

DEVELOPMENT AND ASSESSMENT OF A BONE SCANNING DEVICE TO ENHANCE RESTRAINT PERFORMANCE

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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.

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 for an in-vehicle monitoring system. Accident studies have been conducted to create a baseline of statistics in terms of casualties and their injuries. Initial bone scanning studies have utilised different types of

equipment and a new prototype scanner has been developed for use in a vehicle environment using ultrasound technology.

Computer based occupant mathematical modelling has been used to establish the potential gains from a working system and also the requirements needed of the restraint systems to achieve these gains. In addition, bone scanning has been conducted, to determine a method to read across from scan values to skeletal condition to provide data for the optimisation of the restraint system.

BOSCOS OBJECTIVES

Background

Over the last decade the quest to improve the levels of vehicle safety has intensified dramatically and is now used as a sales feature by marketing departments. But as the criteria for vehicle crashworthiness have changed from vehicle deformations and decelerations to occupant related parameters (body accelerations, forces, deflections, etc.) a recognition of the implications of human diversity has been slow. This is illustrated by the fact that whilst there are child and adult anthropometric devices (dummies) available for use in vehicle testing, in the case of vehicle type approval (certification) test requirements are defined solely for a 50th percentile adult male driver representation. Consequently, it is easy to perceive that the safety systems in motor vehicles

are developed, tested and approved for optimum use by a narrow band of the driver population whose physical characteristics are not representative of the whole of the driver population.

With the mass of sensors that are now beginning to appear in motor vehicles, the ability to determine information about the driver, e.g. an indication of their mass, the position of the seat and the position of the driver on the seat, is much greater. However, even those parameters that can now be quantified give only limited information that can be used to extend the narrow optimum occupant protection band to a greater proportion of drivers. To successfully extend this band we need to have more information about the individual occupants of each car if they are also to be better protected. The type of information that is needed concerns the physical injury tolerance limits of each individual so that the restraint systems can be 'tuned' by on-board processing to deliver the optimum protection for a specific crash/impact event. This means that the maximum levels of protection can be delivered for each vehicle occupant improving the likelihood, not merely of survival, but of minimal injuries.

A preliminary assessment of technologies such as a "smart personal card" or a button transponder reveals considerable opportunity for misuse and inappropriate settings of the restraint system. The BOSCOS project (BOne SCanning for Occupant Safety) focuses on the development of a fully passive system which will ideally operate without the positive action of the seat user. The BOSCOS project is a Foresight Vehicle Project funded by the UK Department for Transport (DfT).

The intention of the Foresight programme is to bring together UK resources and expertise to create components and systems for the vehicles of the future. Within this programme, the specific aim of the BOSCOS project is to initiate development of a new product that will improve vehicle occupant safety (reducing fatalities and lowering the severity of injuries) and also have a direct influence on UK Health and Societal costs (hospital costs, rehabilitation costs, pain and suffering and industry costs associated with loss of personnel).

Overview of Phase 1

In the first Phase, the possible technologies that are available were assessed for their suitability to an in-vehicle monitoring system. Accident studies were conducted to create a baseline of statistics in terms of casualties and their injuries, followed by

an extrapolation of this data, taking into account the effect of technologies already in vehicles but not yet providing sufficient statistics to quantify their effectiveness. Initial bone scanning studies began to build a database for use in later tasks. Further studies established the correlation between the scanning value and bone properties and the correlation between the bone properties and bone strength.

Overview of Phase 2

In the second Phase the technology was reviewed for its use in an in-vehicle application and the actions needed to achieve this were identified and followed through to establish the methods of accomplishing the objective. Computer based occupant mathematical modelling established the potential gains from a working system but also the requirements needed of the restraint systems to achieve these gains - these will serve as part of the specification for a successful system. Further bone scanning was conducted, leading to the specification of the most suitable car occupant bone(s) that can be scanned in a vehicle environment to provide data of the best quality to the electronic control unit (ECU) for optimisation of the restraint system.

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 [1]. 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 [2, 3, 4].

