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REVIEW ARTICLE

Prognostic Value of CRASH and IMPACT Models for Predicting Mortality and Unfavorable Outcome in Traumatic Brain Injury; a Systematic Review and Meta-Analysis

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Abstract: **Introduction:** The Corticosteroid Randomization After Significant Head injury (CRASH) and the International Mission for Prognosis and Analysis of Clinical Trials (IMPACT) are two prognostic models frequently used in predicting the outcome of patients with traumatic brain injury. There are ongoing debates about which of the two models has a better prognostic value. This study aims to compare the CRASH and IMPACT in predicting mortality and unfavorable outcome of patients with traumatic brain injury. **Method:** We performed a literature search using Medline (via PubMed), Embase, Scopus, and Web of Science databases until August 17, 2022. After two independent researchers screened the articles, we included all the original articles comparing the prognostic value of IMPACT and CRASH models in patients with traumatic brain injury. The outcomes evaluated were mortality and unfavorable outcome. The data of the included articles were analyzed using STATA 17.0 statistical program, and we reported an odds ratio (OR) with a 95% confidence interval (95% CI) for comparison. **Results:** We included the data from 16 studies. The analysis showed that the areas under the curve of the IMPACT core model and CRASH basic model do not differ in predicting the mortality of patients (OR=0.99; p=0.905) and their six-month unfavorable outcome (OR=1.01; p=0.719). Additionally, the CRASH CT model showed no difference from the IMPACT extended (OR=0.98; p=0.507) and IMPACT Lab (OR=1.00; p=0.298) models in predicting the mortality of patients with traumatic brain injury. We also observed similar findings in the six-month unfavorable outcome, showing that the CRASH CT model does not differ from the IMPACT extended (OR=1.00; p=0.990) and IMPACT Lab (OR=1.00; p=0.570) in predicting the unfavorable outcome in head trauma patients. **Conclusion:** Low to very low level of evidence shows that IMPACT and CRASH models have similar values in predicting mortality and unfavorable outcome in patients with traumatic brain injury. Since the discriminative power of the IMPACT Core and CRASH basic models is not different from the IMPACT extended, IMPACT Lab, and CRASH CT models, it may be possible to only use the core and basic models in examining the prognosis of patients with traumatic injuries to the brain.

Keywords: Brain injuries, traumatic; prognosis; survival analysis; mortality; patient outcome assessment

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1. Introduction

Traumatic brain injury (TBI) is a significant cause of morbidity and mortality worldwide. It is one of the most common complications of intentional and unintentional accidents, with a global prevalence of 8.4%. Based on existing reports, the incidence and prevalence of TBI due to head trauma have significantly risen since the 1990s (1). This presents a

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unique challenge for hospitals because available healthcare resources are likely to become overburdened by higher rates of TBI.

Physicians can identify intracranial injuries from head traumas through imaging modalities such as computed tomography (CT) scan and magnetic resonance imaging (MRI). However, there are challenges to imaging trauma patients suspected of TBI. While scanning patients has become essential for trauma diagnostic work-up, not all hospitals are equipped with CT machines or technicians. Other challenges include the deterioration of hemodynamically unstable patients in the radiology suite and high exposure to ionizing radiation (2, 3). As a result, healthcare providers are researching different tests and measures to diagnose TBI, especially in patients unable to undergo head imaging.

The Glasgow coma scale (GCS) measures the level of consciousness in a person following trauma and classifies TBI as mild, moderate, and severe. Despite several clinical decision rules to help identify clinically significant head injuries, physicians continue to face the challenge of deciding who needs a brain CT while minimizing unnecessary radiation exposure. While minor head injury is commonly seen in the emergency department, investigators have found that only 16% of these patients will have an acute intracranial lesion (4). This means that if every patient with mild head injury was to undergo cerebral imaging, 84% of these studies would be normal and unnecessary. To reduce unnecessary imaging and waste of hospital resources, a prognostic scoring system can be helpful.

Although multiple prognostic models for predicting mortality and disability following traumatic brain injuries exist, none are widely used in clinical practice. Most of these models are limited based on small population size and lack external validation. Most models were designed based on data from developed countries, which are not clinically practical to the majority of head trauma and accidents that occur in developing countries (5, 6).

The Corticosteroid Randomization After Significant Head injury (CRASH) model is one of the best prognostic tools for TBI, designed in recent years. It has two separate outcome prediction models for high and low-middle income countries. As a result, the CRASH model can be applied to different populations unlike other prognostic models. Designed by the Medical Research Council (MRC) with a sample size of more than 10,000 people, the CRASH model predicts 14-day mortality and 6-month unfavorable outcome (7).

Although this model's discrimination and external validation have been evaluated in several studies (8-12), the findings have been contradictory.

Another prediction model for patients with TBI, which has received more attention recently, is the International Mission for Prognosis and Analysis of Clinical Trials in TBI (IMPACT) (11). This model also aims to predict the outcome of mortality and unfavorable outcome for patients with TBI. CRASH and IMPACT are the most externally validated models for predicting mortality and unfavorable outcome in TBI patients. Many studies have evaluated both models and confirmed their validity. In a study by de Cássia Almeida Vieira et al., results show that both models have a similar prognostic value in predicting mortality and unfavorable outcome in severe TBI (13). However, there is still a difference of opinion regarding which of these models works better for predicting the outcome of brain injuries. Therefore, we aim to compare the value of these two prognostic models, CRASH and IMPACT, in predicting mortality and unfavorable outcome of head trauma patients.

2. Methods

2.1. Study design

The present study is a systematic review and meta-analysis to compare the value of the two prognostic models of CRASH and IMPACT in predicting mortality and unfavorable outcome of patients with traumatic brain injury. For this purpose, we thoroughly searched the available databases and electronic resources to find all articles related to the topic of our study. This study was designed based on the guidelines for meta-analysis of observational studies. The searching and summarizing data method has been reported in the previous meta-analyses of the researchers of this study (2, 14-23). Here, we explain a summary of the activities carried out to achieve the goals of this study.

2.2. Description of PICO

The description of PICO in the present study is as follows:

The problem or study population (P): Human studies conducted on brain trauma patients

Targeted intervention (I): Predictive value of CRASH and IMPACT models

Comparisons (C): Comparison with the survival group or favorable outcome

Outcome (O): Mortality and unfavorable outcome are the primary outcomes of this study

2.3. Search strategy

In the current research, we selected the keywords using three strategies: Medline database MeSH and Embase database Emtree, experts' opinions in the field, and the review of keywords and the titles of related articles. Then, using an appropriate combination of these keywords, an extensive search was conducted in the electronic databases of Medline (via PubMed), Embase, Scopus, and Web of Science until August 17, 2022. We presented the Medline search strategy in Appendix 1. In addition to the systematic search, we performed

