Neurocrit Care (2020) 32:469–477
https://doi.org/10.1007/s12028-019-00760-1

NEUROCRITICAL CARE SOCIETY

ORIGINAL WORK

Impact of Cervical Collars on Intracranial Pressure Values in Traumatic Brain Injury: A Systematic Review and Meta-Analysis of Prospective Studies

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Abstract

Background: Spinal cord injury (SCI) is present in around 2–4% of trauma victims. More than half of this injuries are located at the cervical region. Twenty percent of victims with cervical spinal trauma and 5% of patients with severe traumatic brain injury (TBI) will have an SCI. Cervical immobilization with rigid or semirigid collars is routinely used as prophylactic or definitive treatment intervention in general trauma care. An important adverse effect of cervical collars application is the increase in intracranial pressure (ICP) values. This systematic review and meta-analysis aim to estimate the overall magnitude of ICP changes after cervical collar application.

Methods: Major electronic databases (Ovid/Medline, Embase and Cochrane Library) were systematically searched for prospective studies that assessed ICP changes after cervical collar applications. Study level characteristics and ICP values before, during and after cervical collar application, were extracted. The meta-analysis was performed using random-effects model.

Results: Five studies comprising 86 patients were included in the systematic review and the quantitative synthesis. The overall increase in ICP after collar application was statistically significant (weighted mean difference [WMD] = 4.43; 95%CI 1.70, 7.17; $P < 0.01$), meaning an overall ICP increase of approximately 4.4 mmHg. The decrease in ICP values after collar removal reached statistical significance (WMD = −2.99; 95%CI −5.45, −0.52; $P = 0.02$), meaning an overall ICP decrease of approximately 3 mmHg after collar removal. ICP values before and after cervical collar application were not statistically significant (WMD = 0.49; 95%CI −1.61, 2.59; $P = 0.65$), meaning no ICP change.

Conclusions: Heterogeneous studies of application of cervical collars as a partial motion restriction strategy after injuries have demonstrated increases in ICP in TBI patients. Increases in ICP can induce complications in TBI patients. Appropriate selection criteria for cervical motion restriction in TBI patients need to be considered.

Keywords: Cervical collar, Intracranial pressure, Intracranial hypertension, Traumatic brain injury, Meta-analysis

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Background

In general, spinal cord injury (SCI) is present in 2–4% of trauma victims. More than half of them are located in the cervical region [1–6]. Twenty percent of victims with cervical spinal trauma and 5% of severe traumatic brain injury (TBI) patients will present a SCI [1–6]. For several years, immobilization with cervical collars or backboards has been the standard of care in the acute phase of trauma management, especially in unconscious patients prior to complementary tests for imaging that confirm or discard the diagnosis [1, 6]. Partial restriction of movement is a more appropriate term than immobilization, since no method known to date guarantees that there will be no spinal mobility [7, 8]. It is estimated that approximately 5% of individuals with spinal injury will deteriorate their neurological status as a result of bleeding, ischemia or edema [6]. Spinal movement after spinal trauma can contribute to secondary damage [6]. Regardless, the inappropriate use of backboards or collars is not innocuous [5–7]. Different adverse effects have been identified that can potentially contribute to worse outcome. Among them, airway compromise and elevation of intracranial pressure (ICP) [5–7] are regularly described. Both alterations can trigger hypoxemia, hyper/hypocapnia and intracranial hypertension, secondary damage factors clearly established and recognized in severe TBI [9]. In order to assess the effects of cervical collar placement on ICP, we decided to evaluate the situation through a systematic review with meta-analysis.

Methods

We conducted a systematic literature search of major electronic databases (MEDLINE, EMBASE, and Cochrane Library) in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement [10, 11]. The written protocol was registered on March 2018 in PROSPERO, The International Prospective Register of Systematic Reviews (CRD42018091630).

Search Strategy

The electronic search strategy was performed in major databases (Ovid/Medline, Embase and Cochrane Library). Concepts were created by using a combination of Medical Subject Headings terms and keywords as follows: 'intracranial pressure,' 'intracranial pressure monitoring,' 'intracranial hypertension' and 'cervical collar.' The search was limited to articles published in English from 1990 to 2018. The literature was presented, classified and discussed by all authors. Moreover, we reviewed the citations of included references to incorporate relevant studies that were not registered in our initial search.

