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Alghamdi, Ibrahim; Bazaie , Naif; Alqurashi, Naif; Ahmed, Zubair

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## Systematic Review

# The Impact of Prehospital Spinal Immobilization in Patients with Penetrating Spinal Injuries: A Systematic Review and Meta-Analysis

Ibrahim Alghamdi <sup>1</sup>, Naif Bazaie <sup>1</sup> , Naif Alqurashi <sup>2</sup> and Zubair Ahmed <sup>1,3,4,\*</sup>

<sup>1</sup> Institute of Inflammation and Ageing, University of Birmingham, Birmingham B15 2TT, UK; ibraghamdi@kku.edu.sa (I.A.); abu\_turki789@hotmail.com (N.B.)

<sup>2</sup> Department of Accidents and Trauma, Prince Sultan Bin Abdulaziz College for Emergency Medical Services, King Saud University, Riyadh 11451, Saudi Arabia; naif012n@gmail.com

<sup>3</sup> Centre for Trauma Sciences Research, University of Birmingham, Birmingham B15 2TT, UK

<sup>4</sup> Surgical Reconstruction and Microbiology Research Centre, National Institute for Health Research, Queen Elizabeth Hospital, Birmingham B15 2TH, UK

\* Correspondence: z.ahmed.1@bham.ac.uk

**Abstract:** Penetrating injuries, such as gunshot or stab wounds, may cause spinal cord injuries and require prehospital spinal immobilization (PHSI) to stabilize the spine. However, the use of PHSI in penetrating spinal injuries remains controversial. This systematic review aimed to investigate the efficacy of prehospital PHSI in patients with penetrating trauma. We systematically searched Google Scholar, Medline (PubMed), The Cochrane Central Register of Controlled Trials (CENTRAL), and EMBASE between January 2000 and July 2021. All studies in English that assessed PHSI in patients (>16 years) with penetrating spinal injuries were included. Quality and risk of bias assessments were performed using the modified Newcastle-Ottawa scale. A narrative synthesis and a meta-analysis was conducted. Our search identified 928 studies but only 6 met our inclusion and exclusion criteria. All of the included studies were conducted in the US and the number of patients ranged from 156–75,567 over 3–9 study years. The majority of patients were gunshot or stab wounds. Three studies demonstrated an increased risk of mortality with spinal collars whilst the remaining three studies failed to show any benefits or the benefits remained unproven. All studies were retrospective studies with some risks of bias. This review highlights that the evidence from the literature on PHSI in penetrating trauma outweighs its benefits; thus, its use is discouraged in penetrating spinal trauma. However, further high-quality research is necessary to reach definitive conclusions and to possibly identify suitable alternatives to PHSI for penetrating spinal trauma.



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**Keywords:** penetrating injury/trauma; prehospital; spinal immobilization; spinal cord

## 1. Introduction

Spinal cord injury (SCI) is a growing public health concern globally, with around 1.2 million new cases each year worldwide, as they result in severe long-term or permanent disability that significantly affects the quality of life [1]. Multiple reports have highlighted that up to 4% of trauma patients suffer a cervical spine injury, of which 20% sustain SCI [2]. The U.K. has approximately 2500 new cases annually [3], whereas in the United States, there are approximately 40–50 cases per million people annually, with significant economic implications (an estimated USD 9 billion) [4]. The primary causes of SCI in patients with penetrating injuries include gunshot wounds (GSW), stab wounds (SW), and accidents involving machinery, equipment, and vehicles [5].

Prehospital spinal immobilization (PHSI) in trauma patients has long been deemed the foundation of prehospital treatment and is used in patients with penetrating or blunt trauma [6]. It is known that spinal immobilization can improve neurological outcomes

in patients with blunt trauma; for instance, unstable vertebral injuries occurring due to blunt injury to the spinal column may lead to subsequent neurologic deficit if not handled properly in the prehospital field [4]. However, such effects have not been proven in the case of penetrating trauma [7], since there is no evidence to indicate that penetrating trauma can generate an unstable spine injury or progression of an SCI [8].

