Decision-support for the management of traumatically injured limb

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1 Background

One of the most difficult decisions for a clinician to make, in both military and civilian settings, is whether to amputate an injured limb or attempt to salvage it. Severely injured, or “mangled” extremities may require amputation, either at the time of initial surgery, or many months later. At the Royal London Hospital, approximately 46 severely injured limbs were amputated over a 48 month period ending in 2008, although the number of mangled extremities was approximately double this. In the field, the conflicts in Iraq and Afghanistan have produced a high number of limb injuries due to the nature of contemporary blast munitions, plus paradoxical improvements in combat body armour and resuscitative techniques saving the lives of casualties who would have died in previous conflicts. Advances in orthopaedics, plastic surgery and vascular surgery have meant that previously unsalvageable limbs can now be saved.

However, radical improvements in prosthetic technology and rehabilitative medicine have also occurred so that modern prostheses combined with sophisticated rehabilitation techniques can restore a patient’s quality of life. Because of its irreversibility, the decision to amputate must be taken cautiously. However, failure to amputate can have significant short-term implications if infection takes hold and in the long term, can entail many years of painful surgery, which may never restore adequate limb function. In these cases, salvage may well have a more profound effect on the patient’s psychological and physical well being than amputation in the first instance.

But how do surgeons make this decision? The decision-making process is poorly described. In many cases, a judgement can be safely made where the injury pattern falls to one extreme (mild limb injury, no case for amputation) or the other (severe injury, no choice BUT amputation). However, in other situations, the injured limb falls in to a grey area where surgical experience is important – but inevitably subjective. Furthermore, with shorter training for surgeons there is less opportunity to acquire such experience. A number of scoring systems that have been developed to help clinicians decide whether to amputate; most of the scores have been formulated from retrospective samples of small numbers of patients and it has been shown that none is useful in the ‘grey area’. As a result, there is little robust guidance for surgeons faced with this highly complex decision. There is no accepted benchmarking practice for determining the “correct” amputation rate for a given hospital seeing a certain spectrum of patients. Finally, with regard to late amputation – where patient involvement in the decision-making process is key to a satisfactory outcome – there are few models and tools available to the clinician to help predict and articulate the necessity for this irreversible step.

2 Objectives

While experience and sound clinical judgement are essential, a validated predictive model allowing the factors that influence the final decision to be exposed is also needed. Such a model could be used to generate guidelines based on patient specific variables, help in predicting overall rates of “expected” versus actual amputations leading to better setting of benchmarks, and developed in to an on-line decision-support tool to help surgeons make real-life decisions. Finally, a variant of the model could be used by clinicians to engage and inform their patients (for example, with ‘what-if’ type analysis) when facing the difficult choice of late amputation, lending confidence to the surgeon and comfort to the patient.

2.1 Approach

The current scoring systems, which are not effective in practice, are derived from datasets of past patients, typically using regression analysis. Our hypothesis is that a) a predictive model must make use of the knowledge of causal mechanisms at work b) data is better interpreted within a causal framework and c) Bayesian networks are a suitable formalism to combine knowledge and data into a useful model. An example of a causal mechanism is the interplay between the condition of the patient and the severity of the limb injury as factors in the decision to amputate; such causal pathways are not directly represented in a scoring system resulting from a regression analysis. The emphasis on causal modelling and the use of Bayesian networks to combine data with knowledge distinguishes this approach from previous ‘artificial intelligence’ uses of Bayesian networks.

The Bayesian network model will be developed from two sources:

1. The causal framework will be determined by a structured review of decision scenarios, based on past cases, by an expert panel representative of the different medical specialities involved in treating mangled extremities.

2. A large bank of data will be use to determine the strength of causal relationships.

There are many challenges to this process: some concern the acceptability of the proposed process: expert opinion is widely considered to be the least reliable form of evidence in medical science: we will address this partly by adopting rigorous processes, including attention to difference of opinion as indicative of lack of knowledge, and also by distinguishing between causal knowledge and statistical (or probability) judgements, where expert opinion is known to be weak.

The process used to construct the model, plus the model itself, are expected to help generate the following outputs:

1. A better understanding of the decision-making process for early and late amputation in both civilian and military spheres.

2. A validated predictive model with better discriminatory power than current limb injury scoring systems, allowing the generation of better clinical guidelines.

3. Benchmarks for hospitals and trauma centres.

4. A decision-support tool to assist in both the early and late management of severe limb injury.

The Bayesian network model will need to a) Incorporate both discrete and continuous variables; b) Interface to different types of data; c) Have a tailored front-end (including online version) that hides all of the underlying complexity from the medical end-users. To meet all of these requirements it is necessary to use the Enterprise Edition of the AgenaRisk Bayesian Network software.

2.2 Knowledge Transfer

There are two types of knowledge transfer in this project. The primary one is to take research on Bayesian networks and embed it into standard medical practice. Decision making for mangled extremities is an example of a medical decision-making problem that a) lacks data from a randomised trial – instead data are from observation of past patients b) involves complex causal pathways. There are many such decision-making problems both in trauma management and other medical fields that are poorly served by existing techniques for creating treatment guidelines. It is therefore anticipated that a successful collaboration will permit exploration of other areas of trauma outcome prediction. The other type of knowledge transfer (that ultimately benefits Agena) is the greater understanding of how Bayesian network models can evolve into more effective decision-support systems whose end-users need have no understanding of the underlying model complexity.

3 The Team and Resources

The project is a collaboration between the Trauma Unit at The Royal London Hospital headed by the consultant trauma and vascular surgeon Lt-Col Nigel Tai and Dr William Marsh and Prof Norman Fenton of the Computer Science Department Queen Mary. The necessary software and support for the proposed decision support system will be provided by Agena Ltd, a company recognised as world leading in applied Bayesian network software. Prof Fenton is a Director of Agena. Between April 2008 and March 2009 all three partners were part of the EPSRC research cluster DIADEM (Data Information and Analysis for clinical DEcision Making). The project is funding a Research Assistant (supervised by Professor Fenton and Dr William Marsh) to work in collaboration between Computer Science, Agena Ltd and the Trauma Unit.