Study Identification and Selection

Inclusion Criteria

Population Prospective studies of adult (> 18 years) patients after suffering moderate to severe TBI; *Intervention* cervical collar application and ICP monitoring; *Comparator* ICP readings during cervical collar application and after cervical collar removal; *Outcome*s primary: ICP increase after cervical collar application; secondary: ICP changes after cervical collar removal.

Exclusion Criteria

Pediatric population, retrospective cohorts, case reports, preclinical studies (animal, in vitro), studies that did not assess ICP.

Data Extraction

Reviews of the literature and data extraction were performed independently. Two authors (R.A.N.P, D.A.G.) independently screened the titles and abstracts of initial results, read relevant articles that met the inclusion criteria and assessed the risk of bias according to guidelines by PRISMA. Relevant information was extracted from each article including baseline characteristics [reference, year, country, presence/absence of TBI, sample size, number of males, mean age and Glasgow Coma Scale (GCS) score] and outcomes characteristics (means and standard deviations of ICP before collar application, during collar application and after collar removal, time of collar application and collar type).

Statistical Analysis

Quantitative data of continues covariates are presented as means and standard deviations. We obtained the weighted mean difference (WMD) running the command *metan* in Stata version 13.0 (Stata, College Station, TX), due to the reliability of ICP measures reported across the studies. Each meta-analyzed value was measured for heterogeneity and expressed as I^2, which describes the total variation across studies in terms of percentages that is due to heterogeneity rather than chance. A value of 0% indicates no observed heterogeneity, with the correspondent Chi-squared test ($I^2 < 50\%$ and $I^2 > 50\%$ were considered insignificant and significant heterogeneity, respectively). We performed the meta-analysis using Stata version 13.0 (Stata, College Station, TX) with random-effects model (DerSimonian and Laid Method) [2]. Microsoft Excel was also used to organize the information and to generate tables and figures prior to statistical analysis.

Results

Literature Identification

From the initial literature search, we identified studies based on the inclusion criteria (21 from MEDLINE, 21 from EMBASE, and 3 from Cochrane Library). After duplicates were removed, 44 potentially relevant articles were screened based on abstract. Of those, 22 articles did not meet the inclusion criteria and were removed. The remaining 22 relevant articles were thoroughly reviewed by D.A.G and R.A.N.P. A total of five studies comprising 86 patients were eligible to be included in the final analysis (Fig. 1).

Study Characteristics

Tables 1 and 2 summarize characteristics of the studies included in this meta-analysis: (reference, year, country, presence/absence of TBI, sample size, number of males, mean age and GCS score) and outcomes characteristics (means and standard deviations of ICP before collar application, during collar application and after collar removal, time of collar application and collar type).

Meta-Analysis

ICP Values Before and During Cervical Collar Application

A total of five studies comprising 86 patients were pooled to calculate the overall change in ICP values before and during cervical collar application. The increase in ICP after collar application was statistically significant (WMD = 4.43; 95%CI 1.70, 7.17; $P < 0.01$; $I^2 = 31.3\%$; P for heterogeneity = 0.21), meaning an overall ICP increase of approximately 4.4 mmHg (Figs. 2a, 3).

