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Original Contributions

THE IMPACT OF HEAD OF BED ELEVATION ON OPTIC NERVE SHEATH DIAMETER IN CERVICAL COLLAR APPLIED HEALTHY VOLUNTEERS

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☐ **Abstract—Background: Guidelines recommend placing a cervical collar (c-collar) until spinal injury is excluded. Previous studies have shown that c-collar placement increases intracranial pressure (ICP), which can worsen outcomes for trauma patients who are at risk of increased ICP. Head of bed elevation (HBE) has been found to decrease ICP. However, there is no consensus in the literature for the optimal degree of HBE to decrease ICP. Objective: We aimed to find an optimal HBE degree to decrease ICP to its baseline values in healthy volunteers with increased ICP caused by c-collar. Methods: This is a randomized controlled and blinded study performed in healthy volunteers. Two sonographers measured the optic nerve sheath diameter (ONSD) of each subject's eyes separately for different time points. Then, we calculated a mean ONSD value for five time points: before c-collar placement (T_0), 5 and 20 min in supine position after c-collar placement (T_5 and T_{20}), and 5 and 20 min after HBE (T_{25} and T_{40}). We randomized the subjects into three groups of HBE: 15, 30, and 45°, and compared the mean ONSD values among groups. Results: All groups were similar with regard to baseline demographics and ONSD measurements before HBE. We found significant increases in mean ONSD values at T_5 and at T_{20} caused by the c-collar. Thirty and forty-five degrees of HBE for 20 min decreased ONSD to its baseline values. The inter-rater reliability of the sonographers was > 0.9. Conclusions: Our results show that c-collar increases ONSD in healthy volunteers. Elevating the head of the bed 30 and 45° for 20 min decreased ONSD to baseline values.**

☐ **Keywords—backrest elevation; cervical collar; head of bed elevation; intracranial pressure; optic nerve sheath diameter; ultrasound**

INTRODUCTION

Head trauma is an important cause of mortality and morbidity and is often associated with increased intracranial pressure (ICP). Coexisting cervical spine injuries are often present in head trauma patients, and it is not always possible to rule out cervical spinal injuries in prehospital settings (1). Advanced Trauma Life Support guidelines recommend that patients be flat and log-rolled, due to concern of possible thoracic or lumbar spinal injury, and continuous immobilization of the cervical spine with a cervical collar (c-collar) until the cervical spine injury is excluded (2,3).

In previous studies, c-collar placement has been found to increase ICP in trauma patients, healthy volunteers, and cadavers (1,2,4). The suggested mechanism for increased ICP is decreased venous flow due to obstruction of both the internal and external jugular veins (1,5). The general volume inside the cranium is not expanded because it is fixed. By decreasing jugular venous flow, the fluid volume of venous blood is increased, leading to increased ICP, as defined in the Monro-Kellie doctrine (6).

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Increased ICP is associated with increased rates of death and poor neurologic outcomes in trauma patients (2). Prompt recognition of increased ICP is important for trauma management (7). Recent studies on head-injured patients have reported that increased optic nerve sheath diameter (ONSD) by sonographic measurement correlates with increased ICP (8,9).

An intraventricular catheter is the gold standard method for ICP measurement (10). However, measurement of ONSD with ultrasound is an effective and noninvasive method. In a recent meta-analysis, Robba et al. reported different specificity and sensitivity values for ICP by sonographic ONSD measurements (74–96% and 88–95%, respectively) (11). Ultrasound measurement is faster, more accessible, and with fewer complications (e.g., infection, hemorrhage, brainstem herniation) compared to invasive methods, such as measurement via lumbar puncture, brain probe, or ventriculostomy (1,2,7,12,13).

Prior studies have shown that head of bed elevation (HBE) is an effective maneuver to decrease ICP in both adults and pediatric patients (14–16). This traditional practice is used commonly in emergency departments (EDs), intensive care units, and prehospital settings because it is a simple and low-cost method that lowers ICP (14,17,18). Over the years, there has been a search for the optimal HBE degree for increased ICP management. Agbeko et al. found that increased degrees of HBE are associated with decreased ICP in pediatric patients with traumatic brain injury (TBI) in their prospective randomized trial with different HBEs (0, 10, 20, 30, and 40°) (19). In contrast, they stated that cerebral perfusion pressure was not affected by HBE changes (19).

