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REVIEW ARTICLE

Diagnostic assessment of computed tomography (CT) in open globe injuries: a systematic review and meta-analysis

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Abstract

Accurate and timely diagnosis of Open Globe Injuries (OGIs) is crucial for implementing appropriate interventions. The goal of the present systematic review study is to evaluate the accuracy of CT in detecting OGI, especially in patients which conducting a detailed ophthalmologic examination or emergent surgical exploration is unavailable. The results of this study can aid clinicians in better management and pre-operative decision-making for patients with OGI's. We systematically searched PubMed, Web of Science, and Scopus for relevant English papers up to August 2024. Included studies must report at least one or more of the following clinical outcomes: specificity, sensitivity, NPV, and PPV of CT scan for detecting OGIs. The details of each study regarding the value of CT in the diagnosis determination of OGI were extracted. Using Stata software version 15, analyses were conducted on sensitivity, specificity, positive and negative predictive values, and the frequency of each CT finding. Twelve published articles were included in the study. The articles encompassed a total of 937 patients. The pooled sensitivity and specificity of CT in diagnosing OGI were 75% (95% CI: 0.65, 0.85, I2: 93.5%, p-value < 0.001) and 83% (95% CI: 0.76, 0.90, I2: 84%, p-value < 0.001), respectively. The pooled positive and negative predictive values of CT were 90% (95% CI: 0.84, 0.96, I2: 91.3%, p value < 0.001) and 79% (95% CI: 0.71, 0.88, I2: 85.6%, p value < 0.001), respectively. The most frequent findings were a change in globe contour, scleral injury, corneal injury, and vitreous hemorrhage, in order. The highest diagnostic sensitivity of CT scan findings was observed for shallow anterior chamber changes and lens dislocation or destruction. Lens dislocation and intraocular foreign body had the highest specificity in CT findings, with a specificity of 100%. Our results supporting the utility of CT scanning in the diagnostic workflow for OGIs, particularly for detecting structural abnormalities and anterior chamber

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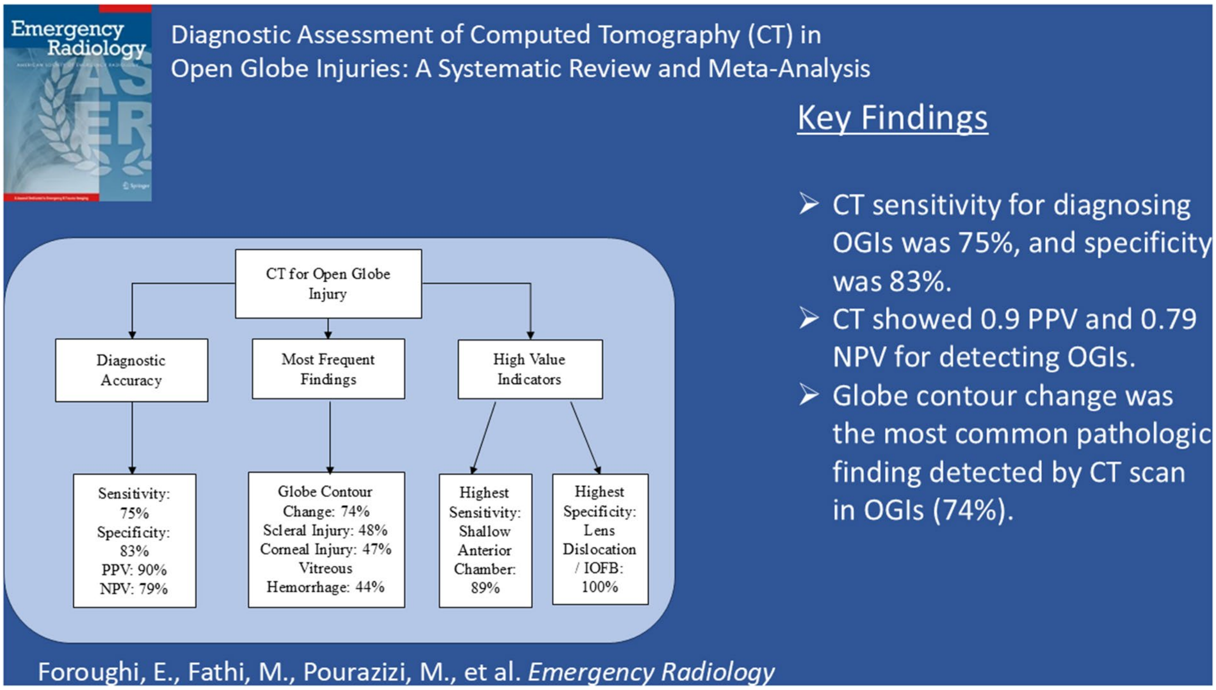
changes, have significant practical implications. They can inform clinical practice and guide the diagnostic approaches in suspected open globe injuries, empowering medical professionals to make informed decisions.

Graphical Abstract



Keywords Open globe injury (OGI) · Sensitivity · Specificity · Computed tomography · Diagnostic value

Background

An open globe injury (OGI) is a severe ocular trauma defined as a full-thickness wound of the eyewall. Although several individuals with OGIs experience substantial recovery, it may lead to blindness and irreversible visual impairment. These severe cases often necessitate eye enucleation or evisceration [1–3]. Ocular morbidity following OGIs has an incidence of 3.5 to 4.5 per 100,000 [4]. The visual outcomes are characterized by and dependent on several factors: the complications that occur, treatment effectiveness, injury severity, and existing comorbidities [5, 6]. Accurate and timely diagnosis of OGIs is crucial for implementing appropriate interventions. Early detection directly influences patient outcomes [7].

