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Original Article

Comparing the Effectiveness of Modified Iranian and Rigid Minerva Braces in Cervical and Thoracic Spine Movements

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ABSTRACT

Background: To facilitate the fusion of the injury site for non-operative treatment or postoperative care, various braces are available to immobilize an unstable cervical spine. Among these, Minerva and Halo braces are the most effective and widely used for immobilizing unstable cervical spine injuries. The performance of cervical braces is commonly evaluated by the degree of motion restriction they provide. This study aimed to compare the function of modified Iranian and rigid Minerva braces using three-dimensional motion analysis as the standard assessment method.

Methods: Twenty-nine healthy male subjects without any history of spinal pain, malformation, or surgery were recruited for this cross-sectional study. A 3D motion capture system was used to record cervical and thoracic spine flexion, extension, lateral bending, and rotation. Range of motion (ROM) was assessed under three conditions: without a brace, with the modified Iranian Minerva brace, and with the rigid Minerva brace.

Results: At the cervical region, immobilization in flexion (89.03% > 87.8%) and rotation (84.85% > 83.19%) was greater with the modified Iranian Minerva, whereas extension (89.37% > 85.95%) and lateral bending (81.26% > 71.71%) were more restricted by the rigid Minerva ($p > 0.05$). At the thoracic region, immobilization in flexion (76.35% < 75.96%), lateral bending (46.92% > 44.5%), and extension (79.44% > 62.58%) were higher with the rigid Minerva, while rotation (53.04% > 41.21%) was more limited by the modified Iranian Minerva ($p > 0.05$).

Conclusion: Both Minerva braces significantly reduced cervical range of motion ($p < 0.05$). The rigid Minerva was more effective in controlling extension and lateral bending, while the modified Iranian Minerva provided greater restriction in flexion and rotation ($p < 0.05$).

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Introduction

In non-operative treatment or postoperative care, various braces can be used to immobilize the unstable cervical spine to facilitate fusion at the injury site [1, 2]. These braces are applied for cervical fractures, soft tissue injuries, postoperative immobilization, destructive injuries, and spinal deformities. The primary purposes of braces are to relieve pain, increase stability, maintain normal posture, and reduce segmental movement between vertebrae associated with cervical fractures [3]. Several studies have evaluated the effectiveness of cervical braces in achieving immobilization; however, most of these investigations were conducted on cadavers, and their findings were primarily based on X-ray evaluations [4, 5].

The Minerva and Halo braces are considered the most effective devices for immobilizing the unstable cervical spine, particularly in cases of upper cervical spine injuries[6, 7]. The Halo brace provides greater external immobilization than the Minerva for the upper cervical spine. It is used for the definitive treatment of upper cervical spine trauma, the reduction of spinal deformities before surgery, and the stabilization of the cervical spine following surgery. However, this brace is associated with several complications, including mortality, diplopia, pin and ring loosening, pin tract infections, dysphagia, pressure ulcers, and inaccurate fitting [8-11]. Although a non-invasive Halo brace exists, it is not widely adopted in Iran due to its high cost.

The rigid Minerva consists of two shells, one anterior and one posterior, connected by two shoulder straps and two trunk straps. A mandibular gliding base is connected to the anterior thoracic plate with the front shell, and this base can be adjusted if needed. The posterior plate is attached to the occipital base, which is also adjustable to ensure proper fit, and a forehead strap provides additional support [15](Figure 1). A variation of the Minerva brace used for postoperative management of cricotracheal resection is a modified version of the rigid Minerva, which omits the mandibular pad and includes a thoracic bar extending to the occiput to maintain 0–20 degrees of cervical flexion [12](Figure 2).

Figure 1: Rigid Minerva

Figure 2: Modified Minerva

The Minerva was recommended as the best choice for unstable fractures[6].