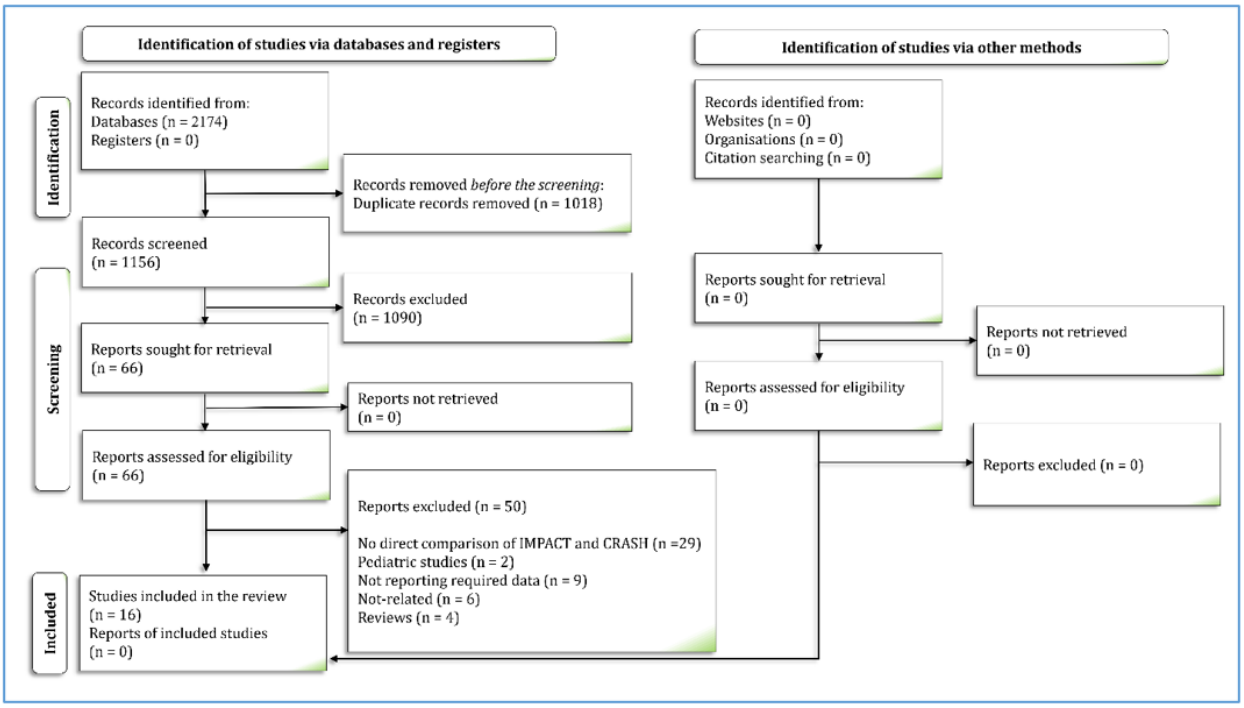

Figure 1: Flow diagram for selection of studies.

a manual search in the Google search engine, Google scholar, and related article sources.

2.4. Eligibility criteria

Inclusion criteria

In the current study, we included the human studies conducted to investigate the prognostic value of CRASH and IMPACT models in predicting mortality and unfavorable outcomes of traumatic brain injury. The research population is human studies without age, sex, and race restrictions.

Exclusion criteria

Failure to compare CRASH and IMPACT prognostic models simultaneously in one study, studies conducted on children, failure to report injury outcomes, failure to report assessment method, and review articles were the study's exclusion criteria.

2.5. Data Extraction

After removing duplicate articles from the systematic search results, two independent researchers performed the initial screening by reading the title and abstract of the articles. The full text of the relevant articles was examined in detail. We included the studies in the present systematic review based on the inclusion and exclusion criteria. We resolved any disagreements through discussion with a third researcher.

The extracted data includes information related to the study design, sample characteristics (age, gender), number of examined samples, the severity of TBI, the interval between the injury and evaluation of IMPACT and CRASH prognostic models, duration of follow-up, and quality assessment of selected articles.

In cases where the data could not be extracted from the article, we contacted the authors of the article. If the corresponding author did not respond to the first email, two follow-up emails were sent (with an interval of one week). In cases of no responses, other article authors were contacted through professional social platforms such as Research Gate and LinkedIn to provide the required information to the researchers.

2.6. Quality assessment of the studies

The quality of the studies was determined using the QUADAS-2 guidelines (24). To evaluate the agreement between the two researchers, we investigated the inter-rater reliability in the quality assessment of the studies. In case of disagreements, we resolved the difference through discussion with the third researcher.

2.7. The level of evidence

The level of evidence was evaluated based on the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework (25). Since all the studies included in this study were observational, the base score of these articles starts from the Low level based on the GRADE guide.

In the presence of a large magnitude of effect, dose-response gradient, and plausible confounders, the score of the level of evidence could be increased between 1 and 3 points.

2.8. Statistical analyses

We performed the analyses in STATA 17.0. All studies were summarized and divided based on their outcome and predictive value.

All included studies reported the area under the curve for the IMPACT and CRASH models with a 95% confidence interval. Therefore, we calculated a pooled area under the curve (AUC) with a 95% confidence interval (95% CI).

IMPACT model has three types: IMPACT core model, IMPACT extended model, and IMPACT Lab model. IMPACT core model is calculated based on clinical findings. IMPACT extended model is calculated based on clinical findings and CT scan investigations (core model + CT scan). IMPACT Lab model includes clinical findings, CT scan, and Blood glucose and hemoglobin level (core model + CT scan + laboratory assessment). The CRASH model also includes two models, basic and CT. The basic model is based on clinical findings, and the CT model requires CT scan findings in addition to clinical findings.

Therefore, to compare the IMPACT and CRASH prognostic models' areas under the curve, we compared the IMPACT core and CRASH basic models together, and the IMPACT extended, IMPACT Lab, and CRASH CT models together. Finally, the odds ratio (OR) was checked with a 95% confidence interval by performing a meta-regression to determine which model has the best prognostic performance.

We used the random effect model in the present study due to the existence of heterogeneity. To check heterogeneity between studies, we used the I2 test. Using Egger's test method, Funnel Plot was used to identify publication bias (26).

3. Results

3.1. Studies' characteristics

The search resulted in 2174 articles. After removing duplicates, we included 1156 studies in our initial screening process. After examining the title and abstract of the included articles, we read 66 of them in detail. The data of 16 studies were included in the final analysis (27-42). These studies included the data of 39,829 patients with suspected traumatic brain injury. The reasons for the exclusion of articles from the present study included failure to examine the prognostic value of IMPACT and CRASH models simultaneously (29 articles), failure to report the required data (9 articles), review studies (4 articles), studies conducted on pediatric population (2 articles) and non-related studies (6 articles). One study had not reported the AUC with 95% confidence interval, so we contacted the authors twice but received no response; therefore, this study was also excluded (43). Details on the number of studies excluded during selection for meta-analysis are provided in Figure 1.

The interval between the occurrence of brain injury and the investigation of IMPACT and CRASH models varied between 12 to 48 hours. The sampling method was prospective in 10 studies, retrospective in 5, and amphi-directional in 1. The severity of TBI ranges from mild to severe. The follow-up period was 180 days in 12 studies, 14 days in 1 study, and 540 days in 1 study. Two studies followed the patients until discharge from the hospital (Table 1).

3.2. Quality assessment and publication bias

We assessed the risk of bias based on the QUADAS-2 tool (Table 2). The risk of bias was high in three studies in the patient selection domain and unclear in six studies in the flow and timing domain. In other domains, all studies had a low risk of bias. We checked the publication bias for the prognostic value of IMPACT and CRASH models in predicting mortality and unfavorable outcome. The analysis showed that in investigating the prognostic value of the IMPACT core model (p=0.045) and IMPACT extended model (p=0.021) in predicting the unfavorable outcome, there is evidence of publication bias (Figure S1 and Figure S2). In other scores, there was no publication bias in predicting mortality or unfavorable outcome.

3.3. Comparing the predictive values for mortality

CRASH basic and IMPACT core model

The analyzes showed that the AUC of the CRASH basic and IMPACT core models in predicting the mortality of head trauma patients are 0.82 (95% CI: 0.77 to 0.86) and 0.80 (95% CI: 0.77 to 0.84), respectively (Figure 2). These two models have no difference in predicting the patients' mortality (diagnostic OR=0.98; 95% CI: 0.93 to 1.04; p=0.550).

CRASH CT, IMPACT extended, and IMPACT Lab

The analyzes showed that the AUC in the CRASH CT, IMPACT extended, and IMPACT lab models in predicting the mortality of head trauma patients are 0.80 (95% CI: 0.74 to 0.86), 0.81 (95% CI: 0.77 to 0.84), and 0.80 (95% CI: 0.76 to 0.85), respectively (Figure 3). Results also showed that the IMACT extended (OR=1.00; 95% CI: 0.94 to 1.07; p=0.968) and IMPACT Lab (OR=1.00; 95% CI: 0.93 to 1.07; p=0.986) have no difference with CRASH CT model in predicting the mortality of head trauma patients.

