BOSCOS - development and benefits of a Bone Scanning System

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ABSTRACT

The objective of the BOSCOS (BOne SCanning for Occupant Safety) project was the development of a system that can make an assessment of the bone characteristics of each vehicle occupant in order to estimate their skeletal strengths. The seatbelt and airbag characteristics can then be adjusted to deliver optimum levels of protection specifically for each occupant. A system introduced into every vehicle has the capacity to save lives and reduce injury levels across the whole spectrum of vehicle occupants. This paper describes the contributions from academic and industrial partners to this UK Department for Transport funded project.

Keywords: BONE STRENGTH, FRONTAL IMPACTS, RESTRAINT SYSTEMS, CHEST DEFLECTION, ULTRASOUND

Commercial pressure focuses restraint design on meeting legal requirements for vehicle approval, but legal requirements use dummies which do not represent the range of car occupant shapes, sizes, and driving positions. A person with lower skeletal characteristics may not be able to withstand the current fixed levels of restraint without sustaining injuries. Conversely, a person with greater skeletal characteristics may be capable of withstanding greater levels of restraint.

Possible technologies that are available have been assessed for their suitability to an in-vehicle monitoring system, including health issues. Protocols have been developed and ethical issues addressed in building relationships with Hospital Trusts to integrate the project’s bone scanning activities with routine scanning procedures and hence correlate results across different technologies. Pre-operative in-vivo measurements were then available for tissue samples that could then be tested in-vitro to quantify mechanical characteristics following surgical procedures.

A prototype scanner based on the use of ultrasound technology has been developed for use in an in-vehicle environment to take measurements from one of the phalanges of the hand. Techniques to correlate such measurements with skeletal condition/characteristics have been examined and quantified in order to provide data for the optimisation of a restraint system.

Accident studies have been conducted to create a baseline of statistics (in terms of casualties and their injuries) and to identify scenarios where an optimised restraint technology could be employed to deliver improved safety benefits. Following these, computer based occupant mathematical modelling has been used to establish the potential gains from a working system but also the requirements needed of the restraint systems to achieve these gains. The correlation of computer simulation injury indices with AIS injury risk predictors has enabled a cost benefit analysis to be conducted that shows a reduction in personnel and societal injury costs for a modest outlay in in-vehicle hardware.

Issues relating to the integration of systems based on the prototype equipment have been examined from a technological and consumer acceptance perspective. Whilst technology issues can be addressed, consumer acceptance would need to be tackled on the basis of improved safety benefits and the perception of a high (information) technology fitment (gadget).

This project was developed under the Foresight Vehicle funding scheme in the UK whereby organisations can put commercial considerations to one side since the project has essentially been of a pre-competitive nature. Whilst the basis of the technology has been established and demonstrated by the Partners, exploitation as a commercial venture is in the future when greater refinement has been added to the hardware and software needed as the basis of a BOSCOS based optimised restraint system. In particular, further development of the ultrasound technology and the read across techniques to determine bone strength will be needed to refine the separation of the population into groups with well defined skeletal capabilities.

SKELETAL PROPERTIES

Existing biomechanical data relating to human bone has shown that with old age, there are statistically significant reductions in load carrying capability, when compared with youth (Yamada, 1970). Yamada showed that bones were only able to resist 78% of the mechanical forces applied to them by the age of 70-79, in comparison to their peak at 20-29.

This reduction in biomechanical competence is supported by data from cadaver crash tests, which show that increasing age leads to greater probability of injury in the thorax and abdomen (Kent et al, 2005, Schmidt et al, 1994 a, b).

The reason for this reduction in the mechanical properties is due to a multitude of factors combining a reduction of the overall density, and structural competence (Figure 1), combined with changes in the biochemical makeup of the bone.

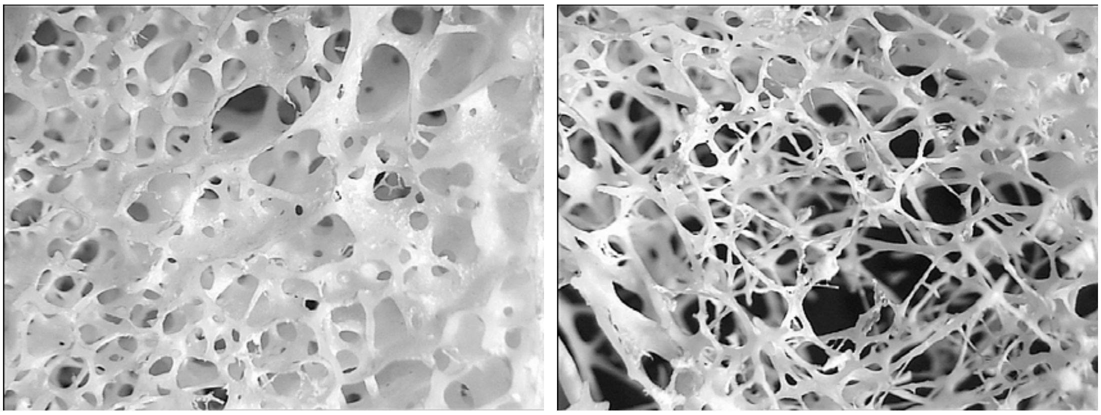

Figure 1. Bone structure of 54 year old female (left) and a 74 year old female (right), spongy bone from the hip, showing the degeneration of both the structure and density.

The easiest parameter for assessment of bone status is the reduction in density. This is the parameter used in the clinical environment for the diagnosis of low bone density and osteoporosis.

There are different systems clinically available for the measurement of the bone density, the technique considered to be the gold standard is dual energy X-ray absorptiometry (DXA). Others are available such as quantitative ultrasound (QUS), magnetic resonance imaging (MRI) and quantitative computed tomography (QCT).

The ultimate aim was to establish specific algorithms and relationships between one of the clinically available techniques so as to accurately predict the condition of the bone based solely on non-invasively acquired data. Existing bio-mechanical data was used as a reference point; however it was anticipated that this was not related quantitatively to the measurements gained from the selected technologies. Data and material was collected during two Winter and one Summer seasons, followed by the material studies on the collected tissue and correlation of the material properties with the clinical work.

THE BOSCOS DEVICE

The prototype system has been developed by McCue plc. using technology from their commercially available CUBA Clinical$^{\text{TM}}$ system – an ultrasound system offering weight benefits and minimal health risks. The system is designed to assess the proximal phalangeal bone of the hand (Figure 2). The reasons for the selection of the finger, and in particular the proximal phalanx bones, for the measurement site are two fold. Firstly the proximal phalanx is used in clinical tests as a means of assessing a patient's bone status, and has been shown to have an ability to predict fracture risk (Ekman, 2002). Secondly it is the most readily available site for assessment of an individual in a car.