Most emergency medical service (EMS) protocols do not distinguish between blunt and penetrating mechanisms of injury; consequently, the existing practices for spinal immobilization after penetrating trauma are founded on the historical belief that neurological deterioration may occur in a patient with spinal column injury if not immobilized, rather than scientific evidence. Thus, conservative interventions, such as immobilization, are only applied in the case of an unstable spine or an ongoing suppression of the spinal cord [6]. Prehospital treatment of patients with critical penetrating trauma is vital, as it influences both patient survival rate and the entire trauma care system. However, patients sustaining penetrating injuries require a different treatment approach than blunt trauma [9]. Penetrating injuries require emergency medical interventions to minimize SCI and decrease the associated morbidity and mortality [10]. Delayed patient transport in the case of penetrating injuries results in prolonging the time until the patient receives the much-needed surgical care and has catastrophic implications [2]. However, even with qualified and experienced prehospital providers, spinal immobilization can consume precious time before a patient is ready for transport.

While PHSI has been widely used for penetrating trauma to the head, neck, or torso, the routine use of spinal immobilization contradicts the practices from prehospital trauma, which discourage spinal immobilization for penetrating trauma presenting without neurological deficit [1]. There is limited evidence supporting the benefits of spinal immobilization, and various studies have raised concerns about spinal immobilization, including its efficiency and the potential adverse effects [11]. Numerous adverse health risks have been associated with spinal immobilization; for instance, PHSI in penetrating trauma has been linked to an increased risk of mortality, raised intracranial pressure, tissue ischemia, respiratory compromise, back and neck pain, and pressure ulcers [11,12].

This systematic review aimed to evaluate the evidence associated with PHSI in patients with penetrating spinal trauma and its impact on mortality and neurological deficits to determine whether PHSI for penetrating spinal trauma is beneficial.

## **2. Materials and Methods**

### *2.1. Literature Search*

We conducted a systematic literature search based on the Cochrane Handbook for Systematic Reviews' guidelines for interventions [13] and the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) [14] to ensure relevance and adequacy of the evidence. Online searches were conducted from January 2000 to July 2021 across several databases, including Google Scholar, Medline (PubMed), The Cochrane Central Register of Controlled Trials (CENTRAL), and EMBASE by both the authors (I.A. and Z.A.).

Medical subject headings were utilized as search terms and combined with other terminologies as suitable across all journals and databases. The following search terms were used for the review: "spinal immobilization", "prehospital", "emergency care/treatment", "trauma/injuries", and "penetrating". Google Scholar was searched for key terms in the undistributed articles using both forward and backward techniques. We also utilized the "related articles" function to widen the literature search and reference screening for efficiency. One reviewer (I.A.) also screened the reference lists of included articles to identify potential additional studies.

### *2.2. Inclusion and Exclusion Criteria*

For pragmatic reasons, the inclusion criteria were articles written in English focusing primarily on the prehospital setting, penetrating injuries/trauma, including patients aged 16 and above of both sexes, and without any ethnic limitations. The review was limited

to human studies with a sample deemed “healthy people” to exclude patients who use cervical collars therapeutically to relieve pain and realign the spinal cord. In the case of more than one publication from a single study, the reviewers selected the article with a comprehensive follow-up and complete reporting of the conducted research.

Studies were excluded if they consisted of patients below 16 years of age, articles published before 1 January 2000, were case reports, editor’s letters, or inadequately reported articles, or included patients with compromised immunity or with non-penetrating spinal injuries. Studies with long-term treatment care comprising various services were also excluded because the review focuses on prehospital care.

### 2.3. Data Collection Process

A literature search was conducted independently by both I.A. and Z.A. based on the study title, summary, keywords, and text. Any disagreement between the reviewers was resolved through discussion. All related articles were selected based on the prespecified inclusion and exclusion criteria for this systematic review. The collected articles were then exported into RAYYAN (Intelligent Systematic Review) (<https://www.rayyan.ai/>, accessed on 25 August 2021) [15] where duplicated articles were eliminated; all article abstracts were examined manually by both reviewers. The full text of all the selected articles was acquired; the variables analyzed include study methodology, intervention, and the relevant outcomes of spinal immobilization and penetrating injuries.

### 2.4. Data Extraction and Synthesis

I.A. performed data extraction using a Microsoft Excel worksheet form that was developed to obtain valuable details from the articles; then, Z.A. verified the data for reliability. The following data were obtained for each included study: (1) study characteristics; (2) patient characteristics; (3) intervention; (4) limitations; and (5) results.

### 2.5. Quality Assessment and Statistical Analysis

The included studies were assessed using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) system [16]. The GRADE system categorizes the quality of evidence in four classes—very low, low, moderate, and high; recommendations according to the GRADE methodology are based on five characteristics—indirectness, inconsistency, imprecision, risk of bias, and publication bias. While evaluating the quality of evidence, the decision-makers need to consider the confidence in estimating each effect and the probability of correctness of these estimates [16].