3.4. Comparing the predictive values for unfavorable outcomes

CRASH basic and IMPACT core model

The AUC for the CRASH basic and IMPACT core models in predicting the 6-month unfavorable outcome of head trauma

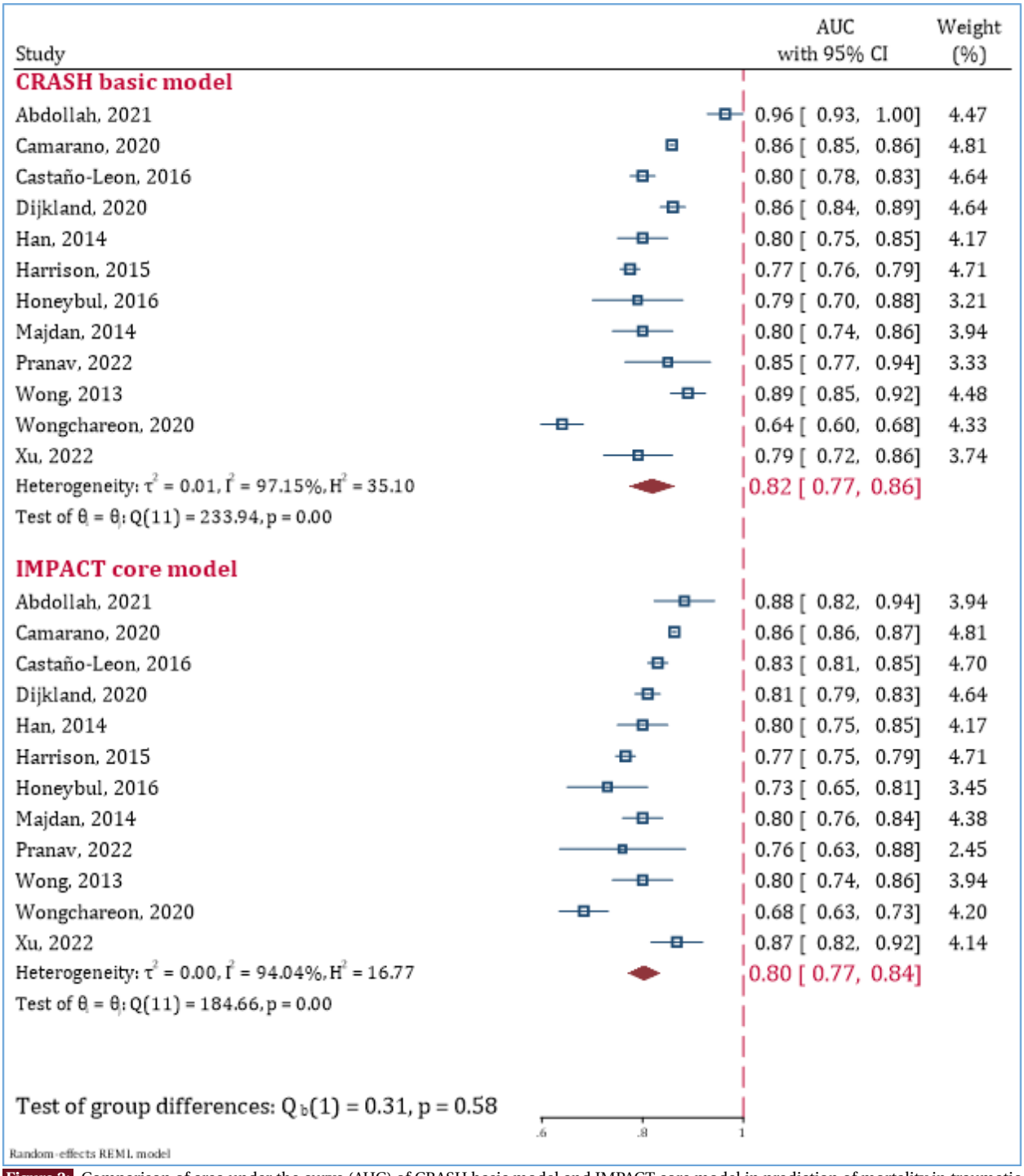

Figure 2: Comparison of area under the curve (AUC) of CRASH basic model and IMPACT core model in prediction of mortality in traumatic brain injury. CI: Confidence interval.

patients were 0.82 (95% CI: 0.78 to 0.86) and 0.80 (95% CI: 0.77 to 0.83), respectively (Figure 4). These two models have no difference in predicting the unfavorable outcome of patients (diagnostic OR=0.98; 95% CI: 0.93 to 1.03; p=0.462).

CRASH CT, IMPACT extended, and IMPACT Lab model

The analysis showed that the area under the curve of the CRASH CT, IMPACT extended, and IMPACT lab models in predicting the unfavorable outcome of head trauma patients

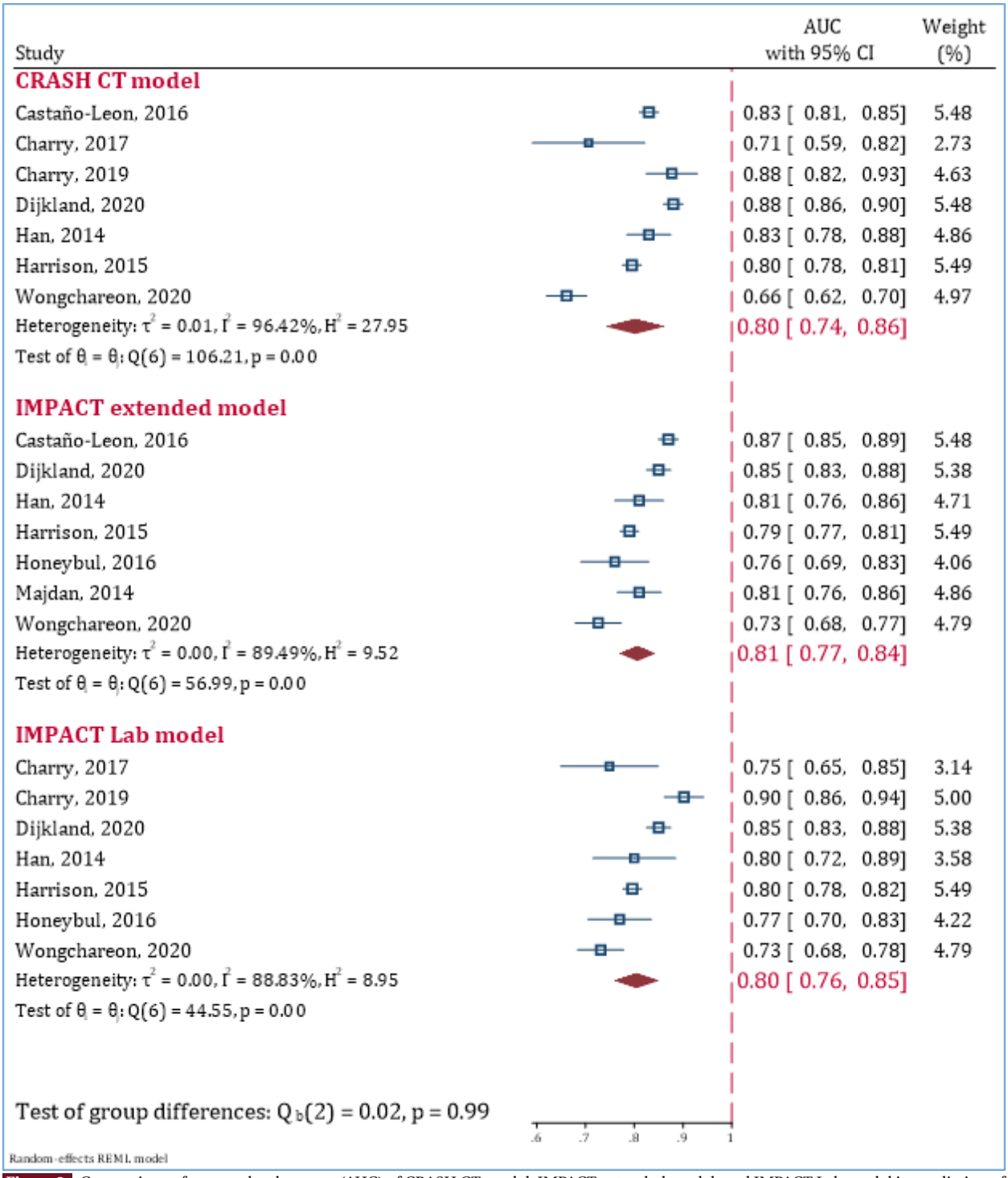

Figure 3: Comparison of area under the curve (AUC) of CRASH CT model, IMPACT extended model, and IMPACT Lab model in prediction of mortality in traumatic brain injury. CI: Confidence interval.

are 0.81 (95% CI: 0.76 to 0.86), 0.82 (95% CI: 0.78 to 0.85), and 0.80 (95% CI: 0.75 to 0.85), respectively (Figure 5). It was also obtained that the IMACT extended (OR=1.01; 95% CI: 0.95 to 1.08; p=0.729), and the IMPACT Lab model (OR=0.99; 95% CI: 0.93 to 1.06; p=0.819) have no difference with CRASH CT in predicting the unfavorable outcome of head trauma patients.