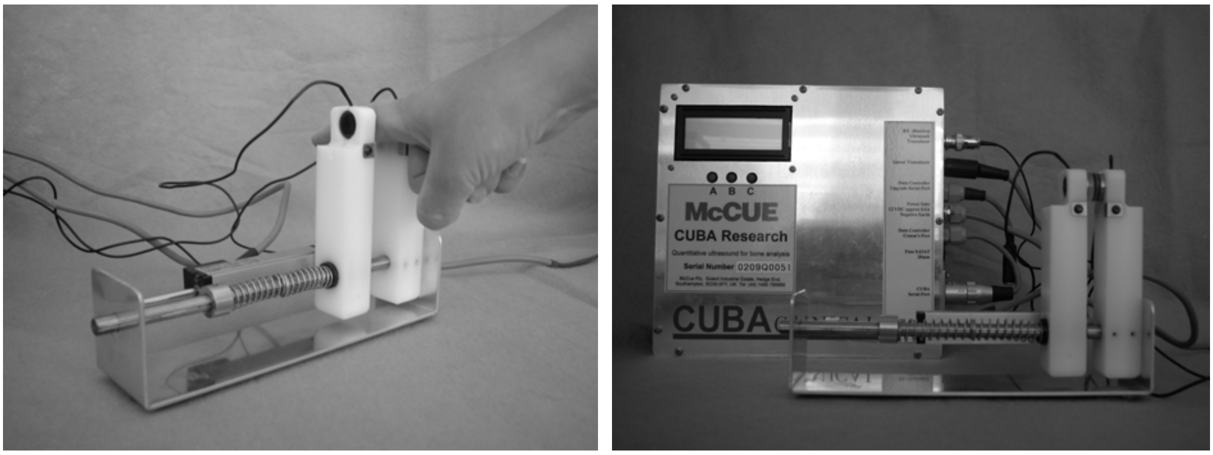

Figure 2. The BOSCOS Ultrasound Device

The system works by positioning two ultrasound transducers either side of the finger and an ultrasound pulse is transmitted between the two transducers through the finger. From the received pulse information on the condition of the bone can be determined from the amplitude of the received wave, and the time taken for the wave transmission through the finger. The prototype system was used to perform investigation on 102 subjects (7 males, 95 females) aged between 24 and 85 years of age (mean: 57 years). 10 waveforms were obtained from each individual, and analysed to give parameters relating to:

- The time incident of the first of the four greatest peaks assessed.
- The time and amplitude difference between the first and second peaks.
- The time between the first and fourth greatest peak.
- The area under the waveform.
- The amplitude of the biggest of the four peaks. (The maximum amplitude).

These parameters were used alone and in combination for the prediction of the bone status of the axial skeleton, as determined by DXA. The results showed that the best combination of the ultrasound parameters with inclusion of an individual's age and weight, enabled the BOSCOS system to predict the status of a persons bone with an R^2 of not better than 50% (R^2 reflects the percentage of variability in the data that can be explained by the regression model). This is as good an R^2 value as those of the various clinically used commercial systems although such systems work without need of knowing the age and weight of the subject. When the prototype's best combined parameter (ultrasound+age+weight) was statistically analysed to assess the sensitivity and specificity of the prototype system, the prototype achieved AUC (area under curve) values in the region of 0.73-0.80 for the system's ROC (receiver operator characteristic) curve. Kent R, Patrie J (2005) have provided guidelines for the utility of discriminatory tools, based on AUC values of ROC curves. Systems with AUC below 0.7 can be considered to have little or no utility, in between 0.70-0.80 moderate utility; and in between 0.80-1.0 good utility. The BOSCOS system as it stands at the moment, shows a moderate level of diagnostic ability. But with the implementation of alternative superior (and more expensive) ultrasound transducers the diagnostic ability of the system will improve.

TISSUE ASESSMENT

To investigate the relationship of clinical ultrasound and the biomechanics of human bone femoral heads were collected from 20 osteoporotic individuals undergoing hip replacement surgery due to broken necks of femur and 8 arthritic individuals undergoing elective surgery. Each individual was assessed using a CUBA Clinical system and a Sunlight Omnisense, to supply information on the bone status at the distal radius, proximal phalanx of the middle finger, mid-shaft tibia and calcaneus. The Sunlight Omnisense system had to be used instead of the BOSCOS prototype for ethical reasons. All scans were performed within three days after the operation had been performed.

Cores, 9mm in diameter, were taken from femoral head of each individual. The cores were cleaned of any marrow and fat using a high pressure water jet and washing in a 1:1 mixture of chloroform and methanol. Each core was then assessed for apparent and material density as well as porosity using the Archimedes principle and volume measurement using a micrometer. Each sample was then extended in length by the addition of a hard wood cap on either end (Figure 3).

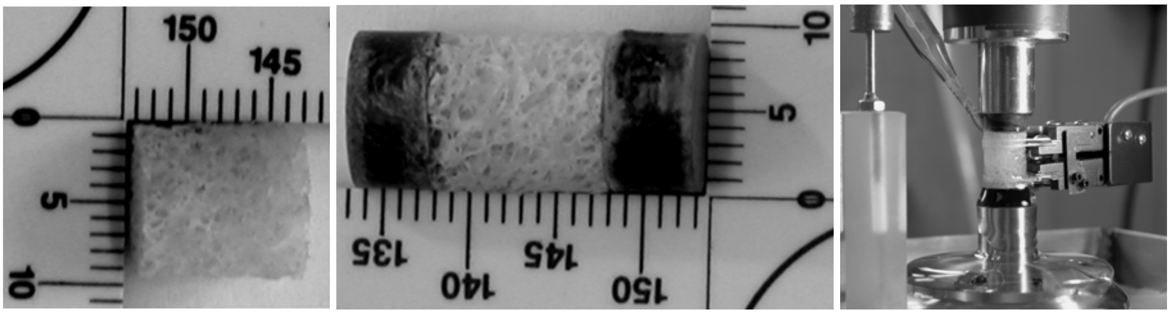

Figure 3a, b, c. Compression sample and test rig design.

