THE INTEGRATION OF A CLINICAL PROGNOSTIC CALCULATOR FOR TRAUMATIC BRAIN INJURY WITHIN AN ELECTRONIC HEALTH RECORD

by

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STATEMENT OF THESIS APPROVAL

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ABSTRACT

Traumatic brain injury (TBI) cases are complex and inherently time sensitive. Clinicians often base treatment decisions upon their individual experiences, training, and many other factors. Prognostic calculators can help enhance the clinician's understanding of the patient's prognosis. Stand-alone, internet-based TBI prognostic calculators exist, including a website developed based on the International Mission for Prognosis and Analysis of Clinical Trials in TBI (IMPACT-TBI) [1,2]. An electronic health record (EHR) integrated prognostic calculator that provides the expected probability of favorable and unfavorable outcomes for an individual patient could make treatment planning for TBI patients more efficient, accurate, and standardized, with the ultimate goal of improving patient outcomes.

The IMPACT-TBI calculator was integrated with the Epic® EHR and made available to clinicians at the University of Utah Health system in Salt Lake City, Utah. The use of the tool was monitored and analyzed to support the providers and improve care. The calculator was used 346 times over 17 months. Trauma service providers were most likely to use the tool, and there was a significant increase in tool use after a demonstration was given to providers.

An IMPACT-TBI prognostic calculator was successfully integrated with a major commercial EHR system. The integration provided insight into strategies for better integration and adoption of advanced clinical decision support tools in the future.

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CHAPTER 1

BACKGROUND

1.1 Traumatic Brain Injury

Traumatic brain injuries (TBI) are common, debilitating, and deadly. TBI is the leading cause of disability and death worldwide for younger adults and the World Health Organization (WHO) recognizes this as a significant public health problem [1-3]. More than 150 patients per 100,000 people worldwide are affected by TBI, and this is a great burden on the healthcare system [3]. A majority of traumatic brain injuries are the result of accidents, meaning all sections of the population are at risk and affected [4].

The expected outcome following a TBI is an important determinant for deciding on appropriate TBI care. Only limited research has been completed to assist with deciding when to pursue an aggressive care path, provide comfort care, or withdraw care. This gap allows for significant improvement in standardizing care provided to patients with moderate or severe TBI.

TBI cases are complex and inherently time sensitive. Treatment of moderate TBI, with a Glasgow Coma Score (GCS) ≤ 12, and severe TBI, with a GCS ≤ 9, is complex and emergent. Physicians typically decide upon treatment strategies within 24 hours and those treatment plans are a primary factor in the patient's outcome. The development of evidence-based TBI care management guidelines by the Brain Trauma Foundation (BTF)

has aided in improving care for TBI patients [5–7]. These guidelines have improved outcomes and helped to standardize care for TBI patients [8]. Clinicians often base treatment decisions upon their individual ideas of probabilities for the patient's prognosis. This can lead to the difficult decision of when to provide aggressive care and when to pursue comfort care. The clinician's expected prognosis for the patient is based upon experience, training, and many other factors. A prognostic calculator could serve not to replace the clinician's judgement, but to enhance the clinician's understanding of the patient's prognosis. A prognostic calculator that provides the expected probability of favorable and unfavorable outcomes for an individual patient could make treatment planning for TBI patients more efficient, accurate, and standardized as well as having the potential to improve outcomes.

1.2 Prognostication

Providers having increased information about a TBI patient's prognosis can potentially increase positive outcomes and reduce disability and mortality. TBI is a difficult condition to care for and BTF guidelines have been aimed at improving and standardizing TBI care. Adherence to these recommendations has been associated with improved patient outcomes [7,8]. The results from a prognostic calculator can inform physicians in a meaningful and substantial way. It has been noted that age is the strongest predictor of outcome [9–11] for TBI, but the magnitude of the influence that age has in clinical practice is not well understood. The newest Brain Trauma Foundation guidelines [7] address many of the factors included in the IMPACT-TBI prognostic calculator. Use of the calculator provides clinicians with more information than thresholds for individual

predictors of mortality and morbidity.