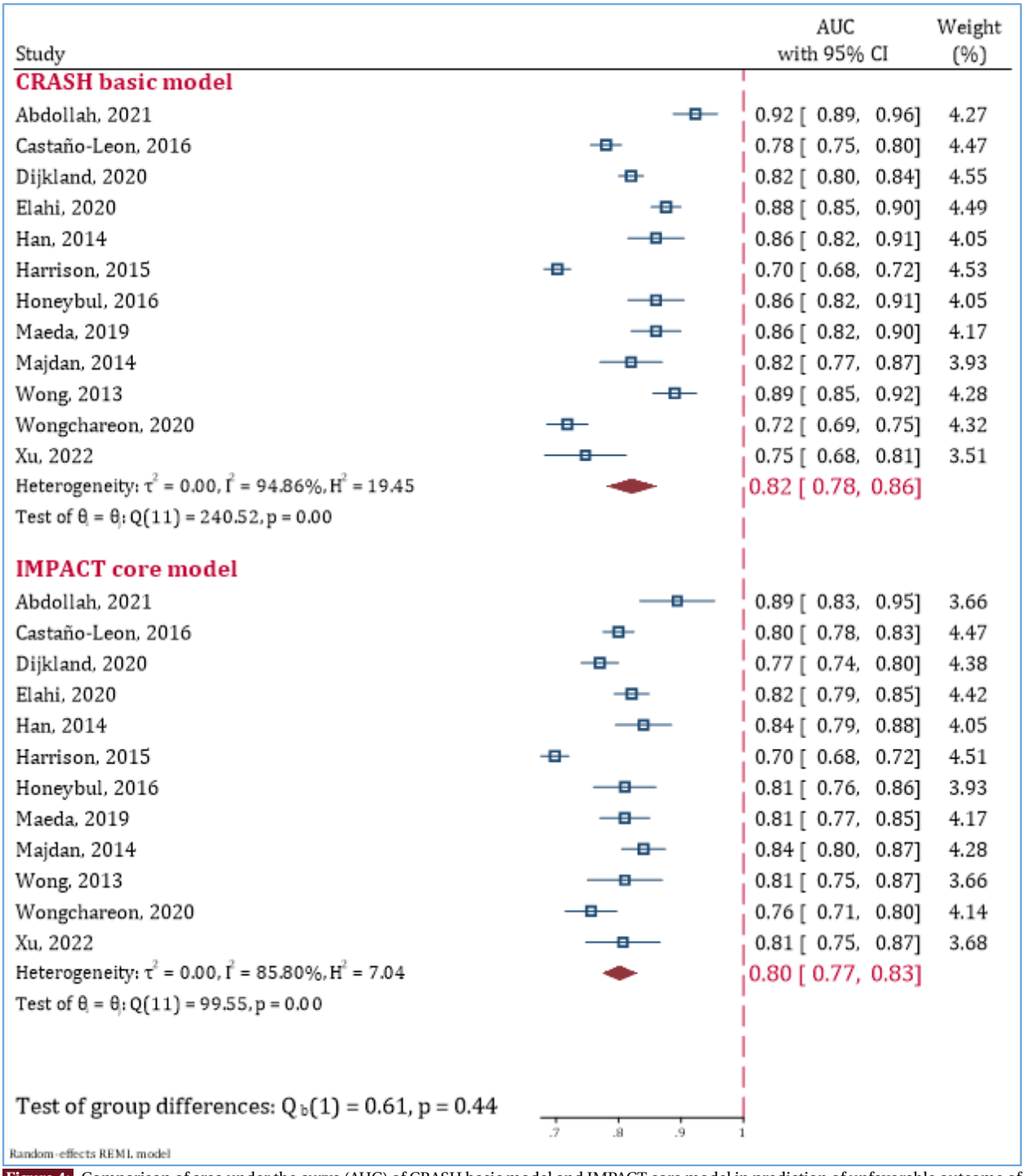

Figure 4: Comparison of area under the curve (AUC) of CRASH basic model and IMPACT core model in prediction of unfavorable outcome of traumatic brain injury. CI: Confidence interval.

3.5. Certainty of evidence

Assessment of certainty of evidence according to GRADE framework showed that the quality of evidence in the prognostic value of CRASH and IMPACT models in the prediction of mortality is low, since there was severe heterogeneity (rated down one point) and a large magnitude of effect (rated up one point).

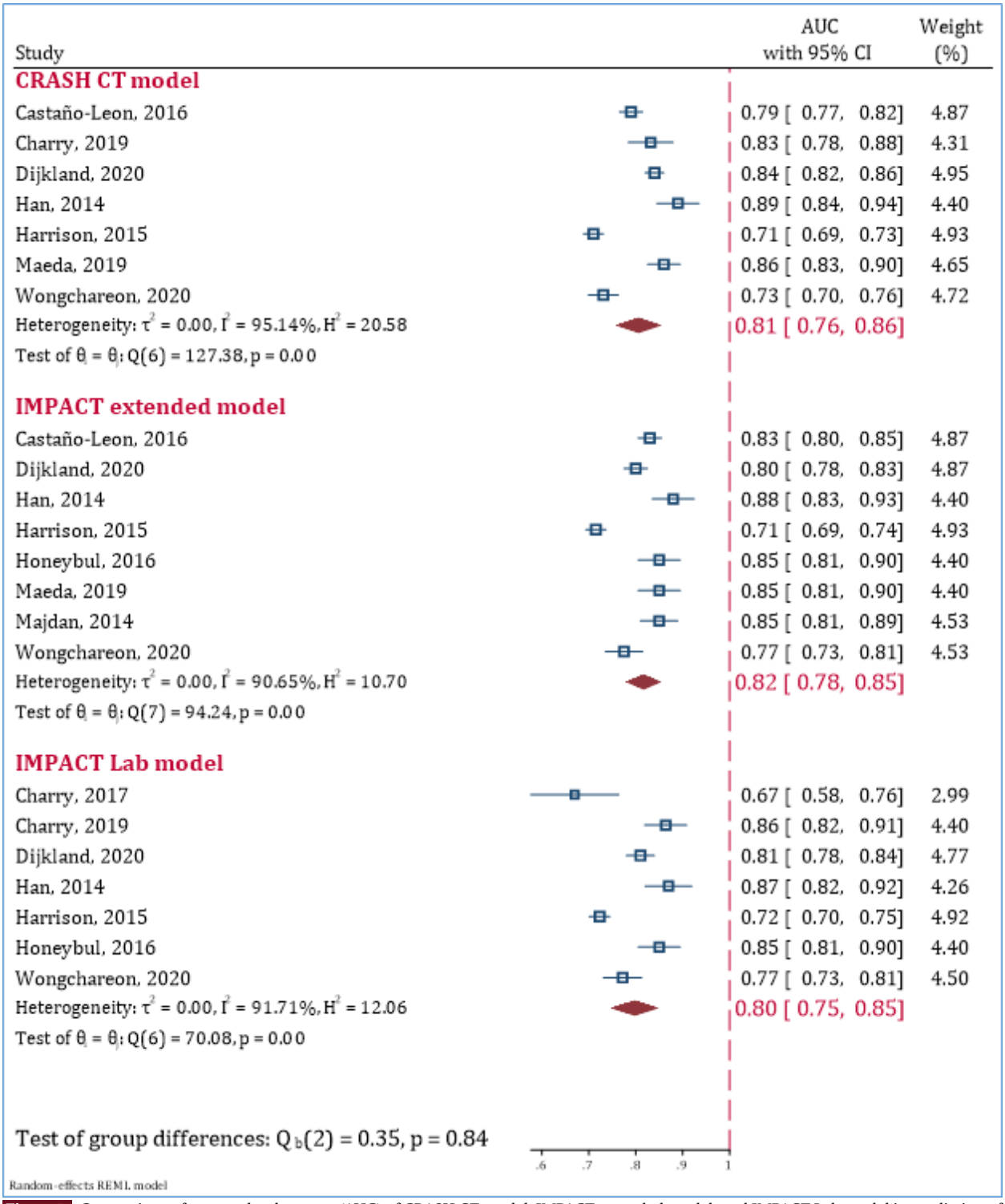

Figure 5: Comparison of area under the curve (AUC) of CRASH CT model, IMPACT extended model, and IMPACT Lab model in prediction of unfavorable outcome of traumatic brain injury. CI: Confidence interval.