Benzel et al. examined Minerva (thermoplastic) and Halo braces using radiography to evaluate intersegmental cervical range of motion (CROM). The results demonstrated that the intersegmental range of motion with the Minerva brace (14.8 ± 4.4°) was less than with the Halo brace (23.4 ± 13.7°), while the range of motion (ROM) in the sagittal plane from occiput to C7 was the same for both braces (5.2°) [14]. In that study, eight participants preferred the Minerva brace, and only three felt secure with the Halo brace [8].

Regarding the modified Iranian Minerva brace currently used in clinics, there is no scientific evidence supporting its effectiveness, highlighting the need for further research. This study aims to obtain detailed information on the performance of the modified Iranian Minerva compared with the rigid Minerva brace, using three-dimensional motion analysis as a standard evaluation method.

Additionally, a commonly used variation of the Minerva brace is the **modified Iranian Minerva**, which closely resembles the Yale brace. The original Yale brace is a lightweight orthosis used to stabilize the cervical spine. It is a long Philadelphia-type brace with a polypropylene load extending across the anterior and posterior parts of the chest, connected by a chest strap [13](Figure 3). The modified Iranian Minerva differs from the Yale cervical brace in that its posterior support is longer, and a forehead strap has been added for enhanced stabilization.

Cervical braces are classified according to the degree of immobilization they provide; greater restriction is associated with lower mortality rates, reduced neurological disability, and fewer adverse effects of trauma, while increasing spinal stability. Several studies have evaluated the effectiveness of the rigid Minerva. In a 2007 study, seven cervical braces (Philadelphia, Aspen, Minerva [rigid], Lerman, Somi, Miami J, and PMT [Pain Management Technology] cervical collar) were compared in 45 healthy subjects.

A B.

Figure 3: Yale Brace (15).

Methods

Twenty-nine healthy men (mean age = 25.72 ± 5.6 years) with no history of spinal or neck pain were included in the study. All participants signed informed consent forms, and their information was kept strictly confidential. None of the participants had systemic skin or skeletal lesions that would preclude brace use. Additionally, they had no history of muscle spasms, arthritis, neurological disorders, or prior neck surgery.

All subjects were evaluated under three conditions: rigid Minerva brace, modified Iranian Minerva brace, and without a brace. This study was a cross-sectional design and was approved by the Ethics Committee of Isfahan University of Medical Sciences (IR.MUI.NUREMA.REC.1401.063), and the RCT code is (—).

An orthotist precisely fitted the braces while the subjects sat on a 60 cm-high stool. Flexion, extension, lateral bending, and rotation were measured five times on both sides. Once the cameras were activated, the subjects were instructed to gradually bend their head as far as possible in a specified direction without moving their shoulders or trunk. After each movement was recorded, the subjects slowly returned to the neutral position. Three tests were performed consecutively in each direction, with at least one minute of rest between movements.

Initially, the CROM (Cervical Range of Motion) of the subject without a brace was measured, followed by a random check of the CROM with the first brace. The second brace was then applied, and all movements were repeated after thirty minutes—measurements and analyses performed by a laboratory specialist.

The modified Iranian Minerva is a long Philadelphia-type brace with a polypropylene shell that extends anteriorly and posteriorly across the chest. The chest straps are connected both at the front and back. The posterior section extends to the top of the head and is secured with a forehead strap. The inner surface of the polypropylene shell is lined with 5 mm foam, and the brace is custom-fitted for each individual (Figure 4).

To measure the cervical and thoracic range of motion, the Qualisys 3D motion capture system (Qualisys Motion Analysis, 41113, Packhusgatan 6, Qualisys AB, Gothenburg, Sweden) was used [16-19]. The system consists of seven infrared cameras, an L-shaped rod with four markers, and a T-shaped rod with two markers. The rods were used for camera calibration with an accuracy of 0.6 mm.

For the first time, Hosseini measured cervical range of motion using the angle formed by the markers relative to each other. This measurement method, first published in 2017, was also applied in this study. Three reflective markers were placed on the forehead, the spinous process of the C7 vertebra, and the spinous process of the T12 vertebra to measure the overall movements of the cervical and thoracic regions[19] Figure 5.

