HUMAN INJURY MODELLING – CAPABILITIES AND LIMITATIONS

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ABSTRACT

Numerical simulation is increasingly being used in the field of biomechanics to predict the response of the human body to traumatic loading. Techniques such as finite element analysis and multi-body modelling are being widely applied to analyse and predict the occurrence of injury to various body parts and the results are now being used in the design of new dummies and the derivation of injury criteria.

This paper discusses the considerations that must be made when examining models of human injury, and exposes areas where knowledge of human tissue and human response is lacking to the extent that such models cannot be created without an unacceptably high degree of uncertainty in the results.

Despite these limitations, numerical simulation is a vital biomechanics research tool and examples are provided demonstrating how numerical models of different parts of the body have been effectively developed and how the results have been interpreted in the light of the assumptions on which they are based.

There is now a need to direct research effort into the development of fundamental data for improved modelling accuracy and this paper aims to inform those outside of the modelling community of the limitations of these models and the considerations that must be made when assessing their results. It also aims to suggest the directions that future research should take in order to provide the data that are essential for improving the usefulness of these models.

INTRODUCTION

Numerical simulation, or computer modelling, is a technique that has grown rapidly in its application within engineering and other disciplines. This trend is set to continue as computational power and software capabilities continue to improve. One area of application where numerical simulation undoubtedly has great potential is that of predicting human tolerance to load, or prediction of injury.

Recent years have seen a considerable increase in the number of publications that make use of numerical simulation to represent the human body, either to demonstrate the construction of a model as an aid to understanding or as a tool to extrapolate or interpret test data. In order to interpret, or visualise, the vast quantities of data that are generated by numerical analyses, a post-processing package is essential that can present the output from the analysis in an easily understandable format. Modern post-processors now have capabilities that allow life-like rendering of the numerical models and can overlay and combine output parameters such as stress and pressure onto these models. Post-processing of software codes that incorporate material failure can also result in visually convincing presentations of injury mechanisms.

As a result of these advanced features of post-processing tools, the results of any model can be presented in a visually, or pictorially, convincing manner that can immediately generate a subjective acceptance of the results. These capabilities are extremely helpful when conveying the outcome of an analysis to someone unfamiliar with the interpretation of numerical output, but a false confidence in the model output can result. Further misconceptions can arise from smoothing or averaging techniques implemented by most post-processors that generate smooth contour presentations of output parameters, but which in doing so can mask underlying errors or discontinuities in the model.

These factors affecting the presentation of numerical modelling results apply to all applications, but the false confidence generated in models can present particular problems in the context of human body modelling. The general observer will usually have little knowledge of the behaviour of human tissue under load, and hence convincing visualisations tend to have a great impact. In addition, modelling techniques tend to clearly delineate anatomical features, which can be very helpful to understand the processes involved, but again can be quite unrealistic when compared to the highly complex human anatomy that the model is intended to represent.

These comments do not imply that human models, in particular those intended to predict injury, have no value, in fact quite the opposite is true. However, any such model must be interpreted in the light of an understanding of the assumptions and inherent limitations of modelling in this field, and this understanding must take priority over subjective assessments based on the realistic rendering of the model output.

This paper sets out the inherent difficulties that exist when modelling the human body, all of which must be considered and addressed both during the modelling process and when interpreting the model results. These considerations are especially vital when decisions or applications are to be made based on the modelling predictions.

THE USE OF NUMERICAL SIMULATION IN AUTOMOTIVE SAFETY

The field of application which has dominated the development of human body modelling is that of automotive safety. Other transport sectors such as aviation and rail are now capitalising on the research (both modelling and physical testing) that has taken place in the field, and the subject is now also generating substantial interest amongst the medical fraternity. Within the automotive context, numerical simulation is used in a number of ways, hence in order to place the application and importance of human modelling within the overall process, the following overview is presented.

The ultimate objective of pursuing safety within the automotive industry is to reduce the occurrence and severity of fatalities and injuries sustained in car accidents. This process must be instigated by an understanding of real world accidents, the conditions that a person may be subjected to within those accidents and the outcome for that person. These data generally arise from analyses of accident databases which provide information on the conditions of an accident, the injuries sustained by the victim(s) and other pertinent data. These analyses also allow prioritisation of injuries and their 'importance' based on the outcome for the victim and for the society that must subsequently support the victim.