The quality and risk for bias for the selected articles were evaluated using the modified Newcastle-Ottawa Scale (NOS) ([http://www.ohri.ca/programs/clinical\\_epidemiology/oxford.asp](http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp), accessed on 17 July 2021) [17]. The high, moderate, and low bias risks were represented by NOS < 4, between 4 and 6, and >6, respectively, as highlighted in the original NOS scale [18]. I.A. assessed the studies for the risk of bias, while Z.A. verified the results for consistency and accuracy. Publication bias was evaluated using Egger’s test, and a *p*-value of <0.05 was considered statistically significant. Assessment of heterogeneity was carried out by examining the differences across studies for methodological heterogeneity. We used Review Manager (RevMan 5.3, Cochrane Informatics & Technology, London, UK) to determine the *Q* and *I*<sup>2</sup> statistics (in percentage) to establish variation between the studies attributed to heterogeneity [19]. A meta-analysis of a subgroup of studies that reported overall mortality rates in PHSI vs. non-PHSI patients was conducted in RevMan 5.3 (Cochrane Informatics & Technology, London, UK), using the dichotomous data function employing a random effects model.

### 2.6. Risk of Bias

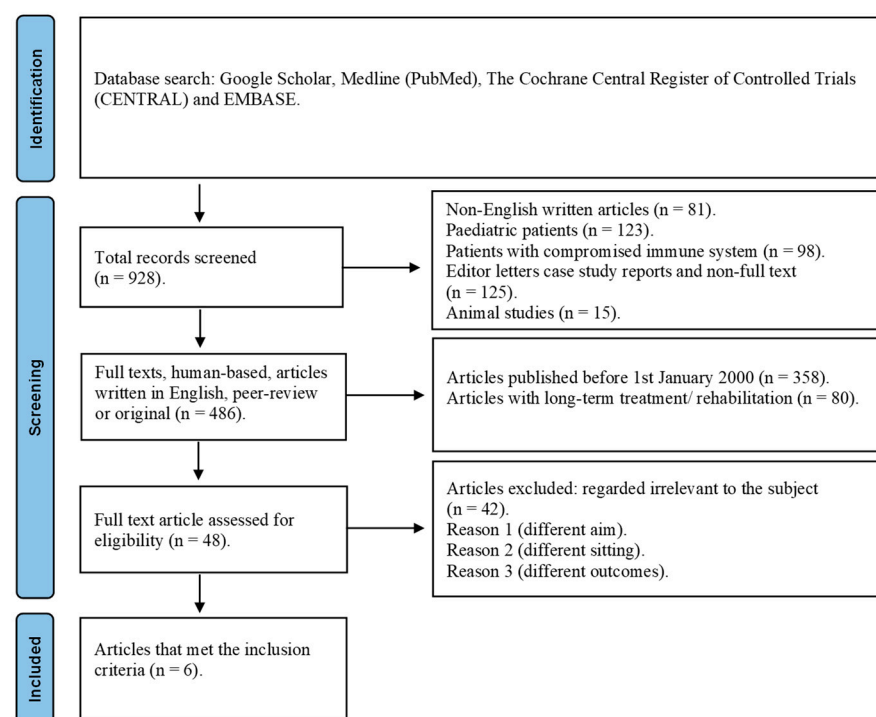
The ROBINS-I tool was utilized to undertake the risk of bias assessment based on the existence or absence of some characteristics into “critical risk”, “serious risk”, “moderate risk”, “low risk”, and “no information”. The assessment was carried out for the following

bias domains: (1) confounding bias; (2) selection bias; (3) bias in the measurement classification of interventions; (4) bias due to deviations from intended interventions; (5) bias due to missing data; (6) bias in the measurement of outcomes; and (7) bias in the selection of the reported result [20,21].

### 3. Results

#### 3.1. Study Selection

The preliminary literature search according to the PRIMA guidelines yielded 928 articles from all data sources. We then excluded non-English texts ( $n = 81$ ), paediatric cases ( $n = 123$ ), non-full texts ( $n = 125$ ), and editor's letters and animal studies ( $n = 15$ ), as well as 358 articles that were published before 1 January 2000. Eighty articles were further excluded because they focused on long-term rehabilitation/treatment. Forty-eight full-text studies were screened for eligibility, of which forty-two were excluded to leave six articles that fulfilled all of the inclusion/exclusion criteria. The PRISMA flow chart is presented in Figure 1.