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 (See Figure 1), combined with changes in the biochemical makeup of the bone.

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 radiographic absorptiometry (RA), single photon absorptiometry (SPA), dual-photon absorptiometry (DPA), single X-ray absorptiometry (SXA), quantitative ultrasound (QUS), magnetic resonance imaging (MRI) and quantitative computed tomography (QCT).

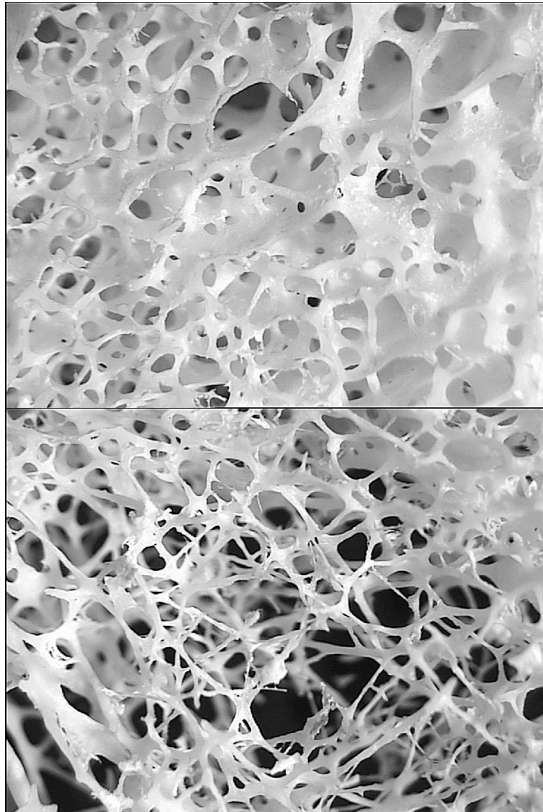


Figure 1. Bone structure of 54 year old female (top) and a 74 year old female (below), spongy bone from the hip, showing the degeneration of both the structure and density.

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. The aim was to complete collecting data and material after 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.

Non-invasive Bone Assessment

To ensure the accurate measurement of bone quality, the subjects bone needs to be assessed

directly. Of the techniques mentioned previously, DXA, SXA, SPA, DPA, RA and QCT are either out-dated, too inaccurate or require the use of X-rays, and therefore contribute too great a risk to the health of the subjects. The remaining two techniques are quantitative ultrasound (QUS) and magnetic resonance imaging (MRI). The practicality of placing a MRI machine into a motor vehicle renders it unsuitable for use. The system best suited to the BOSCOS design is quantitative ultrasound (QUS).

Health Concerns

According to popular belief ultrasound is relatively risk free. However, ultrasound waves are a form of energy, and in order for the wave to be absorbed, and the amplitude reduced, this energy has to be dissipated.

The two problems arising from this are heating and cavitation. Despite mineralised bone having the highest absorption coefficient (10dB/cm.MHz) [5] the intensity level of the ultrasound used in the assessment of bone is below the levels outlined by the Food and Drug Administration as being safe from heating effects. The mechanical index indicates the risk of cavitation; the higher the mechanical index the greater the probability of a biological effect. The values published for the ultrasound of bone are between 0.22-0.28, with values below 1 considered to be safe [6].

