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TBI prognosis calculator: A mobile application to estimate mortality and morbidity following traumatic brain injury

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A B S T R A C T

Objective: Traumatic Brain Injury (TBI) is a significant public health problem and a leading cause of worldwide mortality and morbidity. Although effective evidence-based guidelines are available to help with management, the first question clinicians and family face is whether or not it is appropriate to intervene at all. To facilitate prognostic assessment and family counseling, we developed mobile application integrating validated TBI prognostic models.

Methods: The medical literature was reviewed to identify existing and validated prognostic models of mortality and morbidity following TBI. After approbation by the selected original model authors, a mobile application incorporating these models was developed.

Results: Of more than 100 published models, we identified the MRC CRASH trial-derived models as the most appropriate TBI prognosis tools for mobile use. These were integrated into an application we called "TBI Prognosis Calculator", which allows quick and interactive estimation of 14-days mortality and 6-months mortality and morbidity using demographic, clinical and radiologic variables. The application was programmed both for iOS-and Android-compatible devices and released as free applications in the platforms' respective distribution channels.

Conclusions: Prompt and accurate prognosis estimation in TBI is promising. Mobile applications have the potential to enable easier and quicker point-of-care access to validated models, providing additional information to improve management and family counseling. We anticipate that clinicians will find "TBI Prognosis Calculator" useful as an adjunct in their prognostic assessment and family counseling.

1. Introduction

Traumatic Brain Injury (TBI) is a significant public health problem and a leading cause of worldwide mortality and morbidity [1]. Although effective evidence-based guidelines are available to help with management [2], the first question clinicians and family often face is whether or not it is appropriate to intervene at all. Indeed, while timely surgical and medical interventions have been shown to reduce mortality [3], long-term functional status has proven much more difficult to improve [1].

Current management of TBI is based on the finding that, while some level of cerebral damage that occurred at the time of injury is likely irreversible, optimal medical and surgical support can prevent secondary damage and hence improve patient outcome [4]. One of the challenges faced throughout the decision-making process is in assessing the level of permanent damage the patient suffered because this assessment should, in theory, determine the long-term functional prognosis. Ideally, accurate prognosis estimation could inform decision-making by identifying patients likely to benefit from aggressive medical and surgical management, as opposed to those for whom treatment withdrawal should rather be considered [5].

Multiple studies have sought to identify reliable prognostic markers in TBI and these markers have been integrated in various mathematical models estimating future death or functional status [6–8]. While the validity of such models has been confirmed [9–15], few clinicians actually use them [16]. Based on published experience in other medical specialties, we postulated that the current models' adoption as point-of-care tools was hindered by 1) the models' complexity [17], 2) their web-based interface [18], 3) the lack of a concise model explanation outside of their initially

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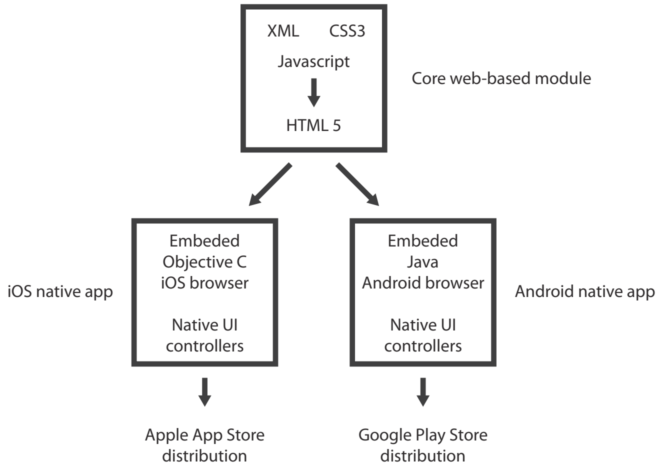

Fig. 1. Application architecture of the TBI Prognosis calculator. A platform-independent, locally stored web-based module provides the algorithm and general user-interface elements. The module is accessed through a natively-compiled, platform-specific embedded browser.

published descriptions [19] and 4) concerns regarding the validity of the models' predictions [20]. While the latter point is a function of the models themselves, the three former elements are essentially user-friendliness issues. To facilitate the clinical use of TBI prognostic models, we developed a mobile application incorporating four MRC CRASH trial-derived models and released it for free on the iOS and Android platforms.

