Original Article

Binocular vision dysfunction after polytrauma

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ABSTRACT

Background: Binocular vision dysfunction is frequently overlooked in polytrauma care despite its established impact on reading, driving, and return to work. We aimed to determine the prevalence and patterns of binocular vision dysfunction in polytrauma patients with ocular involvement and to identify independent clinical predictors.

Methods: We conducted a retrospective cohort study of adults (≥ 18 years) admitted to Sina Hospital Trauma Center, Tehran between January 2021 and December 2023 with an Injury Severity Score (ISS) ≥ 16 and ophthalmology-confirmed ocular involvement. Four binocular parameters; near point of convergence, stereoacuity, fusional vergence amplitudes, and accommodative facility, were extracted from consultation records when available. Prevalence estimates were calculated using the Wilson score method, and multivariable logistic regression identified independent predictors.

Results: Among 2923 polytrauma admissions, 438 patients (15.0%) had ocular involvement; 312 (71.2%) had complete binocular data (mean [standard deviation] age 37.8 [14.2] years; 84.6% [n = 264] male). At least one binocular dysfunction was identified in 134 patients (42.9%; 95% confidence interval [CI], 37.4–48.6). Convergence insufficiency was most common (n = 119, 38.1%; 95% CI, 32.8–43.7), followed by reduced stereopsis (n = 87, 27.9%; 95% CI, 23.1–33.2), accommodative dysfunction (n = 67, 21.5%; 95% CI, 17.2–26.4), and reduced fusional vergence amplitude (n = 54, 17.3%; 95% CI, 13.4–22.0). Only 24.7% (n = 77) of patients received formal optometric referral during acute admission. Independent predictors were blunt orbital trauma (adjusted odds ratio [aOR] 2.81, 95% CI, 1.67–4.73), concomitant traumatic brain injury (aOR 2.14, 95% CI, 1.29–3.55), and age 18–35 years (aOR 1.92, 95% CI, 1.12–3.28) (all $P < 0.05$).

Conclusions: Binocular vision dysfunction affects nearly half of polytrauma patients with ocular involvement yet is substantially under-recognized and under-referred. Incorporating a brief binocular screening into routine post-trauma ophthalmologic assessment may represent a low-cost strategy to mitigate long-term visual and functional disability. Future prospective, multicenter studies employing standardized optometric assessment protocols and longitudinal follow-up are warranted to better define the natural history of these observed binocular dysfunctions and to evaluate the impact of early detection and targeted intervention on functional outcomes.

KEYWORDS

multiple traumas, polytrauma, injury severity scores, ISS score, binocular vision, ocular convergence, stereopsis, ocular motility disorder, convergence insufficiency, retrospective study

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INTRODUCTION

Ocular trauma represents a major and largely preventable cause of visual morbidity in low- and middle-income countries, disproportionately affecting these settings due to occupational and environmental exposures; including road traffic incidents, domestic injuries, and interpersonal violence, within contexts of limited protective measures and constrained access to timely eye care [1, 2]. Iran is no exception. Population-based studies report a lifetime prevalence of ocular trauma ranging from 5.2% in school-age children to 7.46% in older adults, with a marked male predominance and the highest burden among those over 30; injuries are predominantly mechanical, most commonly due to motorcycle-related accidents and sharp objects [3–6].

Monocular visual outcomes after trauma are routinely assessed, binocular and oculomotor dysfunction are not. However, evidence from traumatic brain injury (TBI) populations demonstrates a high prevalence of visual dysfunction even in the absence of direct ocular injury, including accommodative dysfunction (42.8%), convergence insufficiency (36.3%), and visual field loss (18.2%) [7]. Convergent findings in concussed athletes further highlight the frequency of binocular and oculomotor impairments, with convergence insufficiency, accommodative dysfunction, and oculomotor-based reading dysfunctions reported in approximately 40%, 25%, and 20% of cases, respectively [8]. Despite this substantial burden, pathways from diagnosis to rehabilitation remain inconsistent, and access to specialized vision care is often limited [9]. These dysfunctions frequently go unrecognized in acute trauma settings, where life-threatening conditions are the clinical priority and structured binocular assessment is not routinely performed. Moreover, symptoms such as eyestrain, diplopia, and difficulty with near tasks may emerge or become more apparent during recovery and reintegration into visually demanding activities rather than during the initial hospitalization [10, 11].

Eye injury registries are essential for systematically capturing epidemiological patterns, informing clinical decision-making, and guiding prevention and rehabilitation strategies [12]. In this context, the National Trauma Registry of Iran (NTRI) was established at Sina Hospital, Tehran in 2016 to enable standardized, longitudinal trauma data collection [13, 14]. Sina Hospital, a level-I trauma center affiliated with Tehran University of Medical Sciences and a major node within the NTRI, manages a large and diverse polytrauma population annually, providing a unique platform for high-resolution clinical analysis [14, 15].

