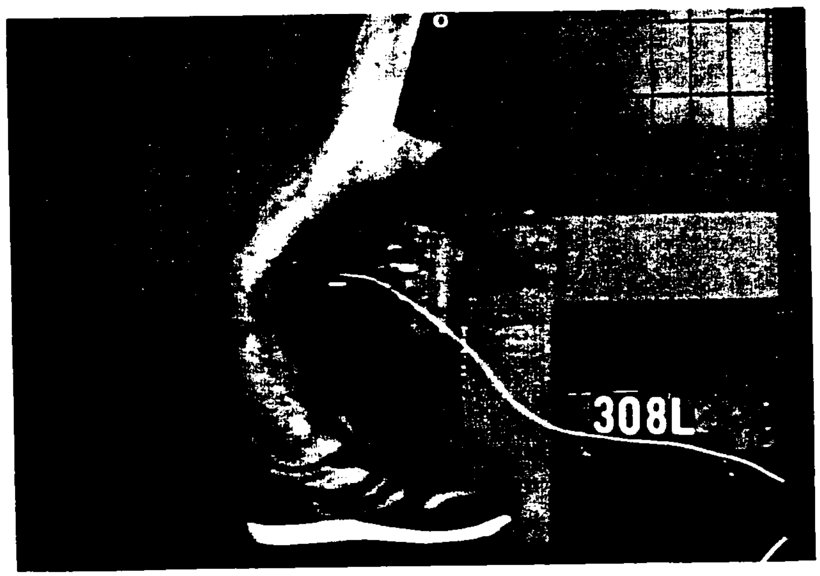
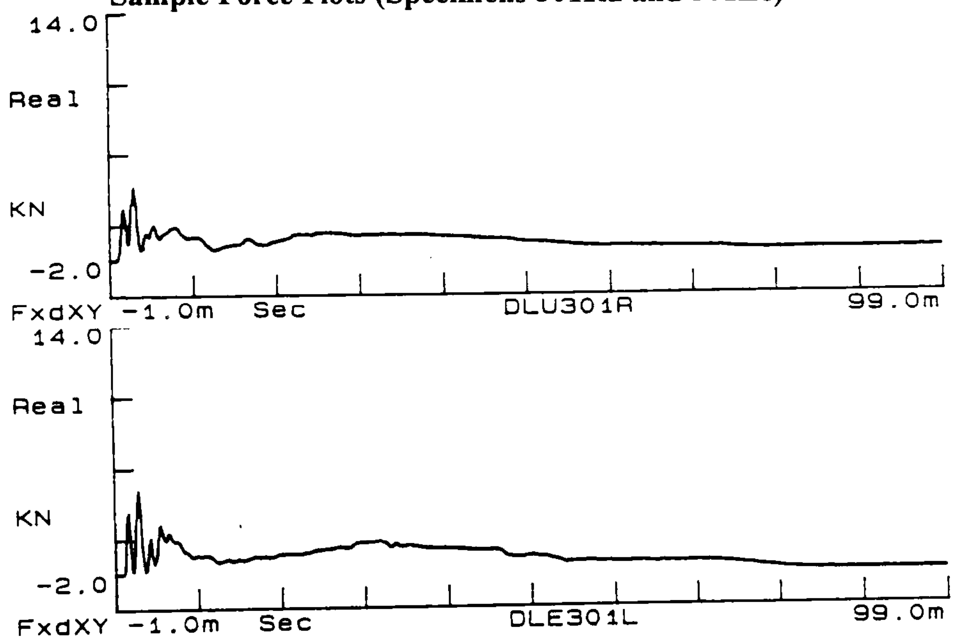


Fig. 2a - Leg 308L. Note the wrapping of this embalmed leg around the impacting pipe. The only lacerations on this specimen were small vertical tears at the interface of the pipe and the shin bone.

Fig. 2b - Leg 301R. This unembalmed leg also wraps around the impacting pipe, but notice the tibia protruding from the posterior aspect of the leg. Overall soft tissue damage was generally greater in the unembalmed specimens.

To reasonably compare the effects of the embalming process on anatomical damage, other experimental variables between matched pairs need to be as similar as possible. As mentioned earlier, matched pairs were selected for use in this study to "factor out" variables associated with differences between humans and careful attention was directed to each test set-up in order to maintain consistency (Unfortunately, set-up differences were evident in the last three tests of unembalmed legs. See **Discussion** section for more detail.). The same impact cart and velocity were used in all tests. Presumably, this would result in similar impact input (forces, accelerations, etc.) to each specimen. The inputs were similar for each test as indicated by the recorded force-time plots. Sample plots from an unembalmed and embalmed specimen are shown in **Figure 3**.

Figure 3
Sample Force Plots (Specimens 301Ru and 301Le)



Discussion

Dissection data clearly indicates that soft tissue damage to fractured embalmed legs was much less than that seen in fractured unembalmed legs. Specifically, damage was greater to the skin, the superficial fascia, muscles and blood vessels; however, the nerves were an exception. In some cases, blood vessels were punctured and large muscle masses were torn for several centimeters, but, to the naked eye, nerves defiantly remained intact. The immediate question is whether this defiance accurately models the live human response to anterior mid-leg trauma. This question is addressed in the following two paragraphs.