Ease of Use

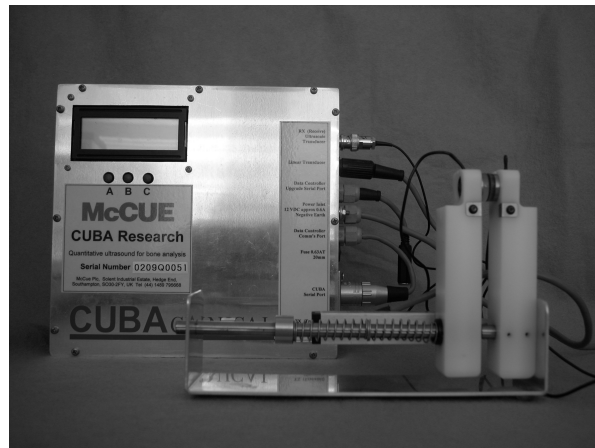
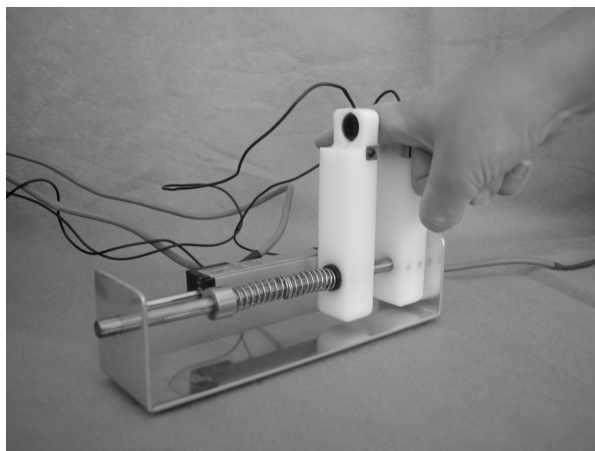
In order to ensure that occupants use the system it must cause minimal inconvenience to the driver. For this reason the BOSCOS scan needs to be performed on a readily accessible bone site, that is generally free from both clothing and jewelry. The finger, and in particular the proximal phalanx bones, are used in clinical tests as a means of assessing a patient's bone status, and have been shown to have an ability to predict fracture risk [7, 8, 9, 10].

The BOSCOS Device

The ultrasound system has been developed by McCue plc. using technology from their commercially available CUBA Clinical™ system. The BOSCOS system is designed to measure the proximal phalanx of the index finger on the non-dominant side of the subject (See Figures 2 and 3). 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. The system takes a

measurement of the separation of the transducers and the time taken for the ultrasound pulse to travel this distance. From this information, the speed of sound can be calculated. The speed of the ultrasound pulse is affected by the quality of the bone it passes through, with good quality bone enabling the pulse to travel faster.

The BOSCOS system compared the newly measured speed to a reference database, allowing for a quantitative evaluation of the subject's bone status in comparison to an expected normal. When the result indicated the subject's measured bone speed of sound was below normal, the subject is deemed to have low bone quality and was therefore at higher risk of sustaining a fracture.



Figures 2 and 3. The BOSCOS Ultrasound Device.

Initial Results

The best we can aim for is for the prototype to perform as well as the commercially available portable QUS scanners. We have therefore conducted extensive studies on the

precision/accuracy and the sensitivity and specificity of two commercially available QUS scanners, the Sunlight Omnisense and CUBA Clinical along with the BOSCOS prototype.

The precision error of a bone scanning technique refers to its ability to produce the same result, when no change, apart from re-assessment, has occurred. [11] For the BOSCOS system the precision error needs to be minimal to ensure repeat measurements do not cause different restraints reaction scenarios. The perfect technique would present a precision error of 0% to show that measurements had no difference between them. Assessment of precision error showed the commercially available finger scanner was capable of a precision error of 0.55%, in comparison to the other techniques that ranged from 0.29-2.88%.

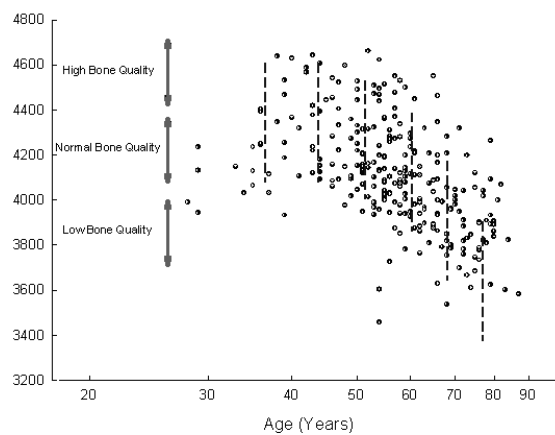


Figure 4. The speed of sound (SOS) measurement values from a commercially available finger scanner versus age for 295 volunteers, showing how the system could be used to sub-classify the population into at least three groups.