2. Methods

The medical literature was reviewed to identify existing and validated prognostic models of mortality and morbidity following TBI. Models were considered for inclusion in the application if they had been developed using a large (>1000 patients) international cohort, externally validated by independent groups and used standard variables available in any trauma center. Available systematic reviews were used to identify models published before 2005. A manual search on Pubmed using the keywords "TBI" and "Prognostic Model" was performed to identify models published between 2005 and 2013. The authors of selected models were contacted and written approval for inclusion in the application was obtained.

The application architecture is presented in Fig. 1. Briefly, the selected prognostic models were programed as a JavaScript routine controlling an HTML 5 interface through the AJAX paradigm. Additional information pages were created as simple HTML 5 documents. These web-based assets were then embedded in application bundles containing a web browser derived from each platform's system classes. Targeted devices and operating systems were phones and tablets running iOS 7.0 and later, as well phones and tablets running Android 2.2 and later. Web-based, iOS and Android assets were developed using Coda 2.0.14 (Panic Inc., Portland, OR), Xcode 5.1.1 (Apple Inc., Cupertino, CA) and Android Developer Tools 22.3.0–887826 (The Android Open Source Project) respectively. Following internal testing in the iOS and Android simulators as well as on the author's devices, the applications were submitted and approved for release on the App Store (Apple Inc., Cupertino, CA) and Google Play (Google Inc., Mountain View, CA). The applications were not submitted for evaluation by the FDA, Health Canada or any government agency.

3. Results

3.1. Review and choice of models

Systematic reviews of the TBI prognosis literature have identified over 100 distinct published models between 1976 and 2005 [21,22]. We identified 14 additional models published between 2005 and 2013 [6,7,23–34]. Of all the published models, most of these were either small, of poor methodological quality or had not been externally validated [21,35]. Five models meeting our selection criteria were identified and are presented in Table 1.

The first large-scale model was developed in 2007 when Maas et al. aggregated the data from 11 studies to produce the IMPACT dataset containing 8509 patients [8,36]. The second was produced in 2008 from the 2004 Medical Research Council CRASH (Corticosteroid Randomisation After Significant Head Injury) Trial which provided the largest prospectively collected database of patients with TBI [37]. Multivariable logistic regression analysis of the CRASH data allowed the identification of 4 clinical and 5 CT variables independently associated with death at 14 days and death or severe disability six months after TBI (see Table 1) [6]. Differential weighting of these variables resulted in the production of four mathematical models tailored for high-or middle-/low-income countries, with or without CT scan results. After external validation using the IMPACT dataset, the models were made available as the CRASH Head Injury Prognosis web calculator [38].

Following the publication of the IMPACT and CRASH models, multiple authors derived secondary models in an attempt to improve prediction accuracy [7,26]. While marginally superior in their respective publications, these secondary models remain less studied than IMPACT and CRASH.

Among the five identified models, no published study demonstrated the superiority of one over the other. At the time of application development, independent external validation of these models confirmed their good performance and found no difference between retrofitted, CRASH-derived predictions and IMPACT-derived predictions [11]. In order to minimize the number of variables required, we settled on using the four original CRASH models. Theoretical advantages compared to the other models include:

- Largest development cohort available.
- Extensive international representation.
- Prospectively collected data.
- Consideration of the country's socio-economic status.
- Easier to access and unambiguous variables.

3.2. Resulting application

The resulting application is shown in Fig. 2. The user is queried for the treating country's socio-economic status and the patient's age, Glasgow Coma Scale score, pupil reactivity and presence of any major extra-cranial injury. Optional CT scan variables can be entered if available. Outcome data consists of the probability of all-cause mortality at 14 days following the trauma and of unfavorable outcome (Glasgow Outcome Scale < 4) at 6 months. The output is calculated automatically using the most appropriate model depending on the country's socio-economic status and CT variables. Throughout the application, help boxes are available to define the variables and ensure proper understanding of the model's features and limitations.