In a randomized crossover experimental study, Winkelman proposed 30 degrees of HBE to decrease ICP significantly (20). However, in another prospective study, 15 degrees of elevation was suggested to be the optimal amount (21). There is no consensus in the literature regarding the optimal HBE degree, due to the lack of reliable evidence (14,17).

In this study, we aimed to find an optimal HBE degree that would decrease ICP to its baseline values in healthy volunteers with increased ICP based on ONSD due to c-collar placement.

MATERIALS AND METHODS

Study Design

We conducted a prospective, randomized, single-center, partially blinded research study at a university hospital. The university's Institutional Review Board (IRB) approved the study protocol (IRB no.: 09.2018.297). We included healthy hospital workers older than 18 years of age who volunteered to participate in this study and excluded subjects with known ocular or intracranial disease. Every subject who participated in this study signed a written informed consent, and this study conformed to the principles in the Declaration of Helsinki.

We positioned the subjects in supine position on an emergency department stretcher (ES OO-SL; Finex, Istanbul, Turkey). Two sonographers measured subject's baseline ONSD values before c-collar placement (T_0), separately. Then we placed a c-collar (EN2050; EN-PLUS, Istanbul, Turkey) of the appropriate size for every subject. At 5 (T_5) and 20 (T_{20}) min after c-collar placement, we repeated ONSD measurements in a supine position and performed HBE (15, 30, or 45°) after these measurements. Two more ONSD measurements were performed at 5 (T_{25}) and 20 (T_{40}) min after the HBE with c-collar in place (Figure 1).

In the procedure room, there was only one subject at a time. The two sonographers were never in the room at the same time. After obtaining their measurements, sonographers left the procedure room and waited outside separately. Sonographers were blinded to each other's measurements and to the degree of HBE of the subjects.

Investigators and Randomization

Three investigators, senior emergencyphysicians with 8–10 years of ED experience, performed the procedures. The first investigator was responsible for positioning the subjects, placing the c-collar, performing HBE, monitoring the vital signs of the subjects, and calling the second and third investigators (sonographers), who perform ONSD measurements, to the room individually.

The two sonographers were both senior e-FAST (extended focused assessment with sonography in

Figure 1. Performing sonographic optic nerve sheath diameter measurement after 45 degrees of head of bed elevation. Subject's eyes are covered with a transparent dressing.

trauma) instructors and performed at least 350 ultrasounds per annum. They were certified for basic and advanced emergency sonography by the national society. The intraclass correlation coefficient (κ) of the two emergency physicians on live humans for sonographic measurement of ONSD was > 0.9 according to local annual quality checks. Both emergency physicians performed 30 sonographic ONSD measurements prior to this study.

We calculated that a total sample size of 36 was needed to detect a return to baseline ONSD values by at least 50% in each group, within the target significance level of 0.05, which achieves 80% power. We increased our final sample size to 45 to compensate for inconclusive tests and division to three.

We randomized the subjects (n = 45) into three HBE groups—group 1: at 15°, group 2: at 30°, and group 3: at 45° (15 for each), for their fourth and fifth time point (25 and 40 min) measurements. The sonographers were randomized for the alignment of every measurement (Research Randomizer, https://www.randomizer.org/).

Data Collection

We covered the eyes of the subjects with a transparent dressing (Tegaderm™; 3M™, Maplewood, MN) and obtained ONSD measurements with a 7.5-MHz linear probe of a color Doppler ultrasound machine (Mindray M5; Mindray, Shenzhen, People's Republic of China) in the ocular setting (Figure 1). Images for ONSD measurement were taken 3 mm posterior to the retina, as suggested in recent studies (Figure 2) (1,8,9). Sonographers, who were blinded to each other, scanned left and right eyes of the subjects individually in both sagittal and transverse planes. Measurements were obtained in supine position before (T_0) and after (T_5, T_{20}) c-collar placement, and in head of bed elevation position (T_{25}, T_{40}) with c-collar in place. We performed a total of 900 measurements (two eyes, two raters) on 45 subjects in five consecutive time points, recorded the measurements of two eyes for each sonographer, then calculated a mean ONSD value. We informed all subjects to breathe normally and not to cough, talk, or elevate their heads during the measurements. Measurements were repeated if these instructions were not met.