However, accident databases can only provide information based on the situation following the accident, whereas injuries are caused by events taking place during the most significant 50 milliseconds or so of the accident itself. Therefore, in order to gain a detailed understanding of these very short duration events, accidents are reconstructed in full with instrumentation fitted to the vehicle and to the occupant surrogates. However, these reconstructions are very expensive and only provide data on a single set of circumstances.

Numerical simulation is therefore used to examine a wider range of real world accident conditions, to carry out parametric and sensitivity studies and to derive greater detail from the test condition. The models can be validated against those conditions which were physically tested.

From an understanding of the real world conditions, it is generally desirable to recreate an 'average', or typical, real world condition in the form of a laboratory test using only one vehicle under a standard and well defined set of conditions. Accident data will again be used to define the conditions, based on the frequency of occurrence of any given accident configuration and the severity of the outcome for the vehicle occupants. This test condition can often become a regulatory test condition for the evaluation of a given vehicle's safety performance.

Once this 'laboratory' standard test condition has been derived and is in widespread use either as an industry standard or as a regulation, numerical models will be developed that can readily predict the outcome of such tests. This application of modelling is particularly important for manufacturers of vehicles who will have an interest in minimising the cost involved in meeting the requirements of such a test.

Given that most laboratory tests are now assessed in terms of the response of human surrogate test devices in the form of crash test dummies or sub-system tests, the accurate representation of test devices in a numerical model is important. Such models are widely used by manufacturers for the reasons described above, and also by researchers who wish to improve the performance of such devices.

In order to interpret the data recorded by test devices (both in physical and model form), the relationship between engineering parameters as measured by the test device (such as force, acceleration, pressure, etc.) must be related to the generation of real injuries. The derivation of these relationships requires a knowledge of the human form and also the mechanisms and phenomena that take place during a high speed impact that lead to fracture of a specific bone, or some other injury.

A number of techniques are available to create the knowledge and understanding necessary to develop the relationships described above:

- Cadaver Testing
- Animal Testing
- Volunteer Testing
- Numerical Simulation

Of these techniques, cadaver, animal and volunteer testing all carry with them potential ethical difficulties which can constrain the amount or type of testing that can be performed. In addition, none of these techniques can provide an entirely accurate prediction of injury generation in a live human. Cadavers have no muscle tension or activity and body fluids tend to 'pool' lower in the body, making the specimen potentially unrepresentative. Animal testing can address these difficulties, but there is then the issue of scaling the results from an animal to a human given that there are differences in anatomy. Volunteer testing again addresses all of the issues of cadaver and animal testing, but the test conditions will obviously be limited to well below injury thresholds and instrumentation will be limited to non-invasive techniques.

Due to the difficulties associated with all of the alternatives, numerical simulation appears to be a very desirable approach to this subject and certainly has the potential to provide the understanding of human injury generation and the relationships required to interpret test device data. These reasons no doubt account for the proliferation of human body simulations in the published literature. However, in order to realise the potential of the technique, testing using the alternative approaches must continue in order to generate the input data necessary for the models, and test conditions against which the models can be validated. If this does happen, then improved models will result and much greater understanding of injury mechanisms will result, making the use of numerical simulation of human injury a field of study with increased significance.

To complete the process of automotive safety improvement, an understanding of human injury generation will result in improved test devices and a more thorough understanding of the implications of their output. This will provide manufacturers with the information necessary to design vehicles that genuinely reduce the risk to occupants, or put another way, 'protect a human rather than a dummy'. This understanding may also change the regulations and standards that a manufacturer is required to meet, with a corresponding improvement in protection. With these improved processes in place, the eventual outcome should be a quantifiable improvement in real world safety as identified by accident data and statistics.

DIFFICULTIES FACED WHEN MODELLING HUMAN INJURY

Human Variability

One of the greatest challenges faced not only by modellers, but also by those using other research techniques, is the inherent variability of the human population. There is obviously a great dimensional variability in mass, overall dimensions, proportions, etc. which has been largely addressed statistically by targeting safety measures at the 5th percentile female, 50th percentile male and the 95th percentile male. However, even amongst individuals with the same dimensional properties, there will be wide variations in the properties of the tissues making up those individuals. Material properties are even more of a challenge to address than geometric dimensions, as there are far fewer data available on which to make statistical assessments. Hence it is very uncertain as to what 'average' properties are, and even less certain as to where the 5th and 95th limits lie.