**Figure 1.** PRISMA flow chart of the screening process.

#### 3.2. Study Characteristics

All six studies reviewed were retrospective studies with both qualitative and quantitative designs performed over a 3–9-year period, with the earliest being from 2001 and the latest being in 2016. All studies were conducted in the USA and included civilian populations only. A total of 122,426 patients were included with significant variability in the number of patients in individual studies; for instance, the maximum number of included patients was 75,567 [22], whereas the smallest sample was 156 patients [23]. Four of the articles reviewed data from trauma registries in level 1 trauma centers—the Strong Memorial Hospital (SMH), New York City [22], the Louisiana State University Health Sciences Centre [24,25], and the Hurley Medical Centre, Michigan [25]. Two studies [1,22] used the National Trauma Data Bank (NTDB), while another study [26] used the Maryland Institute for Emergency Medical Service Systems State Trauma Registry. Table 1 presents the characteristics of the included studies.

**Table 1.** Characteristics of included studies.

Study	Location	Study Period	Study Setting	Number of Patients	Percentage Receiving PHSI	Type of Injury	ISS/GCS	Mortality PHSI/Non-PHSI
Schubl et al. [23]	New York, USA	4 years	Level 1 trauma center	156	37.2%	GSW = 20.5% SW = 79.5%	11 (range 4–22 patients)	10.3% vs. 2.0%
Haut et al. [1]	USA	3 years	NTDB	45,284	4.3%	GSW = 42.3% SW = 57.7%	<9 (49.5%); 9–15 (28.5%); 16–25 (9.4%); >25 (12.6%)	14.7% vs. 7.2%
Turnock et al. [25]	Michigan and Louisiana, USA	5 years and 9 years	Level 1 trauma centers	231	Charity Hospital 54.90% Hurley Hospital 25.58%	Charity Hospital GSW = 38.56% SW = 61.44% Hurley Hospital GSW = 48.84% SW = 51.16%	Not reported	11.7% vs. 3.5%
Vanderlan et al. [24]	Louisiana, USA	9 years	Level 1 trauma center in Louisiana	188	62.3%	GSW = 94% SW = 6%	GCS 3 (n = 30); 15 (n = 4), 8 (n = 1)	14.4% vs. 4.3%
Brown et al. [22]	New York, USA	3.5 years and 5 years	Level 1 trauma centers and NTDB	75,567	Strong Memorial Hospital, 54% NTDB N/A	GSW = 100%	Not reported	Not reported
Cornwell et al. [26]	USA	3 years	Maryland State Trauma Registry data	141	N/A	GSW = 100%	ISS > 13	Not reported

Notes: PHSI = Prehospital spinal immobilization; GSW = Gunshot wounds; SW = Stab wound; N/A = Not available; GCS = Glasgow coma scale; ISS = injury severity score.



The primary findings of the included studies in terms of demonstrating the benefits of PHSI were minimal compared to overall potential risks. Four of the studies suggested that there was an increased risk of mortality associated with spinal immobilization [1,23–25] whilst the remaining two studies did not report overall mortality rates [22,26]. Vanderlan et al. [24] demonstrated an increase in mortality associated with spinal collars; in total, 35 patients died. Haut et al. [1] reported twice the rates of mortality in spinal immobilization samples. Schubl et al. [23] found that the odds of mortality were higher in PHSI patients; in total, eight patients died. The main conclusions of each study related to spinal immobilization are detailed in Table 2.

**Table 2.** GRADE quality and summary of study conclusions.

References	Study Type	GRADE Quality	Study Conclusions
Schubl et al. [23]	Retrospective analysis	Moderate	Odds of mortality were higher in patients who underwent prehospital spinal immobilization than those without.
Haut et al. [1]	Retrospective analysis	High	Risks of spinal immobilization in penetrating injury outweigh the benefits. The study supports the recommendations by the PHTLS that suggest the discontinuation of PHSI in penetrating trauma in favor of a favorable selective approach.
Turnock et al. [25]	Retrospective analysis	High	No benefits of spinal immobilization.
Vanderlan et al. [24]	Retrospective review	Moderate	PHSI increases the risk of mortality in penetrating trauma patients.
Brown et al. [22]	Retrospective analysis	High	Potential benefits of PHSI remain unproven. PHSI might be beneficial for patients with spinal fractures and require surgical immobilization without SCI. PHSI may further complicate care after a gunshot injury to the torso, and a small sample from the study benefited from PHSI.
Cornwell et al. [26]	Retrospective analysis	Moderate	Minimal advantages are gained by the immobilization of patients sustaining torso gunshot wounds. Need for re-evaluating the use of thoracolumbar immobilization.