Stand-alone, web-based TBI prognostic calculators exist, including a website developed based on the International Mission for Prognosis and Analysis of Clinical Trials in TBI (IMPACT-TBI) [1,12]. The IMPACT-TBI prognostic calculator was created and validated, both initially and externally, with the goal of predicting TBI outcomes in both moderate and severe TBI cases and to help guide appropriate management [10,11,13]. The IMPACT-TBI model uses the patient's age, admission motor scores, admission pupil reactions, admission blood pressure (BP), admission peripheral capillary oxygen saturation (SpO2), Marshall classification of computerized tomography (CT) scan [14], presence of traumatic subarachnoid hemorrhage (tSAH) on CT scan, presence of epidural mass on CT scan, admission glucose, and admission hemoglobin (Hb). The IMPACT-TBI prognostic calculator produces prognoses for the probability of an unfavorable outcome (also the favorable outcome by way of the inverse calculation) and a probability of mortality in 6 months. The prognostic calculator produces estimates based upon the first three variables—patient's age, motor scores, and pupil reactions—which are also called the "Core" model. The next stage of prognostic calculations includes the next five variables: BP, SpO2, Marshall classification of CT scan [14], presence of tSAH on CT scan, and presence of epidural mass on CT scan; this is referred to as the "Core+CT" model. Finally, the "Core+CT+Lab" model also includes glucose and Hb vales to produce the outcome predictions. These predictions are presented both as text and a simple bar graph by the stand-alone web-based calculator.

The IMPACT-TBI model can explain approximately 80% of the variability in TBI patient outcomes; [13] as a result, the American College of Surgeons has noted the

usefulness of the IMPACT-TBI calculator for moderate to severe TBI cases to guide management [15]. However, prior studies have shown that nearly 50% of neurosurgeons are not aware of the existence of the IMPACT-TBI prognostic calculator and that, of those who are aware, less than half report using the tool [16]. An international survey of surgeons who handle moderate and severe TBI cases was conducted to understand current awareness, use, and potential changes in care that could or do result from the clinical use of the IMPACT-TBI prognosis calculator [16]. Clinicians are oftentimes not aware of the IMPACT-TBI calculator, but many stated that it could or does influence their care [16]. Providing prognostic calculation to the physicians that care for TBI injured patients has the potential for standardizing care, improving outcomes, and better informing the treatment team, patients, and the families of patients.

Other prognostic calculators for TBI exist, including the Corticosteroid Randomisation After Significant Head Injury (CRASH) studies and resulting models [17]. The trial was similar in size and scope to the IMPACT-TBI trials, but developed a model that was slightly less accurate; also, the CRASH prognostic calculator used fewer variables. Both models have been validated during their creation and in subsequent testing [10,11,13,18]. The CRASH model also focused more as a trial on corticosteroid use than the IMPACT-TBI calculator, therefore making the IMPACT-TBI prognostic model a better choice for the purposes of our EHR integration.

1.3 Integration Aims

Despite its recognized potential for improving clinical care and outcomes, IMPACT-TBI is not widely known or used. Reasons for this limited impact of the IMPACT-TBI tool include lack of integration within clinical workflows, inefficiencies

when used, and lack of a coherent strategy for the communication of the results. These barriers were addressed in this project by deeply integrating the prognostic calculator within the EHR and more specifically the clinician's workflow. The aims for the integration of the IMPACT-TBI calculator were:

I. Increase clinicians' use of the IMPACT-TBI prognostic calculator during treatment of TBI patients.

II. Define and expound upon the barriers and potential opportunities for clinical use of an EHR integrated prognostic calculator.