Part of this difficulty arises from the variability introduced into the data by the test methods employed. Much of the available data were generated many years ago, and the test methods were often not rigorously documented, or there may be doubt over the reliability of the test data. The difficulties are exacerbated by the properties of human tissue which make the results dependent on the condition of the tissue samples, the orientation of the test specimen, the rate of loading, and other factors which may not have been recorded during the tests.

Additional variability between individuals can be introduced by factors such as age and health, and while these factors can be documented, the question arises as to which properties should be implemented in a numerical model. Average, or 50th percentile properties may seem to be the logical choice, but a greater number of the population would be protected if weaker tissue properties are used.

An advantage of numerical simulation is that the sensitivity of injuries to variations in material properties can be addressed in a relatively straightforward manner, however addressing geometrical variances can involve substantial effort.

Geometry

The human body has evolved over time to be very tolerant to imposed loading. This is achieved through smoothly contoured bones and materials that transition seamlessly into each other, for instance muscle tissue becomes tendon which in turn becomes bone, all in a continuously changing manner. Load carrying anatomical characteristics such these therefore have very few 'stress raisers' such as may be found in conventional engineering structures where joints and discontinuities are largely unavoidable. Part of the reason for the body's form is that it has the ability to adapt to the loading applied to it. For instance it is notable that the bones of an athlete's leg are considerably stronger than those of a person with a sedentary lifestyle.

These characteristics make the body remarkably resistant to injury, but at the same time make it very difficult to model. Numerical analysis codes such as finite element analysis are engineering tools and therefore assume that different components of a system are well delineated and can easily be represented as separate parts, linked together by some means. As the human body does not conform to this pattern, the software and analysis techniques that are used have to be adapted to create as close a representation of the body's anatomy as possible. However, until there is a marked change in modelling philosophy, there will always be a conflict between the software requirement to represent the subject as well defined blocks of material with homogenous properties, and the body's natural form as continuously variable substance (especially along principal load paths).

Representation of anatomy is further complicated by the nature of the materials involved. Human tissues other than bone are generally soft and do not have a well defined form. Hence, while it would be desirable to represent, for instance, a ligament as a well defined linear structure acting between two attachment points, the true anatomy does not lend itself to the capture of suitable dimensions. The insertion, or attachment, points of a ligament can be very hard to discern, and even measurement of the width or thickness of a ligament can prove very troublesome. Many anatomy texts include pictorial representations of such features that show them as very well defined structures (Figure 1).

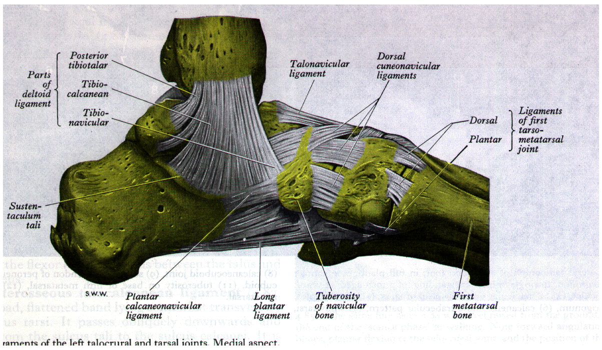

Figure 1. View of foot typical of anatomical texts (courtesy of Gray's Anatomy).

This is helpful as the modeller can create a numerical representation that looks very similar (Figure 2).

However neither of these representations relates to the true situation such as may be seen from a photograph taken during a dissection (Figure 3).

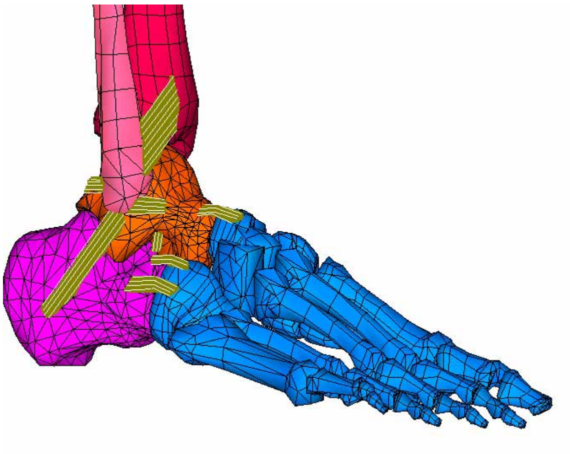

Figure 2. Idealisation of foot for modelling.