Positioning of the samples between the platens was ensured by a 1mm deep depression on both loading platens, which constrained the samples and ensured that the sample was vertically aligned. The samples were preconditioned sinusoidally at 1Hz and a stroke of 50 microns and then tested in compression at a rate of 0.15mm s^{-1} (strain rate ~ 1% s^{-1}). In order to gain data relating to the change in length of the specimen during testing three transducer readings were used: (i) a miniature extensometer with a 6mm gauge length, was attached directly to the sample surface; (ii) a Linear Variable Differential Transformer (LVDT) attached between the loading platens; (iii) another LVDT was built into the testing rig to control stroke motion.

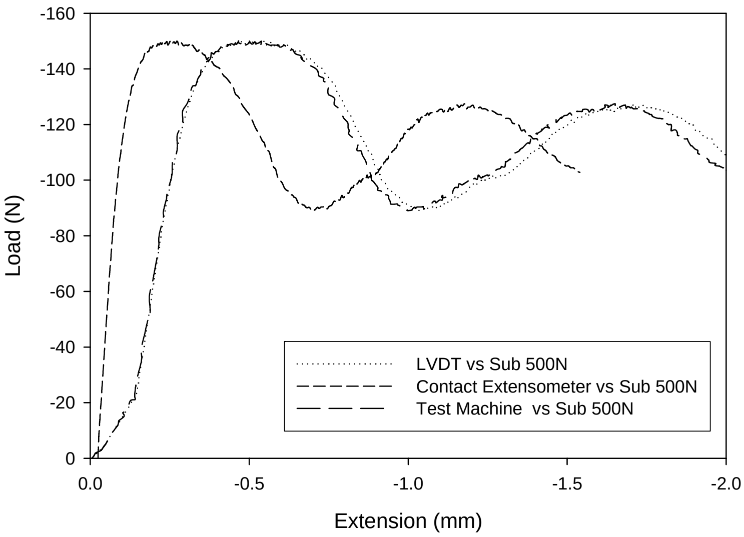

Figure 4. Comparative output of force/deformation curves from the 3 extension transducers.

From the resultant load extension curves (Figure 4) it was possible to obtain reliable values of Young's Modulus, yield and failure strain and yield and failure stress.

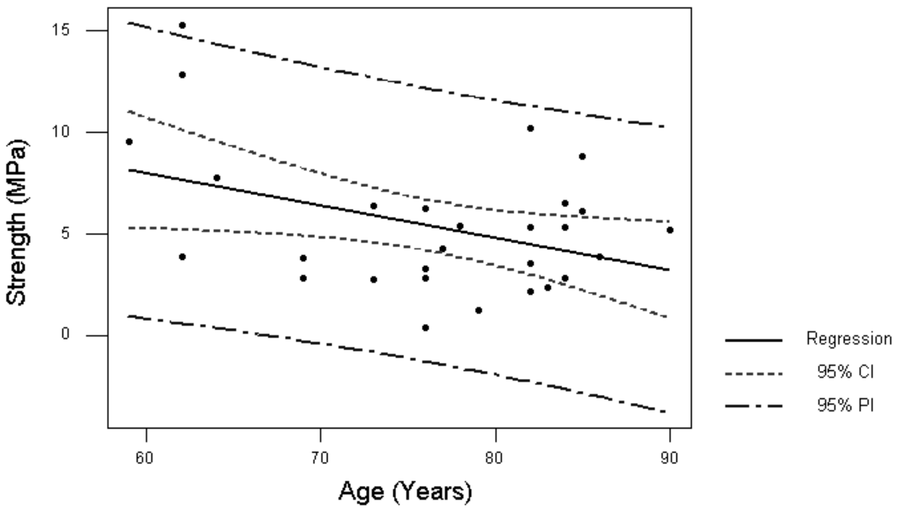

Figure 5. Comparison of strength with age.

Note: 95% CI represents the 95% confidence intervals, which provide information of the range of possible values for a data set, with 95% of the results falling within these bands.
95% PI represents the 95% prediction intervals, which provide boundaries into which 95% of any new values added would be predicted to fall.

Figure 5 shows a clear reduction (statistically significant, $p<0.05$) in the strength of the trabecular bone in relation to age. When the strength is compared against the ultrasound assessment of the proximal phalanx (Figure 6) a positive statistically significant ($p<0.05$) relationship is seen between the two variables.

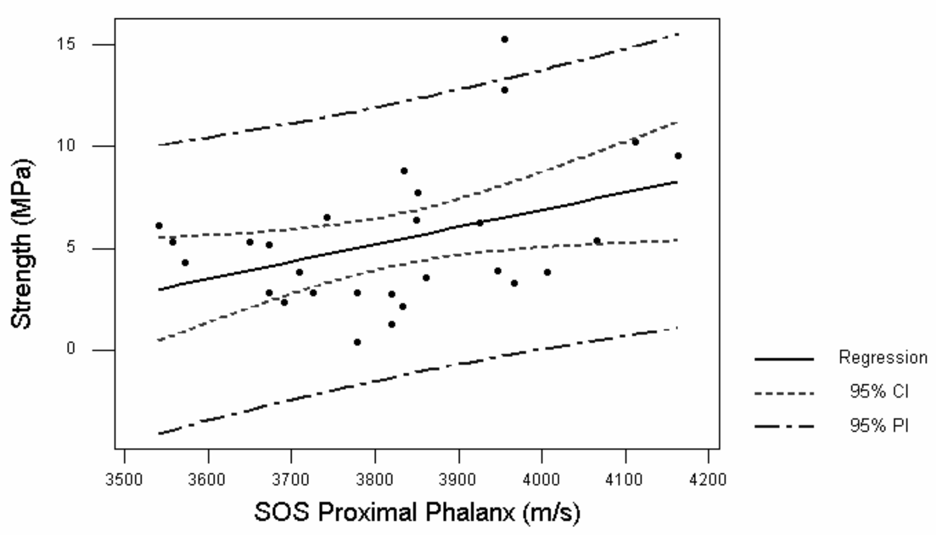

Figure 6. Comparison of strength with speed of sound measurements from the proximal phalanx.