In 2015, Inokuchi and colleagues assessed the validity and reliability of this device using 12 healthy participants, measuring the total cervical range of motion with the 3D motion analysis system. Reliability was evaluated by three factors: the Intraclass Correlation Coefficient (ICC), the Standard Error of Measurement (SEM), and the Minimum Detectable Change (MDC). The reported ICC(1,2) values ranged from 0.736 to 0.950. SEM values for all range of motion movements were low (e.g., flexion 1.3° and extension 4.5°). MDC values were 3.6° for flexion and 12.5° for extension.

The average difference between the measurements was minimal (from 0.1° in flexion to 10.9° in rotation). Correlation analysis showed high R^2 values (0.745–0.607), and Pearson's correlation coefficient was estimated at 0.863–0.779. Bland and Altman's analysis indicated that the differences in flexion, extension, and lateral bending were clustered close to zero and unrelated to the measurement scale. In contrast, the differences for rotation were scattered around 10°. This study confirmed the high validity and reliability of three-dimensional motion analysis for measuring cervical range of motion [20].

Figure 4: Modified Iranian Minerva

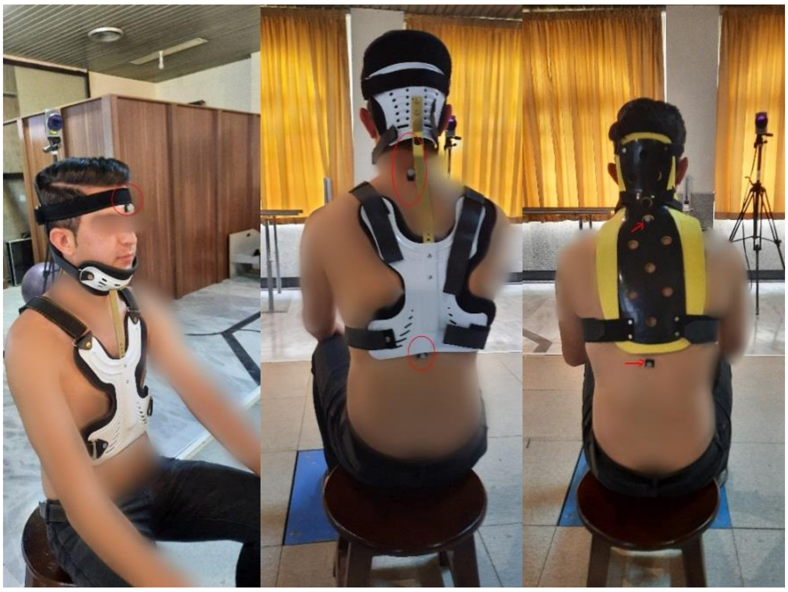

Figure 5: Markers Placements

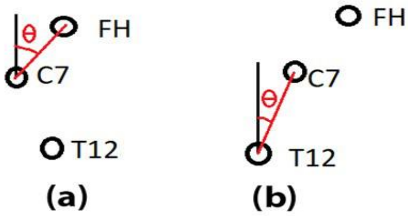

Figure 6: Ɵ Represents the angle of the cervical spine (a) and the thoracic spine (b). FH: forehead; C7: seventh cervical vertebra; T12: twelfth thoracic vertebra.

The percentage of motion restriction reported in studies is represented by the mean restriction of percentage (MRP), which is calculated as the percentage difference between ROM with and without a cervical brace, divided by the CROM without a brace. In clinical situations, a safe margin must be considered for patients with cervical spine injuries. Consequently, a minimum immobilization limit (MIL) was introduced, calculated by subtracting the standard deviation from the MRP. Ultimately, a classification of immobilization for each brace, measured by this method, was established. This classification includes: poor (MIL < 20%), fair (MIL 20–40%), moderate (MIL 40–60%), substantial (MIL 60–80%), and nearly complete (MIL ≥ 80%)[14].