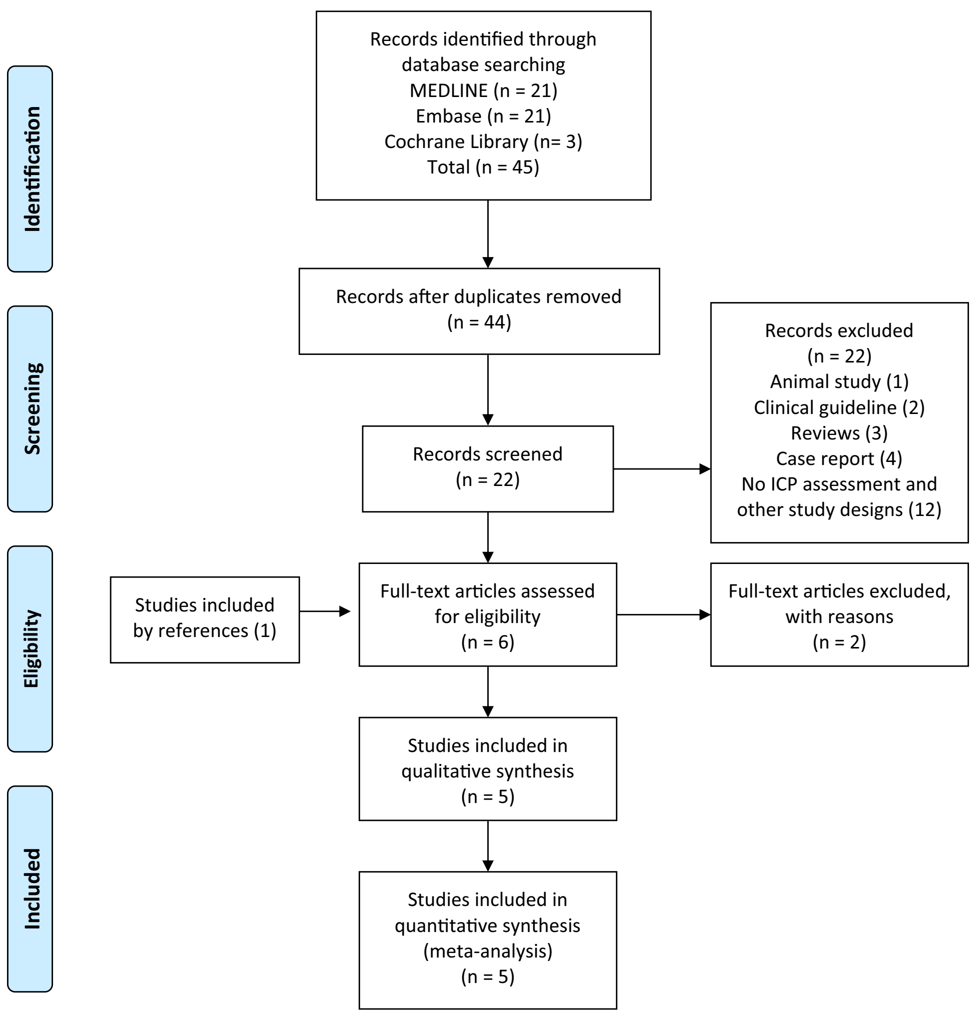

Fig. 1 PRISMA flow diagram

Table 1 Baseline characteristics of included studies

Study	Year	Country	TBI	Sample size	Males (%)	Mean age (SD)	GCS (SD)	ICP measurement	Commentaries
Mobbs et al. [12]	2002	Australia	Yes	10	8 (80%)	29.3 (10.29)	6.8 (2.32)	Invasive (Medtronic, external ventricular drain, Camino)	9/10 patients with raised ICP after cervical collar application. Mean difference 4.4 mmHg (range −3 to +12 mmHg), $P<0.05$
Davies et al. [13]	1996	United Kingdom	Yes	19	NR	NR	NR	Invasive (Camino microventricular catheter)	Mean rise in ICP of 4.5 mmHg (SD = 4.1 mmHg) $P<0.001$. No correlation between ICP and mean arterial pressure, starting ICP, central venous pressure or heart rate
Hunt et al. [14]	2001	United Kingdom	Yes	30	18 (60%)	NR	NR	Invasive (Codman microsensor)	Mean rise in ICP of 4.6 mmHg, $P<0.0001$. No significant changes in cardiorespiratory parameters
Kuhnigk et al. [15]	1993	Germany	Yes	18	NR	NR	NR	Invasive (epidural transducer)	No significant changes in ICP after cervical collar application were reported
Porter et al. [16]	1999	United Kingdom	Yes	9	7 (77.8%)	23	NR	Invasive	Mean rise in ICP of 9.9 mmHg, 95%CI: 6.7−13.1 mmhg