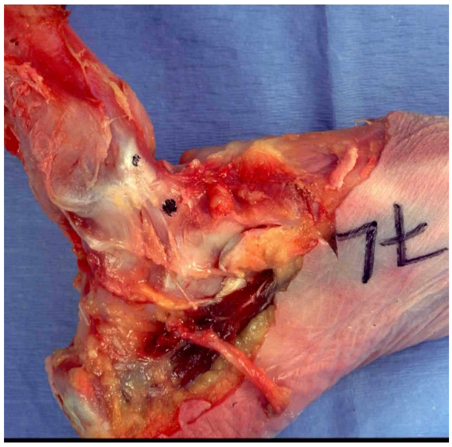

Figure 3. True anatomy of foot.

It is now becoming easier to generate accurate geometric models of human anatomy due the availability of good surface geometries from organisations specialising in the generation of such data. In addition, a rapidly developing technology is that of directly creating a geometry from MRI scan 'slices' of an individual. This latter technique has a number of potentially great advantages. Firstly, each anatomical feature can be captured, including cartilage, bone, soft tissues, etc. Secondly, the geometry of a living individual can be captured and represented using numerical techniques. This latter aspect may eventually allow the generation of models that can provide results specific to an individual. The technology is being developed along with automation of the process, including generation of a finite element mesh.

As a result of these innovations, the capture of the anatomical geometry is now well addressed in relation to the other difficulties faced by the modeller in this field. However, the comments made above on the true nature of the anatomy should be borne in mind when considering the apparent geometrical accuracy of a model, along with considerations of the variability of the human population.

Loading

Many parts of the human body can be modelled in isolation and are often presented as such (for instance the spine – Figure 4). However, in order to obtain meaningful data from the model it must be subjected to a loading representative of a real world situation. In the case of automotive safety such a situation would be a collision. In this event the loading on the spine would be transferred to it via many other parts of the body. For instance, contact between the thorax and the steering wheel or air-bag would compress the rib cage and thoracic cavity, applying load to the spine through the ribs along with direct compression from the lungs and other thoracic organs. In addition, loads may be applied to the legs, and thence to the pelvis and into the lumbar spine. The mass of the head will usually cause flexure of the neck and this again will apply loading to the cervical and thoracic spine.

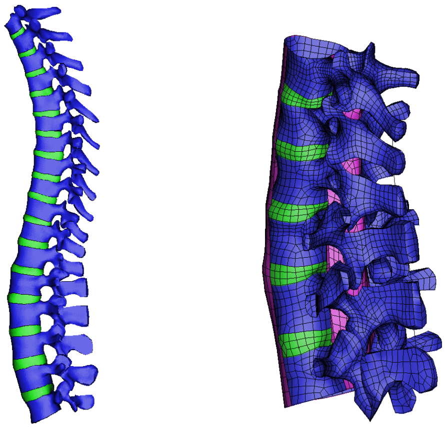

Figure 4. Isolated model of the spine.

The implication of the above is that most of the body would have to be included in a model, solely to correctly load the spine which is the region of interest. This is obviously a very inefficient approach to modelling, and if adopted may require a compromise in the level of detail used to represent the spine in order to solve the model in a reasonable length of time.

An approach developed to address this problem is the combination of human models with dummy models. Models of test dummies are generally efficient to analyse and are validated against their physical equivalent. Although it is accepted that current dummies are not entirely biofidelic, their response is reasonably close to that of a human and hence would be a reasonable substitute for regions of the body that are not of direct interest to the analysis. The technique developed in the case of the spine involved the removal of the dummy spine and thorax components, and their replacement with models of the human equivalent. Through judicious consideration of the interfaces between the human and dummy components, a model has been developed that can predict the spine response in an impact without the need for detailed modelling of the remainder of the human body (Figure 5). The model has been validated against low speed rear impact volunteer tests.

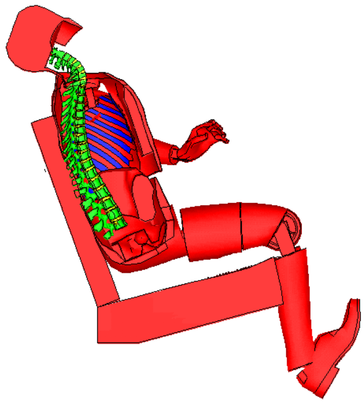

Figure 5. Human spine model combined with Hybrid III to generate correct loading.