For data analysis, SPSS version 20 (IBM Corp., Released 2011. *IBM SPSS Statistics for Windows, Version 20.0*, Armonk, NY, USA) was used. The normality of the parameters was assessed using the Shapiro–Wilk test, and the data were found to be normally distributed. Differences in the range of motion with and without the modified Iranian and rigid Minerva braces, as well as between the two braces, were analyzed using the paired samples t-test.

Results

Mean degrees of cervical spine motion (occiput relative to C7) with and without Minerva braces are presented in Tables 1 and 2. The percentage of CROM (cervical range of motion) immobilization is also reported in these tables. The mean flexion range with the modified Iranian and rigid Minerva braces was reduced by 89.03% and 87.80%, respectively (41.40° without a brace compared to 4.54° with the modified Iranian brace and 5.05° with the rigid brace; $P = 0.00$). The use of the modified Iranian and rigid Minerva braces decreased the extension range by 89.37% and 90.35%, respectively ($P = 0.00$). The mean range of rotation decreased by 84.85% and 83.19% with the use of the modified Iranian and rigid Minerva braces, respectively, while lateral bending to the right and left decreased by 81.26% and 81.86% with the use of the modified Iranian and rigid Minerva braces, respectively ($P = 0.00$).

In the thoracic region (C7–T12), the mean range of flexion, extension, rotation, and lateral bending decreased by 76.35%, 75.96%, 62.58%, 58.89%, 70.94%, 70.60%, 44.5%, and 46.92% for the modified Iranian and rigid Minerva braces, respectively ($P = 0.00$).

Overall, the ROM of the cervical spine was more effectively immobilized than that of the thoracic region. A comparison between the modified Iranian and rigid Minerva braces is shown in Table 1.

Table 1: Average ROM (range of motion) and mean percentage of cervical spine motion restriction (occiput to C7 and C7 to T12) with and without the modified Iranian brace, along with a comparison between them. MIL refers to the minimum immobilization limit. The table also presents the average ROM and mean percentage of immobilization of the cervical spine (occiput to C7 and C7 to T12) with and without the rigid brace. *P*-values between the two conditions were 0.00.

Motions (OCCIPUT-C7)	No Braces	S.D(No Braces)	With a Modified Brace	S.D. (With Modified Iranian brace)	Average Percent of Motion Restriction	MIL	With a Rigid Brace	S.D. (With Rigid	Average Percent of	MIL	P-Value	P Value (Between Two Braces)
Flexion	41.40	±3.9	4.54	±1.91	89.03	84.42	5.05	±1.91	87.80	83.2	0.000	0.222
Extension	44.67	±5.84	4.75	±1.63	89.37	85.77	4.31	±1.96	90.35	85.95	0.000	0.222
Rotation	28.26	±7.55	4.28	±1.70	84.85	78.84	4.75	±1.71	83.19	77.57	0.0000	0.06
Lateral Bending	28.17	±6.215	5.28	±2.03	81.26	74.04	5.11	±2.83	81.86	71.71	0.000	0.060
(C7-T12)												
Flexion	5.20	±2.5	1.23	±1.16	76.35	54.04	1.25	±1.07	75.96	55.38	0.000	0.955
Extension	3.26	±2.01	1.22	±0.97	62.58	32.83	0.67	±0.67	79.44	58.89	0.000	0.306
Rotation	2.96	±2.84	0.86	±0.53	70.94	53.04	0.87	±0.66	70.60	41.21	0.000	0.971
Lateral Bending	2.92	±2.32	1.07	±0.55	44.5	32.73	0.93	±0.62	68.15	46.92	0.000	0.274

Discussion

Methods of stabilizing the cervical spine vary significantly [21].