III. Understand the limitations of current EHR tooling and customization as related to prognostic calculators.

CHAPTER 2

METHODS

Prior to the integration of the IMPACT-TBI prognostic calculator, physicians (primarily neurosurgeons) would access the calculator online (http://www.tbi-impact.org), enter the data, and copy and paste the results into their current note. This was a time-consuming process that was not only outside the medical record, but also made sharing the results difficult.

2.1 Methods Overview

The study that was completed was a feasibility study of integrating the IMPACT-TBI prognosis calculator within the electronic health record. The participants were providers at University of Utah Hospital. This project was completed as a quality improvement project for the hospital; therefore, it was exempted by the University of Utah's Institutional Review Board from review. The measurement variables were date, time, clinician, clinician's service, and completed calculations for each use of the integrated IMPACT-TBI calculator.

2.2 Calculator Integration

The IMPACT-TBI prognostic calculator [1] was integrated and implemented at University of Utah Health Care in Salt Lake City, Utah on February 11, 2016. This hospital system uses the EpicCare® electronic health record. The prognostic calculator was integrated as a custom block of data entry fields known as a SmartForm™ (Figure 2.1), which allowed clinicians to access the tool while writing their progress note or history and physical examination note while logged into the neurosurgery service. Clinicians could also add the integrated calculator section to any note using a custom link known as a SmartLink™ (.NEUIMPACT). These methods were integrated into the workflow of the clinician's documentation for any patient.

When a clinician used the integrated calculator, a section was automatically added to the provider's current note describing the data entered and the results of the calculation. This allowed other providers to see in the note which data points were used and the predicted 6-month mortality, unfavorable outcome, and favorable outcome for each of three models that may have been completed.

The calculator integration was an improvement upon the internet-based version partially because the way the integrated calculator works is to calculate each of the models (Core, Core+CT, and Core+CT+Lab) after every data point entry, as opposed to only when the user pressed calculate on the internet-based calculator. The real-time updating of the data was useful to allow providers to see the IMPACT-TBI prognosis predictions as soon as enough data had been entered.

Also made available with the integrated calculator was a custom side-bar report that presented the required information needed to fill out the calculator (also in Figure 2.1).