### 3.3. Results of Individual Studies

Vanderlan et al. [24] retrospectively evaluated records of 188 patients sustaining penetrating cervical spine trauma from a level 1 trauma center in Louisiana, USA, between 1994 and 2003. They reported 35 deaths (35/153) (total mortality rate = 23%), of which 94% were due to GSW, while the rest happened due to SW. Of these 35 deceased patients, 27 (77%) were immobilized. The authors reported that cervical spine immobilization was associated with an unadjusted increased risk of mortality compared to the non-immobilized group in isolated cervical spine injuries ( $n = 107$ ) (odds ratio, OR: 8.82; 95% CI: 1.09–194;  $p = 0.038$ ). Additionally, cervical spine immobilization was associated with an increased risk of death (OR: 2.77;  $p = 0.016$ ; 95% CI: 1.18–6.49). Whether the transport delay or the cervical spine immobilization application was responsible for the deaths could not be ascertained, although the authors stated the non-availability of transport times.

Haut et al. [1] described 45,284 patients suffering penetrating trauma between 2001 and 2004 (retrieved from the NTDB). They reported an overall mortality rate of 8%, and those patients receiving spinal immobilization were twice as likely to die versus non-immobilized patients (14.7% vs. 7.2%, respectively,  $p < 0.001$ , OR of death in spine collar patients: 2.06).

Additionally, the immobilized patients were more likely to have moderate to severe injuries with an injury severity score (ISS) > 15 compared to the non-immobilized patients (31.2% vs. 20.4%;  $p < 0.001$ ). Furthermore, increased mortality in patients with lower ISS (<15) was associated with spine immobilization (adjusted OR: 3.40; 95% CI: 1.48–7.81). The authors suggested that time wasted on spinal immobilization should be utilized to deal with significant life-threatening situations.

Brown et al. [22] retrospectively analyzed all patients with penetrating trauma to the torso from two datasets, the SMH ( $n = 357$ ) and the NTDB ( $n = 75,210$ ) registry of USA, between 2003 to 2007 and 2001 to 2005, respectively. In the SMH sample, only 54% underwent spinal immobilization, and none required surgical stabilization. Furthermore, only 26 (0.03%) patients in the NTDB population had vertebral fractures without an SCI and required spinal surgery. The authors argued that an immediate and permanent deficit happens at the time of injury, and these patients would not benefit from PHSI since an unstable spinal fracture without SCI is rare. Moreover, SCI is more likely to be a direct injury to the cord from the bullet in a GSW rather than from a fractured surrounding vertebra. Thus, the authors concluded that the achieved benefit from PHSI is insignificant.

Cornwell et al. [26] reviewed the Maryland State Trauma Registry data and identified 1000 patients with torso GSW. Of these, only 141 suffered a vertebral fracture and/or SCI, and 73 survivors sustained a complete neurologic deficit at the time of presentation; the other 58 had no deficits or an incomplete lesion. Only 2 patients (0.2%) out of 58 survivors required operative stabilization. The authors concluded that immobilization should be re-evaluated because thoracolumbar immobilization is seldom beneficial in GSW of the torso.