Leveraging three years of registry data from this center, the present study aims to quantify the prevalence and characterize the spectrum of binocular vision dysfunction among polytrauma patients with confirmed ocular involvement, and to identify their independent clinical predictors. By addressing this under-recognized dimension of post-traumatic visual dysfunction, the study seeks to generate evidence to support the integration of structured optometric assessment into routine trauma care pathways and rehabilitation protocols.

METHODS

This retrospective, registry-based observational study was conducted using data from the Sina Hospital Trauma Center, a tertiary-level regional referral center for severe trauma in northwestern Tehran, over a 36-month period from 1 January 2021 to 31 December 2023. The study protocol was approved by the Ethics Committee of Tehran University of Medical Sciences (IR.TUMS.SINAHOSPITAL.REC.1402.048) and adhered to the principles of the Declaration of Helsinki. Given the retrospective design and use of de-identified data, the requirement for individual informed consent was waived. At the time of hospital admission, all patients had provided written informed consent for clinical evaluation and treatment within routine care protocols.

We included all adult patients (≥ 18 years) admitted during the study period with an Injury Severity Score (ISS) ≥ 16 [16] and documented ocular involvement. Ocular involvement was defined by the presence of an International Classification of Diseases, Tenth Revision (ICD-10) diagnosis code within the S00–S05 range [17] or documentation of a formal ophthalmology consultation during the index admission. Patients with a known history of binocular vision disorders, prior strabismus surgery, or insufficient or poor-quality clinical documentation precluding reliable data extraction were excluded.

Two reviewers independently extracted demographic and injury-related variables, including age, sex, mechanism of injury, ISS [16], and Glasgow Coma Scale (GCS) score at presentation [18], from the institutional electronic trauma registry. Discrepancies were resolved through adjudication by re-review of the original source records. Binocular vision parameters were abstracted from optometry or ophthalmology consultation notes when all four components had been documented: near point of convergence (NPC), measured using the push-up method with an accommodative target [19]; stereoacuity assessed using Titmus or Randot tests [20]; fusional vergence amplitudes measured with prism bar [21]; and accommodative facility evaluated with ±2.00 D flipper lenses [22]. Predefined deficit thresholds were based on established clinical norms: NPC ≥ 6 cm or eliciting diplopia [23]; stereoacuity > 40 arc seconds [24]; fusional vergence break ≤ 15 prism diopters base-out at NPC [22]; and accommodative facility < 8 cycles per minute [25]. The presence of any one abnormal parameter was sufficient to classify a patient as having a binocular vision dysfunction [26].

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY, USA). The distribution of continuous variables was assessed using the Shapiro–Wilk test. Normally distributed data are presented as mean (standard deviation [SD]), non-normally distributed data as median (interquartile range [IQR]); categorical variables are summarized as frequencies and percentages. Prevalence estimates were calculated with 95%

confidence intervals (CIs) using the Wilson score method, selected a priori for its superior performance over the Wald method, particularly for proportions near distributional extremes. Univariate associations with the presence of any binocular vision dysfunction were evaluated using the chi-square test or Fisher's exact test for categorical variables and the Mann-Whitney U test for continuous variables, as appropriate. Variables with $P < 0.10$ in univariate analyses were entered into a multivariable binary logistic regression model to identify independent predictors. Adjusted models were constructed using simultaneous (enter) methods, and results are reported as crude and adjusted odds ratios (ORs) with corresponding 95% CIs. Model fit was assessed using the Hosmer-Lemeshow goodness-of-fit test. Statistical significance was defined as a two-tailed *P*-value < 0.05.

RESULTS

Over the 36-month study period, 2923 patients met polytrauma criteria, 438 (15.0%) of whom had documented ocular involvement. Complete binocular vision data were available for 312 patients (71.2%), who constituted the analytical cohort. Mean (SD) age was 37.8 (14.2) years, and 264 patients (84.6%) were male. Road traffic injuries were the predominant mechanism of injury (198 [63.5%]), followed by a high prevalence of blunt ocular trauma (219 [70.2%]). Concomitant TBI was documented in 167 patients (53.5%). Median (IQR) ISS was 22 (17–29). Detailed baseline characteristics of the cohort, overall and stratified by the presence of a composite binocular vision dysfunction, are presented in Table 1.

Overall, 134 patients (42.9%; 95% CI, 37.4–48.6) met criteria for at least one binocular vision dysfunction. Convergence insufficiency was the most prevalent abnormality, affecting 119 patients (38.1%; 95% CI, 32.8–43.7), followed by reduced stereopsis in 87 (27.9%; 95% CI, 23.1–33.2%), accommodative dysfunction in 67 (21.5%; 95% CI, 17.2–26.4%), and reduced fusional vergence amplitudes in 54 patients (17.3%; 95% CI, 13.4–22.0%) (Table 2). Despite this substantial burden, only 77 patients (24.7%) received a formal optometric referral during acute admission, indicating that the majority of affected individuals were discharged without specialized binocular vision assessment or follow-up.