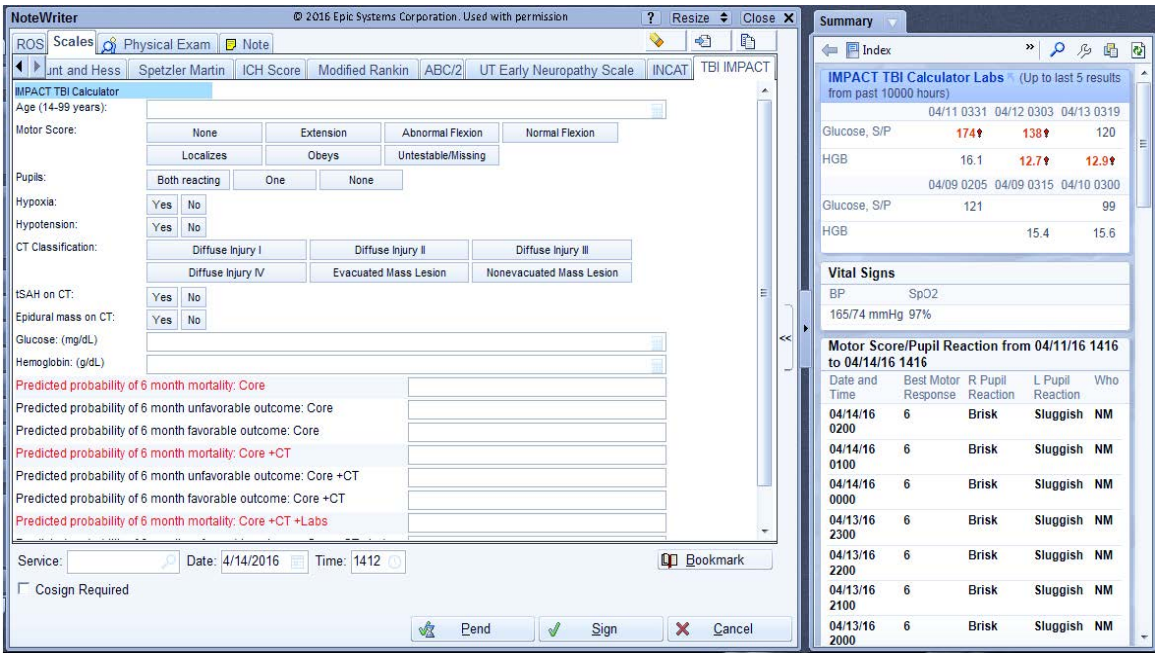

Figure 2.1. IMPACT-TBI prognostic calculator integrated within Epic®.

Age was automatically presented in the patient header and so was excluded from this report. The report provided the motor scores, pupil reactions, BP, peripheral capillary SpO2, glucose, and Hb in reverse chronological order from the time of admission. Also presented in the side-bar report were links to radiology imaging, so that the CT scan, if available, was accessible without leaving the current activity.

The presentation of the report displaying the data required for the IMPACT-TBI prognostic calculator was iteratively designed with the clinicians to reduce the time required to find the desired information. The order of the presentation of the data was determined both by the most likely number of results and by the difficulty of locating the information without the sidebar. Therefore, links to head CT were supplied first, then the lab values for glucose and Hb, then BP and SpO2, and finally motor score and right and left pupil reactivity. The bottom section of the report, containing motor score and pupil reactivity, also in Figure 2.1, was almost always populated with the most data and so that section was moved to the bottom of the panel for efficient organization of the Side-Bar® report.

2.3 Provider Education

Education for clinicians was simply a reminder that the tool existed and a brief demonstration during Grand Rounds. The rationale for this approach was to determine adoption of the tool with minimal training and education. An email about the availability of the integrated IMPACT-TBI prognostic calculator was sent to neurosurgeons on February 12, 2016. General surgery clinicians and trauma clinicians were presented a demonstration of the tool on June 23, 2016 during Grand Rounds and asked to use the

tool for cases fitting the criteria for moderate and severe TBI. Neurosurgeons and some trauma providers received a demonstration of the tool at Grand Rounds on June 14, 2017.

CHAPTER 3

RESULTS

Between February 12, 2016 and September 21, 2017, the integrated IMPACT-TBI prognostic tool was used in 346 unique instances. The tool usage was monitored by querying all notes that used the SmartForm™ associated with the tool. The date and time that the note was completed were recorded. The model level that was completed when using the tool – Core, Core+CT, or Core+CT+Lab – was recorded. Also recorded was the note writer's service area of neurosurgery, general surgery, or trauma. Finally, the GCS documented in the note was recorded.

Figure 3.1 shows the use of the IMPACT-TBI prognostic calculator over time, stratified by the note writer's service area. During the first five months, all 17 of the uses were by neurosurgeons. From August 2016 on, the clear majority of the uses of the tool were by providers in the trauma service. The use of the tool presented in a bi-modal distribution, with the first increase in usage occurring within 2 months of the demonstration and the reminder about the tool's availability. The second peak for tool usage corresponded with the second demonstration of the tool. Over the 20 months that were monitored, the average number of tool uses per month was more than 17.

The tool's use was compared to the number of potential use cases, where GCS $\leq$ 12, at the University of Utah hospital over the same period. There was no distinct