	Age	*Distal Radius*	*Proximal Phalanx*	*Mid-shaft Tibia*	*BUA* Calcaneus*	*SOS Calcaneus*
Ultimate Strength	-0.387	0.362	0.403	0.221	0.307	0.372
	(0.038)	(0.054)	(0.033)	(0.259)	(0.105)	(0.047)
Young's Modulus	-0.016	0.178	0.349	0.183	0.152	0.221
	(0.933)	(0.357)	(0.068)	(0.351)	(0.431)	(0.249)
Yield Strength	-0.395	0.311	0.414	0.209	0.357	0.444
	(0.034)	(0.1)	(0.029)	(0.287)	(0.058)	(0.016)

*** BUA – Broadband Ultrasound Attenuation, a measure of the attenuation an ultrasound signal undergoes as it passes through the bone. The quality of the bone affects the level of attenuation.**

Table 1. Pearson's correlation coefficients (p-value) between age, clinical ultrasound measurement values and biomechanical parameters (grey cells, p<0.05).

Similar results (Table 1) were observed for the other clinical measurements versus the ultimate and yield strength, and modulus of elasticity values, however only the proximal phalanx and SOS of the calcaneus achieved any level of statistical significance. The results show that ultrasound assessment of the phalanx has the potential ability to predict the mechanical properties of the axial skeleton.

REAL-WORLD INJURY ASSESSMENTS

REAL WORLD in-depth crash injury data was used to identify the types of crashes and occupants who would most benefit from the BOSCOS system and to determine the injury/cost reduction benefits of such a system. The accident data provided a basis for the modelling of the current injury situation. This baseline was the starting point from which to assess the potential effectiveness of modified restraint systems. The real-world data was collected by the UK Co-Operative Crash Injury Study (CCIS), which samples accidents based on vehicle age and injury outcome (Mackay et al, 1985). To enter the sample, an accident must include at least one towed car less than seven years old in which an occupant was injured. The data are also collected within a stratified sample which is biased towards 'fatal' and 'serious' injury outcome. Of all crashes occurring in the geographical sampling regions, approximately 80% of all fatal and serious accidents, and 10-15% of slight injury crashes are investigated.

Because the CCIS sampling is biased toward serious and fatal injury outcomes, it was necessary to weight the data so that it was representative of the whole population of injury, tow-away accidents. To do this, weighting factors were calculated which correct the under-representation of slight injury accidents. Accidents which occurred between 1995 and 2005 were examined.

IMPACT TYPE: Initially, it was intended to examine as many different impact types as possible. 73% of belted front seat occupants who sustained an AIS 2+ injury were involved in either frontal or side impacts. Impacts such as rollovers and under-runs were not considered, since not only is occurrence of these impact types low, but mathematical modelling of such impacts is difficult due to their inherent variability. Although side impacts make up around 23% of occupants with MAIS 2+ injury, it was decided not to attempt to apply the BOSCOS system to side impacts at this stage and to restrict the investigation to frontal crashes only, which still covered 57% of the MAIS 2+ occupants in the database. However, it was anticipated that the application of BOSCOS to side impacts could provide the basis for further development work in the future.

BODY REGIONS AND TYPES OF INJURY: The next stage of problem definition was to identify the body regions and types of injury that were most likely to be mitigated with the introduction of a BOSCOS system. Since the basis of such a device was to adapt the restraint system according to the skeletal strength of the occupant, it follows that skeletal injuries are those most likely to be reduced. Obviously a reduction in skeletal injury resulting from "softer" restraints is also likely to be accompanied by a reduction on the occurrence of soft tissue injuries, although the exact influence on these types of injuries will be harder to determine.

Figure 7 shows the location of skeletal injuries for belted drivers with airbags (Lenard et al, 1998a). It is clear that the body regions of concern in this context were the chest and extremities. Since injuries to the chest are likely to pose a higher threat to life than those to the extremities, AIS 2+ chest injuries provided the focus for the initial development of BOSCOS.

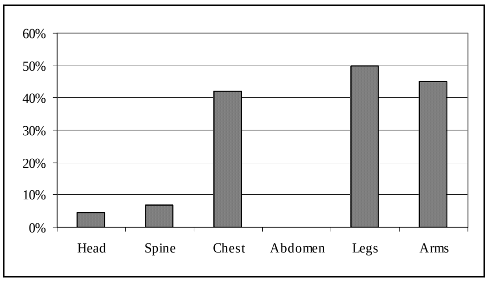

Figure 7. Location of skeletal injury for belted drivers with airbags

The BOSCOS sample consisted of 4821 belted drivers in cars equipped with airbags and pretensioners involved in frontal crashes. Table 2 shows the distribution of maximum chest injury severity for those drivers.

Chest AIS	N	%
0	2927	60
1	1590	33
2+	304	7
Total	4821	100

Table 2. Maximum Chest Injury Severity for Belted Drivers (weighted data)

304 drivers sustained AIS 2+ chest injury. 214 (70%) had sustained their injuries from the seat belt. Injury causation for the remaining 30% was unclear and likely due to a combination of mechanisms. The BOSCOS system would benefit these drivers as well but to a more limited extent. 71% of all serious (AIS 2+) chest injuries were fractures to the ribs or sternum. In crashes where the crash severity is known, as determined by an ETS calculation, 75% of injuries occurred at speeds lower than 56km/h, the current basis for legislative testing. ETS is the vehicle delta v, calculated on

the assumption that deformation was caused by impact with a fixed rigid barrier (Lenard et al, 1998b). Since 96% of these cases below 56km/h sustained little or no facia intrusion (<4cm) it is clear that there is the potential for an adaptive restraint system to provide significant benefit to chest injury risk.

OCCUPANT TYPES: It is widely accepted that human bone strength decreases with age, and as such it is expected that the benefits of a BOSCOS system will be of greater magnitude to the elderly. With the ageing population of the UK, the societal benefit as a whole will increase as more and more older drivers and passengers become exposed to the increased risk of injury attributable to a decrease in bone strength. It is expected however that a BOSCOS system will also be of benefit to younger occupants with weaker bone structures. The ability of the BOSCOS system to measure bone strength means that sufferers of conditions such as osteoporosis will be detected and the restraint system tailored to them as much as is practicable.

ACCIDENT MATRIX

The BOSCOS target group consisted of 214 drivers with AIS 2+ chest injury from the seat belt. This group was used as the basis for the next stage of the work – development of a matrix of accident scenarios to be replicated with mathematical models.

One of the limitations of mathematical modelling is that models have to be validated by full-scale crash tests to ensure that the results produced are valid. Since the motor industry has a need to optimise performance for legislative and consumer tests, there is no guarantee that extrapolating the models outside these types of impact will produce valid results. For this reason, the BOSCOS target group was categorised into the following impact types (scenarios) to represent the crash conditions associated with AIS 2+ seat belt injury. The percentages in brackets show how much of the target group was covered by each scenario.