In multivariable logistic regression analysis, three variables were independently associated with the presence of any binocular vision dysfunction. Blunt orbital trauma emerged as the strongest predictor (aOR 2.81, 95% CI, 1.67–4.73; $P < 0.001$). Concomitant TBI was also independently associated with increased odds of dysfunction (aOR 2.14, 95% CI, 1.29–3.55; $P < 0.05$). In addition, younger age (18–35 years vs. ≥36 years) was independently associated with increased odds of binocular vision dysfunction (aOR 1.92, 95% CI, 1.12–3.28; $P < 0.05$). Crude and adjusted effect estimates are presented in Table 3.

Table 1. Baseline characteristics of the study cohort, overall and stratified by presence of a composite binocular vision dysfunction (≥ 1 abnormal parameter)

Characteristic	Overall (n = 312)	≥1 binocular vision dysfunction (n = 134)
Age (y), Mean ± SD	37.8 ± 14.2	36.1 ± 13.5
Sex (Male / Female), n (%)	264 (84.6) / 48 (15.4)	115 (85.8) / 19 (14.2)
Road traffic injury, n (%)	198 (63.5)	89 (66.4)
Blunt ocular trauma, n (%)	219 (70.2)	108 (80.6)
Concomitant TBI, n (%)	167 (53.5)	83 (61.9)
ISS (score), Median (IQR)	22 (17–29)	23 (18–30)
Optometric referral during acute admission, n (%)	77 (24.7)	29 (21.6)

Abbreviations: y, years; SD, standard deviation; n, number of participants; %, percentage; TBI, traumatic brain injury; ISS, injury severity score; IQR, interquartile range. Note: Binocular vision dysfunction defined as ≥ 1 abnormal parameter among near point of convergence, stereoacuity, fusional vergence, or accommodative facility.

Table 2. Prevalence of binocular vision dysfunction among evaluable patients (n = 312)

Binocular Vision Dysfunction	n (%)	95% CI
Convergence insufficiency	119 (38.1)	32.8 to 43.7
Reduced stereopsis	87 (27.9)	23.1 to 33.2
Accommodative dysfunction	67 (21.5)	17.2 to 26.4
Reduced fusional vergence amplitudes	54 (17.3)	13.4 to 22.0
≥1 binocular vision deficit	134 (42.9)	37.4 to 48.6

Abbreviations: n, number of participants; %, percentage; CI, confidence interval. Note: Values are n (%) with 95% confidence intervals calculated using the Wilson score method; patients may have more than one deficit; the composite outcome (≥ 1 deficit) includes any abnormal parameter.

Table 3. Univariate and multivariable logistic regression, predictors of any binocular vision dysfunction

Predictor	Crude OR (95% CI)	Adjusted OR (95% CI)	*P*-value
Blunt orbital trauma	3.04 (1.83 to 5.06)	2.81 (1.67 to 4.73)	**<0.001**
Concomitant traumatic brain injury	2.31 (1.41 to 3.79)	2.14 (1.29 to 3.55)	**0.003**
Age 18–35 years (reference: ≥36 years)	2.05 (1.22 to 3.46)	1.92 (1.12 to 3.28)	**0.018**

Abbreviations: OR, odds ratio; CI, confidence interval. Note: *P*-values < 0.05 are shown in bold; Reference category for age: ≥ 36 years; Multivariable model adjusted for all three variables simultaneously.

DISSCUSSION

In this registry-based study of polytrauma patients with ocular involvement, we identified a substantial and under-recognized burden of binocular vision dysfunction affecting nearly one in two patients. Convergence insufficiency emerged as the predominant abnormality, followed by dysfunction in stereopsis, accommodation, and fusional vergence. Despite this high prevalence, fewer than one-quarter of patients received optometric referral during the acute admission, highlighting a significant gap between clinical need and service delivery. Blunt orbital trauma, concomitant TBI, and younger age independently predicted the presence of binocular vision dysfunction, suggesting that both injury characteristics and patient factors contribute to risk stratification. Our findings underscore that binocular vision dysfunction is common, clinically relevant, and insufficiently addressed within current trauma care pathways.

Nearly half of polytrauma patients with ocular involvement in this cohort had at least one binocular vision dysfunction, a prevalence of 42.9% that equals or exceeds rates reported in international civilian TBI series [27–31]. The impact of TBI on the visual system is well established, and binocular vision dysfunction represents one of its most functionally disabling yet least recognized manifestations [31, 32]. These dysfunctions are not only detectable but also treatable, as targeted vision therapy has been shown to improve oculomotor function, reading performance, and patient-reported outcomes in individuals with post-TBI visual dysfunction [33]. Convergence insufficiency was the most prevalent abnormality, affecting 38.1% of this cohort; this aligns with reviews of post-TBI visual dysfunction pointing to vergence and accommodative pathways as the circuits most vulnerable to acceleration-deceleration injury [7, 34, 35]. What makes the present data clinically sobering is not the frequency of binocular vision dysfunction per se, but the gap between that frequency and the referral rate: three-quarters of affected patients left the acute service without ever seeing an optometrist.