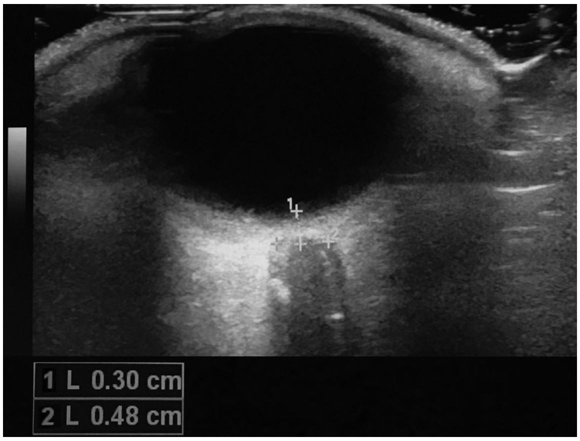

Figure 2. Sonographic image of an optic nerve sheath diameter measured 3 mm posterior to the retina.

We monitored blood pressure, respiratory rate, heart rate, and oxygen saturation for every subject for the entire session. First investigator and the sonographers recorded all data on separate datasheets. Then all data were combined, refined, and simplified on a single electronic database.

Statistical Analysis

We reported continuous variables as mean ± standard deviation with 95% confidence intervals (CI) because normality in distribution was observed by the Kolmogorov–Smirnov test. The significance of the difference between groups was assessed by analysis of variance (ANOVA) test. Categorical variables were reported as proportions and counts, and chi-square test was used to compare proportions among groups. Student's *t*-test was used as the post-hoc test for ANOVA test, and significance threshold was accepted as $p < 0.016$ after Bonferroni correction. The inter-rater reliability of the sonographers for all time points was reported as intraclass correlation values and 95% CI. MedCalc Statistical Software, version 17.9.7 (MedCalc Software bvba, Ostend, Belgium) was used for statistical analysis.

RESULTS

In this study, 45 subjects (median age 23.0 years) were enrolled. Twenty-two (49%) of the subjects were female and mean body mass index was 24.6 kg/m^2. All three groups were similar with regard to baseline demographic characteristics and ONSD values at T_0, T_5, and T_{20} before randomization (Table 1). There were significant increases in mean ONSD values at T_5 (0.80 mm, 95% CI 0.69–0.91) and at T_{20} (0.86 mm, 95% CI 0.75–0.97) compared to baseline ONSD measurements (T_0) ($p < 0.001$). The increase in mean ONSD value at T_{20} was also significant compared to T_5 (0.05 mm, 95% CI 0.04–0.06; $p < 0.001$).

All subjects were randomized into three groups (n = 15 each) with 15, 30, and 45 degrees of HBE after T_{20} measurements. The differences of mean ONSD values at T_{25} and T_{40} between the three groups were significant (Table 1). The post-hoc analysis showed that this difference was originated from the difference between groups at 15° and 30°, and groups at 15° and 45° ($p < 0.001$).

Table 1. Characteristics and Optic Nerve Sheath Diameter Values Before and After Head of Bed Elevation