Ophthalmologic examination, followed by emergent surgical exploration, is a gold standard method for diagnosis and management of OGI. Obtaining a Computed tomography (CT) scan can provide valuable information, especially when the direct examination is difficult [8]. The number and type of CT findings are possible and practical staging in OGI, thus instilling confidence in decision-making. CT scans in diagnosing orbital and intraocular foreign bodies (IOFB) are practical, effectively demonstrating their locations and illustrating details of facial or intracranial damage [9]. CT imaging in OGIs reveals several feature findings that can be related to visual outcomes and injury severity. These informative findings include scleral irregularity or globe collapse, abnormal vitreous density, and the presence of intraocular foreign bodies or air (lens dislocation, choroidal layer thickening, posterior segment hemorrhage, and orbital emphysema [10]. Significantly, posterior segment hemorrhage strongly predicts visual outcome, with grade III hemorrhage showing 100% positive predictive value for profound vision loss. The multiplicity of CT findings often correlates with more severe injuries and poorer visual prognosis [11]. Thus, a systematic review and meta-analysis are needed to consolidate these findings and assess their consistency across studies. The goal of the present systematic review study is to evaluate the accuracy of CT in detecting OGI, especially in patients who cannot be upright for detailed ophthalmologic examination or in the setting the emergent surgical exploration is unavailable. The results of this study can aid clinicians in better management and preoperative decision-making for patients with OGI's.

Methods

The study's project follows PRISMA guidelines [12]. Before beginning the research, all authors thoroughly evaluated the study's inclusion and exclusion criteria and the keywords used to find relevant material. The ethical approve number for this study of Clinical Research Development Unit (CRDU) of Loghman Hakim Hospital, Shahid Beheshti University of Medical Sciences, Tehran, is (IR.SBMU.RETECH.REC.1403.659). This systematic review was registered in the PROSPERO database under the registration number CRD420251014912.

Study selection and search strategy

A comprehensive and systematic search was conducted across various databases, including PubMed, Scopus, and Web of Science, up to August 2024. "Eye Injuries" OR "globe injuries" OR "globe rupture" OR "Open globe injury" OR "Ocular Trauma Score" OR "visual outcome" AND "X-ray computed Tomography" OR "imaging" OR "diagnostic imaging" OR "CT" were among the terms we used in our search. To identify any pertinent studies that might have been left out, we also looked through the references of linked papers. Using inclusion and exclusion criteria to weed out irrelevant literature, we assessed the abstracts and titles of possible research publications.

Inclusion and exclusion criteria

The inclusion criteria of this study were as follows: (1) original studies, including retrospective and prospective cross-sectionals or population-based studies; (2) written in English; and (3) At least one or more of the following clinical outcomes: specificity, sensitivity, NPV, and PPV of CT scan for detecting open globe injuries reporting the details of each CT findings in OGIs. Exclusion criteria included reviews, conference abstracts, in vitro studies, animal trials, case reports, case series, and duplicate publications.

Data extraction and quality assessment

Two writers (EF and MF) independently evaluated the titles and abstracts of the selected publications. The EndNote software (version 9.9) was used to eliminate duplicate research. To make our final decisions, we reviewed the entire content of the remaining articles. To minimize bias, the authors conducted all processes independently. Disagreements between the two researchers were settled through discussion. If differences persisted, a third author (MP) reviewed the study and made the ultimate decision. The methodological quality of each included paper was evaluated individually using a Joanna Briggs Institute checklist [13].

Data collection

The data from relevant papers were extracted using the following approach:

(1) Study information (author, year of publication, and study design).

(2) Study participants' characteristics (number of patients, gender, and average age).

(3) Details about the diagnostic value of CT, including specificity, sensitivity, NPV, and PPV for detecting open globe injuries.

(4) Details about the frequency of CT findings, specificity, sensitivity, NPV, and PPV for each CT finding.

(5) Details about the trauma mechanism.

Statistical analysis

A meta-analysis was conducted using Stata version 15 (StataCorp, USA) to assess the diagnostic accuracy of CT in detecting OGIs. Pooled estimates for sensitivity, specificity, PPV, and NPV were calculated for both overall CT performance and individual CT findings. Data were included in the meta-analysis only if sufficient numerical data were available. All analyses were performed using a random-effects model due to the anticipated methodological and clinical heterogeneity among studies. Statistical heterogeneity was assessed using the I^2 statistic, with values greater than 50% indicating substantial heterogeneity. Forest plots were generated to visualize the diagnostic estimates and their corresponding 95% confidence intervals.

Publication bias

To evaluate the presence of publication bias, Begg's and Egger's tests were applied. A p-value of <0.05 was considered indicative of potential publication bias. Additionally, funnel plots were constructed to provide a visual representation of potential asymmetry in the included studies. Egger's test further employed linear regression analysis using slope and intercept parameters to quantify any potential small-study effects contributing to asymmetry.

Result

Our initial search found 867 publications, including 428 in PubMed, 98 in Web of Science, and 341 in Scopus. After removing duplicate entries, 787 articles remained. The titles and abstracts of these papers were reviewed, and 744 were excluded because the eligibility criteria were not met. The whole text of 43 articles was examined in further detail. Of these, 12 articles fulfilled the final inclusion criteria. Studies were published between 2000 and 2021. Checking the references of the 12 listed papers results in no further relevant articles (Fig. 1).

Study characteristics

All of the included studies were published in English. In total, 937 patients participated in the investigations, with a mean of 72 (ranging from 34 to 136). All of the included studies were retrospective. Dikci et al. 2021 [14] the study assessed the CT diagnostic value in two distinct groups: children and adults. In the studies with more than one expert reports the CT scans, we considered the average of the reported value in the analysis. Table 1 shows the characteristic details of total diagnostic accuracy.