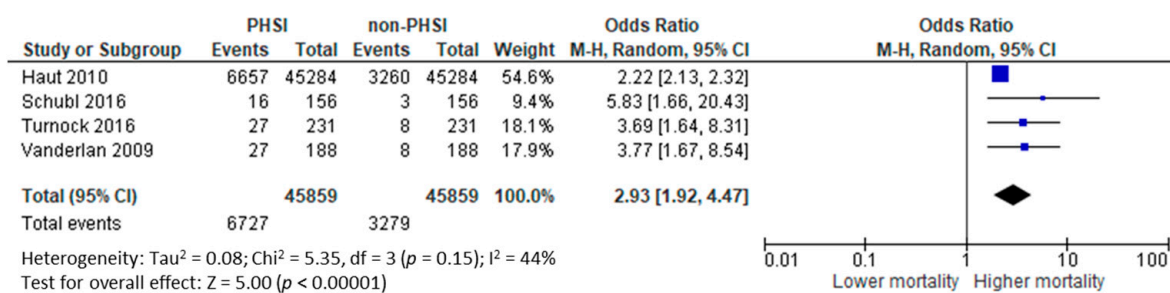
Schubl et al. [23] studied 156 patients sustaining firearm injury to the head and/or neck admitted to a level 1 trauma center between 2010 and 2014 to assess the importance of cervical spine immobilization. GSW injury accounted for 28% ( $n = 36$ ) while SW for 72% ( $n = 120$ ) of the injuries. Eighty-eight patients had no CS injury (56%), and the prevalence of CS fracture was higher with GSW (6/36; 13.9%) compared to SW patients (1/120; 0.83%;  $\chi^2 (1) = 12.76$ ;  $p = 0.003$ ). Out of the six patients with GSW and CS fractures, four presented without neurologic deficits, one developed quadriplegia, and another developed upper extremity neurologic deficits. Patients who underwent PHSI were five times (CI: 1.06–24.3) more expected to die than those without PHSI (OR: 5.54; CI: 1.08–28.4). They concluded that only two of their patients had unstable fractures, of which one developed delayed transient neurological symptoms, which may not have been influenced by prehospital treatment.

Turnock et al. [25] performed a two-center retrospective analysis and suggested an increased risk of indirect neurological injury linked to cervical spine immobilization. The study had 231 patients, of which 35 died (mortality rate = 18%; 35/196). Of the surviving patients, four patients experienced indirect neurological injury—two suffered neurological injury secondary to disruption of carotid arterial flow, one patient had indirect central cord syndrome, and one sustained cervical SCI secondary to shock with central cord ischemia. They indicated that an increased risk of neurological injury was associated with cervical spine immobilization (relative risk: 1.635,  $p < 0.001$ ; 95% CI: 1.23–1.95).

### 3.4. Meta-Analysis for Overall Mortality in PHSI vs. Non-PHSI Patients

Among the six reviewed studies, four studies reported mortality rates in PHSI vs. non-PHSI patients and these data were compared using a meta-analysis and an odds ratio (OR) calculation. The data suggested that the use of PHSI correlated with a significantly higher rate of mortality, with an overall OR of 2.93 (95% CI 1.92, 4.47;  $p < 0.00001$ ) (Figure 2).





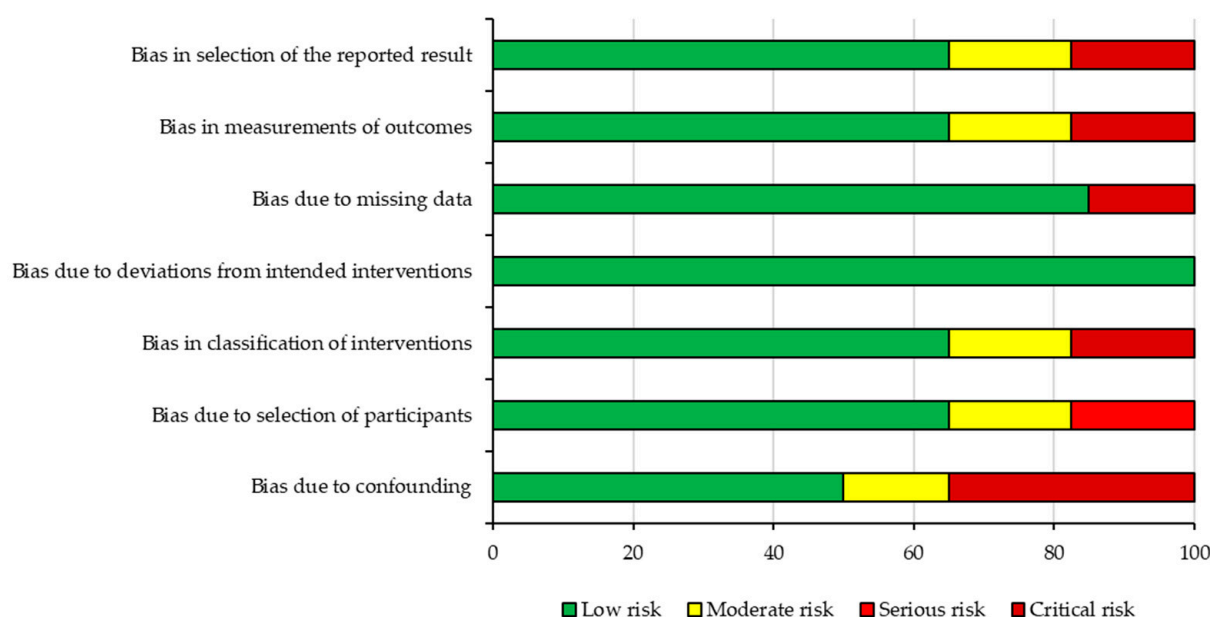
**Figure 2.** Meta-analysis for overall mortality rates in PHSI vs. non-PHSI patients.