However, the level of evidence in the prognostic value of CRASH and IMPACT models in the prediction of unfavorable outcome are low to very low. There was a large magnitude of effect in all subscales; therefore, the level of evidence was

Table 1: Characteristics of eligible studies

Study	Sample size	Male (n)	Age*	Injury to assessment (hrs)	Sampling method	TBI severity	Assessed scale	Outcome	Follow-up (day)
Abdollah; 2021; Malaysia	281	NR	NR	0	Prospective	All severities	Core / Basic	Mortality / unfavorable	14 / 180
Camarano; 2020; US, Canada	26228	NR	45 (27-63)	0	Retrospective	Moderate to severe	Core / Basic	Mortality	14
Castaño-Leon; 2016; Spain	1301	NR	40 (24-52)	48	Prospective	Moderate to severe	Core / Basic / Extended / CT	Mortality / unfavorable	180
Charry; 2017; Colombia	127	107	>18	12	Retrospective	Moderate to severe	Extended / CT / Lab	Mortality	180
Charry; 2019; Colombia	309	240	>18	12	Retrospective	All severities	Extended / CT / Lab	Mortality / unfavorable	180
Dijkland; 2020; Europe	1742	NR	51 (32-67)	24	Prospective	All severities	Core / Basic / Extended / CT /Lab	Mortality / unfavorable	14 / 180
Elahi; 2020; Tanzania	2972	2452	31.1 (15.2)	0	Prospective	All severities	Core / Basic	Unfavorable	In-hospital
Han; 2014; Singapore	300	NR	53 (20.7)	0	Prospective	Severe	Core / Basic / Extended / CT / Lab	Mortality / unfavorable	14 / 180
Harrison; 2015; UK	2975	2263	>16	24	Prospective	All severities	Core / Basic / Extended / CT / Lab	Mortality / unfavorable	180
Honeybul; 2016; Australia	319	260	32 (21-47)	0	Prospective	All severities	Core / Basic / Extended / CT /Lab	Mortality / unfavorable	540
Maeda; 2019; Japan	635	442	age>16	0	Retrospective	Severe	Core / Basic / Extended / CT	Unfavorable	180
Majdan; 2014; Austria	778	NR	50 (28-69)	48	Prospective	All severities	Core / Basic / Extended / CT	Mortality / unfavorable	180
Pranav; 2022; USA, Uganda	877	746	31.3 (NR)	0	Prospective	All severities	Core / Basic	Mortality	In-hospital
Wong; 2013; Hong Kong	178	127	56 (20)	0	Prospective	All severities	Core / Basic	Mortality / unfavorable	14 / 180
Wongchareon; 2020; South America	466	NR	28 (21-43)	24	Retrospective	Severe	Core / Basic / Extended / CT / Lab	Mortality / unfavorable	14 / 180
Xu; 2022; China	341	243	54 (17.4) / 56.2(15.4)	12	Amphidirectional	Moderate to severe	Core / Basic	Mortality / unfavorable	14 / 180

*, Data are presented as rang, mean (±SD) or median (IQR).
Basic: CRASH basic model; Core: Impact core model; CT: CRASH Computed Tomography model; Extended: IMPACT extended model; Lab: IMPACT laboratory model; NR: Not reported; TBI: Traumatic brain injury

rated up one point. In addition, significant inconsistency was observed and the score was rated down one point in all subscales. Finally, the analyses showed possible publication bias in assessing the prognostic value of IMPACT core and IMPACT extended models. Therefore, the level of evidence for the prognostic value of IMPACT core and IMPACT extended models were judged as very low (Table 3).

4. Discussion

Low to very low level of evidence shows that the IMPACT and CRASH models have similar values in predicting mortality and unfavorable outcome of patients with traumatic brain injury. Similar findings were also observed in the sub-scores of the two models. As a result, the prognostic values of all sub-scores in predicting mortality and unfavorable outcome of traumatic brain injury secondary to trauma are similar.
The results of the present study showed that IMPACT extended and IMPACT Lab models have equal value in pre-

Table 2: Risk of bias assessment of included studies

Study	Risk of Bias				Applicability		
	Patient selection	Index tests	Reference standard	Flow and timing	Patient selection	Index tests	Reference standard
Abdollah; 2021	Low	Low	Low	Low	Low	Low	Low
Camarano; 2020	Low	Low	Low	Unclear	Low	Low	Low
Castaño-Leon; 2016	Low	Low	Low	Low	Low	Low	Low
Charry; 2017	High	Low	Low	Unclear	Low	Low	Low
Charry; 2019	High	Low	Low	Unclear	Low	Low	Low
Dijkland; 2020	Low	Low	Low	Low	Low	Low	Low
Elahi; 2020	Low	Low	Low	Unclear	Low	Low	Low
Han; 2014	Low	Low	Low	Low	Low	Low	Low
Harrison; 2015	Low	Low	Low	Low	Low	Low	Low
Honeybul; 2016	Low	Low	Low	Low	Low	Low	Low
Maeda; 2019	Low	Low	Low	Low	Low	Low	Low
Majdan; 2014	Low	Low	Low	Low	Low	Low	Low
Pranav; 2022	Low	Low	Low	Unclear	Low	Low	Low
Wong; 2013	Low	Low	Low	Low	Low	Low	Low
Wongchareon; 2020	Low	Low	Low	Low	Low	Low	Low
Xu; 2022	High	Low	Low	Unclear	Low	Low	Low

Low: Low risk of bias; High: High risk of bias; Unclear: Unclear risk of bias.

dicting mortality and unfavorable outcome of patients with traumatic brain injury. In addition to IMPACT extended variables, the IMPACT Lab model requires serum biomarkers such as blood sugar and hemoglobin level. Therefore, using the IMPACT extended model in the clinical setting is better because it requires fewer variables for calculation. It should be noted that the CRASH CT model can only be calculated by adding CT scan findings to CRASH basic, making it easier to use clinically.

The area under the curve of CRASH basic and IMPACT core models are similar in predicting the outcome of patients with traumatic brain injury. To calculate the CRASH basic model score, variables such as the country's economic status (developing or developed country), level of conciseness, pupils' reaction to light, and major extracranial injury are needed. The IMPACT core model requires variables such as age, motor score, and pupils' reaction to light, which are not much different from the CRASH basic model. Therefore, using either of the two models will have a similar application in managing patients with traumatic brain injury.

One of the aims of the present study was to investigate the prognostic value of IMPACT and CRASH models based on the severity of brain injury. The articles included in our analysis reported mild, moderate, and severe injury severity (8, 12, 44-50). However, most of the studies did not perform analysis based on the severity of injuries.