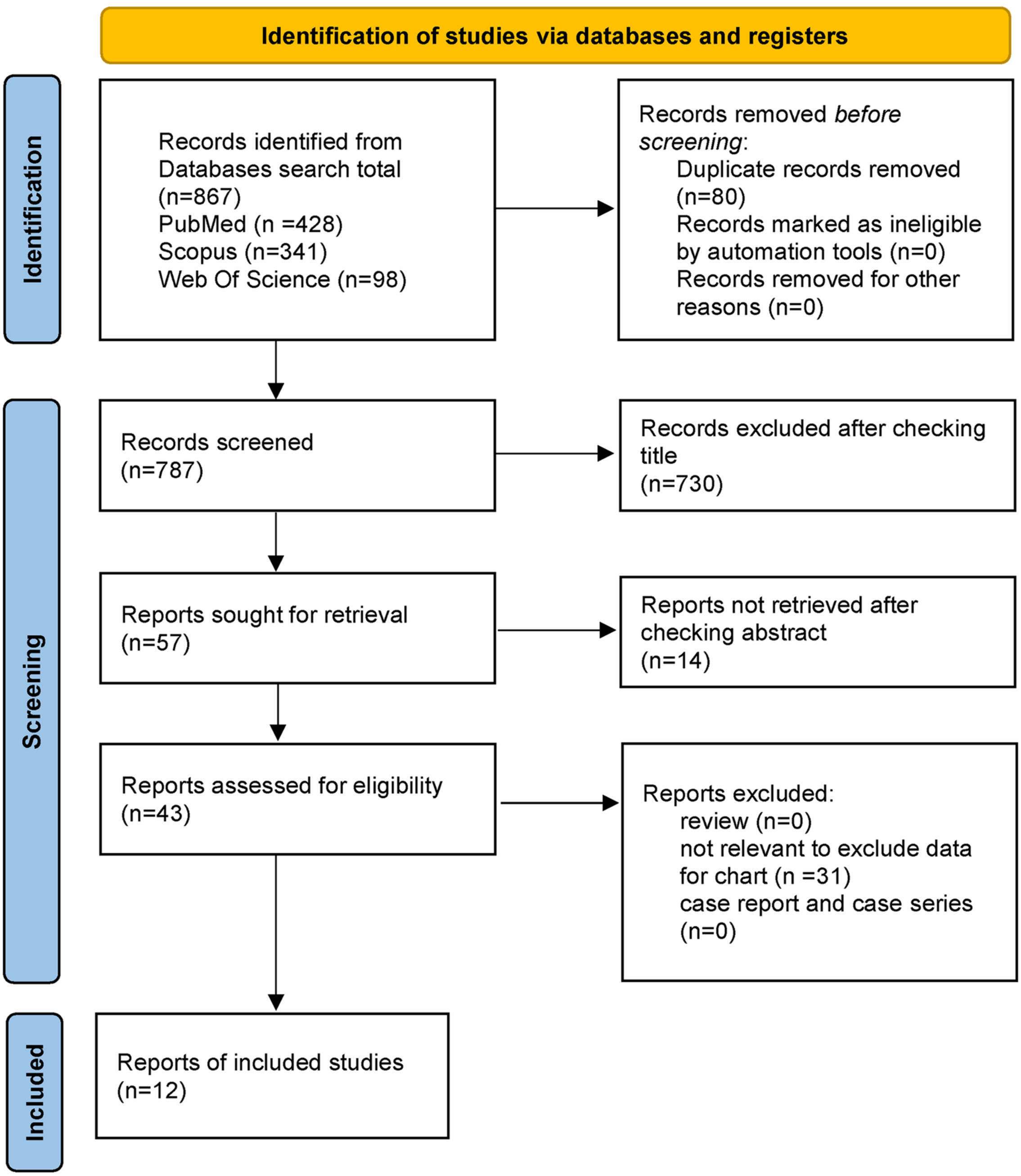


Fig. 1 PRISMA diagram

Table 1 Characteristic details about the total diagnostic value of CT in OGI's

Author, year	Country	Type of CT imaging	Total OGI's	Total age (years)	Sensitivity	Specificity	PPV	NPV
Joseph, 2000 [25]	United States	MDCT	80	NR	0.75	0.93	NR	NR
Arey, 2005 [17]	United States	NR	35	NR	0.71	0.76	NR	0.57
Arey, 2007 [16]	United States	NR	34	> 18	0.71	0.79	NR	0.52
Kim, 2010 [18]	Korea	MDCT, SDCT	28	NR	0.92	0.85	NR	NR
Hsin Yuan, 2013 [19]	China	MDCT, SDCT	75	45.1	0.76	0.85	NR	0.82
Allon, 2016 [20]	Israel	NR	125	36	0.45		NR	NR
Chou Yun, 2016 [21]	Taiwan	MDCT	136	41	0.75	0.948	0.8	0.92
Crowell, 2017 [22]	United States	MDCT	35	39.5	0.97	0.51 to 0.75	1.00	0.82
Gad, 2017 [23]	United States	MDCT	122	NR	0.865	0.955	0.925	0.919
Schneider, 2019 [24]	United States	NR	77	> 18	0.74	NR	NR	NR
Amir Arabi, 2021 [15]	Iran	MDCT	61	39	0.95	0.71	0.92	0.8
Seyhan Dikci, 2021 [14]	Turkey	MDCT	82	40.34	0.623	NR	NR	NR
Seyhan Dikci, 2021 [14]	Turkey	MDCT	47	10.8	0.489	NR	NR	NR

OGI: Open Globe Injury, PPV: Positive Predictive Value, NPV: Negative Predictive Value, NR: not reported, MDCT: Multi-detector CT scanner, SDCT: Single-detector CT scanner

CT sensitivity and specificity in the diagnosis of open globe injuries

The overall percentage of sensitivity of CT scans in diagnosing OGIs has been reported in eleven studies [14–24]. The lowest and highest results were reported by Allon et al. 2016 [20] 0.45(95% CI: 0.36, 0.54) and Crowell et al. 2017 [22] 0.97(95% CI: 0.91, 1.03), respectively. Our overall analysis reports a pooled sensitivity of 75% (95% CI: 0.65, 0.85, I^2: 93.5%, p-value < 0.001) (Fig. 2).

The specificity of CT scans in detecting ocular trauma has been reported in eight studies [15–19, 21–23]. The results varied from 0.63 (95% CI: 0.46, 0.79) [22] to 0.95 (95% CI: 0.91, 0.99) [21] and 0.95(95% CI: 0.92, 0.99)(22). A pooled analysis of specificity reported an overall specificity of 83% (95% CI: 0.76, 0.90, I^2: 84%, p-value < 0.001) (Fig. 3).

CT positive (PPV) and negative predictive value (NPV) in the diagnosis of open globe injuries

The positive and negative predictive values were reported in eight [15–17, 19, 21–23, 25] and seven [15–17, 19, 21–23] studies, with the pooled of 90% (95% CI: 0.84, 0.96, I^2: 91.3%, p value < 0.001) (Fig. 4) and 79% (95% CI: 0.71, 0.88, I^2: 85.6%, p value < 0.001), respectively (Fig. 5). Results ranged from 0.80 (95% CI: 0.71, 0.98) [19–21] to 1.00 (95% CI: 1.00, 1.00) [22] for PPV and from 0.52 (95% CI: 0.35, 0.69) [16] to 0.92 (95% CI: 0.87, 0.97) [21, 23] for NPV.