The Halo brace provides the greatest cervical spine stabilization [5, 22, 23]. However, it is associated with complications such as poor fit, risk of death, loss of reduction, pin-track infections, displacement of anterior strut grafts, premature removal of the halo vest, and other miscellaneous issues [24-26]. These complications may discourage patients from wearing the Halo brace. Minerva is an alternative for cervical spine stabilization that presents fewer complications than the Halo brace[8]. Some reported complications include soiling of straps due to their placement directly over the forehead and shoulders, necessitating consistent skincare. Mild fever, temporary hoarseness, and stiffness of facial muscles have also been reported [27]. However, Tommy et al. did not observe these complications in their series [12].

All cervical braces provide adequate support; however, their efficiency appears to surpass that of the SOMI (Sterno-Occipital-Mandibular Immobilization) brace, which limits cervical motion by approximately 93% in flexion, 42% in extension, and 66% in both lateral bending and rotation [28]. It is important to note that the types of motion analysis methods used varied between studies. Based on the results of this and previous studies, it can be concluded that the immobilization efficiency of these braces in the cervical region exceeds that of other available braces, including the Aspen collar, Miami brace, and two-post and four-post collars [22, 23, 28-30].

This study concluded that flexion and extension immobilization of the cervical region by both the modified Iranian and rigid Minerva braces was nearly complete. Lateral bending and rotation immobilization with these braces in the cervical region were substantial. Except for lateral rotation movement in the modified Iranian brace, all other movements in both braces were moderately immobilized. Karimi et al. reported cervical region Minerva ROM limitations ranging from 90% to 86.23%, which aligns with the findings of this study due to the use of similar methods [19]. Dennis et al. observed that thermoplastic Minerva provided nearly complete immobilization at 83.64%, substantial restriction in lateral bending at 74.42%, and rotation restriction when measuring intersegmental flexion and extension via radiography [31]. However, the use of X-rays exposes subjects to radiation risks [32, 33].

Zhang et al. evaluated four braces, including the Minerva, by measuring CROM immobilization using the Vicon 3D motion capture system. In their study, the Minerva brace reduced flexion, extension, rotation, and lateral bending by 70.6% (substantial), 35.4% (fair), 50.7% (moderate), and 20.8% (fair), respectively. However, this method did not differentiate between movements of the neck, head, and trunk, which may have contributed to the differing outcomes observed [34].

Nevertheless, the modified Iranian and rigid Minerva braces do not differ significantly in limiting the range of motion, and both provide high immobilization, making them suitable options for cervical fracture healing following the Halo brace or as alternatives to the Halo brace in certain situations. One advantage of the rigid Minerva is its adjustability, which the modified Iranian Minerva lacks. This feature makes the rigid Minerva more favorable for clinicians. Patient comfort, especially during prolonged brace use, should be a focus of future studies [23, 35, 36]. While immobilization is the primary factor, comfort, ease of application, and airway accessibility must also be considered. Discomfort can lead to non-compliance, reducing the effectiveness of an otherwise excellent brace. Similarly, a brace that is difficult to apply may be poorly fitted. These factors should be incorporated into cervical brace design [18]. Evaluation of cervical intervertebral immobilization was not possible in this study due to a lack of access to radiographic imaging, which, as noted earlier, carries health risks. Future studies might consider measuring cervical intervertebral immobilization using cadaver models, although results may differ from clinical trials.

Evaluating subjects with cervical fractures was not feasible in this study, as neck movement could exacerbate their injuries. For future research, it is recommended to assess immobilization in volunteers who apply and adjust the brace themselves, reflecting real-life usage conditions, which may produce different outcomes.

Conclusion

Both Minerva braces significantly reduced the neck's range of motion ($p < 0.05$). The rigid Minerva was more effective in restricting extension and lateral bending, whereas the modified Iranian Minerva provided greater immobilization in flexion and rotation.

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Ethical Approval

The Esfahan University of Medical Science Ethics Committee Approved The Study (IR.MUI.NUREMA.REC.1401.063). IRCT approval: (IRCT20221129056658N1)

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