Characteristics	Group 1 (15°)	Group 2 (30°)	Group 3 (45°)	Total	*p* Value
Age, y, median (IQR)	23.0 (21.0–25.0)	24.0 (21.0–26.0)	23.0 (21.0–25.0)	23.0 (21.0–25.0)	0.765
Female, n (%)	8 (53)	7 (47)	7 (47)	22 (49)	0.915
BMI, kg/m^2	25.06 ± 2.80	24.56 ± 2.61	24.06 ± 2.76	24.57 ± 2.70	0.608
ONSD at T_0	4.10 ± 0.23	4.09 ± 0.18	4.09 ± 0.26	4.09 ± 0.22	0.983
ONSD at T_5	4.89 ± 0.35	4.90 ± 0.51	4.91 ± 0.43	4.90 ± 0.43	0.993
ONSD at T_{20}	4.97 ± 0.35	4.96 ± 0.53	4.96 ± 0.43	4.96 ± 0.43	1.000
ONSD at T_{25}	4.96 ± 0.35	4.61 ± 0.27	4.61 ± 0.27	4.73 ± 0.33	**0.003**
ONSD at T_{40}	4.65 ± 0.33	4.08 ± 0.30	4.08 ± 0.33	4.27 ± 0.41	**<0.001***
Δ ONSD T_{20}-T_{25}	0.01 ± 0.007	0.34 ± 0.26	0.34 ± 0.21	0.06 ± 0.03	**<0.001***
Δ ONSD T_{20}-T_{40}	0.31 ± 0.07	0.88 ± 0.26	0.88 ± 0.20	0.69 ± 0.33	**<0.001***
Δ ONSD T_{25}-T_{40}	0.31 ± 0.70	0.53 ± 0.91	0.54 ± 0.91	0.46 ± 0.13	**<0.001***
Δ ONSD T_{25}-T_0	0.85 ± 0.34	0.52 ± 0.17	0.52 ± 0.31	0.63 ± 0.32	**0.003***
Δ ONSD T_{40}-T_0	0.54 ± 0.34	-0.01 ± 0.19	-0.01 ± 0.35	0.17 ± 0.39	**<0.001***

BMI = body mass index; IQR = interquartile range; ONSD = optic nerve sheath diameter; SD = standard deviation; T = time; Δ = difference.
Values are mean ± standard deviation, unless otherwise indicated. $p < 0.05$ is set as significant.
Significant *p*-values are shown in bold.
* $p < 0.016$ is set as significant after Bonferroni correction.

The difference between groups at 30° and 45° was not significant at T_{25} and T_{40} ($p > 0.98$). The decreases in mean ONSD values were significant at T_{25} and T_{40} compared to values at T_{20} and T_0 (baseline ONSD). This difference also originated from the difference of groups at 15° and 30°, and groups at 15° and 45° ($p < 0.001$). The differences between groups at 30° and 45° were not significant ($p > 0.99$) (Table 1). Although all three groups had significant decreases of mean ONSD values, only the groups at 30° and 45° achieved the baseline ONSD values at T_{40} (Figure 3). The inter-rater reliability of the sonographers was > 0.9 at all time points.

DISCUSSION

In this study, we found that c-collar increased ICP in healthy volunteers and HBE significantly decreased this increased ICP to its baseline values. Maissan et al., in their study with healthy volunteers, found that subjects placed with c-collar had significantly higher values of ONSD compared to those without c-collars (5.5 ± 0.7 mm vs. 5.2 ± 0.6 mm; $p < 0.001$) (1). In another paper from the United States, Woster et al. reported a significant increase of ONSD at 5 and 20 min after c-collar application in healthy subjects (2). Our results were similar to these studies. We found a significant

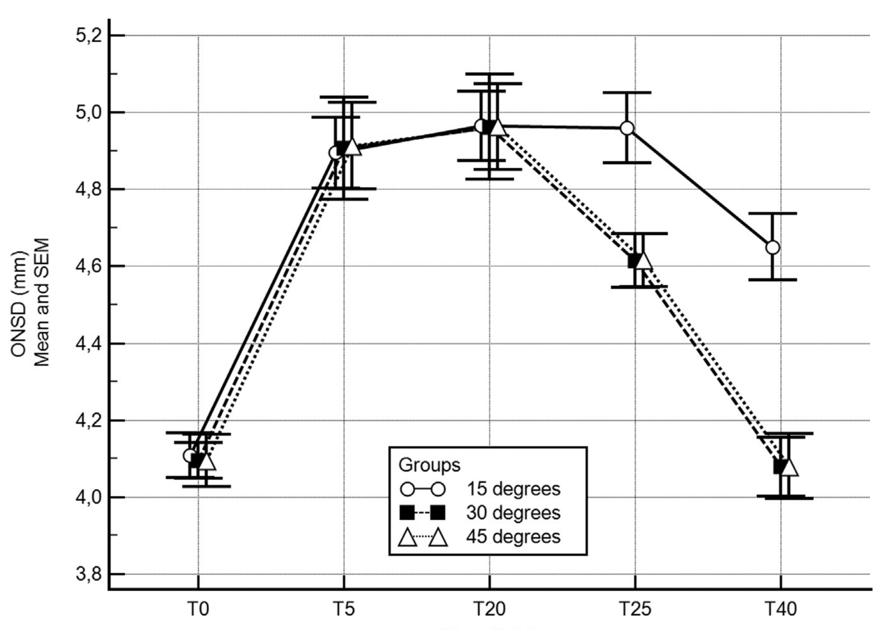

Figure 3. Optic nerve sheath diameter (ONSD) values of the groups by time points. SEM = standard error of the mean.