CT scan pathologic findings in OGI

Eleven studies reported the details about each pathologic finding in the CT scan of patients with OGI. We have sorted the frequency of each finding of the CT scan results in OGI in Table 2. The most frequent findings were a change in globe contour, scleral injury, corneal injury, and vitreous hemorrhage, in order.

Diagnostic value and accuracy of each CT finding in detecting OGI

Due to the heterogeneity in findings and the wide range of total sensitivity and specificity reported on the included studies, we conducted a meta-analysis on each CT finding's sensitivity, specificity, PPV, and NPV. The sensitivity and specificity of CT scans in diagnosing OGI were evaluated separately based on each of the pathological findings from the CT scans, which are available in Table 3 (Figures S1-S8). The highest diagnostic sensitivity of CT scan findings was observed for shallow anterior chamber changes and lens dislocation or destruction, with sensitivities of 89% and 78%, respectively. Lens dislocation and intraocular foreign body had the highest specificity in CT findings, with a specificity of 100%.

Based on trauma mechanisms

Three studies evaluated the sensitivity of CT imaging in detecting OGI based on the mechanism of trauma [14, 15, 17]. According to the results reported in these studies, we divided the mechanisms into two groups: blunt and sharp, penetrating or high-velocity trauma. Our meta-analysis results showed the higher sensitivity in blunt traumas 0.75 (95% CI: 0.71, 0.80, I-squared: 67.2%, p value:0.027) vs. 0.63(95% CI: 0.58, 0.68, I-squared: 82%, p value:0.001) in penetrating traumas (Figure S9 and S10).

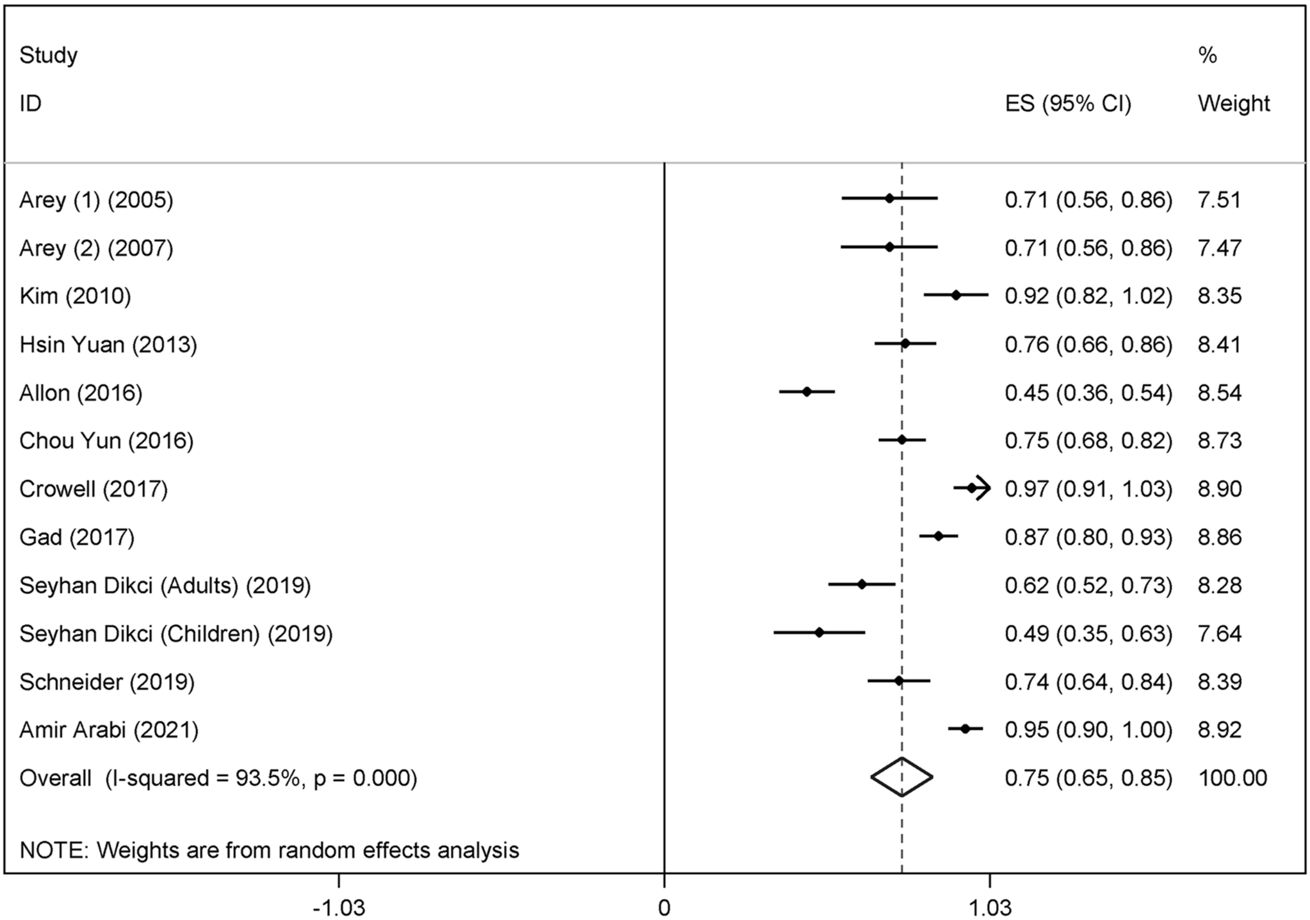


Fig. 2 CT sensitivity in detecting OGI. forest plot displaying the pooled sensitivity of CT scans for diagnosing open globe injuries. The sensitivity was calculated across multiple studies, with confidence intervals presented for each study and the overall pooled estimate

Publication Bias

Figure 7 shows Begg's funnel plot based on the application of CT in detecting OGIs. The interpretation of our Begg's funnel plot ($p=0.805$ and Egger's test ($p=0.397$) suggests no significant publication bias in the included studies. Consequently, it is reasonable to conclude that the reports included in this meta-analysis have been published with both positive and negative outcomes, as depicted in Figs. 6 and 7.

Sensitivity analysis

The sensitivity analysis's findings show that even when individual studies were eliminated one after the other, the overall conclusions did not change significantly. The reliability of CT's diagnostic accuracy in identifying OGIs was demonstrated by the fact that the removal of any one study had no discernible impact on the pooled estimations for sensitivity, specificity, PPV, or NPV.