To evaluate the discrimination of the two prognostic models, most of the included studies confined their results to only the area under the curve. Nonetheless, it should be kept in mind that the area under the curve is the early stage in the assessment of the diagnostic accuracy and predictive value of a model. At the same time, the analysis based on a cut point that reports sensitivity and specificity is more useful in the clinical setting (51). In this regard, in addition to a systematic search, the researchers of the present study also conducted an extensive manual search to find an article that compares the prognostic value of the IMPACT and CRASH models based on a cutoff point. This additional search resulted in very few studies. Most studies that report sensitivity and specificity based on a cut point did not use a prespecified threshold and often tried to find the best cut point based on the Youden index (52). As a result, the cut points used are very different, making it impossible to pool the data in this section. Also, some studies used unconventional cutoff points, which made the sensitivity too low to report higher specificity (50, 53). However, in prognostic tools and screening tests, sensitivity is more valuable than specificity. In this regard, the results reported by Wongchareon et al. (n=466) indicated that the sensitivity of CRASH core and CRASH CT models in prediction of 14-day mortality as 8% and 13%, which were associated with a specificity of 99% and 97%, respectively. They also reported the sensitivity of IMPACT core, extended, and lab models equal to 36%, 44%, and 36%, and their specificities as 87%, 87%, and 89%, respectively (53). Camarano et al. determined the optimal cutoff threshold using Youden's index; the CRASH basic and IMPACT core model's cutoff values were 33.1% and 42.8%, respectively. Using these cutoff thresholds, they reported the sensitivity and specificity of the CRASH basic and IMPACT core model for predicting in-hospital mortality. For CRASH basic and IMPACT core models, the sensitivity was 78% and 80%, and the specificity was 80% and 78%, respectively (52).

Table 3: Certainty in evidence based on GRADE framework

Outcome/ model	Sample size	Effect size	Risk of bias	Imprecision	Inconsistency (I^2)	Indirectness	Publication bias	Judgment and level of evidence
Mortality								
CRASH basic	35800	0.82 (0.77, 0.86)	Not serious	Not serious	Serious	Not serious	Not present	**Low:** Rated down 1 /point - Presence of serious inconsistency Rated up 1 /point Large magnitude of effect
IMPACT core	35056	0.80 (0.77, 0.84)	Not serious	Not serious	Serious	Not serious	Not present	**Low:** Rated down 1 /point - Presence of serious inconsistency Rated up 1 /point Large magnitude of effect
CRASH CT	7020	0.80 (0.74, 0.86)	Not serious	Not serious	Serious	Not serious	Not present	**Low:** Rated down 1 /point - Presence of serious inconsistency Rated up 1 /point Large magnitude of effect
IMPACT extended	7169	0.81 (0.77, 0.84)	Not serious	Not serious	Serious	Not serious	Not present	**Low:** Rated down 1 /point - Presence of serious inconsistency Rated up 1 /point Large magnitude of effect
IMPACT laboratory	5502	0.80 (0.76, 0.85)	Not serious	Not serious	Serious	Not serious	Not present	**Low:** Rated down 1 point - Presence of serious inconsistency Rated up 1 /point Large magnitude of effect
Unfavorable outcome								
CRASH basic	12302	0.82 (0.76, 0.86)	Not serious	Not serious	Serious	Not serious	Not present	**Low:** Rated down 1 /point - Presence of serious inconsistency Rated up 1 /point Large magnitude of effect
IMPACT core	11558	0.80 (0.77, 0.83)	Not serious	Not serious	Serious	Not serious	Likely	**Very low:** Rated down 2 /points - Presence of serious inconsistency - Possible publication bias Rated up 1 /point Large magnitude of effect
CRASH CT	7528	0.81 (0.76, 0.86)	Not serious	Not serious	Serious	Not serious	Not present	**Low:** Rated down 1 /point - Presence of serious inconsistency Rated up 1 /point Large magnitude of effect
IMPACT extended	7804	0.82 (0.78, 0.85)	Not serious	Not serious	Serious	Not serious	Likely	**Very low:** Rated down 2 /points - Presence of serious inconsistency - Possible publication bias Rated up 1 /point Large magnitude of effect
IMPACT laboratory	5502	0.80 (0.75, 0.85)	Not serious	Not serious	Serious	Not serious	Not present	**Low:** Rated down 1 /point - Presence of serious inconsistency Rated up 1 /point Large magnitude of effect

GRADE: Grading of Recommendations Assessment, Development and Evaluation; CRASH: Corticosteroid Randomization After Significant Head injury; IMPACT: International Mission for Prognosis and Analysis of Clinical Trials; CT: computed tomography.

We also found two studies in which only one of the models was evaluated. In the first study, Hashemi et al. stated that the patients whose expected risk based on the CRASH basic and CRASH CT model is equal to 63.9 and 51.2, respectively, are high-risk patients in terms of 14-day mortality. The study also introduced 43.2 and 78.7 as cutoff points for the 6-month unfavorable outcome (54). In another study using children and adolescents as the patient population, Fazel et al. showed that the best cutoff points for identifying high-risk head trauma for 14-day mortality in children using CRASH basic and CRASH CT models are 46 and 30. This study reported the cutoff points for 6-month unfavorable outcome as 17 and 13 (55).

Another limitation was the retrospective design of some of the included studies. The retrospective method affects the risk of bias in the patient selection, flow, and timing do-

main. When data is collected retrospectively, the sampling is not random, which results in a high risk of bias. Similarly, flow and timing in diagnostic or prognostic studies should be such that the index test is checked first and then the reference standard (24). In retrospective studies, the outcome of the patients is known from the beginning. Therefore, it is impossible to be sure of the risk of bias in the flow and timing domain. As a result, the risk of bias in these studies in the flow and timing domain was considered unclear.

Simplicity should be kept in mind when designing a scoring system. The fewer variables to calculate in a prognostic model, the easier its use. Both the CRASH and IMPACT models have a core / basic model that requires variables only from history and physical exam. They also have more complex models (CT, extended, and Lab models) that include CT scans or laboratory findings in addition to the clinical findings of the patients. As figures 2 to 5 demonstrate, the area under the curve in the IMPACT core and CRASH basic model is not much different from IMPACT extended, IMPACT Lab, and CRASH CT models. Therefore, it may be possible to check the outcome of patients only based on CRASH basic and IMPACT core models. This finding has been confirmed by other studies (47, 50).

After a TBI, prognostic models can help the medical team allocate resources and improve the quality of care given (13). As results showed, both models have a good discrimination power to predict TBI patients' prognosis. Their clinical use can prevent the health care system from unnecessary imaging and save time and money, and reduce the patient's exposure to ionizing radiation. We suggest a systematic review and meta-analysis of the diagnostic value of CRASH and IMPACT models in detecting intracranial hemorrhage in TBI patients.

5. Conclusion

Our results demonstrate the similar performance and predictive value of both models in predicting mortality and unfavorable outcome of patients with traumatic brain injury. The analysis showed that the IMPACT core model and CRASH basic model have equal prognostic value in predicting mortality and unfavorable outcome for patients with traumatic injuries to the brain. So, both models can aid in estimating the prognosis for TBI patients in clinical practice. The CRASH CT model is like the IMPACT extended and IMPACT Lab models. Since the discriminative power of the IMPACT Core and CRASH basic models is not different from the IMPACT extended, IMPACT Lab, and CRASH CT models, it may be possible to rely only on the core and basic models in examining the prognosis of patients with traumatic brain injury.

6. Declarations

6.1. Acknowledgments

None.

6.2. Conflict of interest

There is no conflict of interest.

6.3. Funding information

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6.4. Authors Contribution

Study design: MY, AS
Data gathering: HZ, MV, SRD, HAR
Analysis: MY
Interpretation: All authors
Drafting: HZ, SRD, HAR
Revising: All authors
Reading and approving final version: All authors

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Appendix 1: Medline (PubMed) search query

Medline (via PubMed)

1. "Decision Support Techniques" [Mesh] OR International Mission for Prognosis and Analysis of Clinical Trials in Traumatic Brain Injury[tiab] OR IMPACT prognostic models[tiab] OR IMPACT prognostic model[tiab] OR IMPACT Rule[tiab] OR IMPACT model[tiab] OR IMPACT CORE[tiab] OR IMPACT basic[tiab] OR IMPACT-CORE[tiab] OR IMPACT-basic[tiab] OR IMPACT CT[tiab] OR IMPACT Lab[tiab] OR IMPACT-CT[tiab] OR IMPACT-Lab[tiab] OR Corticosteroid Randomization after Significant Head Injury[tiab] OR CRASH prognostic models[tiab] OR CRASH prognostic model[tiab] OR CRASH Rule[tiab] OR CRASH model[tiab] OR CRASH Core[tiab] OR CRASH basic[tiab] OR CRASH CT[tiab] OR CRASH-basic[tiab] OR CRASH-CT[tiab]