- Full overlap – Greater than 85% overlap. ETS between 25 km/h and 45 km/h (40%)
- Offset – Less than 55% overlap. ETS of 28 km/h (31%)
- One chassis rail plus engine - An overlap of 75% and ETS of 40 km/h (24%)

BASELINE MATHEMATICAL MODELLING

A series of mathematical modelling studies were conducted to investigate the four accident scenarios. Madymo models were developed for two vehicle sizes to represent typical driver configurations - vehicles A (small size) and B (large size).

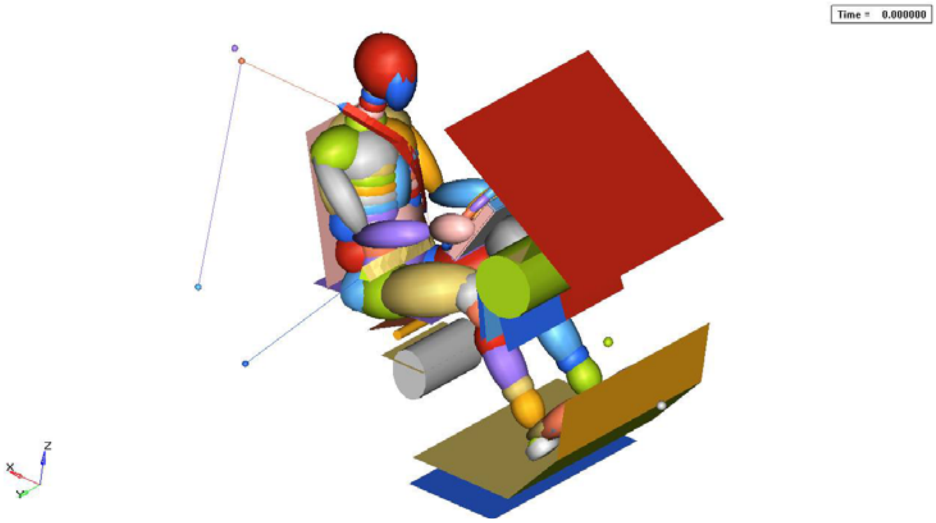

Figure 8. Madymo Model Set-Up

A Hybrid III dummy model was used with a seating and interior design unique to each vehicle together with the standard airbag and three-point seatbelt systems. For vehicle A, a seat belt load limiter value of 6kN was selected for the baseline simulations (Figure 8).

The models were able to predict the levels of acceleration, belt loads and trajectories of body parts. For each different configuration these criteria provided an indication of the severity of the crash pulses.

The base line simulation results for the four scenarios are shown in Table 3. The 45kph scenario gives the highest HIC and CTI calculation, whereas the 28kph 55% offset gives the lowest injury indices.

Base	45kph	25kph	40kph	28kph
	100%	100%	75%	55%
HIC	392	66	271	65
Head Accel.	565	246	494	222
Upper Torso Accel.	377	241	365	206
Lower Torso Accel.	523	275	493	252
Sternum Deflection	29.1	22.1	28.4	22.1
CTI calculation	0.73	0.50	0.71	0.46

Table 3. Baseline Results

ASSESSMENT AND VALIDATION OF CHEST INJURY RISK

It was necessary to provide a method of read across from simulation output to a real injury value using injury risk curves in order to give an estimate of real-world benefit for the BOSCOS system. For chest injuries the simulations provided dummy chest deflection, acceleration and the Combined Thoracic Index (CTI). The CTI is a measure of chest injury severity based on a combination of chest compression and acceleration. Injury risk curves for each parameter were derived from data provided by NHTSA (Eppinger et al, 1999). Table 3 shows the predicted injury risk from each of these parameters compared to the risk from accident data. The accident data was focussed into groups which very closely matched the simulated scenarios both in terms of front overlap and crash severity.

	Vehicle A			Vehicle B			Real Crashes	
Impact Type	2+ risk acceleration	2+ risk chest deflection	2+ risk CTI	2+ risk acceleration	2+ risk chest deflection	2+ risk CTI	2+ risk accident data	ETS range km/h (N)
45 km/h 100%	68%	35%	33%	66%	37%	30%	24%	40-50 (63)
25 km/h 100%	52%	27%	11%	46%	28%	9%	6%	20-30 (184)
40 km/h 75%	68%	34%	33%	54%	37%	19%	20%	35-45 (59)
28 km/h 55%	45%	26%	9%	43%	32%	9%	10%	23-33 (188)

Table 4. Predicted versus Real Risk Of AIS 2+ Chest Injury

Table 4 shows the CTI giving a much better approximation to real world injury risk than either acceleration or deflection alone. For both vehicle simulations, acceleration and deflection appear to overestimate the risk of AIS 2+ chest injury. CTI was therefore the chest injury measure of choice for assessing the benefits of BOSCOS.

PARAMETRIC MATHEMATICAL MODELLING

Using the vehicle A baseline mathematical model a number of different simulations were executed to evaluate different seatbelt load limiter settings, different airbags and pre-tensioner settings. One of the changes was made to the load limiter value to reduce the load level to 2kN. By reducing the load limit the chest was not expected to experience a severe loading from the seatbelt and it would allow the seatbelt to pay-out more webbing when compared to the baseline simulations.

For the higher speed scenarios the extra pay-out of the seatbelt did not improved the indices with the CTI increasing to 0.97 for the 45kph scenario (Table 5). However at the lower speed scenarios the CTI has decreased from 0.46 to 0.35.

2kN	45kph	25kph	40kph	28kph
	100%	100%	75%	55%
HIC	336	68	357	61
Head Accel.	571	248	536	231
Upper Torso Accel.	569	207	450	159
Lower Torso Accel.	534	359	502	253
Sternum Deflection	30.8	19.2	30.8	16.7
CTI calculation	0.97	0.43	0.83	0.35

Table 5. 2kN Load Limiter Results

The load limiting value could be modified for different crash pulses, although as has been shown by these simulations it would be of most benefit at the lower crash speeds. With information regarding the skeletal strength of the occupant the restraint system could make a decision to change the load limiting value at an appropriate time through the crash cycle, not necessarily at the start of the impact. The drop in CTI value is an example of how a BOSCOS type system can reduce the injury indices for a specific crash pulse by selecting a 2kN load limiter in preference to the standard 6kN value. The example of the 2kN load limiter change in dummy indices has been developed later on in this paper to show how the change of CTI level influences a change in AIS level over a number of real world accidents.