Using data obtained from 295 subjects, the finger showed the highest correlation with age 0.533 (p value < 0.001) (See Figure 4). The p -value is the level of statistical significance; a value below 0.05 (95% confidence) is considered to be of statistical significance.

The prototype system was used along side DXA assessment of the total hip and lumbar spine (Hologic QDR-4500C; Hologic Inc. Bedford, MA, USA); QUS assessment of the calcaneal (heel) bone (CUBA Clinical; McCue plc. Winchester, UK), proximal phalanx and distal radius (Sunlight Omnisense; Sunlight Medical, Rehovot, Israel), in a study on a group of 102 subjects (7 males, 95 females) aged between 24 and 85 years of age (mean: 57 years). The correlation between the new phalangeal assessments and age gave a correlation

of $r = -0.597$ (p value < 0.001), and regression analysis (See Figure 5) gave the relationship:

$$\text{Phalanx SOS} = 4604.66 - 9.15609 \text{ age}$$

$$R^2 = 35.7\%$$

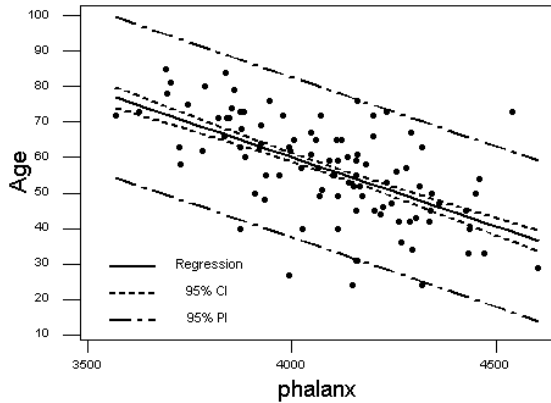


Figure 5. Regression plot of age vs phalangeal SOS

Not knowing the actual condition of the bone the performance of the prototype was assessed against a ‘composite’ parameter by combining the average of scaled values of the CUBA clinical, Sunlight Omnisense and DXA.

For each individual patient the proximal phalanx of the index finger was assessed using the BOSCOS system, and 10 waveforms with results were saved (See Figure 6).

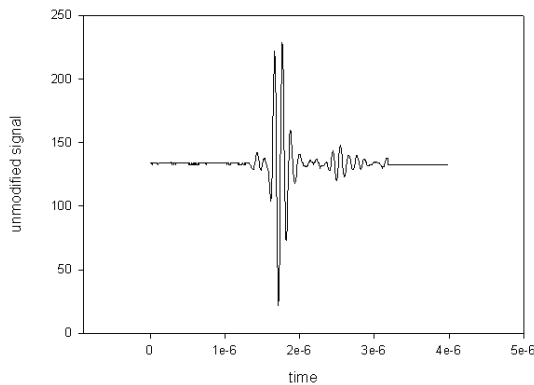


Figure 6. A representative ultrasound pulse after transmission through bone.

The pulses were converted to absolute values in relation to the baseline and the time and amplitude of the four greatest peaks was noted (See Figure 7). The ultrasound pulse was analysed by retrieving information about:

- 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)

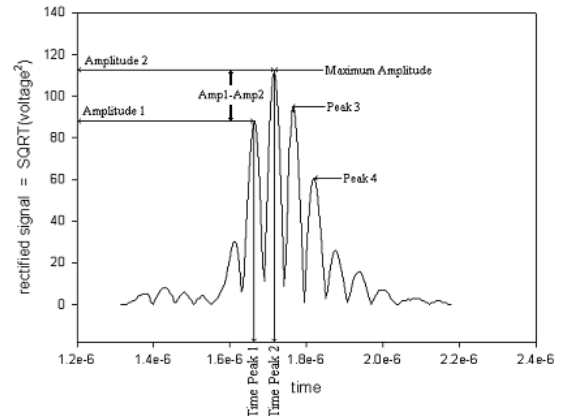


Figure 7. The ‘extrapolated’ parameters produced from the positive waveform.