2. "Brain Concussion"[Mesh] OR "Brain Injuries"[Mesh] OR "Brain Injuries, Traumatic"[Mesh] OR Brain Concussion[tiab] OR Brain Injuries[tiab] OR Brain Injuries, Traumatic[tiab] OR Brain Concussions[tiab] OR Concussion, Brain[tiab] OR Commotio Cerebri[tiab] OR Cerebral Concussion[tiab] OR Cerebral Concussions[tiab] OR Concussion, Cerebral[tiab] OR Concussion, Intermediate[tiab] OR Intermediate Concussion[tiab] OR Intermediate Concussions[tiab] OR Concussion, Severe[tiab] OR Severe Concussion[tiab] OR Severe Concussions[tiab] OR Concussion, Mild[tiab] OR Mild Concussion[tiab] OR Mild Concussions[tiab] OR Mild Traumatic Brain Injury[tiab] OR Injuries, Brain[tiab] OR Brain Injury[tiab] OR Injury, Brain[tiab] OR Injuries, Acute Brain[tiab] OR Acute Brain Injuries[tiab] OR Acute Brain Injury[tiab] OR Brain Injury, Acute[tiab] OR Injury, Acute Brain[tiab] OR Brain Injuries, Acute[tiab] OR Brain Lacerations[tiab] OR Brain Laceration[tiab] OR Laceration, Brain[tiab] OR Lacerations, Brain[tiab] OR Brain Injuries, Focal[tiab] OR Brain Injury, Focal[tiab] OR Focal Brain Injury[tiab] OR Injuries, Focal Brain[tiab] OR Injury, Focal Brain[tiab] OR Focal Brain Injuries[tiab] OR Brain Injury, Traumatic[tiab] OR Traumatic Brain Injuries[tiab] OR Trauma, Brain[tiab] OR Brain Trauma[tiab] OR Brain Traumas[tiab] OR Traumas, Brain[tiab] OR Encephalopathy, Traumatic[tiab] OR Encephalopathies, Traumatic[tiab] OR Traumatic Encephalopathies[tiab] OR Injury, Brain, Traumatic[tiab] OR Traumatic Encephalopathy[tiab] OR Traumatic Brain Injury[tiab] OR TBI[tiab]

3. #1 AND #2

Embase

1. 'international mission for prognosis and analysis of clinical trials in traumatic brain injury':ab,ti OR 'impact prognostic models':ab,ti OR 'impact rule':ab,ti OR 'impact model':ab,ti OR 'impact core':ab,ti OR 'impact basic':ab,ti OR 'impact-core':ab,ti OR 'impact-basic':ab,ti OR 'impact ct':ab,ti OR 'impact lab':ab,ti OR 'impact-ct':ab,ti OR 'impact-lab':ab,ti OR 'corticosteroid randomization after significant head injury':ab,ti OR 'crash prognostic models':ab,ti OR 'crash prognostic model':ab,ti OR 'crash rule':ab,ti OR 'crash model':ab,ti OR 'crash core':ab,ti OR 'crash basic':ab,ti OR 'crash ct':ab,ti OR 'crash-basic':ab,ti OR 'crash-ct':ab,ti

2. 'brain injury'/exp OR 'brain injury' OR 'head injury'/exp OR 'head injury' OR 'traumatic brain injury'/exp OR 'traumatic brain injury' 3. #1 AND #2

Scopus

1- TITLE-ABS-KEY("International Mission for Prognosis and Analysis of Clinical Trials in Traumatic Brain Injury" OR "IMPACT prognostic models" OR "IMPACT prognostic model" OR "IMPACT Rule" OR "IMPACT model" OR "IMPACT CORE" OR "IMPACT basic" OR "IMPACT-CORE" OR "IMPACT-basic" OR "IMPACT CT" OR "IMPACT Lab" OR "IMPACT-CT" OR "IMPACT-Lab" OR "Corticosteroid Randomization after Significant Head Injury" OR "CRASH prognostic models" OR "CRASH prognostic model" OR "CRASH Rule" OR "CRASH model" OR "CRASH Core" OR "CRASH basic" OR "CRASH CT" OR "CRASH-basic" OR "CRASH-CT")

2- TITLE-ABS-KEY ("Brain Concussion" OR "Brain Injuries" OR "Brain Injuries, Traumatic" OR "Brain Concussion" OR "Brain Injuries" OR "Brain Injuries, Traumatic" OR "Brain Concussions" OR "Concussion, Brain" OR "Commotio Cerebri" OR "Cerebral Concussion" OR "Cerebral Concussions" OR "Concussion, Cerebral" OR "Concussion, Intermediate" OR "Intermediate Concussion" OR "Intermediate Concussions" OR "Concussion, Severe" OR "Severe Concussion" OR "Severe Concussions" OR "Concussion, Mild" OR "Mild Concussion" OR "Mild Concussions" OR "Mild Traumatic Brain Injury" OR "Injuries, Brain" OR "Brain Injury" OR "Injury, Brain" OR "Injuries, Acute Brain" OR "Acute Brain Injuries" OR "Acute Brain Injury" OR "Brain Injury, Acute" OR "Injury, Acute Brain" OR "Brain Injuries, Acute" OR "Brain Lacerations" OR "Brain Laceration" OR "Laceration, Brain" OR "Lacerations, Brain" OR "Brain Injuries, Focal" OR "Brain Injury, Focal" OR "Focal Brain Injury" OR "Injuries, Focal Brain" OR "Injury, Focal Brain" OR "Focal Brain Injuries" OR "Brain Injury, Traumatic" OR "Traumatic Brain Injuries" OR "Trauma, Brain" OR "Brain Trauma" OR "Brain Traumas" OR "Traumas, Brain" OR "TBI (Traumatic Brain Injury)" OR "Encephalopathy, Traumatic" OR "Encephalopathies, Traumatic" OR "Traumatic Encephalopathies" OR "Injury, Brain, Traumatic" OR "Traumatic Encephalopathy" OR "Traumatic Brain Injury")

3- #1 AND #2

Web of Science

1- TS=("International Mission for Prognosis and Analysis of Clinical Trials in Traumatic Brain Injury" OR "IMPACT prognostic models" OR "IMPACT prognostic model" OR "IMPACT Rule" OR "IMPACT model" OR "IMPACT CORE" OR "IMPACT basic" OR "IMPACT-CORE" OR "IMPACT-basic" OR "IMPACT CT" OR "IMPACT Lab" OR "IMPACT-CT" OR "IMPACT-Lab" OR "Corticosteroid Randomization after Significant Head Injury" OR "CRASH prognostic models" OR "CRASH prognostic model" OR "CRASH Rule" OR "CRASH model" OR "CRASH Core" OR "CRASH basic" OR "CRASH CT" OR "CRASH-basic" OR "CRASH-CT")

2- TS= ("Brain Concussion" OR "Brain Injuries" OR "Brain Injuries, Traumatic" OR "Brain Concussion" OR "Brain Injuries" OR "Brain Injuries, Traumatic" OR "Brain Concussions" OR "Concussion, Brain" OR "Commotio Cerebri" OR "Cerebral Concussion" OR "Cerebral Concussions" OR "Concussion, Cerebral" OR "Concussion, Intermediate" OR "Intermediate Concussion" OR "Intermediate Concussions" OR "Concussion, Severe" OR "Severe Concussion" OR "Severe Concussions" OR "Concussion, Mild" OR "Mild Concussion" OR "Mild Concussions" OR "Mild Traumatic Brain Injury" OR "Injuries, Brain" OR "Brain Injury" OR "Injury, Brain" OR "Injuries, Acute Brain" OR "Acute Brain Injuries" OR "Acute Brain Injury" OR "Brain Injury, Acute" OR "Injury, Acute Brain" OR "Brain Injuries, Acute" OR "Brain Lacerations" OR "Brain Laceration" OR "Laceration, Brain" OR "Lacerations, Brain" OR "Brain Injuries, Focal" OR "Brain Injury, Focal" OR "Focal Brain Injury" OR "Injuries, Focal Brain" OR "Injury, Focal Brain" OR "Focal Brain Injuries" OR "Brain Injury, Traumatic" OR "Traumatic Brain Injuries" OR "Trauma, Brain" OR "Brain Trauma" OR "Brain Traumas" OR "Traumas, Brain" OR "Encephalopathy, Traumatic" OR "Encephalopathies, Traumatic" OR "Traumatic Encephalopathies" OR "Injury, Brain, Traumatic" OR "Traumatic Encephalopathy" OR "Traumatic Brain Injury" OR "TBI")