GCS Glasgow coma scale, *ICP* intracranial pressure, *NR* not reported, *SD* standard deviation, *TBI* traumatic brain injury, *95% CI* 95% confidence interval

Table 2 Characteristics of ICP measures (mmHg) before, after and by removing the application of cervical collar

Study	Year	TBI	Sample size	Before collar application		During collar application		After collar removal		Time	Collar type
				Mean	SD	Mean	SD	Mean	SD		
Mobbs et al. [12]	2002	Yes	10	20.5	14.2	25.8	11.5	NR	NR	3–5 min	Stifneck
Davies et al. [13]	1996	Yes	19	13.3	5.7	18.3	7.3	14.4	6	20 min	Stifneck
Hunt et al. [14]	2001	Yes	30	14.1	6.6	18.8	8.4	14.3	6.6	5 min	Stifneck
Kuhnigk et al. [15]	1993	Yes	18	17	6.1	17.7	6.4	17.2	5.9	10 min	Mixed
Porter et al. [16]	1999	Yes	9	12.8	5.0	22.7	9.0	NR	NR	NR	Semirigid

ICP intracranial pressure, *SD* standard deviation, *TBI* traumatic brain injury

ICP Values During Collar Application and After Collar Removal

Three studies including 67 patients after suffering from TBI were pooled to calculate the change in ICP values during cervical collar application and after cervical collar removal. The decrease in ICP values reached statistical significance (WMD = −2.99; 95%CI −5.45, −0.52; $P=0.02$; $I^2=11.1\%$; P for heterogeneity = 0.33), meaning an overall ICP decrease of approximately 3 mmHg after collar removal (Fig. 2b).

ICP Values Before Collar Application and After Collar Removal

Three studies including 67 patients after suffering from TBI were pooled to calculate the change in ICP values