### 3.5. Bias Assessment

Among the six reviewed papers, those of Brown et al. [22], Haut et al. [1], and Turnock et al. [25] shared a bias due to confounding factors. Brown et al. [22] had a risk of confounding bias because of the uncertainty around the extent of prehospital injury. Moreover, the prehospital processes, such as lifesaving treatments at the scene leading to spine immobilization, are not stated. Additionally, there were missing entries in the study since all patients in the NTDB did not have complete medical procedure data. The confounding bias in the study by Haut et al. [1] is because the database used for retrieving records was not specific in terms of the prehospital scene, transport times, and the true nature of the care process. Additionally, the study showed a risk of bias in the classification of interventions, where only one intervention (spine immobilization) was selectively reported to develop the results (higher mortality in penetrating trauma). The bias is because of the difference in reporting the mortality statistics for other prehospital interventions.

Turnock et al. [25] also had a confounding bias; the fact that patients in the Charity group, compared to the Hurley group, had a higher mortality rate corroborates our finding. Furthermore, there was bias in participant selection—two of the eight participants (in cervical SCI group) were considered unstable for the study even though the intervention (cervical spine immobilization) was necessary and affected the overall outcome. This bias is evident when citing the similarity in intervention and outcome. Vanderlan et al. [24] demonstrated a bias in the classification of interventions—the intervention (cervical spine immobilization) applied to penetrating cervical trauma is concluded to increase the mortality. However, the classification of this intervention is not concluded for patients with and without CPR and whether the risk of death increased. This bias led to the misclassification of cervical spine immobilization being related to the outcome (death) or the risk of the outcome.

Cornwell et al. [26] showed bias in measuring outcomes. While recording potential risks of the intervention resulting from the delay, no data are provided concerning the delays, such as if the mortality rate was based on the intervention and delay or delay only. Such bias in measuring the outcome is likely due to information bias, where assessors expect the intervention to bring results based on their previous knowledge. Lastly, Schubl et al. [23] also had a bias in the selection of results. The writers raised bias based on the outcome by suggesting that the intervention (cervical spine immobilization) could also be applied even if practitioners are not presented with sufficient neurological assessment. Presenting these data anecdotally means that the researchers already expected the findings and the data to lean toward their perceived outcome, signifying bias. A summary of the risk of bias assessment across each domain is presented in Figure 3.



**Figure 3.** Summary diagram for risk of bias in included studies.

#### 4. Discussion

This systematic review analyzed published studies reporting the impact of PHSI on penetrating spinal trauma, our findings suggest that PHSI is correlated with a significantly increased rate of mortality. We found that most of the studies disagreed with the routine use of PHSI in the case of penetrating spinal trauma. While a limited number of previous studies have highlighted the benefits of PHSI, more studies indicate that it may be harmful, especially in cases of penetrating spinal injuries. Thus, we can conclude that the literature does not currently support the use of PHSI in penetrating spinal trauma patients, and high-quality research is required to further clarify this position.

##### 4.1. Common Themes

A common theme identified in most of the articles reviewed is the ambiguity around the benefits of PHSI in penetrating spinal injuries. Most studies suggest that PHSI is associated with increased mortality and, to some extent, neurological deficits. Cornwell et al. [26] suggested that PHSI has minimal significance in penetrating spinal injuries. While our current findings concur with multiple studies that indicate toward unproven benefits of PHSI, most studies discourage the use of PHSI in penetrating spinal trauma. Therefore, most patients with isolated penetrating spinal injuries do not require complete cervical spine immobilization. Cornwell et al. [26] further emphasized the need for discrete recommendations on PHSI application in penetrating spinal injuries to minimize waste in EMS and the unnecessary challenges of airway management in these patients.