BOSCOS BENEFIT STUDY

INJURY RISKS: The benefits of the BOSCOS system were measured in terms of both a reduction in injury risk and a corresponding reduction in injury costs. Seat belt performance parameters were changed in the simulations of crash conditions causing AIS 2+ chest injury to real drivers. The belt system giving the lowest risk of AIS 2+ injury for older drivers was then chosen and fed into the accident data to give an indication of optimum benefit. The NHTSA risk curves (Eppinger et al, 1999) for CTI are based on the 50% probability of risk for cadavers adjusted down to a 25% probability for the driving population. For BOSCOS, the chest injury risk curves were adjusted back to the injury probability for cadavers to give an indication of risk for people with weaker bones (Figure 9).

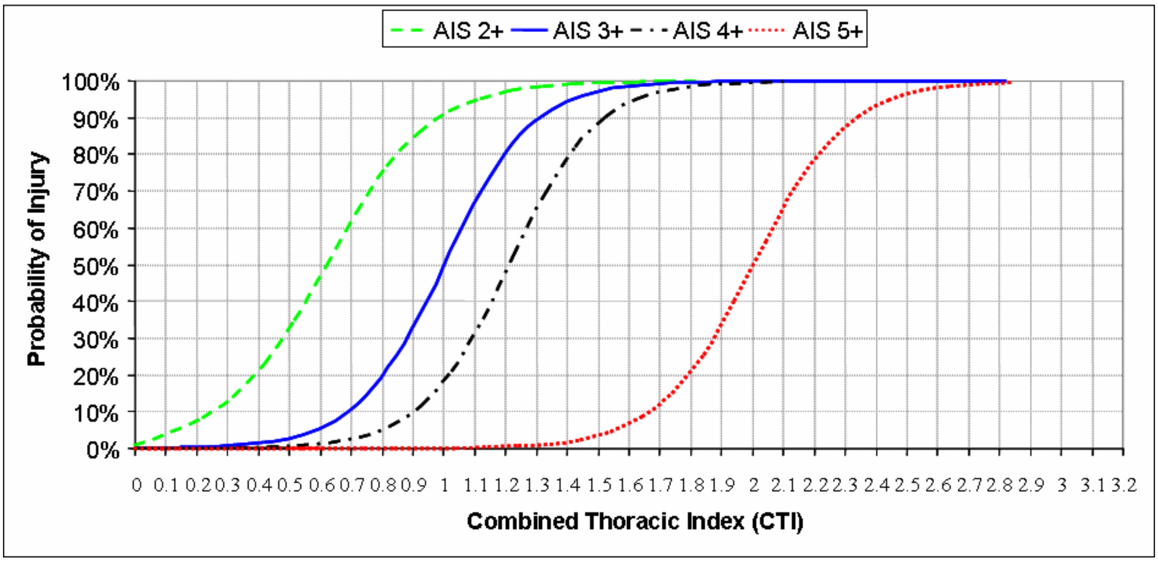

Figure 9. Chest Injury Risk Curves for Weaker Bones

Simulation results showed that employing a 2kN load limiter in low speed crashes gave the greatest risk reduction in AIS 2+ chest injuries for persons with weaker bones. Figure 10 and Figure 11 show the injury risks for a 2kN load limiter compared to those for other seatbelt types in low speed crashes. It can also be seen that head and thigh injury risks are predicted as negligible in the low speed crashes, irrespective of the belt system used.