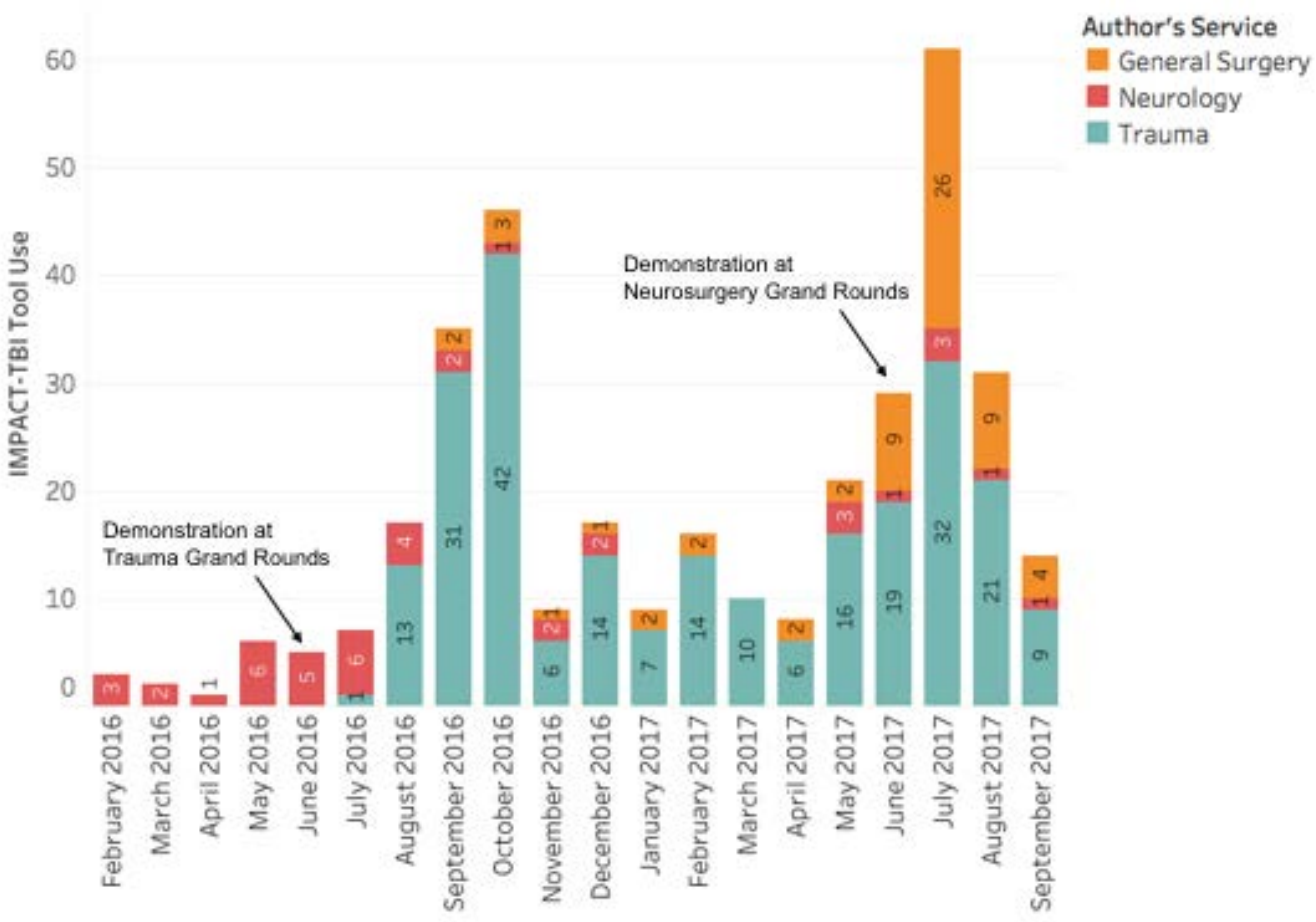

Figure 3.1. Usage of the integrated IMPACT-TBI prognostic calculator tool by month.

variation in the proportion of the cases where the calculator was completed with relation to any apparent seasonal variation

Table 3.1 shows the IMPACT-TBI tool usage by service area and which model was completed. Trauma providers accounted for 69.4% of the tool usage, general surgery providers accounted for 18.2% and neurosurgeons accounted for 12.4%. Of the times the IMPACT-TBI prognostic calculator was completed, 49.5% (171) of the uses were for the Core model. 6.4% (22) of the tool uses were for the Core+CT model and 44.2% (153) of the uses were for the Core+CT+Lab model. Both general surgery and trauma providers were more likely to use the Core model, whereas 41 of 43 tool uses by neurosurgeons were for the Core+CT+Lab model.