Discussion

Our systematic review and meta-analysis include a substantial sample size of 12 studies with 937 patients, demonstrating the diagnostic utility of CT scanning in open-globe injuries. The pooled analysis revealed moderate to high diagnostic accuracy, with a sensitivity of 0.75 and specificity of 0.83, and favorable predictive values (PPV: 0.90, NPV: 0.79). Among the CT findings, changes in globe contour emerged as the most prevalent pathologic finding (74%), followed by scleral (48%) and corneal injuries (47%). Notably, CT demonstrated perfect specificity (1.00) for detecting lens dislocations and intraocular foreign bodies, while showing high sensitivity (0.89) for anterior chamber changes. Numerous investigations on the OGIs have consistently shown characteristic orbital CT findings [26, 27]. Some comprehensive studies have demonstrated that CT imaging is not adequately sensitive when used alone in detecting all open-globe injuries [22, 25]. For OGI patients, obtaining a CT scan may be equally valuable for

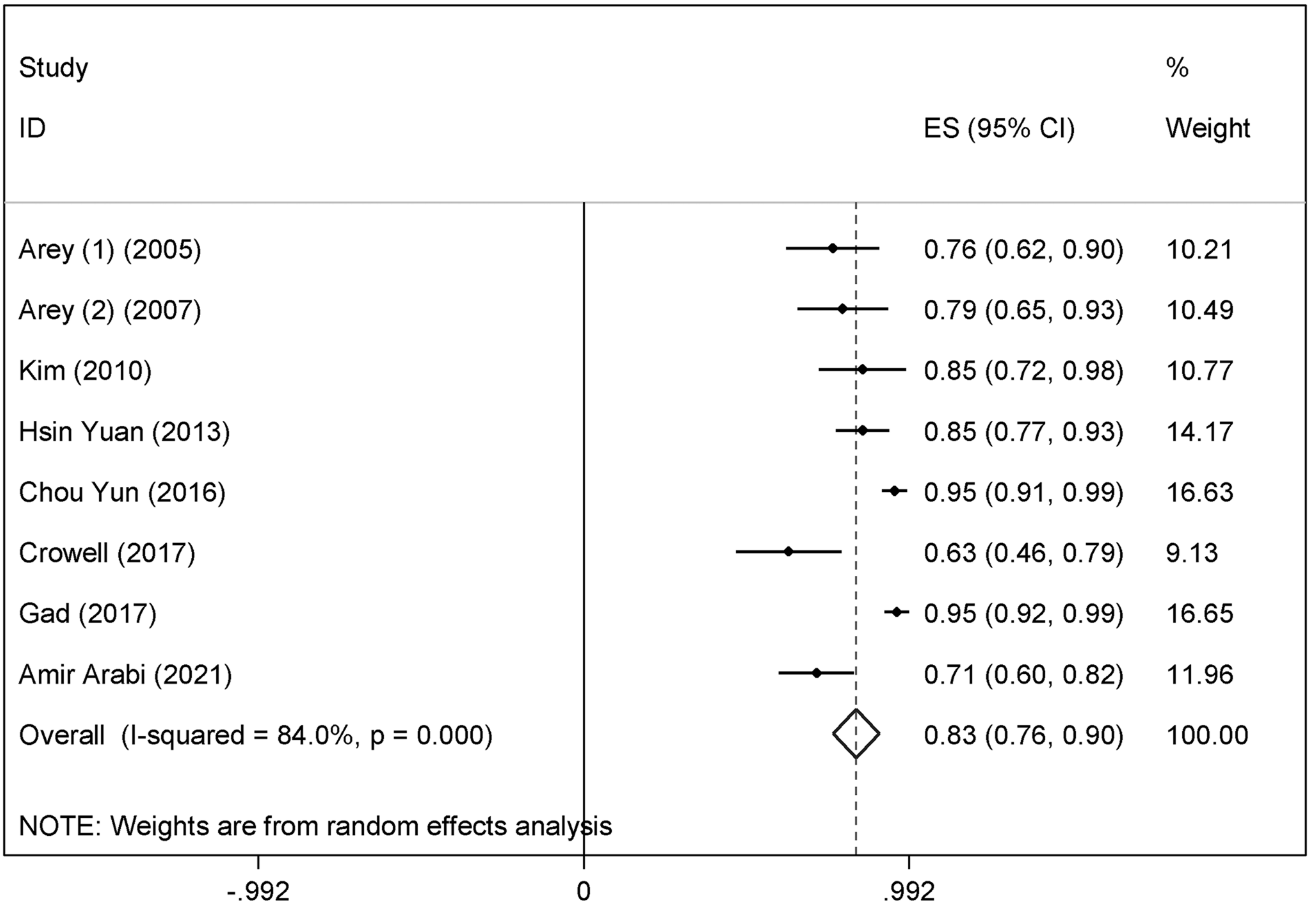


Fig. 3 CT specificity in detecting OGI. forest plot showing the pooled specificity of CT scans in diagnosing open globe injuries. The specificity is calculated for each study, and the overall pooled specificity is presented with confidence intervals

predicting visual outcomes and scaling eye trauma severity. The number and type of CT findings are possible and practical for prognosticating and staging in OGI, thus instilling confidence in decision-making [10]. Because the reported results were not consistently aligned and because this clinical condition is critical in ophthalmologic practice, we have decided to carry out this systematic investigation to reach a comprehensive and definitive conclusion (Fig. 8).

Early recognition of globe rupture following trauma is essential to enable timely surgical intervention and prevent visual loss. While CT scan plays a central role in the assessment of ocular trauma, its sensitivity should be used cautiously compared with clinical examination. Certain CT findings, such as globe deformity, volume loss, or the presence of air within the eye, function as simple diagnostic markers, which enhances the sensitivity of OGI and enabling evidence-based management [25]. However, CT scanning is not faultless. Chen et al. has found in their research that approximately 10% of clinically confirmed OGIs were without pathognomonic CT features, pointing to a non-trivial false-negative rate [28].

