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Methods for reasoning from geometry about anatomic structures injured by penetrating trauma

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Abstract

This paper presents the methods used for three-dimensional (3D) reasoning about anatomic structures affected by penetrating trauma in TraumaSCAN-Web, a platform-independent decision support system for evaluating the effects of penetrating trauma to the chest and abdomen. In assessing outcomes for an injured patient, TraumaSCAN-Web utilizes 3D models of anatomic structures and 3D models of the regions of damage associated with stab and gunshot wounds to determine the probability of injury to anatomic structures. Probabilities estimated from 3D reasoning about affected anatomic structures serve as input to a Bayesian network which calculates posterior probabilities of injury based on these initial probabilities together with available information about patient signs, symptoms and test results. In addition to displaying textual descriptions of conditions arising from penetrating trauma to a patient, TraumaSCAN-Web allows users to visualize the anatomy suspected of being injured in 3D, in this way providing a guide to its reasoning process.

Keywords: Decision support; 3D modeling; Expert systems

1. Introduction

Penetrating trauma is a medical and social problem that affects most regions of the United States. United States penetrating trauma statistics from the Centers for Disease Control and Prevention (CDC) between 1999 and 2002 show a 10.35% crude death rate (number of deaths per 1000 people) from firearm injuries (a total of 117,352 deaths) and a 0.88% crude death rate from stab injuries (a total of 9951 deaths) [1]. An examination of the leading causes of death in the US between 1999 and 2002 shows that homicides and/or suicides feature among the top 10 leading causes of death in the US for people between the ages of 1 year and 64 years. Deaths from firearms make up a significant portion of these deaths, with more than 55% of deaths by homicide occurring from firearms in persons between the ages of 10 years and 44 years, and more than 35% of all deaths by suicide occurring from firearms in persons between the ages of 10 and 64 years of age [2].

To explore the ways in which computer-based decision support could be beneficial in managing penetrating trauma cases, TraumaSCAN was developed [3]. TraumaSCAN is a computer system for assessing chest and abdominal penetrating trauma. It computes the probability of injury to anatomic structures and the probability of consequent conditions, such as pneumothoraces and hemothoraces, using geometric reasoning about anatomic structure involvement and probabilistic reasoning with Bayesian networks. In a retrospective assessment of 26 gunshot wound cases utilizing external wound location, bullet location, and other patient findings as input, TraumaSCAN was shown to have good sensitivity and specificity, with areas under the ROC curve ranging from 0.835 (in the worst case) to 0.992 (in the best case) for 11 conditions present in the cases assessed [4]. While the Bayesian network and approach used for probabilistic reasoning in TraumaSCAN have been described in detail elsewhere [4], the anatomic reasoning approach has not.

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TraumaSCAN was developed in C and C++ and ran only on Silicon Graphics machines (to take advantage of that platform's dedicated graphics hardware). Advances in graphics hardware now make it feasible to perform 3D graphics computations in real-time on a desktop PC or laptop, though many graphically intensive programs run slower on these computers. Since these advances present an opportunity for increased dissemination and deployment, a platform-independent version of TraumaSCAN called TraumaSCAN-Web [5] has recently been developed at the Decision Systems Group to replace the original. TraumaSCAN-Web utilizes Java, Java3D (an application programmer interface created by Sun for programming complex 3D graphics scenes in Java) and Open-GL (an open-source graphics library that is a standard for developing portable 3D graphics applications). It utilizes a Bayesian network model that updates the number of penetrating trauma related conditions that can be assessed and corrects an error discovered in the previous model and described in an earlier paper [4]. TraumaSCAN-Web also incorporates new methods for geometric reasoning about injuries to anatomic structures from gunshot and stab wounds. A recent analysis of TraumaSCAN-Web's performance on retrospective multi-center data was performed. Of the 23 conditions modeled in TraumaSCAN-Web, the patient data contained 19. The 23 conditions modeled in TraumaSCAN-Web cover damage to chest and abdominal soft organs (e.g., the lungs, heart, diaphragm, liver, stomach, kidneys, and intestine), some major blood vessels, and common conditions arising from these injuries such as pneumothoraces, hemothoraces and cardiac tamponade. Injuries to skeletal structures and minor blood vessels are not explicitly assessed. Areas under the ROC curve (AUCs) for this data ranged from 0.519 to 0.975 for gunshot injuries and from 0.701 to 1.0 for stab injuries [6]. This paper examines in detail the methods used in TraumaSCAN-Web for anatomic reasoning about ballistic and stab injury to chest and abdominal structures.

2. Related work

Related work on computer based systems for assessing penetrating trauma includes TraumAID [7,8], an expert system for assisting physicians with the diagnosis and treatment of conditions arising from penetrating trauma to the chest and abdomen. TraumAID uses a rule-based reasoner to identify diagnostic and therapeutic goals that are appropriate for a particular patient's state and provides textual feedback to the user. It does not explicitly model anatomy and anatomic relationships, and so cannot provide the deeper reasoning about anatomic involvement in injury that TraumaSCAN-Web does.

Work on probabilistic modeling of the consequences of penetrating trauma includes Hirshberg et al.'s [9] study of neural networks as a means of predicting the need for damage control in abdominal gunshot injuries. Their study shows that bullet trajectory information and blood pressure findings are important predictors of outcomes for patients with abdominal gunshot wounds. It complements results observed for TraumaSCAN-Web, which incorporates mechanism of injury information via geometric models of damage to anatomic structures. TraumaSCAN-Web also utilizes patient findings related to blood pressure values, such as hemodynamic shock, in its Bayesian network model, which is used to produce a more diagnostically refined assessment of the effects of thoraco-abdominal penetrating trauma.

Related research on understanding the effects of gunshot injuries on humans includes: utilizing 3D graphics methods for determining the paths taken by projectiles [10]; estimating the incapacitation to humans caused by different types of projectiles [11]; examining approaches for reducing ballistic casualties [12]; modeling and simulating penetrating injury to the extremities [13]; examining how missiles interact with tissue [14]; and, using high-speed video photography to analyze the wounding mechanics of a variety of low-velocity projectiles [15]. These studies examine the effects of projectiles on tissue through simulation and other means to assess the magnitude of resulting injuries. These approaches provide a wealth of information on ballisticpenetration paths, utilizing explicit knowledge of the types of projectiles used, projectile velocities and directions of entry into tissue. TraumaSCAN-Web, on the other hand, is designed to approach the assessment of penetrating trauma using only those details that would ordinarily be available to health care providers presented with a trauma patient. Thus, the process of assessing injury effects in TraumaSCAN-Web is implemented in such a way that the system proceeds in the absence of detailed information on projectiles and their characteristics, as this information is rarely available to providers prior to treating a trauma patient.

3. Methods: geometric reasoning in traumaSCAN-Web

Reasoning about the consequences of penetrating injury should take into account the mechanism of injury and the structures of the body to which injury occur. As described above, TraumaSCAN-Web's reasoning about injury consequences has to proceed in the absence of information about bullet type, bullet velocity, or direction of entry. The fact that there may be limited information available about the mechanism of injury is one of the uncertainties associated with assessing the effects of penetrating trauma.

In the case of stab wounds, reasoning about injury consequences is complicated by the fact that the direction and penetration depth of a weapon may be unknown. For multiple gunshot wounds, there are different complications. One is that it is not always possible to tell whether a wound is an entry or an exit wound. This implies that two external wounds that are in reality both entry wounds (or both exit wounds) might be hypothesized as being an entry-exit pair, and incorrect inferences about affected structures may result. Another complication is that many different pairings are possible among entry and exit wounds or entry wounds