These parameters were used alone and in combination with weight and age for the assessment of the composite measure.

The results showed that a combination of the ultrasound parameters with weight and age enabled the BOSCOS system to predict the status of a persons bone with an R^2 of not better than 50% (the R^2 represents the coefficient of determination, which is a measure of how well the regression model defines the data). However, by making use of available superior technology, the predictive ability of the system may well be improved, which could enable the differentiation of individuals into groupings according to their bone status. Further work is required to enable an understanding of what the measurement value (taken from the phalanx) means, in terms of actual bone properties, with respect to the rest of the skeleton.

REAL-WORLD INJURY ASSESSMENTS

Real-world data

The primary reasons for the use of accident data in BOSCOS were to identify the types of crashes and occupants who would most likely benefit from the system in order to address conditions where real people in real crashes were being injured. The accident data was to provide a basis for the modelling of the current injury situation. This baseline was the starting point from which to assess the potential effectiveness of modifying restraint system performance parameters based upon an estimate of occupant skeletal strength. The real-world data used within

the BOSCOS project was collected by the UK Co-Operative Crash Injury Study (CCIS), which samples accidents based on vehicle age, vehicle damage and injury outcome. To be included in the database, the accident must have included at least one car that was at most seven years old at the time of the crash, was towed away from the accident scene and in which an occupant of the car was injured. The data are also collected within a stratified sample which is biased towards 'fatal' and 'serious' injury outcome crashes. Of all crashes occurring in the geographical sampling regions, approximately 80% of all fatal and serious accidents, and 10-15% of slight injury crashes were investigated.

Because of the bias within the CCIS data towards 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.

Problem Definition

Impact Type

During the initial stages of the project 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 very difficult due to their inherent variability.

Although side impacts make up around 23% of injured (MAIS 2+) occupants, it was decided not to attempt to apply the BOSCOS system to side impacts at this stage for the following reasons:

- Side restraint systems have far less time in which to operate, hence the extent to which their deployment can be adjusted to differing scenarios and occupant types is limited.
- Due to its retrospective nature, the CCIS data contained relatively few crashes with cars fitted with side airbags, hence making an assessment of the effectiveness of the BOSCOS device compared to current technology is difficult.

Therefore, at this stage it was decided to restrict the investigation to frontal crashes only,

which still covered 57% of the 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 8 shows the location of skeletal injuries for belted drivers with airbags. It is clear that the body regions of concern in this context were the chest and upper and lower extremities. Since injuries to the chest are likely to pose a higher threat to life than those to the extremities, chest injuries provided the focus for the initial development of BOSCOS.

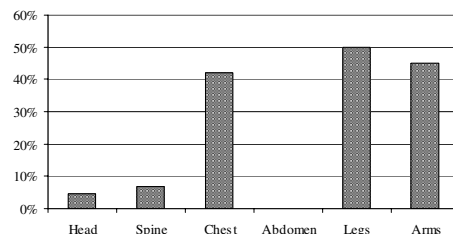


Figure 8. Location of skeletal injury for belted drivers with airbags.

71% of all serious (AIS 2+) chest injuries for belted drivers were fractures to the ribs or sternum. Of these skeletal injuries, 66% were considered to have been caused by the restraint system (either belt or airbag), whilst 53% of all AIS 2+ chest injuries were attributed to the restraint system. 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 [12]. 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 aging 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.

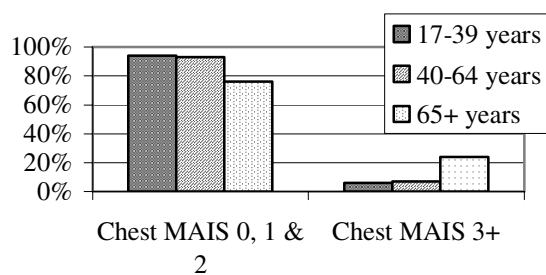


Figure 9. Distribution of maximum chest AIS of belted drivers by age group.