Validation

All numerical simulations should be validated in order to ensure that their predictions are reliable. Without validation, confidence cannot be held in the model's predictions as there are numerous ways in which errors may be inadvertently introduced into the model. Validation requires the correlation of the model output against the results of a physical test, and in the case of human modelling this implies testing of human specimens. However, as already discussed, live humans cannot be tested at injury levels and cadaver tests are not fully representative of a live human, hence it must be accepted that true validation can never take place for models of human injury.

A technique that could be argued to provide true validation of a model is accident reconstruction. In this case a known accident is fully represented by the model with the expectation that the model would predict the injuries actually sustained by the victim. However, in order to carry out this procedure rigorously, the victim's anatomy would require accurate modelling, including the tissue properties. With current technology, it is unlikely that this will become an approach that has greater credibility than validation against, for instance, cadaver testing.

Over the past 3 to 4 decades biomechanical reserach has been taking place on both full cadavers and on parts of the human body in isolation. These data have the potential to provide useful validation for numerical models, but the reality is that the test conditions are often not well documented and hence it is very difficult to simulate the test and consequently validate against the published results.

As well as the quality of the published data, the nature of the validation should also be considered carefully. The objective of the human models is to predict injury and this is usually based on predictions of stress or strain, hence it is important that these parameters are predicted accurately. However, validation is usually made against parameters not directly related to injury such as kinematic behaviour or other derived values, and this does not constitute validation of the model's ability to predict injury. Given this fact, it again becomes virtually impossible to truly validate a model of this type, as even with cadaveric specimens, the measurement of stress or strain in part of the anatomy involves destruction of the tissues that control the response.

In order to address the issues related to validation, biomechanical tests now include instrumentation specifically for the purposes of model validation. Indeed, some tests are now carried solely for that purpose. As a result, the quality and availability of validation data is constantly increasing and this can only lead to more representative and reliable models over time.

While many models aimed at the prediction of human injury could be accused of being unvalidated by the preceding arguments, this does not imply that such models are of no value. Even models built around little or no validation data can provide insight, or provoke hypotheses, as to injury mechanisms. As a research tool in this context, any numerical model can add to the generation of knowledge by reinforcing or expanding ideas as to how injuries are caused.

The conclusion from the above is that all models should only be interpreted to the extent of their validation and the degree of confidence in their accuracy. Hence some simulations may be suitable only for the generation of ideas from which numerical or quantitative interpretations should not be made, and other models which are based on limited validation data may be used for proposed quantitative data, such as suggested threshold levels for injury. However, numerical results for use in regulations, standards and other important applications should only be based on numerical simulation results if validation has been carried out to a very high level.

Materials

<u>The nature of human tissue.</u> The issue of material data for use in numerical models creates difficulties in two principal ways:

- Measurement of material data
- Implementation of that data in software codes.

The difficulties arise largely from the nature of human tissue which can be described as:
- Viscoelastic
- Strain rate dependent
- Strain stiffening as illustrated in Figure 6.

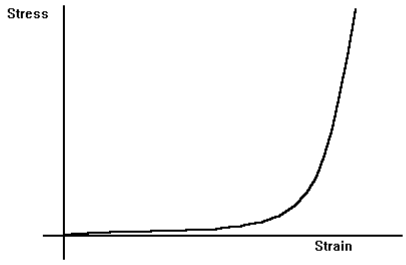

Figure 6. Stress vs. strain curve typical for human tissue demonstrating strain stiffening.

All three of these characteristics are important to varying degrees depending on the tissue type, and hence the ability to measure and implement such properties is important for the prediction of injury.

Difficulties in the measurement of material data arise from the nature of the tissue itself and the fact that tests must be carried out at varying strain rates up to and beyond those experienced by human tissue in the event of a vehicle accident. The difficulties are compounded by the inherent variability of human tissue as discussed earlier. This variability means that in order to obtain an accurate understanding of the response of tissue in relation to strain rate, either a very high number of tests must be carried out in order to make statistical analysis relevant, or the same sample must be tested, without incurring damage, at different strain rates in order to observe the corresponding change in behaviour.

As well as quantifying the dependence of the material behaviour on strain rate and other independent variables, the failure of the material must be tested as well, as prediction of this event is the ultimate purpose of the numerical models. Any one sample can only be tested to failure once, and hence the capture of failure characteristics, and in particular the variation of failure condition with loading rate, proves to be a difficult parameter to define.