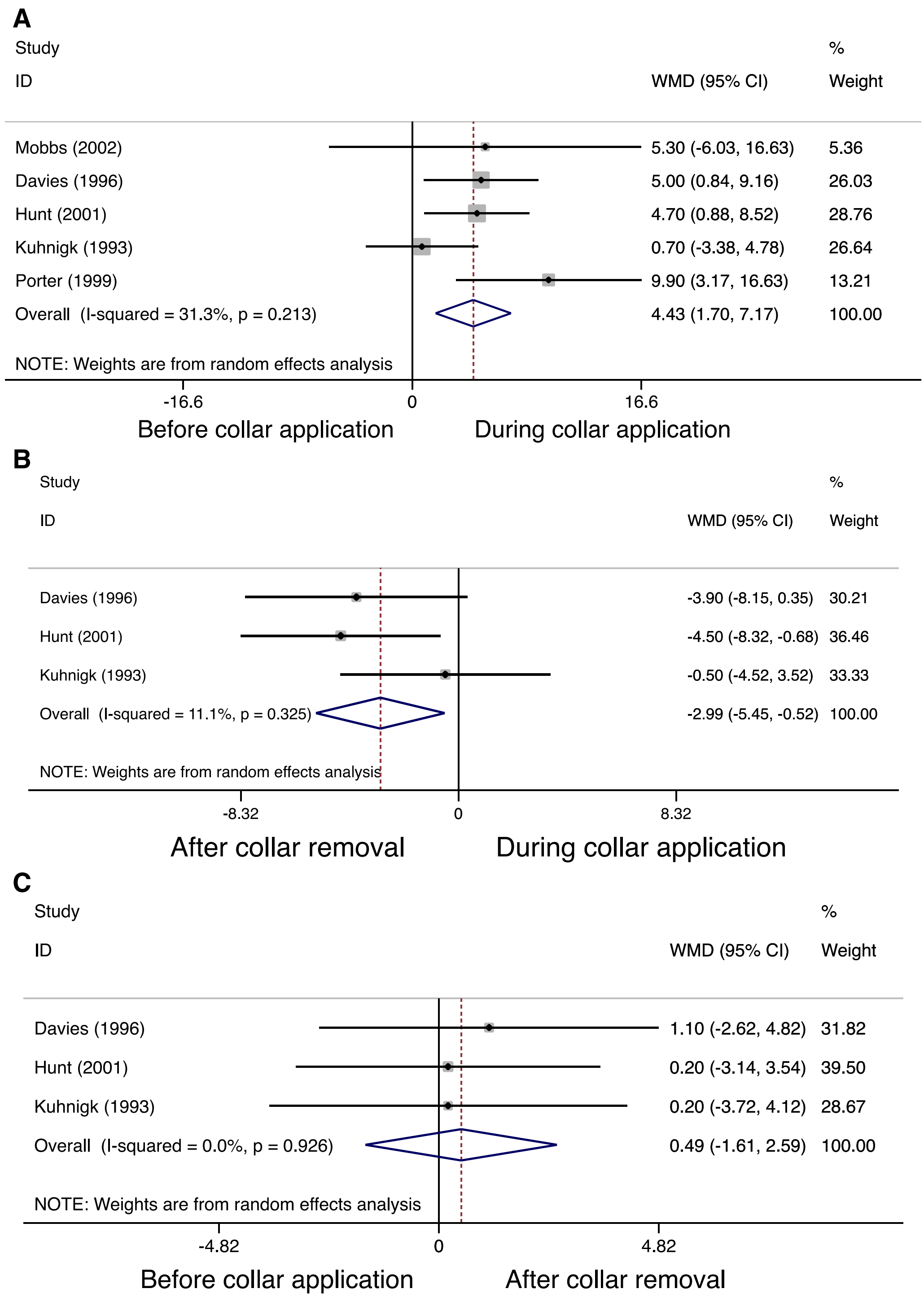

Fig. 2 Forest plots of ICP changes. **a** Before and during collar application, **b** during collar application and after removal, **c** before collar application and after removal

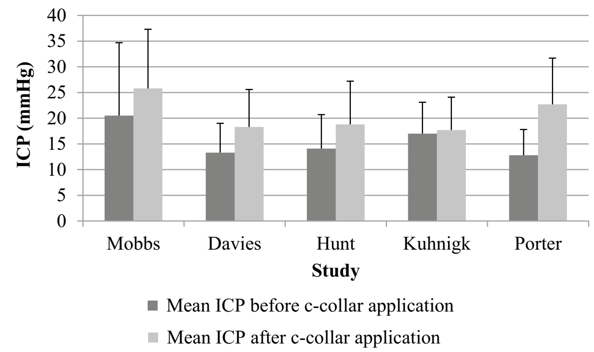

Fig. 3 Bar graph comparing changes in ICP readings before and after collar application. Error bars are represented in terms of standard deviations

Table 3 Summary of subgroup analysis before and during cervical collar application

Subgroup	No. of studies	*N*	Effect size		*P* value
			WMD	95%CI	
Type of cervical collar					
Stifneck	3	59	4.86	2.13, 7.60	< 0.01
Other	2	27	4.90	− 4.085, 13.88	0.23
Time of application					
≤ 5 min	2	40	4.76	1.14, 8.38	0.01
> 5 min	2	37	2.83	− 1.38, 7.04	0.19

WMD weighted mean difference

before cervical collar application and after cervical collar removal, being the difference no-statistically significant (WMD = 0.49; 95%CI − 1.61, 2.59; $P = 0.65$; $I^2 = 0\%$; P for heterogeneity = 0.93), meaning no ICP change (Fig. 2c).

Subgroup Analysis

Results of subgroup analysis are summarized in Table 3. The use of rigid collar (Stifneck) was strongly associated with raised ICP after cervical collar application compared to other semirigid collars (WMD = 4.86; 95%CI 2.13, 7.60; $P < 0.01$), indicating an overall increase of approximately 5 mmHg. The time of application ≤ 5 min was significantly associated to increases in ICP values after cervical collar application meaning an increase of approximately 5 mmHg (WMD = 4.76 95%CI 1.14, 8.38; $P = 0.01$).

Publication Bias and Sensitivity Analysis

The small sample size of this meta-analysis would potentially lead to an increased risk of bias. However, despite the small sample size, no asymmetry in funnel plots was found, and sensitivity analysis did not found a single study influencing the pooled results. In addition, study design and measures of ICP were reliable across the studies.