Finally, the GCS recorded in the note where the tool was used was abstracted. The score recorded in the note ranged from 3 to 15. The average GCS for the times the tool was used was 12.3. The average noted GCS score varied significantly by service, with neurosurgeons' notes having an average noted GCS of 7.6, general surgery providers' notes having an average of 13.3, and trauma providers' notes having an average of 12.8. A one-way analysis of variance showed that neurosurgeons' patients had significantly lower noted GCSs when the tool was used ($p < 0.0001$).

Table 3.1. IMPACT-TBI tool usage by service area and model completed.

	Core Model	Core+CT Model	Core+CT+Lab Model	Total by Service
General Surgery Service	44	7	12	63 (18.2%)
Neurosurgeons	1	1	41	43 (12.4%)
Trauma Service	126	14	100	240 (69.4%)
Total by Model	171 (49.4%)	22 (6.4%)	153 (44.2%)	346

CHAPTER 4

DISCUSSION

The integrated IMPACT-TBI prognostic calculator was used more often and more widely than anticipated. Many potential improvements could be made to enhance its use and usefulness, and there are many future research questions that this project could inform about the integration of clinical decision support tools within the electronic health record.

4.1 Calculator Usage

The expectation for use of the integrated prognostic calculator was tempered based on prior research on clinical decision support tool adoption [21]. The education and prompting for use were limited to minimize disruption to the clinicians providing emergent care and to evaluate the adoption of a tool when simply made available, demonstrated and reminded, as is often the case for health IT tools implemented for operational purposes. The distribution for the timeline of the tool's use was bimodal with increases after the demonstrations were performed. Part of this finding could potentially be attributed to the trauma team adding, with no prompting from the medical record team, the link that contained the integrated IMPACT-TBI calculator into its default clinical note template.

In the beginning, after making the integrated tool available to service providers, it was used nearly exclusively by neurosurgeons. Then, a demonstration was provided for trauma providers on June 23, 2016 and there was a marked increase in the usage of the tool over the following months. Use of the calculator then decreased and leveled off from December 2016 to May 2017. The second peak in the usage of the integrated IMPACT-TBI calculator occurred after another demonstration performed at the neurosurgery Grand Rounds on June 14, 2017. It is inferred that the change in tool usage was due to the demonstrations, but there could also be variation in the number of applicable TBI cases by month or season.

During the beginning of the implementation, only neurosurgery providers were using the calculator, which is understandable because the project had initially been implemented upon their request. After the demonstration in June 2016, trauma providers began using the tool significantly more. This increase in usage by trauma providers would also account for some of the reduction in the use of the tool by neurosurgeons. This is because if the tool had already been completed by the trauma provider, then the neurosurgeons seeing the same patients later in their hospital course would most likely not need to reuse the tool. Finally, after the second demonstration, there was a significant increase in the use of the tool by general surgery, but it was not as sustained or consistent as the use by the trauma providers.

The calculator is intended to be used for patients with moderate or severe TBI (GCS $\leq$ 12) upon hospital admission. There was a significant difference in the GCS recorded in the note based on the author's clinical service. Neurosurgeons were the only service group to use the calculator where the average score was less than 12, at an

average of 7.6. The GCS used in the note may or may not have been the same as the admission GCS and could have potentially changed. The frequency of usage of the integrated tool could indicate that the trauma providers simply began filling it out for all patients when the note containing the link appeared, which could have led to trauma providers using the tool even for patients who had a GCS above the recommended threshold.