The pattern of binocular vision dysfunction observed in our cohort is broadly consistent with prior literature on TBI, while reflecting the added complexity of concomitant ocular trauma. Convergence insufficiency was the most prevalent deficit (38.1%), closely aligning with pooled estimates from a meta-analysis of TBI populations reporting a prevalence of 36.3% [7]. In contrast, accommodative dysfunction in our study (21.5%) was lower than the 42.8% reported in TBI without ocular injury, possibly reflecting differences in case mix or under-detection in routine clinical documentation [7]. The high burden of vergence-related abnormalities in our cohort is further supported by evidence from military populations, where convergence insufficiency is significantly more frequent in individuals with blast-related mild TBI, highlighting vulnerability of vergence and accommodative pathways to traumatic insult [34]. Rehabilitation-focused studies demonstrate that these dysfunctions are not only prevalent but also clinically actionable, with targeted interventions frequently addressing convergence, accommodation, and binocular coordination in TBI populations [35, 36]. Our findings extend existing evidence by demonstrating that binocular vision dysfunction remains highly prevalent even in patients with combined ocular and systemic trauma, underscoring the need for systematic detection and integration of vision rehabilitation into trauma care pathways.

The mechanistic case for why blunt orbital trauma and TBI both appear in the regression model is not obscure. Acceleration-deceleration forces strain the posterior commissure and the dorsal midbrain vergence integrator; the trochlear nerve, owing to its long intracranial course, is uniquely exposed to contrecoup shear. Blunt orbital injury layers a second mechanism on top of this, restrictive strabismus and sensory fusion loss from direct extraocular muscle or orbital wall disruption [37–40]. The co-occurrence of blunt orbital trauma and TBI as independent predictors of binocular vision dysfunction is biologically plausible. Traumatic brain injury is driven by rapid acceleration-deceleration forces that induce diffuse axonal injury and shear stress within vulnerable neural pathways, including those subserving ocular motor control. These forces can disrupt brainstem and supranuclear networks responsible for vergence, accommodation, and coordinated eye movements, leading to persistent binocular vision dysfunction. Blunt orbital trauma introduces an additional, peripheral mechanism: extraocular muscle injury, entrapment, or orbital wall fractures can mechanically restrict ocular motility and impair sensory fusion, resulting in strabismus and diplopia. The convergence of central (neurological) and peripheral (mechanical) injury pathways provides a coherent explanation for the strong and independent associations observed in our regression model [37–40]. These central and peripheral mechanisms are likely complementary rather than redundant, reflecting the combined impact of diffuse neural injury and local orbital disruption on binocular function. This dual-pathway model may explain why both variables retained independent significance after mutual adjustment. With respect to age, young adults in Iran are disproportionately affected by road traffic injuries, with the highest burden observed in individuals

within the economically active age range. In parallel, this group faces greater vocational and educational visual demands, rendering binocular vision dysfunction more likely to translate into measurable functional impairment [37, 41–43]. In this context, even modest binocular vision dysfunction, particularly convergence insufficiency, may have a disproportionate functional impact, given its established effects on reading efficiency, visual comfort, and sustained near-task performance in younger populations exposed to high visual demands, including digital device use [44].

The persistent under-recognition is explicable, though not excusable. Acute trauma protocols, structured by Advanced Trauma Life Support, prioritization, airway, circulation, disability [45], and monocular acuity is the only ocular metric routinely captured [46]. Binocular vision assessment depends on subjective responses and sustained fixation, requiring a cooperative and attentive patient [47], yet is often impractical in acute trauma settings due to limited equipment and reduced patient cooperation. Beyond that, the symptoms of convergence insufficiency; near-vision blur, asthenopia, diplopia on reading, are easily attributed to pain medication, fatigue, or head injury and simply not reported during the early post-injury phase [32]. Many binocular and oculomotor deficits may not be fully appreciated during the acute phase of injury and instead become clinically evident as patients resume visually demanding activities, by which time the initial episode of trauma care has often concluded [48, 49]. Consistently, nearly half of patients exhibited undetected binocular vision dysfunction.

What would a pragmatic response entail? Incorporating a brief binocular screening protocol, comprising NPC measurement and a gross stereoacuity assessment, into the standard post-trauma ophthalmology consult would provide a rapid, low-cost triage tool, requiring minimal equipment and no more than a few minutes to perform. Patients who screen positive could then be referred for comprehensive optometric evaluation prior to discharge. Evidence from comparable resource-constrained settings supports such stepwise approaches as cost-effective, and vision therapy for post-TBI convergence insufficiency is now supported by level-I evidence [26, 50–53]. Hence the principal barrier is not technical feasibility but integration of this pathway into routine trauma care.

This study has several limitations that should be considered when interpreting the findings. First, its retrospective design means that binocular assessments were performed as part of routine care rather than through a standardized screening protocol, likely favoring more symptomatic patients and potentially overestimating the true prevalence of binocular vision dysfunction. Second, incomplete binocular data led to the exclusion of 28.8% of eligible patients, introducing selection bias of uncertain direction. Third, the single-center setting in a large urban trauma facility may limit generalizability to other contexts, particularly district hospitals or rural environments where injury patterns and resource availability differ. Notwithstanding these limitations, the study leverages a high-volume trauma registry and provides, to our knowledge, one of the most detailed characterizations of binocular vision dysfunction in polytrauma patients with ocular involvement in Iran. Future prospective, multicenter studies employing standardized optometric assessment protocols and longitudinal follow-up are warranted to better define the natural history of these observed binocular dysfunctions and to evaluate the impact of early detection and targeted intervention on functional outcomes.