Discussion

In this systematic review and meta-analysis, studies were examined in order to observe the changes in ICP due to the rigid and semirigid cervical collar application. Routine immobilization of the cervical spine has been advocated worldwide and included in several trauma training programs like the advanced trauma life support course for all patients with head injury until a cervical spine injury has been excluded. In clinical practice, this usually means that almost all patients with severe head injuries must have collars applied at the scene. In patients with severe head injury, increase in jugular venous pressure may have effects on cerebral blood flow, meaning changes in ICP. In such cases, head injury may have already caused increased ICP from hypoxia, hypercarbia, cerebral edema and intracranial hematoma, while cerebral blood flow could be reduced from hypotension and loss of cerebral autoregulation. Changes of 4–5 mmHg could have significant effects, and a small rise in jugular venous pressure could have disastrous consequences on cerebral blood flow as well [17].

ICP elevation is a characteristic, complex and multifactorial pathophysiologic phenomenon, but is not the only finding or mechanism of deterioration in severe TBI [18]. It represents only one more element inside a long equation, or integration of several mechanisms of lesion, including cerebral autoregulation impairment, metabolic dysregulation, tissue hypoxia, mitochondrial dysfunction and others. Furthermore, a number of questions are not answered yet, for example, the cut-off for ICP values in which the likelihood of poor outcomes increase is not given in a clinical scenario that includes determinants such as age, evolutive profile, magnitude of ICP increase, type of lesion and other.

A number of studies have examined spine movement in simulated environments (e.g., cadavers with or without rigor mortis or healthy volunteers) using a wide range of devices and assessment criteria, and the results of these studies are somewhat contradictory and confusing. Tape is the most effective measure for partial motion control. Overall, any form of immobilization is superior to no immobilization, no available method is optimal, and there is no solid evidence to support the commonly accepted treatment standards of today and application of cervical collar should be minimized in order to prevent secondary injuries in TBI patients [3, 4].

Until now, no human patient study has demonstrated clear benefit from the application of a rigid cervical collar in patients with neck injury. In contrast, and described in this review, several observational studies including case reports, case series and few clinical studies have shown increases in ICP due to cervical collar [7–10]. Additional narrative reviews, a previous systematic review [5] and our current review have shown important flaws in published articles about this topic, with difficulties due to several biases in order to obtain clear evidence of association of the cervical collar in patients' outcomes especially related with disability or mortality. Several intermediate outcomes like discomfort, pressure ulcers and jugular vein obstruction have been discussed also without the possibility to obtain critical evidence [17]. Care in management of the cervical spine includes manual motion restriction, positioning the patient in a comfortable position and use of head blocks or other soft devices. The patient should also be advised and taught to reduce neck movement. Selection of optional devices for the transport or partial motion restriction in trauma patients should include the vacuum mattress, but patients can also be motion restricted on a normal ambulance stretcher. Patients can be taught to remain still if they are awake, and conscious head blocks can be attached to the ambulance stretcher for unresponsive patients [1, 5].

There has been controversy of the possible benefits in terms to timely cervical spine clearance in awake and comatose patients. In awake patients, it is important to state that besides the absence of cervical spine lesion documented by imaging, the patients should be asymptomatic, without clinical signs of cervical spine lesion, in order to remove cervical immobilization under conditions of safety. According to the recommendations provided by the Tenth Edition of the advanced trauma life support, the need for radiologic evaluation before cervical spine clearance should be given by the use of validated clinical decision tools such as the Canadian C-Spine Rule and NEXUS [2, 3, 6]. In symptomatic patients (i.e., neck pain or midline tenderness), computed tomography (CT) from occiput to T1 with sagittal and coronal reconstructions should be performed. When CT is not available; lateral, anteroposterior and open-mouth odontoid radiographs are required to examine the cervical spine. However, suspicious areas on radiographs may require CT to rule-out cervical spine lesion in order to remove the collar subsequently [6].