Joseph et al. [25] analyzed the medical records of 200 patients who underwent CT scans to evaluate ocular injury. The diagnosis of globe rupture exhibited a positive predictive value of 88–97%, with a sensitivity of 75% and a specificity of 93%. In a research including 59 patients with severe ocular trauma, Hoffstetter et al. [29] discovered that globe distortion and volume loss were the predominant outcomes in approximately one-third of instances where the clinical diagnosis of globe rupture was uncertain. These studies indicate that CT is beneficial for assessing ocular damage; nevertheless, it should not be solely relied upon for diagnosing globe rupture due to the potentially catastrophic outcomes of an undiscovered injury [30].

Our meta-analysis data partially aligns with these statements about CT limitations. Specifically, our findings show CT's overall sensitivity of 75% (CI: 0.65, 0.85) with a negative predictive value of 79% (CI: 0.71, 0.88), indicating that

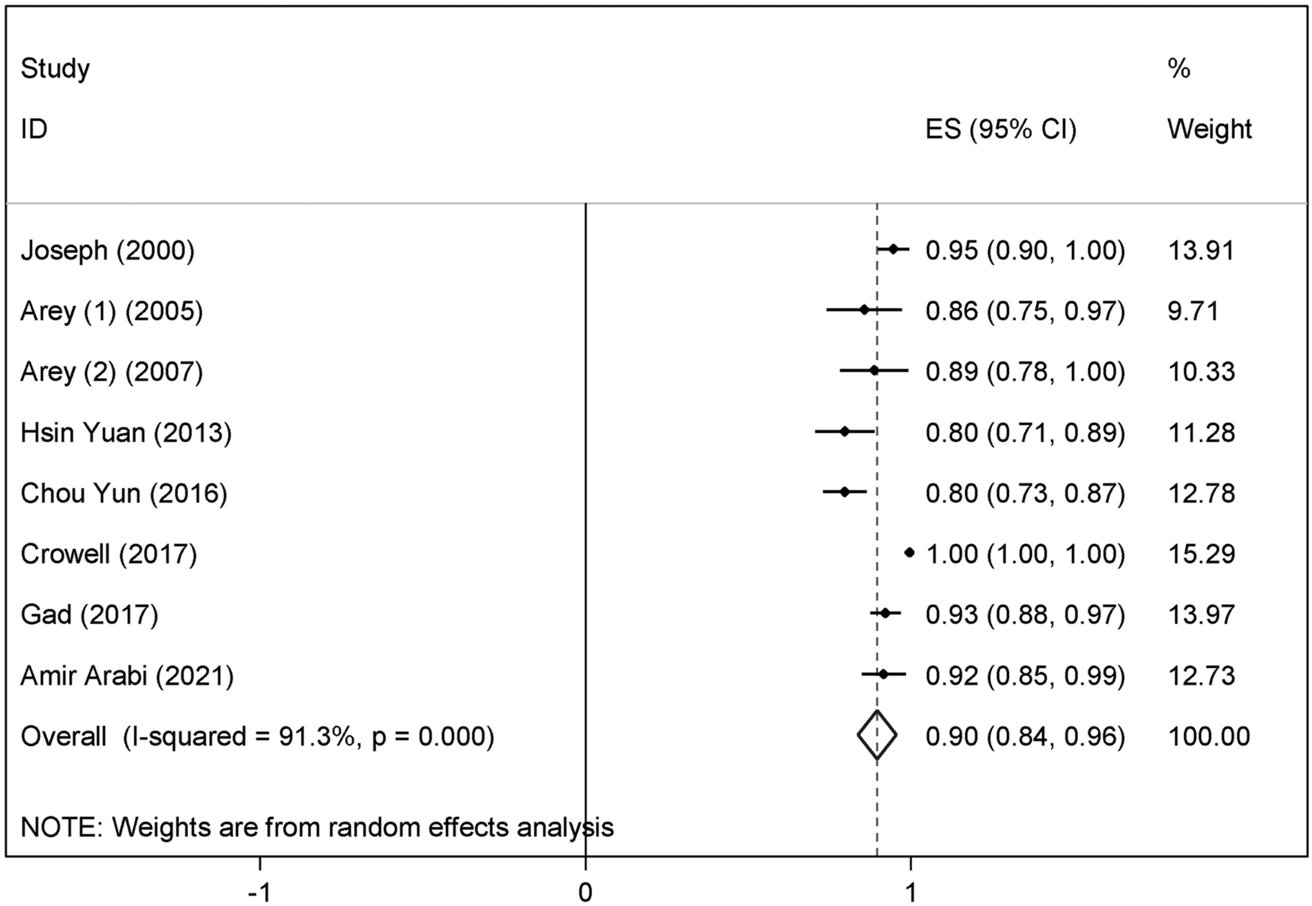


Fig. 4 PPV of CT in detecting OGI. forest plot displaying the pooled PPV of CT scans in diagnosing open globe injuries, summarizing the results from multiple studies

CT scans can indeed miss some OGIs, as suggested by the cited studies. This highlights the need for further research to improve the accuracy of CT scans.

CT scans can serve as an auxiliary tool in diagnosing OGI, especially in children, where a detailed examination cannot be performed. The results of our study show a 100% specificity for the diagnosis of foreign bodies using CT scans. This finding can be particularly helpful in diagnosing OGI trauma in children, which is often challenging [31, 32]. Individuals with high-energy traumas who cannot sit upright and undergo a thorough examination may benefit from this approach. In follow-up cases where examination of the posterior segment is not feasible due to changes in the anterior chamber, CT scans become particularly valuable. Indeed, numerous clinical investigations focused on OGIs have consistently illustrated the fundamental importance of CT imaging [11, 33]. Specifically, CT scans are particularly helpful in determining the necessity of acute surgical intervention [33]. Moreover, the combination of preoperative clinical information and detailed CT images following OGIs can effectively assist clinicians in predicting visual acuity, thus providing radiologists with a practical tool for optimal patient management [11].