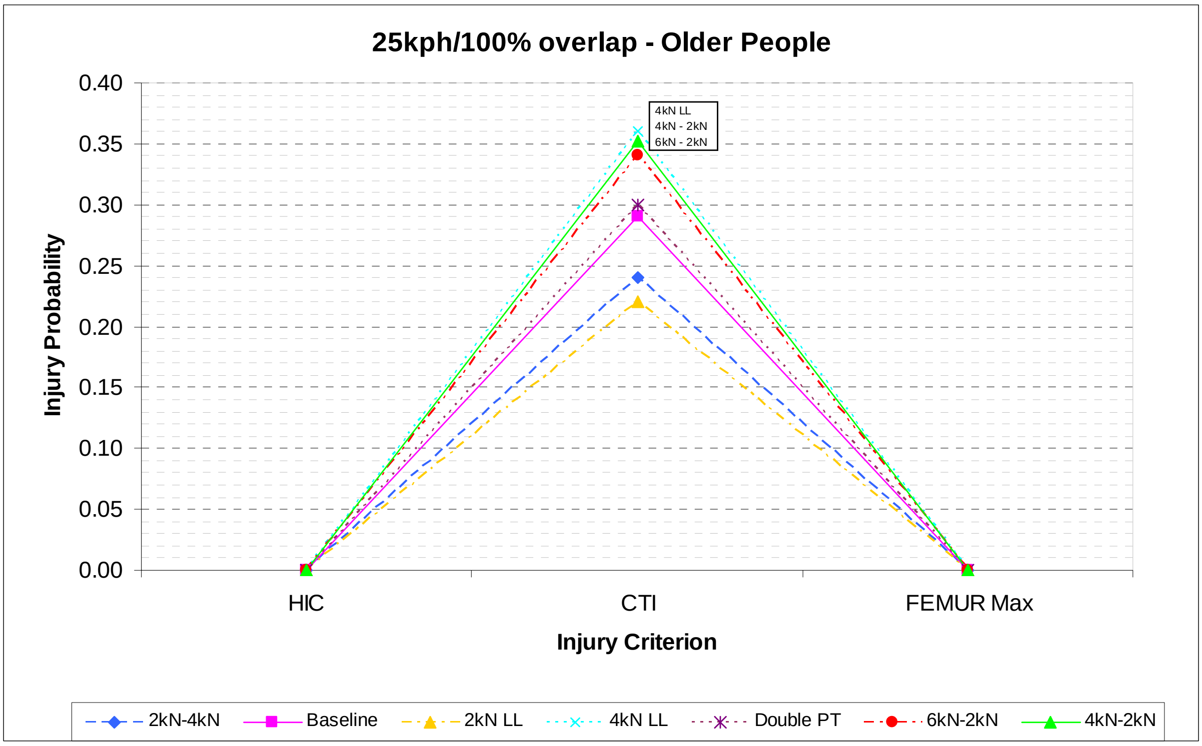

Figure 10. Injury Risk for Weaker Boned Persons in 25 km/h Full Overlap

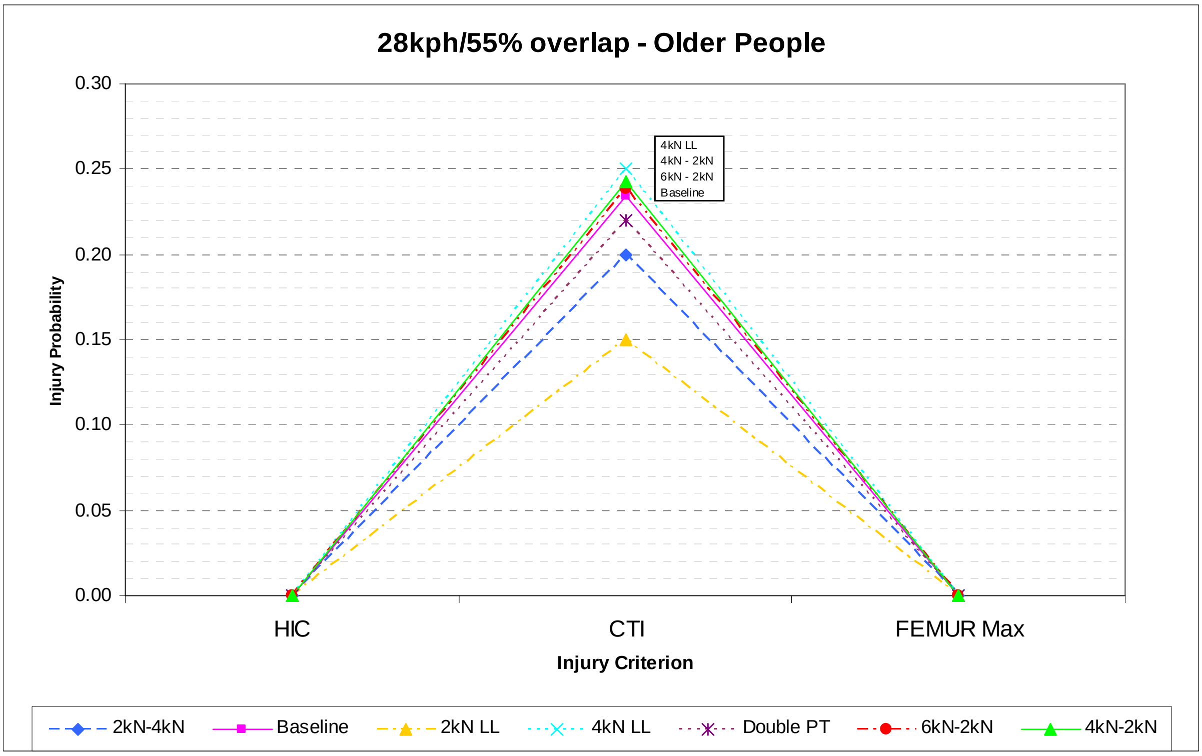

Figure 11. Injury Risk for Weaker Boned Persons in 28 km/h Offset

Although the AIS 2+ chest injury risk was lowest using the 2KN load limiter, the benefits calculation required the most probable injury outcome in terms of a discrete AIS level injury. A technique developed in the European Commission VC Compat project (VC-COMPAT, 2003) was used to determine the chest AIS for weaker boned people in the simulated low speed crashes. The calculation is shown in Figure 12.

Expected AIS level

$$E(X_{CTI}) = \sum_{i=1}^{6} w_i P_{wi}(X_{CTI})$$

$E(X_{CTI})$ = Expected AIS score for injury X_{CTI}
X_{CTI} = Injury criterion value X_{CTI}
W_i= Discrete value of AIS level (e.g. $W_2 = W_2+ - W_3+$)
$P(X_{CTI},W_i)$ = Probability of injury criterion value X_{CTI} at given AIS level W_i, e.g. $P(1,W_2) = P(1,W_2+) - P(1,W_3+)$

Figure 12. Calculation of Discrete AIS level

CTI values for the low speed simulations suggest that weaker boned persons would likely receive only AIS 1 chest injury with a 2KN load limiter. Therefore, it was assumed that, in the real crashes represented by the low speed simulations, AIS 2+ chest injuries for men over 60 and women over 50 could be reduced to AIS 1, if bone strength was known and a 2KN load limiter deployed. This change in injury outcome was used to show the potential benefits of BOSCOS for the whole population of drivers with AIS 2+ chest injury from the belt.

The benefits of changing the restraint system parameters were not as apparent in the higher speed simulations. To give a predicted chest injury outcome of AIS 1 in those impacts, the necessary reduction in CTI for the best performing restraints was calculated. Changing CTI from 0.67 to 055 in the 40 km/h model and from 0.71 to 0.53 in the 45 km/h model would show an enhancement of the system by benefiting higher severity crashes in the accident population. This change was used to show the benefits of an Enhanced BOSCOS system for the whole population of drivers with AIS 2+ chest injury from the belt.

Figure 13 shows the potential real-world benefits of BOSCOS and an Enhanced BOSCOS system compared to the current baseline risk of AIS 2+ chest injury from the seat belt.

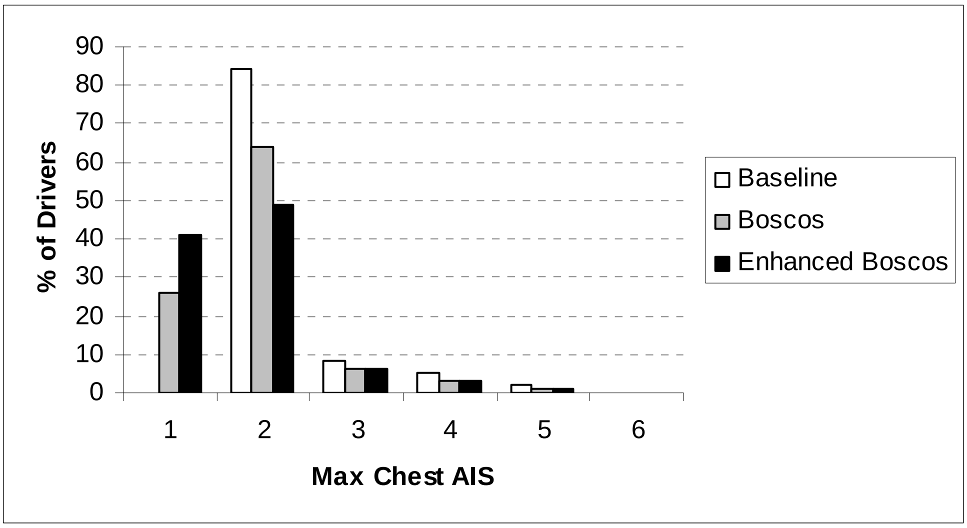

Figure 13. Injury Reduction Benefits for Drivers with AIS 2+ Chest Injury from the Seat Belt (N=214)

There is a clear indication that tailoring belt performance to bone strength could give injury reduction benefits. Figure 13 shows that a sizeable number of AIS 2 chest injuries could be downgraded to AIS 1 utilizing BOSCOS in low speed impacts. Additionally, there would also be some benefit for the small number of drivers with more serious chest injury. Reductions to chest loads in higher speed impacts gives additional benefit. Under those circumstances however, care would be needed to ensure head injury protection was not compromised.