In general, there are three generic tissue types that are important to characterise for simulation purposes, these being:

- Bone
- Ligaments and tendons
- Soft tissues

Each of these types of tissue requires a different test method and the generation of different parameters in order to characterise it. It is important to test fresh (or fresh frozen) tissue as preservation techniques such as embalming will alter the tissue properties. An implication of using fresh tissue is that once the specimen is at room temperature, all testing must be carried out within a short space of time before the tissue begins to degrade.

Bone. Bone is the easiest tissue type to quantify as conventional measurement techniques can be used such as tensile and bending tests. However, there are different types of bone and each can be directional in nature, requiring tests in different orientations to characterise fully its behaviour. As bone fractures are frequently caused in accidents, and most fractures are serious in nature, it is important to capture the failure behaviour and mechanism of bone in numerical simulations. Work is therefore now being carried out to understand and capture the behaviour of bone just prior to fracture.

Data on bone properties can generally be implemented using conventional elastic-plastic material models in which a tabulated plastic regime can be specified to capture the failure characteristics. Rate dependency is generally straightforward to specify with these models and viscoelasticity can also be incorporated.

Ligaments and tendons. Ligaments and tendons tend to operate under largely axial loading, and hence testing tends to concentrate on loading in this direction. The behaviour of these parts is usually very dependent on loading rate, although their behaviour can range from being extremely stiff and strong, to being relatively compliant. The stress-strain response of ligaments and tendons tends to display the strain stiffening characteristic (Figure 6) very clearly, hence any test methods need to be capable of capturing this phenomena at differing strain rates.

The physical testing of these parts presents difficulties in mounting the specimens. The tissue itself is generally very soft, but the parts themselves are quite small hence freeze clamping is not always practical. A very effective technique that has been developed at the University of Nottingham/TRL Biomechanics Laboratory is to dissect the ligament from the body together with sections of the bones to which attaches. By careful dissection, the ligament can then be mounted into a test rig in its anatomically correct position relative to the bones, and tested at differing rates.

Ligaments can potentially undergo high strains before failure occurs, and this can cause stability problems when implementing measured data in many material models. Strain stiffening effects also create implementation difficulties as the initial stiffness can be close to zero. The unloading behaviour of the material must also be considered as this also has the potential to cause instability unless a tabulated unloading curve is specified. Transition between the loading and unloading curves must also be carefully specified, as the shape of the stiffening curve could inadvertantly create a situation in which the unloading curve lies ‘above’ the loading curve, thereby generating energy in the model.

Considerations of viscoelastic effects should also be made when considering transitionary behaviour between strain rates. The viscoelasticity can create a ‘lag’ in the stress-strain response, meaning that the stress state at any particular time may be ‘path dependent’, i.e. the stress state depends on what has happened in the material up until that point in time.

Many of the problems described can be overcome by representing the ligaments as spring elements that can be closely specified. However, ligaments have width and interact with the bone topology on which they lie and this would have to be addressed if an accurate representation is to be derived.

Soft Tissues. The characterisation of soft tissue properties presents another set of difficulties. Soft tissues may be organs (such as the brain, liver or kidney), skin, muscle bulk or fatty tissues, but each present the same general challenges when attempting to measure their behaviour. For soft tissues, it is generally the viscoelastic properties that dominate, and indeed rupture of the material can be a direct result of its viscoelasticity. Mounting of specimens is again an issue given that the tissue in question is extremely pliable, and can also exhibit directional properties.

The conventional approach to capturing the response of soft tissues is rheological testing, in which the material is excited over a range of frequencies and the response recorded. Such a test technique captures the material's properties, but these data can be very difficult to implement in numerical simulation codes. The conventional outputs from rheological testing are 'real' and 'imaginary' values of shear modulus (G' & G''). However, when defining viscolelastic parameters, finite element codes usually require a long and a short time shear modulus together with a decay constant (G_o, G_∞ & ß respectively). The translation of parameters from G' & G''to G_o, G_∞ & ß requires a curve fitting approach and this can introduce errors into the material model. As a result, rheological testing is not considered to be an ideal method for obtaining material properties specifically for testing. In addition, failure characteristics of the material are not obtained using this method.