CONCLUSIONS

Binocular vision dysfunction is common among polytrauma patients with ocular involvement, affecting nearly half of cases in this cohort, yet remains largely unrecognized within routine trauma care. Blunt orbital trauma, concomitant TBI, and younger age independently identify patients at increased risk. These findings highlight a clinically meaningful gap between the burden of binocular vision dysfunction and its detection during acute care. Incorporating a brief, targeted binocular vision screening into standard post-trauma ophthalmologic assessment may represent a pragmatic and low-resource strategy to improve identification and referral. Given that several of these anomalies, particularly convergence insufficiency, are amenable to treatment, earlier recognition has the potential to mitigate persistent visual symptoms and improve functional recovery.

ETHICAL DECLARATIONS

Ethical approval: The study protocol was approved by the Ethics Committee of Tehran University of Medical Sciences (IR.TUMS.SINAHOSPITAL.REC.1402.048) and adhered to the principles of the Declaration of Helsinki. Given the retrospective design and use of de-identified data, the requirement for individual informed consent was waived. At the time of hospital admission, all patients had provided written informed consent for clinical evaluation and treatment within routine care protocols.
Conflict of interests: None.

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REFERENCES

1. Pelletier J, Reagan K, McLeod S, Kronk N, Dickson K, Ohman K, Santos M. Epidemiology of ocular trauma in limited-resource settings: a narrative review. Front Med (Lausanne). 2025 Aug 25;12:1585527. doi: 10.3389/fmed.2025.1585527. PMID: 40927196; PMCID: PMC12415046.
2. Daryabari SH, Jadidi K, Torabi H, Hassani M, Kiarudi MY, Saeedifar M. Refractive and visual outcomes of traumatic cataract surgery: a ten-year perspective. Medical hypothesis, discovery & innovation in optometry. 2024;5(3):112-8. doi: 10.51329/mehdioptometry205.
3. Hashemi A, Khabazkhoob M, Mehri A, Yekta A, Mortazavi A, Hashemi H. Epidemiology of Ocular Trauma in the Elderly: A Population-Based Study. J Curr Ophthalmol. 2023 Aug 11;35(1):79-85. doi: 10.4103/joco.joco_53_23. PMID: 37680290; PMCID: PMC10481976.
4. Hashemi H, Pakzad R, Khabazkhoob M, Yekta A, Emamian MH, Fotouhi A. Prevalence of ocular trauma in 6-12-year-old children living in Shahroud, Iran. BMC Ophthalmol. 2022 Jul 26;22(1):320. doi: 10.1186/s12886-022-02541-5. PMID: 35883120; PMCID: PMC9316335.
5. Hashemi H, Khabazkhoob M, Emamian MH, Shariati M, Mohazzab-Torabi S, Fotouhi A. Past History of Ocular Trauma in an Iranian Population-Based Study: Prevalence and its Associated Factors. Middle East Afr J Ophthalmol. 2015 Jul-Sep;22(3):377-82. doi: 10.4103/0974-9233.159766. PMID: 26180480; PMCID: PMC4502185.
6. Mir A, Baseri MM, Farmanfarma KK. Factors affecting ocular trauma in Iran: A systematic review study. Health Sci Rep. 2024 Aug 30;7(9):e2281. doi: 10.1002/hsr2.2281. PMID: 39221056; PMCID: PMC11362837.
7. Merezhinskaya N, Mallia RK, Park D, Bryden DW, Mathur K, Barker FM 2nd. Visual Deficits and Dysfunctions Associated with Traumatic Brain Injury: A Systematic Review and Meta-analysis. Optom Vis Sci. 2019 Aug;96(8):542-555. doi: 10.1097/OPX.0000000000001407. PMID: 31343512.
8. Dutta P. Characteristics of binocular vision and oculomotor function among sports-concussed athletes. Indian J Ophthalmol. 2023 May;71(5):2076-2082. doi: 10.4103/ijo.IJO_1932_22. PMID: 37203084; PMCID: PMC10391497.