In a study examining 182 cases, Ameli, K., and Colleagues [10] revealed that specific findings - namely, the presence of intraocular foreign air or body, thickening of the chorioretinal layer, and abnormal vitreous density - were significantly related to the lower Ocular Trauma Score. Additionally, they found that the presence of two or three CT scan findings was strongly correlated with higher OTS. These established findings align partially with the results of our meta-analysis. Specifically, our meta-analysis, which maintained a focused emphasis on prevalence rates and diagnostic accuracy, provides a comprehensive understanding of the most prevalent findings in OGIs. Notably, it demonstrates that vitreous hemorrhage represents a common

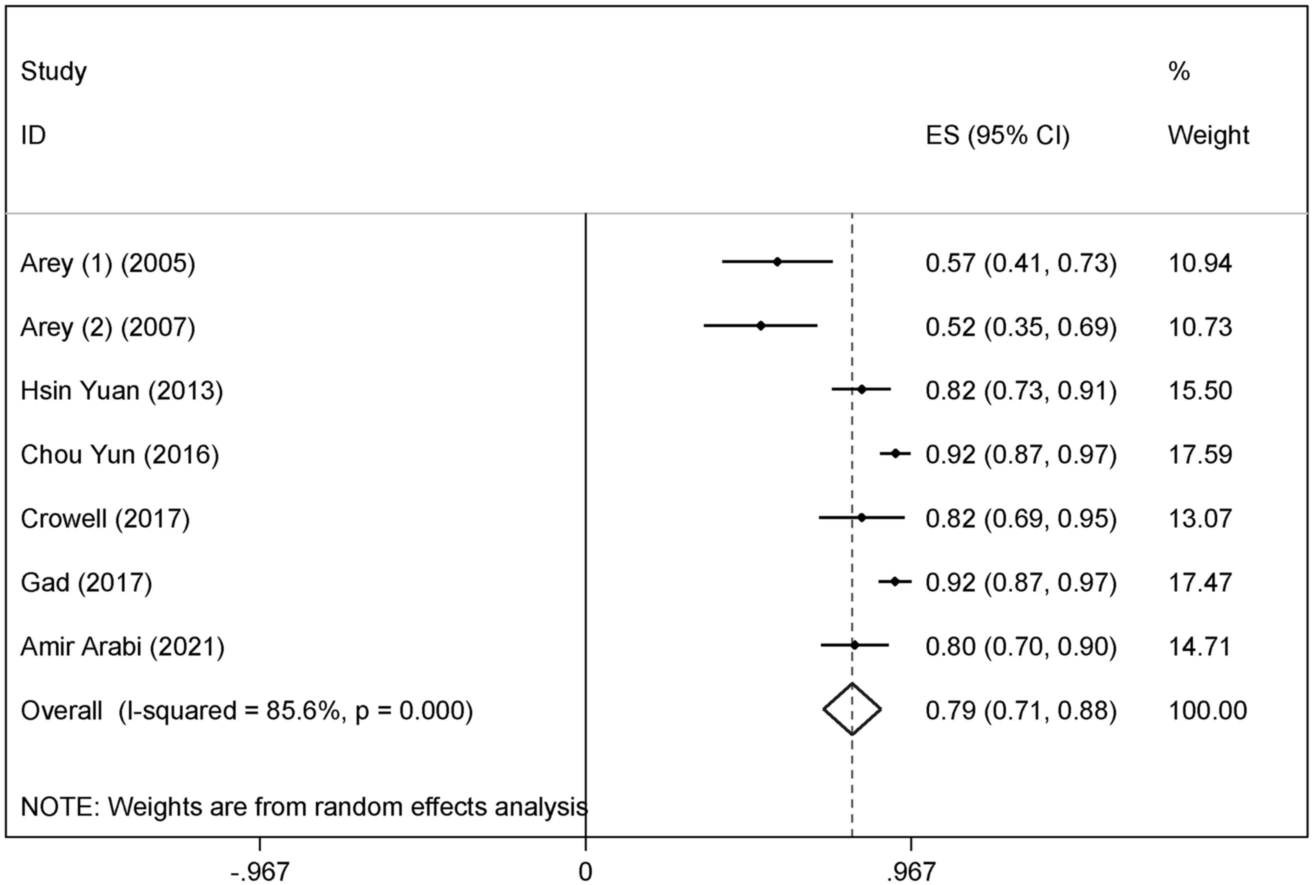


Fig. 5 NPV of CT in Detecting OGI Forest plot illustrating the pooled NPV of CT scans for detecting open globe injuries, including individual study results and the overall pooled estimate

Table 2 Prevalence of CT scan pathologic findings in OGI

CT scan findings	Overall prevalence
Change in globe contour	0.74
scleral injury	0.48
corneal injury	0.47
Vitreous Hemorrhage	0.44
anterior chamber deformation or rupture	0.42
Volume change	0.38
absence of lens or dislocation	0.37
orbital fracture	0.32
Retinal or choroidal detachment	0.29
Intraocular hemorrhage	0.19
intraocular air	0.19
Intraocular foreign body	0.12

finding with a 44% prevalence rate. In comparison, scleral/globe contour changes show an even higher prevalence (74% for globe contour changes and 48% for scleral injury), thus supporting the conclusion that these indeed represent the most prevalent findings in OGIs. However, it is important to note that while Ameli's study suggests that multiple CT findings correlate significantly with OTS scores, our meta-analysis specifically focused on prevalence rates and diagnostic accuracy without analyzing any relationships to outcome measures.

A significant limitation is the potential for recall and selection biases, as most studies are retrospective in design. Additionally, the gold standard for confirming OGIs varies

Table 3 The sensitivity and specificity of CT scans in diagnosing OGI based on each of the pathological findings

CT Scan Findings	Sensitivity	95% CI	I^2	*p*-value	Specificity	95% CI	I^2	*p*-value
Lens dislocations or destruction	0.78	0.61, 0.94	91.9%	0.000	1.00	0.99, 1.01	0.0%	0.951
Intraocular foreign body	0.65	0.49, 0.82	92.3%	0.000	1.00	1.00, 1.00	0.0%	0.685
Shallow anterior chamber/ ACD changes	0.89	0.85, 0.93	0.0%	0.973	0.92	0.83, 1.00	82.4%	0.003
Globe deformity/ globe cantor or wall irregularity	0.67	0.55, 0.78	67.8%	0.045	0.93	0.90, 0.96	0.0%	0.983