1. Perhaps live nerves are rarely transected in mid-leg anterior impacts and the lack of damage seen in this study is appropriate. If so, then the resistance to laceration may be explained by several mechanisms: a) The anatomy of the lower limb may afford nerves a tremendous amount of protection from anterior impacts to the mid-leg. Most of the large nerves are situated posterior to the bones of the leg; therefore, fractures would absorb much of the energy of impact prior to involvement of the nerves. b) Transection may not be the most common mechanism of injury. Stretching is often cited as the cause of central nervous system injuries such as diffuse axonal injury (DAI). Compression of the brain is the primary cause of concussions. Maybe peripheral nerves of the leg are most often injured in similar manners without being torn.

2. If nerve transection is commonly seen after "real-world" anterior mid-leg impacts then there may be factors which were not, or could not be accounted for: a) Live nerves may simply be more fragile than those of a cadaver. b) Perhaps when all of the components of the leg have their normal turgor, the nerves are put in a more precarious position. c) Nerve transection may occur secondary to the impact. This would include violent motion of the fractured limb immediately after impact or improper splinting/transport, etc. It may also include the human body's post-traumatic responses. Nerves may be impaired due to inflammatory processes or vascular compromise, but transection may occur during contraction of the musculature immediately after impact. This natural mechanism may result in laceration of the nerves as they are pinched between sharp bone fragments.

It is believed that differences in the set-up resulted in a slightly different test configuration for the three unembalmed legs that did not fracture. One of these three is shown in **Figure 4**. Films show that these legs were not positioned as upright as the previous ones. Instead, these legs may have been flexed such that an acute angle was formed with the concrete (i.e. the knee was tilted forward). In addition to absorbing the impact in a different manner, this tilt introduced more freedom of movement of the leg with respect to the knee during impact. This would be consistent with medical observations regarding the laxity of intracapsular knee ligaments while the leg is flexed. This was verified in the high speed films. Because of this variation in test set-up the inertial constraints were altered resulting in no fractures.

Figure 4
Impact Resulting in No Fracture

Fig. 4 - Leg 316L. This was the last unembalmed leg to be tested and the third in a row that did not fracture. Note that there is no wrapping around the impactor and some posterior translation at the knee is evident.

Acknowledgement

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DISCUSSION

PAPER: **Dynamic Impacting of Unembalmed versus Embalmed Human Cadaver Leg**

PRESENTER: David J. Porta, University of Louisville

Q: Guy Nusholtz, Chrysler Corporation
I noticed there were some oscillations in your force trace. Was your load washer compensated?

A: I'll direct that to Mr. Kress.

A: Mr. Kress
There were no oscillations on bare bones. We're going through the accelerations of the mass. What we're seeing is partly the effect of the bumper coming out from the car and we're also seeing the slack from interference. It is much harder to get rid of those oscillations on a cool day.

Q: So you don't think there are any problems, especially with the mass of the impact device and the load washer acting as a spring?

A: The mass is fairly low, below a pound and you are talking about the mass of leg.

Q: Thank you.

Q: Jeff Crandall, University of Virginia
I just want to make a comment in terms of the pressurization. You said you had some ideas. I wondered what those ideas were. Were you thinking of putting a marker or dye in?

A: Actually, we tried that in this study and I got some bad advice from some radiologists about the percentages to use. We were trying to use an iodine marker in here at the same time. In the future, obviously we are not going to use a crude embalming machine for pressurization. We've recently hooked up with a cardiophysiologist and he has access to a ventricular-assist device and even a Jarvic 7 artificial heart; so, for future studies, we are hoping to make use of these things where we can regulate systolic and diastolic pressure under a great degree of certainty.
As far as the dye studies go, we are just getting into that. We're hoping to. Yes, that would clearly tell us if we're getting fluid through the impact zone, obviously.

Q: I think you may want to look at your embalming technique too. With formaldehyde, it is actually constrictive, generally. So what you may want to do, what a lot of people do, is, in order to get better distribution, they sort of step the amount of formaldehyde. They embalm initially with smaller concentrations and then step them up. So if you don't get good distribution with the dye or with whatever system you try, you may try that.

A: Well, thank you. We'll look into that.

Q: How about the Winckler fluid? Is there much constriction with that?

A: The Winckler fluid. We do it in two stages, over two days,and we normally adjust the amount of formaldehyde in. So I would suggest with whatever you do, you start with a much lower concentration. You don't want to start with too low a concentration or you get too much water and you throw your osmotic properties off, so it's a fine tailoring system, but if you tracked it with a dye, I think maybe you'd find what the optimal was.

Q: Thank you.

Q: Narayan Yoganandan, Medical College of Wisconsin
What was the rationale for selecting? I assume it is a two meter or a six feet travel after the impact of contact or disbursement? Is that correct? Maybe I missed it.

A: The ram travels just less than two feet as it is pushing the cart and then the cart travels freely on the rail system for less than a meter before impacting the leg.

Q: So you don't have any control as to how much the specimen is being driven in?