9. Winkler SL, Finch D, Wang X, Toyinbo P, Marszalek J, Rakoczy CM, Rice CE, Pollard K, Rhodes MA, Eldred K, Llanos I, Peterson M, Williams M, Zuniga E, White H, Delikat J, Ballistrea L, White K, Cockerham GC. Veterans with Traumatic Brain Injury-related Ocular Injury and Vision Dysfunction: Recommendations for Rehabilitation. Optom Vis Sci. 2022 Jan 1;99(1):9-17. doi: 10.1097/OPX.0000000000001828. PMID: 34882607; PMCID: PMC8720069.
10. Subramanian PS, Barton JJS, Ranalli P, Smith C, Francis CE, Frishberg B. Consensus Statement on Visual Rehabilitation in Mild Traumatic Brain Injury. Neurol Clin Pract. 2022 Dec;12(6):422-428. doi: 10.1212/CPJ.0000000000200071. PMID: 36540149; PMCID: PMC9757109.
11. Trieu LH, Lavrich JB. Current concepts in convergence insufficiency. Curr Opin Ophthalmol. 2018 Sep;29(5):401-406. doi: 10.1097/ICU.0000000000000502. PMID: 29994854.
12. Asadi F, Ramezanghorbani N, Almasi S, Rangraz MH. Eye Injury Registries: A Review on Key Registry Processes. Iran J Public Health. 2021 Dec;50(12):2495-2508. doi: 10.18502/ijph.v50i12.7922. PMID: 36317027; PMCID: PMC9577153.
13. Saeednejad M, Zafarghandi M, Khalili N, Baigi V, Khormali M, Ghodsi Z, Sharif-Alhoseini M, O'Reilly GM, Naghdi K, Khaleghi-Nekou M, Piri SM, Rahimi-Movaghar V, Bahrami S, Laal M, Mohammadzadeh M, Fakharian E, Pirnejad H, Pahlavanhosseini H, Salamati P, Sadeghi-Bazargani H. Evaluating mechanism and severity of injuries among trauma patients admitted to Sina Hospital, the National Trauma Registry of Iran. Chin J Traumatol. 2021 May;24(3):153-158. doi: 10.1016/j.cjtee.2021.01.009. Epub 2021 Feb 6. PMID: 33640244; PMCID: PMC8173574.
14. Sharif-Alhoseini M, Zafarghandi M, Rahimi-Movaghar V, Heidari Z, Naghdi K, Bahrami S, Koohi-Habibi S, Laal M, Moradi A, Ghodsi Z, Khormali M, Abdolhoseinzadeh M, Khaleghi-Nekou M, Salamati P. National Trauma Registry of Iran: A Pilot Phase at a Major Trauma Center in Tehran. Arch Iran Med. 2019 Jun 1;22(6):286-292. PMID: 31356094.
15. Baigi V, Zafarghandi MR, Khormali M, Rahimi-Movaghar V, Salamati P. Data quality and patient coverage at Sina Hospital Trauma Registry affiliated with the National Trauma Registry of Iran. Archives of Trauma Research. 2023 Nov 1;12(3):124-9. doi: 10.48307/atr.2023.178219.
16. Hildebrand F, Lefering R, Andruszkow H, Zelle BA, Barkatali BM, Pape HC. Development of a scoring system based on conventional parameters to assess polytrauma patients: PolyTrauma Grading Score (PTGS). Injury. 2015 Oct;46 Suppl 4:S93-8. doi: 10.1016/S0020-1383(15)30025-5. PMID: 26542873.
17. World Health Organization (2022). 'ICD-10 Version:2019: Superficial injury of head, Fracture of skull and facial bones, and Injury of eye and orbit'. Available at: https://icd.who.int/browse10/2019/en#S00.1 (Accessed: April 10, 2026)
18. Munakomi S, Margetis K, Iverson LM. Glasgow Coma Scale. 2025 Jun 23. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2026 Jan–. PMID: 30020670.
19. Hashemi H, Pakbin M, Ali B, Yekta A, Ostadimoghaddam H, Asharlous A, Aghamirsalim M, Khabazkhoob M. Near Points of Convergence and Accommodation in a Population of University Students in Iran. J Ophthalmic Vis Res. 2019 Jul 18;14(3):306-314. doi: 10.18502/jovr.v14i3.4787. PMID: 31660110; PMCID: PMC6815340.
20. Lee SY, Koo NK. Change of stereoacuity with aging in normal eyes. Korean J Ophthalmol. 2005 Jun;19(2):136-9. doi: 10.3341/kjo.2005.19.2.136. PMID: 15988931.