Figure 9 shows the distribution of maximum chest AIS for belted drivers of varying age groups. It is apparent that injury risk remains constant for the 17-39 and 40-64 age groups, but that there is a clear shift towards more AIS 3+ injuries for the 65+ age group. However, it is expected that a BOSCOS system will also be of benefit to younger occupants.

Although risk of chest injury in AIS terms is similar for ages 17 to 64, a number of clinical studies [13, 14] show that morbidity from rib fractures can increase from a much younger age, possibly as young as 40 onwards. As such, although the risk of specific injuries may not increase in the 40-64 age group, the risk of complications and associated increased costs of treatment (and ultimately cost to society) can increase.

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.

Development of Accident Matrix

Analysis of the real-world data presents an obvious target group, for which a BOSCOS system should provide an improvement in occupant protection. This group was broadly defined as belted drivers and front seat passengers in vehicles fitted with pre-tensioners and who sustained an injury attributed to the restraint system. Whilst it is likely that others outside this target group would also benefit from BOSCOS, this group was the most appropriate on which to base the next stage of the work – development of a matrix of accident scenarios.

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:

- Full overlap – This type of model will be used to represent all the real-world impacts with an overlap greater than 85%. The ETS selected for this group were 25km/h and 45km/h, since these were the 25% percentile and 75% percentile respectively of the real-world full overlap crashes.
- Offset – Since an offset test is designed to test the crash performance assuming that one longitudinal member absorbs the majority of the impact energy, this type of model will represent all real-world impacts with an overlap up to 55%. However, 90% of the real-world offset crashes fell between 23km/h and 33km/h and therefore a median speed of 28km/h was chosen to represent this group. Impacts to poles and trees only represented 4% of the BOSCOS group. The data was insufficient to develop a scenario for modelling. Improving safety in a small offset impact should, however, also address some of these narrow object impacts.
- The remaining group consists of crashes where only one of the vehicle's longitudinals was directly loaded, but a significant proportion of the energy was absorbed by loading of the engine block.

In effect, a wide overlap impact but directly impacting only one longitudinal. An overlap of 75% and ETS of 40km/h was deemed suitable to model this group of crashes.

Serious injuries were divided into sub-groups according to treatment length, extent and duration of pain and recovery time.

BASIS OF COST BENEFIT STUDY

Background to Cost Benefit Study

In order to assess the potential benefits of BOSCOS, it was necessary to evaluate changes in injury risk and their associated costs. In this way, any benefits can be shown clearly as monetary values, which are directly comparable to costs incurred by proposed BOSCOS systems.

‘Willingness to Pay’ Approach

Several cost benefit scales were considered including the HARM concept developed in the US by Malliaris et al in the early 1980s [15] and Miller et al, 1991 [16]. HARM was considered inappropriate for use in BOSCOS because injury costs in Europe do not exist in a form usable by HARM. For this reason, it was decided to consider the ‘Willingness to Pay’ approach, which was developed by the UK Department for Transport (DfT) to calculate costs of injury in the UK.

The Willingness to Pay approach to injury costing was first used in 1988 by DfT to value the cost of road accident fatalities. The concept behind it is to consider what people would be prepared to pay in order to reduce the risk of being killed in a road accident. According to TRL Report 163 [17] this approach is ‘consistent with cost benefit analysis, in that decisions reflect the preferences and attitude to risk of people who are likely to be affected by them.’ In 1993 the same method was used to revise the values for non-fatal road accidents and in 1994 other accident costs were also derived. There are two areas of costs which have been defined; casualty related costs which include lost output, human costs and medical and support costs and accident related costs which encompass property damage, insurance administration and police costs.

Severity of an accident is defined as fatal, serious or slight. A serious injury is defined in TRL Report 163 as covering a wide range ‘from a fractured finger, to those resulting in severe permanent disability, or death more than 30 days after the accident.’

Table 1.