An alternative technique in common use for high strain rate property derivation is drop testing. This technique involves dropping a weight onto a sample of the material and recording the deflection and transmitted force in the material. The test condition is then represented using the simulation software and the material properties are adjusted until the test result is duplicated. This process can be repeated for a number of impact masses and speeds until a full description of the material behaviour is derived. This approach to the derivation of material parameters carries with it a certain amount of risk as it is possible to use an incorrect underlying material model, or to adjust the wrong parameters, in the process of obtaining a match to the test result. The result of this would be a material that could be unrepresentative outside of the conditions tested.

Testing is now beginning to take place with the explicit objective of deriving material properties for simulation. This testing programme is making use of techniques that will allow the direct implementation of the test data in material models currently available in simulation codes.

Many of the comments relating to implementation of ligament data also apply to soft tissues. However, soft tissues can be subjected to complex loading, not just loading in an 'axial' direction. The material properties therefore have to be applicable to general 3 dimensional solid, or 'brick' elements and cannot be approximated through the use of spring elements. This compounds the problems caused by strain stiffening and rate dependency effects. It is likely that in order to capture soft tissue behaviour accurately in numerical simulations, new material models will be required in the software packages.

GUIDELINES FOR THE ASSESSMENT OF NUMERICAL SIMULATIONS OF HUMAN INJURY

Based on the arguments presented in this paper, the following principles, or guidelines, are suggested that should be addressed when considering a numerical simulation of human injury.
The geometry of the model should accurately represent the anatomical features in question, but a good visual rendition of the parts does not necessarily imply an accurate representation. A model that includes unnecessary anatomical detail can give rise to difficulties with the implementation of suitable material properties, hence a simplified model can sometimes be more accurate. However, all simplifying assumptions must be fully justified.

The material data used in any model should always be questioned as this is the area where the greatest errors can be introduced. The material model that has been assumed for each anatomical component should be stated and justified in terms of its fitness-for-purpose. It is not necessarily the most complex or universally accurate material model that should be used if, for instance, the material behaves in a linear-elastic manner over the range of interest.

The source of the material data used in the model should be stated or referenced and the manner in which the data has been physically measured should also be questioned, especially if it has had to be manipulated in order to implement it in the numerical model.

Account should be taken of the variability that exists in the human population. This may take the form of a statistical treatment of the model output, or it may be intended from the outset that a given proportion of the population will be addressed by attempting to represent a 5^{th}, 50^{th}, or other percentile specimen. Using whatever means, some statement to the treatment of this issue should be made so that the model result can be applied appropriately within the context for which it was intended.

The loading on the model should represent the situation under consideration. This can be a straightforward process where, for instance, the impact conditions to the head are known, but even in this case the motion of the head may be influenced by the neck stiffness. In the case of embedded anatomy such as the organs or the spine, the load transfer to these parts must be representative, and it must be demonstrated that this has been carefully considered.

All models should be validated. If no validation exists then little confidence may be had in the results. However there are situations where an unvalidated, or partially validated, model may have some use. The parameters on which the validation has taken place should always be examined to determine whether these parameters are relevant to the final purpose of the model. Also, the data against which the model is being compared should be examined to determine whether they are suitable (for instance cadaver data may not necessarily be suitable for validation of a live human model).

CONCLUSIONS

Numerical simulation of human injury is a rapidly expanding area of study and it will continue to grow as the alternative means of research all have ethical and other disadvantages.

The development of increasingly powerful and visually convincing post-processing tools can provide a deceptive perception of the accuracy of a model.

The assumptions that have been made in any numerical simulation should always be questioned and justified by the modeller. There are many uncertainties in the physical understanding of human injury and many widely varying quantities that can influence the outcome of tests and simulations. These issues must therefore be addressed in any simulation exercise.

The application of any numerical model must always be made in the context of the confidence in its predictive abilities. Models with minimal validation may still provide useful insights into the function of the human body, but quantitative analyses and application into standards or regulations can only be made using models that are validated to the greatest extent possible and in which full confidence is held.

Guidelines have been suggested that, when applied to a numerical model, should highlight any deficiencies in its construction and will lead to an assessment of the ability of the model to predict human injury.

RECOMMENDATIONS

In order for numerical modelling to progress in terms of its applicability and predictive power, the focus of research must shift from the generation of increased numbers of models and the detail captured in those models, to the generation of real world information on material behaviour and validation data. Numerical models are now largely capable of representing what we know of the real world, so we must now concentrate on increasing our knowledge and understanding of physical phenomena, because as soon as new knowledge is generated, it can be assumed that a numerical model will be developed to make use of that knowledge.