INJURY COSTS: Evaluating changes in injury costs gives a measure which can be used to offset costs incurred by proposed BOSCOS systems. Several cost benefit scales were considered including HARM (Malliaris et al, 1985, Miller et al, 1991). HARM was not considered because injury costs in Europe do not exist in an appropriate usable form. Instead, the ‘Willingness to Pay’ approach was used (Hopkirk and Simpson, 1995). This approach enables the calculation of the human cost of serious and slight injuries. A Standard Gamble questionnaire was used to carry out a survey, asking people how much they would be willing to pay to reduce the risk of injury, relative to the cost of a fatality (Road Casualties Great Britain, 2002). The respondents were also asked to specify the level of risk at which they would opt for treatment of an injury. It was then possible to convert the survey results into values relative to the cost of death and as a percentage value of death. Therefore the human cost of each injury state can be expressed as a percentage of the human cost of a fatality. Human costs do not include medical and support costs, lost output of the individual, or accident damage, although these can also be calculated. ‘Human costs reflect the non-resource element of the cost of road accident casualties; the pain and distress suffered by accident victims, their family and friends, and in the case of fatalities, the intrinsic loss of enjoyment of life, beyond the consumption of goods and services.’ (Hopkirk and Simpson, 1995.)

The serious and slight injury states considered are shown in Table 6.

Injury State	% of death	(2002 prices)
Recover 3-4 months (Out-patient): F	2.0	£24,998
Recover 3-4 months (In patient): W	2.0	£24,998
Recover 1-3 years (in-patient): X	5.5	£68,744
Mild permanent disability (Out patient): V	5.5	£68,744
Mild permanent disability (In patient): S	15.1	£188,733
Some permanent disability with scarring: R	23.3	£291,224
Paraplegia/quadriplegia: N	100	£1,249,890
Severe head injuries L	100	£1,249,890
Cost of UK road accident fatality		£1,249,890
Whiplash		£43.944
Other Slight injury		£8,966

Table 6. Injury State Costs

It was possible to map the individual chest injuries in the BOSCOS sample onto the costing scale (VSRC Injury Costings, 2005). All except two of the database chest injuries can be attributed to the AIS level costs shown in Table 7. This enables the calculation of the cost of a chest injury, based on its AIS level. Multiplying the cost of the maximum chest injury severity by its occurrence allows the chest injury cost comparison shown in Table 8.

Example	AIS Level	2002 Cost
Rib Fracture	1	£8,966
Sternum Fracture	2	£24,998
Unilateral Lung Contusion	3	£24,998
Flail Chest	4	£68,744
Tension Pneumothorax	5	£68,744

Table 7. Cost of Thoracic Injuries in BOSCOS Dataset by AIS Level

AIS level	Baseline	BOSCOS	Enhanced BOSCOS
1	£0	+ £502,096	+ £780,042
2	£4,524638	- £1,124910	- £1,899848
3	£449,964	- £99,992	- £99,992
4	£756,184	- £343,720	- £343,720
5	£274,976	- £137,488	- £137,488
Total (£)	6,005762	4,801748	4,304756
Total (€)	8,708355	6,962535	6,241896

Table 8. Cost Benefits of BOSCOS System & Enhanced BOSCOS System

Table 8 shows that had a BOSCOS system been implemented in the data sample areas, over the time frame studied and for the types of crash and vehicles considered then around 1.7 million Euro would have been saved due to chest injury costs. BOSCOS implementation in higher speed crashes would have improved the cost saving by a further 0.7 million Euro.

DISCUSSION

The BOSCOS project was an initial investigation into the possibility of in-car scanning to deliver more optimally adjusted restraint systems for individual occupants' biomechanical limits. The prototype scanner is just that, a prototype and further development will be needed to improve signal resolution and achieve a miniaturised version that can be successfully integrated into a vehicle at each occupant seating position. The development of a larger database would improve read across from the phalangeal scan to the skeletal capabilities of the ribs. In addition, the number of computer simulations conducted was lower than the number a restraint system manufacture would conduct to fully optimise a product for a particular vehicle.

Nevertheless, the estimate of BOSCOS benefits show a 20% reduction in injury costs if the system were to be implemented for women over 50 and men over 60 in low speed crashes. That in itself is a substantial benefit for a restraint system. In addition, were the system to be implemented in higher speed crashes, then the benefits would rise to 28%.

These savings however are quite probably an under-estimate of BOSCOS benefits because they were calculated only for the CCIS sample of crashes. If we were able to take account of the whole of the UK and the rest of Europe and include benefits for younger, weak boned drivers, then add a factor for the increase in numbers of elderly car drivers over the next two decades the BOSCOS potential could be very substantial indeed. The Organisation for Economic Co-operation and Development estimate that, in western countries by the year 2030, one in every four persons will be aged 65 or over (Morris et al, 2002). It is estimated that, over the next three decades private car travel by this sector of the population is likely to increase at a rate consistent with growth in the number of older adults in the population as a whole.

CONCLUSIONS

The BOSCOS project has set out to identify the best means of calculating the bone strengths of vehicle occupants. The ultrasound technology has been selected as the most effective and safe tool to use and highlighted its benefits through scans of human subjects. Different ultrasound devices have been evaluated and a new prototype devise has been built which could be adapted for in-car use. Real world vehicle accident data has been assessed to determine which accidents are causing chest injuries. A number of accident scenarios have been selected and they have been used in the mathematical modelling. New restraint technologies have been identified which could be enhanced with the addition of BOSCOS type technology and demonstrated to have lower injury risk potential. A method has been established to map dummy indices to real-world injury risk by AIS levels. Furthermore, the risk levels have been associated with costs which showed that a BOSCOS system can provide a saving in chest injury costs.

CCIS – acknowledgment.

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