Injury State Descriptors, Hopkirk & Simpson, 1995

Injury Code	Injury State
F	Recover 3-4 months (Out-patient)
W	Recover 3-4 months (In-patient)
X	Recover 1-3 years
V	Mild permanent disability (Out-patient)
S	Mild permanent disability (In-patient)
R	Some permanent disability with scarring
N	Paraplegia/Quadriplegia
L	Severe head injuries

The Willingness to Pay approach was implemented to determine the ‘human cost’ of an accident. A Standard Gamble questionnaire was used to carry out a survey of 450 people, asking them how much they would be willing to pay to reduce the risk of injury, relative to the cost of a fatality.

The respondents ranked the injury states and placed each one on a scale from 0-100. The majority regarded injury state L as being as bad as or worse than death and injury state N as only slightly better than death. 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 value 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. The cost for a slight injury, including whiplash, has also been determined.

New injury costing method – VSRC

Medical researchers at the VSRC have mapped 300-400 trauma injuries from the CCIS database from the AIS level (AIS 1990 revision), [18] to the injury states defined by Hopkirk and Simpson in TRL Report 163. This enables the calculation of the human cost of a trauma injury according to its AIS code. In TRL Report 163, complete lists are given for slight and serious injury costs as a percentage of the overall value of a fatality in 1994. The 2003 figure for a fatal casualty is given in Road Casualties Great Britain 2003: Annual Report and therefore all 2003 human costs for an injury can be calculated [19].

Cost benefit calculations

Using the injury costs defined by the VSRC, it is possible to give a monetary value to reductions in injury risk achieved by the BOSCOS project.

For example, if simulations are performed using increasing load limiter settings, on a strong and a weak occupant (in terms of skeletal strength), then the different chest injury risks can be assessed for each occupant using appropriate risk curves. The risk of head injury with the differing load limiter values can also be simulated. The costs can be derived for each type of injury, according to occupant strength and load limiter. The optimum load settings can then be determined for each type of occupant depending on skeletal strength. Using the proposed BOSCOS system, it would be possible to adjust the level of the load limiter as required, depending on what is most beneficial in terms of occupant injury, therefore reducing potential injury costs.

NEW TECHNOLOGIES OF RESTRAINT SYSTEMS

The present protection system on front seats features a belt system, incorporating a pretensioner, a load limiter, and an airbag. This protection system is not capable of changing its performance characteristics during a crash event. The ability of an occupant protection system to adapt itself to dominant crash condition parameters, such as impact speed and type, occupant size and mass, bone characteristics offers a great improvement in occupant protection for a wider range of crash conditions, as well as occupants.

New technologies are being rolled out to address these issues. These technologies will require new sensors in order to detect certain parameters e.g. the BOSCOS scanner and new actuators in order to protect the occupant.

The car occupant restraint industry has so far mainly focused on “In-crash systems” aimed at mitigating the consequences of an accident. However, for example, Autoliv’s Total Safety System concept has widened the scope of safety enhancing areas to include both “pre-crash systems” and “post-crash systems”. The pre-crash systems are often active systems that are aimed at preparing the safety systems for an imminent crash or, preferably, avoiding the crash altogether. Post-crash systems are devised to increase the

occupant’s chances of surviving after a serious accident.

Components and sub-systems must therefore be designed to interact with each other as one system. Seat belt pretensioner and frontal airbags, for instance, are tuned to complement each other via the same electronic control unit to give the best possible protective effect. In addition, the deployment of the frontal airbags should be adjusted depending on crash severity, seat belt use and occupant characteristics.

Future restraint systems should provide protection for all kinds of occupants in various seat positions with or without seat belts (infants, elderly people, petite females, and large males).

In real life, crashes are almost never “head-on” frontal collisions into a rigid unmoveable object at one specific speed (as in most crash tests required by the government regulators). Consequently, future safety systems should be able to do more than just determine if an accident is a frontal crash, a side impact, a rear-end collision or a rollover.