21. Antona B, Barrio A, Barra F, Gonzalez E, Sanchez I. Repeatability and agreement in the measurement of horizontal fusional vergences. Ophthalmic Physiol Opt. 2008 Sep;28(5):475-91. doi: 10.1111/j.1475-1313.2008.00583.x. PMID: 18761485.
22. Wajuihian SO. Normative values for clinical measures used to classify accommodative and vergence anomalies in a sample of high school children in South Africa. J Optom. 2019 Jul-Sep;12(3):143-160. doi: 10.1016/j.optom.2018.03.005. Epub 2018 Jun 19. PMID: 29887298; PMCID: PMC6612036.
23. Convergence Insufficiency Treatment Trial Study Group. Randomized clinical trial of treatments for symptomatic convergence insufficiency in children. Arch Ophthalmol. 2008 Oct;126(10):1336-49. doi: 10.1001/archopht.126.10.1336. PMID: 18852411; PMCID: PMC2779032.
24. Lakshmanan Y, George RJ. Stereoacuity in mild, moderate and severe glaucoma. Ophthalmic Physiol Opt. 2013 Mar;33(2):172-8. doi: 10.1111/opo.12021. Epub 2013 Jan 9. PMID: 23297812.
25. García A, Cacho P, Lara F, Megías R. The relation between accommodative facility and general binocular dysfunction. Ophthalmic Physiol Opt. 2000 Mar;20(2):98-104. PMID: 10829131.
26. Chen N, Liao M, Yang C, Liu L. Accommodation and stereopsis in adults with traumatic brain injury. Clin Exp Optom. 2020 Nov;103(6):877-884. doi: 10.1111/cxo.13056. Epub 2020 Mar 12. PMID: 32166808.
27. Rauchman SH, Zubair A, Jacob B, Rauchman D, Pinkhasov A, Placantonakis DG, Reiss AB. Traumatic brain injury: Mechanisms, manifestations, and visual sequelae. Front Neurosci. 2023 Feb 23;17:1090672. doi: 10.3389/fnins.2023.1090672. PMID: 36908792; PMCID: PMC9995859.
28. Mona-Lisa M, Kaisa M, Taina N, Antti H, Ivan M, Susanna M, Jan J. Evaluation of Visual Disturbances After Mild Traumatic Brain Injury-A One-Year Follow-up Study. J Head Trauma Rehabil. 2025 May-Jun 01;40(3):E208-E215. doi: 10.1097/HTR.0000000000001010. Epub 2024 Nov 7. PMID: 39531319; PMCID: PMC12594135.
29. McDonald MA, Holdsworth SJ, Danesh-Meyer HV. Eye Movements in Mild Traumatic Brain Injury: Clinical Challenges. J Eye Mov Res. 2022 Jun 14;15(2):10.16910/jemr.15.2.3. doi: 10.16910/jemr.15.2.3. PMID: 36439910; PMCID: PMC9691323.
30. McDonald MA, Holdsworth SJ, Danesh-Meyer HV. Eye Movements in Mild Traumatic Brain Injury: Ocular Biomarkers. J Eye Mov Res. 2022 Jun 16;15(2):10.16910/jemr.15.2.4. doi: 10.16910/jemr.15.2.4. PMID: 36439911; PMCID: PMC9682364.
31. Viswanathan S, Port N, Master CL, Pardue MT. Impact of traumatic brain injury on vision. Vision Res. 2023 Mar;204:108176. doi: 10.1016/j.visres.2022.108176. Epub 2022 Dec 23. PMID: 36566559; PMCID: PMC10695695.
32. Almutairi NM. Visual Dysfunctions in Mild Traumatic Brain Injury: A Focus on Accommodative System Impairments. Life (Basel). 2025 May 6;15(5):744. doi: 10.3390/life15050744. PMID: 40430172; PMCID: PMC12113616.
33. Smaakjær P, Wachner LG, Rasmussen RS. Vision therapy improves binocular visual dysfunction in patients with mild traumatic brain injury. Neurol Res. 2022 May;44(5):439-445. doi: 10.1080/01616412.2021.2000825. Epub 2021 Nov 15. PMID: 34781837.
34. Fortenbaugh FC, Gustafson JA, Fonda JR, Fortier CB, Milberg WP, McGlinchey RE. Blast mild traumatic brain injury is associated with increased myopia and chronic convergence insufficiency. Vision Res. 2021 Sep;186:1-12. doi: 10.1016/j.visres.2021.04.004. Epub 2021 May 14. PMID: 34000559; PMCID: PMC8273108.
35. Winkler SL, Finch D, Llanos I, Delikat J, Marszalek J, Rice C, Rakoczy C, Wang X, Pollard K, Cockerham GC. Retrospective Analysis of Vision Rehabilitation for Veterans With Traumatic Brain Injury-Related Vision Dysfunction. Mil Med. 2023 Aug 29;188(9-10):e2982-e2986. doi: 10.1093/milmed/usad120. PMID: 37186008.
36. Winkler SL, Marszalek J, Wang X, Finch D, Rakoczy C, Delikat J, Kelleher V, Williams M, Zuniga E, Rice C, Pollard K, Cockerham G. Veterans with Traumatic Brain Injury-related Ocular Injury and Vision Dysfunction: Vision Rehabilitation Utilization. Optom Vis Sci. 2022 Jan 1;99(1):3-8. doi: 10.1097/OPX.0000000000001824. Erratum in: Optom Vis Sci. 2022 Mar 1;99(3):319. doi: 10.1097/OPX.0000000000001870. PMID: 34882609.
37. Zhang K, Truong T, He CH, Parsikia A, Mbekeani JN. Traumatic Brain Injury in Admitted Patients with Ocular Trauma. Turk J Ophthalmol. 2024 Aug 28;54(4):212-222. doi: 10.4274/tjo.galenos.2024.27737. Epub 2024 Aug 7. PMID: 39108021; PMCID: PMC11590704.
38. Zima L, Moore AN, Smolen P, Kobori N, Noble B, Robinson D, Hood KN, Homma R, Al Mamun A, Redell JB, Dash PK. The evolving pathophysiology of TBI and the advantages of temporally-guided combination therapies. Neurochem Int. 2024 Nov;180:105874. doi: 10.1016/j.neuint.2024.105874. Epub 2024 Oct 2. PMID: 39366429; PMCID: PMC12011104.
39. Ivancevic VG. New mechanics of traumatic brain injury. Cogn Neurodyn. 2009 Sep;3(3):281-93. doi: 10.1007/s11571-008-9070-0. Epub 2008 Nov 23. PMID: 19031012; PMCID: PMC2727160.
40. Lin CH, Lin PC, Hsieh CH. Extraocular Muscle Trauma: Clinical Approach to Diagnosis and Surgical Management of Rectus Muscle Disruptions. World J Plast Surg. 2025;14(2):46-55. doi: 10.61186/wjps.14.2.46. PMID: 41019245; PMCID: PMC12476249.
41. Hârtie VL, Anton N, Boișteanu O, Comanescu MP, Pătrășcanu E, Bologa E, Șulea D, Danielescu C, Turliuc MD. Traumatic Brain Injury and Its Ophthalmologic Implications. Rom J Ophthalmol. 2025 Oct-Dec;69(4):475-481. doi: 10.22336/rjo.2025.75. PMID: 41971212; PMCID: PMC13065145.