A: You're concerned with when we decide to stop the cart?

Q: Exactly.

A: OK. The leg we tested over the past eight years, and we've got it down to a very good science that the leg releases from the bumper before we start the stopped cart. Then, shortly thereafter, we start stopping the cart, so there is minimal interference with our whole system. So a leg is already done its stretch mode, kicked back and released from the cart and then we stop the cart, maybe on the lower left, after the leg and the cart start to settle.

Q: One other question. You said there was a difference between embalmed forces and unembalmed forces in the embalmed legwork. Were they statistically different or they were just different?

A: Yes. They are statistically different. I can't quote you the number right now, but there is not a huge difference, but what you're seeing is a mass cut. We have not been able to detect any statistical difference in the bone factor as far as the peak load in which it sells dynamically. This is simply accelerating masses up to a force and that is what our forces represent, so one would think that a stiffer system would give you a higher force that would be statistically significant.

Q: Maybe you want to take those specimens, if you still have them, and ash them to see what was the relationship, of the force which created the f.acture to the density of the specimen; because, as I saw it, there were different age groups, like forty years to ninety-four years, something like that. So some of them might be due to the age factor. You know, maybe you can eliminate one of them by using the bone, mineral or density estimation.

A: Yes and also an equal part in a lot of these studies has been, and it will be in this particular project too, is to get extremely good anthropometric measurements, including cortex thickness all along shaft bones and that gives us a good feel of level of osteoporosis, level of differences between the left and right leg if one happens to be used more. It may have higher equipment.

Q: As I understand it, none of these legs have some kind of a knee joint replacement?

A: Right. These were all clean legs.

Q: Clean legs. Thank you.

Q: John Melvin, General Motors
I may have missed it, but why are you interested in embalming these legs?

A: Well, it is clearly easier to handle embalmed specimens, so for future studies if we can determine how close the damage is from the embalmed to the fresh, we're figuring it is a little safer to use embalmed material.

Q: I see, because back about 30 years ago when this whole business got started, we were using embalmed cadavers and the feeling was they weren't very representative for a lot of injury situations and we went to the fresh cadaver at that point. Just for many of the reasons that you are finding here. Soft tissues are much too leathery and too stiff and, therefore, do not respond in a similar manner.

Something that I've been interested in, it was shown in studies of embalmed versus unembalmed skull fractures that you do get much more comminuted fractures in embalmed bone.

This is not a strength issue. If you look at the strength of an embalmed bone in a simple tension test, it is slightly higher probably than fresh bone, but the fracture toughness of the fresh bone is dramatically changed by the fixation and when you are talking about the propagation of the crack in a bone, which is what you are calling, "comminution," and which is usually diagnosed as a much more severe injury that is not as comminuted, you need to have bone that is representative of living bone in terms of its fracture toughness, and I think that is why it's probably not a good idea to embalm bone if you are interested in the degree of injury from fracture.

A: Good point, and it's pretty clear, it's true, that embalmed soft tissue is not as good as unembalmed. A lot of our reason or motivation behind doing this study is we and other researchers have had the need or want and desire to infer soft tissue damage from osteological damage, so we have a desire to know: are the bones fracturing similar? We haven't seen the difference as far as the result in fractures in the embalmed, versus what the fragmentation looks like, and the actual fracture when they are doing deep fractures. Now we notice that some didn't here, due to the degrees of freedom in the system. The question that came to our mind with regard to the soft tissue behind it is, does the stiffness, does this different type of mass attachment, actually do something to the beam itself in there, the bone that we care about. Because if indeed a fragile bone is developed and we want it to be used in the hybrid dummies to have frangibility, we want to make sure that the design of that bone is representative live bone. If you want to use any kind of embalmed bone data, which we have a great deal of, we wanted to make sure it is valid use of that data in order to design a bone from. So that was some of our motivation behind doing this work.

Q: Jeff Crandall, UVA

If I could just make a general comment on Dr. Melvin's remarks, I think that there are certain advantages to embalming and I don't think we should lump all embalming together; and I hope that came across in my talk. Certainly, you mentioned the risk of infectious disease can be severely minimized using embalmed tissue and I think there are other advantages that I didn't talk about. You can actually intentionally alter properties, maybe in local regions, which might be beneficial if you wanted to stiffen the neck, for example, just to get kinematics correctly and weren't interested in the injury assessment.

The other thing I wanted to talk about is that I wanted to ask the question: I heard Tyler comment that you still had the specimens and you'd preserved them still or you had them still. I wondered if you could take, perhaps, a bone specimen or one of the soft tissue specimens and do a controlled test on it. Look at perhaps tensile or compressive properties of the bone. Perhaps conduct a tensile test and actually look at the constitutive components of the whole leg and try to break it down that way to try and detail what gave the response differences.

A: We would love to do that. I don't know if we'll do that by the first week of January for the paper, but we would love to do that.

Q: Last question. Just a comment. If you are going to run those tests, do a fracture mechanics test, OK? It's much more involved, but you'd better do one because that's what really controls the description of the fracture of bone. Thank you.

A: Yes. Thank you too.