increase in ONSD at 5 (T_5) and 20 (T_{20}) min after c-collar placement compared to baseline ONSD values (T_0) when no c-collar was placed.

HBE is a traditional maneuver that is shown to decrease ICP effectively (14–16). In a study with 53 patients, Tankisi and Cold suggested that 15 degrees of head elevation is the optimal amount of elevation for the maximum decrease (21). Winkelman, in his randomized crossover experimental study, found that 30 degrees of HBE significantly decreased ICP in adult patients with TBI compared to supine-positioned patients (20). Marik et al. stated that a head elevation up to 30° reduces ICP significantly (22).

However, there are no guideline recommendations or literature consensus regarding the optimal degree of HBE to decrease ICP (14). In 2017, Alarcon et al. performed a systematic review to assess the effects of HBE in patients with TBI (17). The authors stated that the optimal degree for HBE that could decrease ICP is uncertain due to inconsistency among studies and the lack of reliable evidence (17).

Limitations

There are several limitations to this study. First, the study cohort consisted of healthy subjects, and results may not be accurately applied to trauma patients. Second, our ONSD values ranged between 4 and 5 mm; however, recent studies placed their cut-off values for elevated ICP at 5–6.5 mm. Our data do not meet the published criteria for elevated ICP. The healthy nature of this cohort may have influenced the results. Third, although sonographers were blinded to the elevation degrees, they could have understood from the amount of HBE. The fourth limitation is the translation of HBE to actual measured ICP because sonographic ONSD measurement is still a surrogate measurement for ICP. Fifth, we used one type of c-collar of appropriate size and one type of HBE. Different types of c-collars and HBEs may have influenced the results differently. Sixth, we did not evaluate the tightness of c-collars because it is hard to standardize, which might have affected the OSND changes. Seventh, our subjects were relatively young. Although trauma patients are mostly younger patients, our results may not accurately represent the results in older populations. Last, all subjects were randomized for HBE after T_{20} and we did not have a control group who remained flat (0°) to evaluate whether ICP elevation persisted after T_{20}.

CONCLUSIONS

C-collar placement in healthy volunteers increases ONSD significantly, which suggests increased ICP. HBE of 30 and 45° for 20 min decreased the increased ONSD by c-collar significantly, to its baseline values. Our results suggest that 30 and 45 degrees of HBE for 20 min may compensate for the ICP-increasing effect of c-collars. Future studies involving trauma patients should enlighten the literature for the effects of HBE in c-collar–applied trauma patients.

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ARTICLE SUMMARY

1. Why is this topic important?

Advanced Trauma Life Support guidelines recommend placing a cervical collar (c-collar) until spinal injury is excluded. Recent studies showed that c-collar application increases intracranial pressure (ICP), which may worsen the outcomes for trauma patients who are at risk of increased ICP. Head of bed elevation (HBE) is shown to decrease ICP. However, there is no consensus in the literature for the optimal degree of HBE to decrease ICP.

2. What does this study attempt to show?

This study attempts to find an optimal HBE degree to decrease ICP to its baseline values, in healthy volunteers with increased ICP caused by c-collar.

3. What are the key findings?

Mean optic nerve sheath diameter (ONSD) values significantly increased 5 and 20 min after c-collar application. Thirty and forty-five degrees of HBE for 20 min decreased ONSD to its baseline values. The inter-rater reliability of the sonographers was excellent.

4. How is patient care impacted?

This study suggests that c-collar significantly increases ONSD in healthy volunteers. HBE of 30 and 45° for 20 min decreases this increased ONSD to baseline values.