42. Sayyed Hoseinian SH, Ebrahimzadeh MH, Peivandi MT, Bagheri F, Hasani J, Golshan S, Birjandinejad A. Injury Patterns among Motorcyclist Trauma Patients: A Cross Sectional Study on 4200 Patients. Arch Bone Jt Surg. 2019 Jul;7(4):367-372. PMID: 31448315; PMCID: PMC6686071.
43. O'Neil M, Gleitsmann K, Motu'apuaka M, Freeman M, Kondo K, Storzbach D, Kansagara D, Carlson K. Visual Dysfunction in Patients with Traumatic Brain Injury: A Systematic Review [Internet]. Washington (DC): Department of Veterans Affairs (US); 2014 Sep. PMID: 25973512.
44. Pillay R, Munsamy AJ. A review exploring convergence insufficiency in younger populations and e-devices in the digital era. African Vision and Eye Health. 2021 Jun 14;80(1):12. doi: 10.4102/aveh.v80i1.623.
45. Kool DR, Blickman JG. Advanced Trauma Life Support. ABCDE from a radiological point of view. Emerg Radiol. 2007 Jul;14(3):135-41. doi: 10.1007/s10140-007-0633-x. Epub 2007 Jun 12. PMID: 17564732; PMCID: PMC1914302.
46. Mohseni M, Gurnani B, Blair K. Blunt Eye Trauma. 2026 Feb 21. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2026 Jan–. PMID: 29261988.
47. Scheiman M, Wick B (2008). 'Clinical management of binocular vision: heterophoric, accommodative, and eye movement disorders' Third Edition (pp. 1-695). Lippincott Williams & Wilkins. ISBN-13: 978-0-7817-7784-1; ISBN-10: 0-7817-7784-4.
48. Gowrisankaran S, Shah AS, Roberts TL, Wiecek E, Chinn RN, Hawash KK, O'Brien MJ, Howell DR, Meehan WP 3rd, Raghuram A. Association between post-concussion symptoms and oculomotor deficits among adolescents. Brain Inj. 2021 Aug 24;35(10):1218-1228. doi: 10.1080/02699052.2021.1959065. Epub 2021 Aug 12. PMID: 34383619; PMCID: PMC8487965.
49. Hussain SF, Raza Z, Cash ATG, Zampieri T, Mazzoli RA, Kardon RH, Gomes RSM. Traumatic brain injury and sight loss in military and veteran populations- a review. Mil Med Res. 2021 Jul 28;8(1):42. doi: 10.1186/s40779-021-00334-3. PMID: 34315537; PMCID: PMC8317328.
50. Nakamura K, Fuchigami T, Morioka S. Eye movement training and gaze analysis for a patient with binocular diplopia after traumatic brain injury: a case report. J Med Case Rep. 2023 Dec 18;17(1):551. doi: 10.1186/s13256-023-04221-4. PMID: 38110994; PMCID: PMC10726626.
51. Harris P, Myers MH. A Pilot Investigation of Visual Pathways in Patients with Mild Traumatic Brain Injury. Neurol Int. 2023 Mar 20;15(1):534-548. doi: 10.3390/neurolint15010032. PMID: 36976675; PMCID: PMC10054811.
52. Reddy AVC, Mani R, Selvakumar A, Hussaindeen JR. Reading eye movements in traumatic brain injury. J Optom. 2020 Jul-Sep;13(3):155-162. doi: 10.1016/j.optom.2019.10.001. Epub 2019 Nov 26. PMID: 31784207; PMCID: PMC7301197.
53. Raghuram A, Cotter SA, Gowrisankaran S, Kanji J, Howell DR, Meehan WP 3rd, Shah AS. Postconcussion: Receded Near Point of Convergence is not Diagnostic of Convergence Insufficiency. Am J Ophthalmol. 2019 Oct;206:235-244. doi: 10.1016/j.ajo.2019.04.008. Epub 2019 Apr 17. PMID: 31004592.