There was significant variation in the model that was completed for a given patient and the variation was significantly correlated with the note author's service area. Neurosurgery providers nearly always completed the Core+CT+Lab form of the calculator (95.4%), as opposed to 41.7% for trauma providers and 19.1% for general surgeons. This discrepancy could be due to a variety of factor including, but not limited to, more familiarity and comfort in using the calculator by the neurosurgeons. Also, the time and expertise needed to review and classify the CT scan could have deterred full calculator completion by trauma and general surgery clinicians. Finally, there were a great many cases where all data points except the CT classification information were filled. In those cases, only the Core model was completed, suggesting that the CT scan classification is the main barrier to use and integration of the IMPACT-TBI prognostic calculator.

4.2 Potential Calculator Improvements

There are various potential improvements and automations that could refine the accuracy and usefulness of the tool and its integration with the electronic health record. One such improvement would be the automatic retrieval and utilization of the desired

data. Many of the more common measures used in the calculator would be easy to automatically retrieve. Age, motor score, pupil reactions, SpO2, blood pressure, glucose, and Hb could all be automatically retrieved and prefilled in the form. Currently, these data points are not filled automatically due to technical challenges associated with trauma patients having assigned names (e.g., “Trauma, Everest”), which led to technical difficulties with this type of an integration.

Similar to the automatic provisioning of data for the calculator, the link to the CT scan for the patient is an area that could be drastically improved. If the radiologist performed the Marshall CT classification and commented in structured data fields on the presence of tSAH and the presence or absence of an epidural mass, then the calculator could be automatically completed in its entirety, with the ability for the clinician to edit the data that had been prepopulated. This is potentially one of the most interesting improvements to the integration and could be accomplished through work with the radiology department.

Automatically integrating the use of the tool within clinical workflows would serve as a significant potential improvement to the calculator integration. An initial approach to such an integration was achieved by the trauma providers through adding the integrated calculator to their default note template so that the tool was automatically available for certain notes. Adding the calculator automatically based upon initial GCS is being planned. The potential improvement of automatically including the IMPACT-TBI calculator when the GCS score threshold is met could help ensure that the calculator is completed in a reasonable timeframe after admission of an eligible patient with TBI. This address concerns about the validity of the calculator for patients not meeting the

eligibility criteria (GCS > 12) or for calculations completed more than 48 hours after admission.

Another potential improvement to the calculator that is currently possible, being evaluated, and stands to increase the effectiveness of the integrated tool is the ability of attending physicians to view the calculated prognosis from within their patient dashboard. This visibility would allow physicians to see a calculated score completed by another provider and could reduce duplicative calculations.

4.3 Limitations

There were some limitations in the analysis of the use and adoption of the integrated IMPACT-TBI prognostic calculator. First, no data was abstracted about the number of patients for whom the calculator should have been used. Second, the analysis used the GCS available at the time of the calculation, rather than the admission GCS. Third, we did not assess which clinician viewed or made decisions based upon the calculated prognosis.

4.4 Future Directions

There are many potential future directions for further research and investigation. This calculator could be improved upon by using Fast Healthcare Interoperability Resources (FHIR) specifications to allow for better integration with a variety of electronic health record systems.

Another future direction is the use of the IMPACT-TBI calculator as a potential guard against nihilism. If the calculator has been completed and if the patient prognosis is

high enough, then a provider moving to comfort care or withdrawal of aggressive care could be alerted of the patient's prognosis and prompted to consider altering the treatment plan. This type of use of the tool could help guard against a nihilistic perspective, help control for potential bias, and help improve patient outcomes.

CHAPTER 5

CONCLUSION

The integration of the IMPACT-TBI Prognostic Calculator into the electronic health record increased both awareness and use of this valuable tool. The approach used in this effort could be applied to the development and integration of other similar decision support tools in the electronic health record. Although there are many potential improvements that could be made, the level of use of the calculator demonstrated that clinicians are willing to use the prognostic calculator as a tool to help guide treatment planning and decision making. Further research is needed to determine the degree to which the prognostic calculator enhances patient care and enables improved outcomes for patients and their families.

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