Turnock et al. [25], Schubl et al. [23], and Haut et al. [1] discouraged the use of spinal immobilization for prehospital management of penetrating spinal injuries, citing that their risks outweigh their benefits. Turnock et al. [25] identified various health risks associated with spinal immobilization, including increased mortality, disrupted airway management, peripheral nerve injuries, respiratory injuries, and central neurological injuries. Patients who receive cervical spine immobilization also suffer from an exacerbated or impaired control of hemorrhage. Most of these studies advocate for a suitable alternative technology to manage PHSI in patients with penetrating injuries.

Notably, some of the reviewed studies examined the neurological outcomes of PHSI in penetrating spinal trauma. Brown et al. [22] and Cornwell et al. [26] concluded that only a small number of patients have an unstable spinal cord; therefore, spinal immobilization does not offer any potential benefits. Brown et al. [22] further highlighted that thora-

columbar immobilization in torso GSW increases the risks of compromising emergency care. Turnock et al. [25] concluded that central neurological injury in penetrating cervical spinal trauma patients was linked to cervical spine immobilization which significantly increases indirect neurological injuries. They reported that patients developed these indirect neurological injuries due to the disruption of arterial flow, right cerebrovascular infarctions, central cord ischemia, and central cord syndrome. Major vascular injuries and hypoperfusion are proven significant risk factors for central neurological injury [25].

Vanderlan et al. [24], Cornwell et al. [26], and Haut et al. [1] also suggested that mortality rates were double among patients with penetrating trauma, an observation that is also supported by our meta-analysis across the four studies that reported mortality. Haut et al. [1] further suggest that patients who have undergone spine immobilizations had higher odds of mortality. A possible explanation is the ability to access definitive care, possibly due to delays in patient transportation; for every ten minutes of delay in definitive treatments, the survival rate declines by 10%, which is disastrous for the most critically injured patients [8]. Patients transported to care facilities with the EMS are even at a higher risk of mortality compared to the non-EMS transported patients who reach the care center early after their injuries [26]. Vanderlan et al. [24] reported that respiratory and vascular compromise were the most likely reasons for fatality in cervical spine immobilization.

Another common theme in this systematic review was the use of a retrospective observational study design. Retrospective studies allow the utilization of large data volumes and selecting factors significant for the study using multivariate evaluation [20]. It is worth mentioning that no randomized controlled trials (RCTs) were encountered in our whole search, despite being one of the most efficient, reliable, and accurate methods of collecting data [27]. We acknowledge that conducting RCTs is challenging owing to the difficulty in acquiring ethical permission to alter the patient care and outcomes without understanding the implications. Additionally, the patient may be incompetent in providing consent to participate and comprehend the involved risks in such a study [20,27].

#### 4.2. Limitations

A significant limitation in this study is that all of the articles included used a retrospective design to collect the data. Additionally, many of them had small sample sizes [22–25] in the SMH group. A limitation specific to Schubl et al. [23] was that the study focused on chest and abdominal penetrating trauma which had a low probability of causing cervical spine injuries. The purpose of the current review is to examine the significance of PHSI in penetrating trauma of the head and neck. Cornwell et al. [26] assumed that paraplegia was secondary to bullet injuries and not from inefficient PHSI. Even though their methodology was not definitive about this, it is noteworthy that the study samples with neurological deficits had an unstable vertebral column. In the studies by Haut et al. [1] and Brown et al. [22], patients from the same databases were analyzed and can be considered duplication as well as most patients lacking data on some prehospital procedures. Additionally, the study used NTDB, which does not report on-scene and transportation durations and does not provide all procedural records and hence could significantly affect the interpretation of the results from these studies. This affects their reporting of the impact of on-scene and transportation delays on the mortality related to PHSI and could be important confounding factors to consider in designing future high-quality studies to address the problems identified in our systematic review.

#### 5. Conclusions

The articles reviewed showed that the risks of applying PHSI in penetrating trauma outweigh its benefits, but the studies were not backed by high-level evidences. Most studies discouraged the use of PHSI because it increased mortality and other health complications such as indirect neurological injury, respiratory injuries, pressure ulcers, and reduced lung volumes. Furthermore, not all patients with penetrating trauma require PHSI; thus, there is a need for a re-evaluation of PHSI. This systematic review emphasizes the importance of

conducting well-designed, prospective RCTs which can provide a good understanding of the benefits and associated complications and help formulate practical guidelines on the use of PHSI in the prehospital environment. We also encourage the use of advanced alternative immobilization technologies, such as vacuum mattresses, scoop stretchers, and ResQRoll.

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