3- #1 AND #2

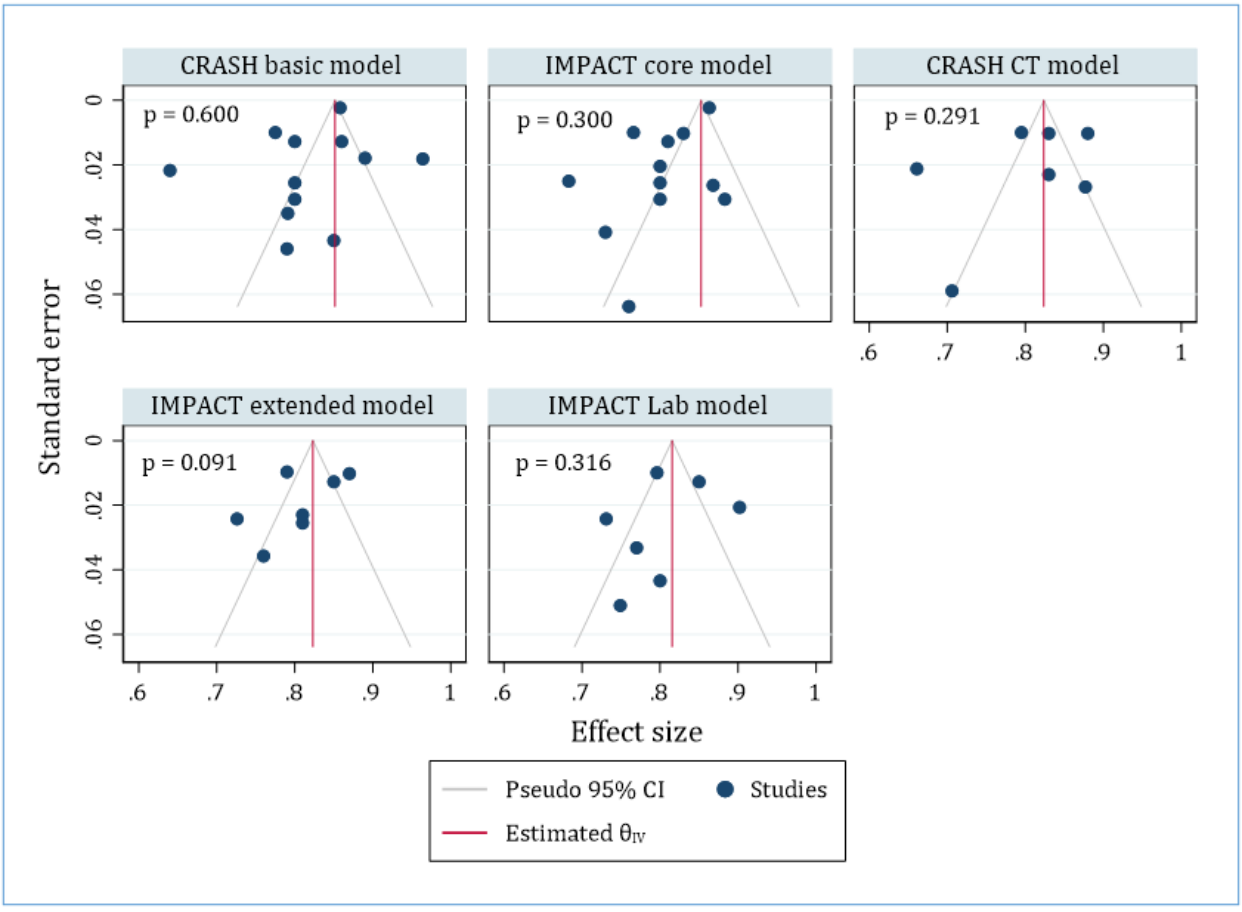

Figure S 1: Publication bias of IMPACT and CRASH prognostic models in mortality prediction across eligible studies. There is no evidence of publication bias across the studies. Effect size is the area under the curve.

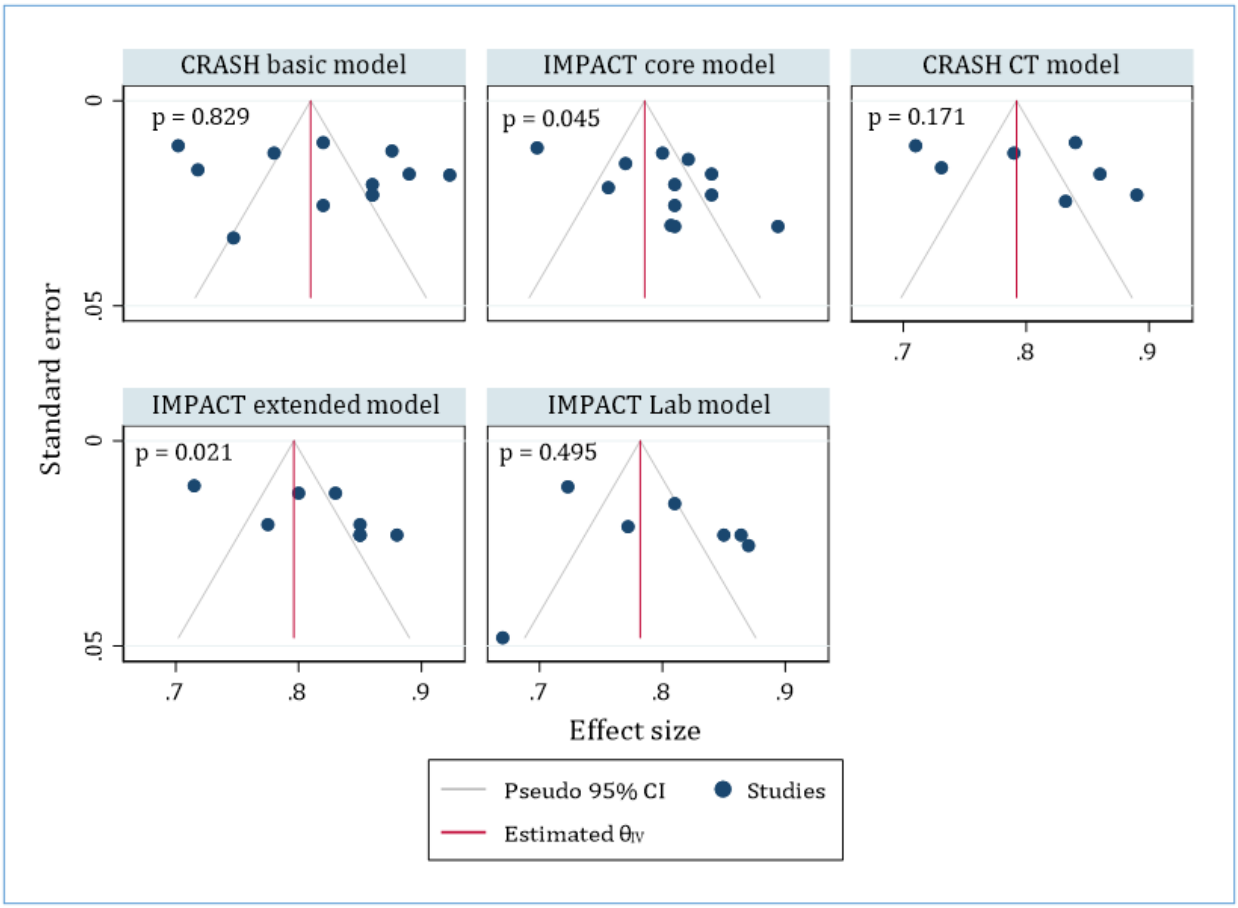

Figure S 2: Publication bias of IMPACT and CRASH prognostic models in predicting 6-month unfavorable outcome across eligible studies. There is evidence of possible publication bias in detecting the prognostic value of IMPACT core and IMPACT extended models. Effect size is the area under the curve.