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Begg's Test

  adj. Kendall's Score (P-Q) =       2
          Std. Dev. of Score =    8.08
           Number of Studies =       8
                          z  =    0.25
                    Pr > |z| =   0.805
                          z  =    0.12 (continuity corrected)
                    Pr > |z| =   0.902 (continuity corrected)
```

Egger's test

Std_Eff	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
slope	.8428247	.380179	2.22	0.068	-.0874398	1.773089
bias	-7.594577	8.334012	-0.91	0.397	-27.98717	12.79802

Fig. 6 Begg and Egger's publication bias

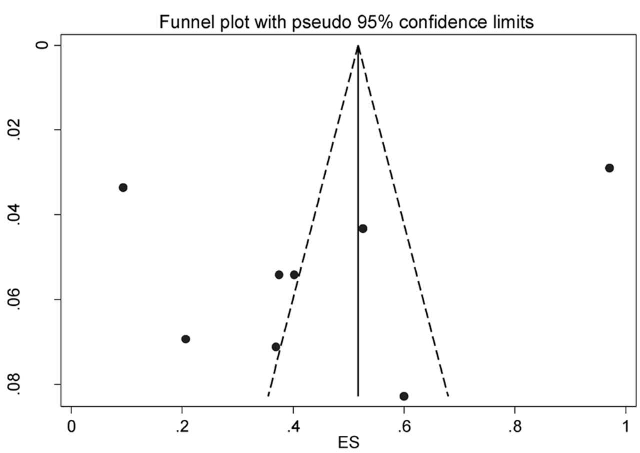

Fig. 7 Funnel plot of the publication bias

across studies; some depend on ophthalmologic examination, while others utilize surgical findings. Further limitations arise from heterogeneity due to diverse CT settings and imaging protocols, which may influence diagnostic accuracy and outcomes. Due to the insufficient reports from the included studies, we were unable to reduce this effect in our analysis. Additionally, our analysis lacked sufficient homogeneous data to validate prognostic models. Future studies should standardize CT protocols and outcome measures. The small sample sizes in certain studies also limit the generalizability of their findings. Lastly, the evaluation of images by different specialists, such as ophthalmologists and radiologists, or radiologists alone, may affect the reliability and consistency of study results.

Conclusion

This systematic review and meta-analysis, a comprehensive evaluation of the diagnostic performance of CT scanning in open globe injuries across seventeen studies, provides practical insights. Our findings demonstrate that CT scanning is a reliable diagnostic tool with moderate to high accuracy across diagnostic parameters. The analysis reveals that structural changes, particularly globe contour alterations, are the most frequently observed CT findings, followed by corneal and scleral injuries. CT scan detects specific pathologic findings, notably lens dislocations, intraocular foreign bodies, and anterior chamber abnormalities. The review identifies blunt trauma and penetrating injuries as the predominant mechanisms of injury, while falls were less common. These findings, which provide robust evidence supporting the utility of CT scanning in the diagnostic workflow for open globe injuries, particularly for detecting structural abnormalities and anterior chamber changes, have significant practical implications. They can inform clinical

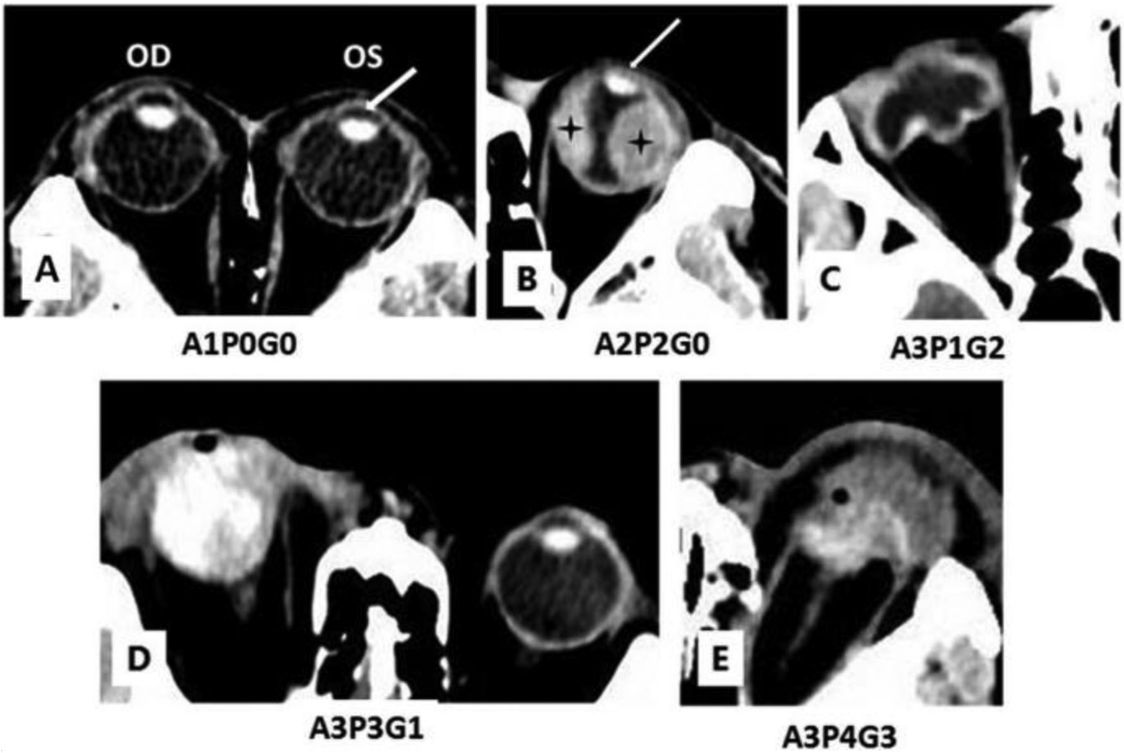

Fig. 8 **A**. Left open-globe injury after being hit in the left eye with a sheet metal. **B**. Left open-globe injury after being hit in the left eye with metal block. **C**. Right open-globe injury after hitting on the door. **D**. Right open-globe injury after being hit in the right eye by an exploding glass bottle. **E**. Left open-globe injury after being hit by exploding fireworks [28]. Copyright © 2024, The Author(s)

practice and guide the diagnostic and prognostic approach in suspected open globe injuries, empowering medical professionals to make informed decisions.

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Data availability Not applicable.

Declarations

Ethical approval and consent to participate IRB Information: Not applicable.

Research involving human participants and/or animals Not applicable.

Support None.

Permission Tables /Figure Not applicable, original data.

Competing interests The authors declare that they have no competing interests.

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