An ideal system should be able to identify and provide protection to car occupants in collisions with various types of vehicles and objects (car-to-car, car-to-truck, etc.) up to a collision speed where there is still a survivable space in the vehicle’s compartment. New technologies may include the concepts described below.

Smart Seat Belt

In a crash, a smart belt starts by tightening the belt, using a pyrotechnic pre-tensioner. This eliminates slack and makes it possible to release some webbing at a later stage, if the load on the occupant becomes too high. The airbag is instead used to absorb more load.

In a traditional system, the loads to the occupant from the seat belt and the airbag are added to each other, when the airbag also starts to restrain the occupant. But in the smart belt, the system just shifts into the second lighter gear so that the load on the occupant’s body can be maintained at a relatively constant level.

Equally important is the fact that the force of the combined systems – and thus the load on the occupant – can be tuned to the severity of each crash. Many future vehicles will have advanced occupant weight sensing systems. In those vehicles, a smart belt could be tuned to each occupant individually. This will be particularly

important for occupants who are more susceptible to high chest loads.

Pre-Pretensioning

The pre-pretensioner will give a more gentle load distribution on the occupants chest in the event of a car crash. The device will tighten the seat belt as early as one tenth of a second before a likely crash, using a fast electrical motor.

The elimination of slack in the belt system can therefore start earlier, even before a crash and the system can be made reversible. Consequently, it is possible to "strap in" the occupant more gently. It also makes it possible to tighten the belt, as a precaution when it is difficult to predict whether there will be a crash or not. The new system will be especially effective in preventing occupants from being thrown forward during severe braking.

Pre-Crash Sensing

In a few tenths of a second before a crash, radar sensors are capable of identifying the relative speed towards an object and the estimated time of impact. This will allow better discrimination of the crash severity and events identified in the BOSCOS accident studies.

Secondly, this will enhance the detection capability and timing of existing safety systems, particularly for relatively small, narrow objects, such as a corner of another vehicle, or pole or lamppost. The pre-crash sensing system will be especially useful in combination with pre-pretensioning.

Even if this pre-crash system gives just a few more milliseconds to inflate the airbags, it could open the possibility to make the airbags "softer" during deployment without compromising their protection capability.

PARAMETRIC MODELLING

In phase 2 of the project a series of mathematical modelling parametric studies were conducted to investigate different accident scenarios. The different scenarios were generated from the accident analysis performed by VSRC and have identified crash configurations where there are AIS 2+ chest injuries attributed to the seat belt. These injuries are in the form of broken bones as well as other soft tissue injuries. Dummy models were used to develop a generic seating and interior design to enable comparisons between different models to be evaluated.

The dummy models are able to predict the levels of acceleration, belt loads and trajectories of certain body parts. For each different configuration these criteria indicate the severity of the crash pulses. Parameters such as the seat belt tension and pre-tensioners were incorporated into the model to represent the range of safety restraint systems which are currently available. An airbag was included in the model, as they play an important role in the protection of vehicle occupants.

Initial simulation results with the selected accident scenarios predict injury indices below those allowed in the higher speed legal or EuroNCAP tests.

CONCLUSIONS

The BOSCOS project to-date 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 device 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 rib fractures. New restraint technologies have been identified which could be enhanced with the addition of BOSCOS type technology. A number of accident scenarios have been selected and they have been used in the initial mathematical modelling.

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FUTURE WORK

In the last phase of the BOSCOS project the technical issues that need to be addressed in the use of the bone scanning technology in a vehicle will be investigated to provide input to the development of the system. During the course of this Phase this process will be reviewed as other tasks define particular aspects of the technology. Final bone scanning will be completed leading to

the definition of the bone property ranges that can be successfully identified by the scanning techniques chosen. A study will establish the sensitivity of the scanner device in a vehicle environment as influenced by factors such as the bone selected for scanning, the possible locations of the device in the vehicle, ambient conditions in the vehicle and occupant diversity. Mathematical modelling will predict occupant injury indices with the new technologies. A cost benefit study will utilise these results to deliver an indication of change in injury risk and the potential gains from a BOSCOS system.

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