It is thought that for comatose patients, the time of clearance should be as soon as cervical spine lesion is ruled out by imaging. The recommendations provided by guidelines for cervical spine clearance in obtunded patients are not clear in terms of the classification among different subgroups of patients with decreased level of consciousness, although the interventions for cervical clearance in this scenario are similar. In the obtunded definition, patients with different degrees of decreased level of consciousness were included, with values of GCS ranging from 8 to 14 [19]. In the mentioned guideline, the definition for obtunded, besides comatose or unconscious patients, also was included intubated patients and those with unreliable examination. The main recommendation was that in obtunded patients the collar should be conditionally removed after a negative high-quality, C-spine CT [19]. In a multicenter, prospective study by the C-spine study group, in which the primary objective was to evaluate the ability of CT to clear the cervical spine, CT was found to be highly sensitive (98.5%) for significant injuries, consequently the collar could be removed with lower risk of secondary injury after a negative CT. The exception was given by the patients with neurologic impairment at admission, in which magnetic resonance imaging should be performed even if CT was negative [20].

This study has important limitations. One of the most important is the small number of prospective and well-designed studies assessing the ICP changes at different times after cervical collar application. In addition, the reported small sample sizes of these studies would lead to restriction in the statistical power calculating the overall ICP changes and their significance after cervical collar application. Another limitation is the lack of consistent reporting of baseline characteristics of included patients (e.g., sociodemographic and clinical features) leading to restriction when performing subgroup or meta-regression analyses. Nonetheless, this study has several strengths. This is the first meta-analysis aiming to estimate the overall magnitude of ICP changes after cervical collar application. The systematic review in the electronic databases was comprehensively and exhaustively performed, and the estimated heterogeneity is low for primary clinical outcome ($I^2 = 31.3\%$) and secondary clinical outcomes ($I^2 = 11\%$ and 0%) leading to reliability of the results.

In relation with the findings in the subgroup analysis, the use of rigid collar (Stifneck) was associated with raised ICP after cervical collar application compared to other semirigid collars. These findings could be explained by the fact that increased ICP may depend of several factors in the setting of TBI as well as other types of acute brain injury [18, 21]. These factors include jugular venous compression as one of the main causes of increased ICP. In this scenario, using rigid collars may lead to a theoretically higher ICP increase compared with other types of semirigid or soft collars, due to the magnitude of jugular compression of the neck [17, 22]. However, our results are not consistent with longer times of application, and the potential mechanisms are not clear when it is thought that longer exposures to raised ICP may increase the risk of potential secondary brain damage. The cut-off of 5 min for cervical collar application timing was established arbitrarily in order to make a distinction between short and long exposures. In our results, the time of application ≤ 5 min was significantly associated with higher ICP increasing compared to applications longer than 5 min.

We cannot exclude the importance of immobilization of the cervical spine. Although there are also no randomized control trials that address the effect of collars on outcomes after cervical spine injury, we encourage to perform further well-designed, prospective and randomized studies aiming to compare the conventional cervical collar with novel systems of cervical immobilization. In addition, the results of this study should be taken with caution due to methodological limitations and the substantial heterogeneity of data in the included studies.

Conclusions

Increases in ICP have been demonstrated by heterogeneous studies of application of cervical collars as a partial motion restriction strategy after trauma. This skill is still part of teaching programs of several trauma care programs worldwide. Increases in ICP can induce complications in TBI patients. Appropriate selection criteria for partial cervical motion restriction in TBI patients need to be considered.

Abbreviations

SCI: Spinal cord injury; TBI: Traumatic brain injury; ICP: Intracranial pressure; GCS: Glasgow coma scale; WMD: Weighted mean difference; SD: Standard deviation; 95% CI: 95% confidence interval.

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Authors' Contributions

RANP was contributed with the design of the study, the literature search, data acquisition, data analysis, statistical analyses, manuscript editing, manuscript preparation, manuscript review and submitted the article to the journal. AR was contributed with data analysis, manuscript editing and manuscript preparation. DAG was contributed with design of the study, definition of intellectual content, the literature search, data acquisition, data analysis, manuscript editing and manuscript preparation.

Source of support

None.

Conflict of interest

The authors declare that they have no conflict of interest.

Ethical Approval/Informed Consent

This article does not contain any studies with human participants or animals performed by any of the authors.

Published online: 12 June 2019

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