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Research article

Cervical misalignment in motorcyclists in relation to new helmet removal recommendations shown with augmented reality resources: A biomechanical analysis

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ABSTRACT

Objective: The aim of this study is to determine the best technique and position for helmet removal in injured motorcyclists by comparing cervical misalignment produced in the supine position and prone position.
Method: Comparative cross-sectional clinical simulation study to quantify CM using biomechanical analysis with the use of inertial systems. The main variable was determined for the flexion-extension motion. The extraction was tested for both positions (prone position and supine position), which were repeated 3 times for each of the 30 volunteers included, and the movement from the initial neutral position was also determined, resulting in a total of 270 biomechanical studies.
Results: A flexion was observed when moving the patient from the neutral position to the SP, due to the size of the helmet, of 1.29° ± 5.12°. Helmet removal in the supine position resulted in an average flexion-extension range of 17.51° ± 6.49°, while the same extraction in prone position recorded an average range of 10.82° ± 8.05°. For the main variable, statistically significant differences were found when comparing prone position and supine position ($p = 0.0087$).
Conclusions: The main conclusion of the study is that the helmet removal should be done in the position in which we find the patient, whether in prone position or supine position. Additionally, the new technique described for the prone position causes less movement of the cervical spine than the usual supine position.

1. Introduction

The World Health Organization (WHO) estimates that 1.3 million individuals die annually from vehicle collisions, with almost half of the deaths composed by vulnerable users (pedestrians, cyclists, and motorcyclists) [1]. According to the 2022 report from the

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General Directorate of Traffic in Spain (DGT), 1145 people died in Spain on that year, with 12% being motorcyclists [2]. Spinal cord injuries (SCI) are catastrophic, independently of their etiology. Trauma-based SCI have a high morbidity and mortality [3] and are a worldwide problem, although the etiology is not the same in every country [4,5]. Traffic accidents are reported to be the main cause of SCI [5], with many of them being preventable [1,6]. In Spain, according to the data from the National Hospital of Paraplegics, as of 2023 there has been an 8% increase observed in SCI compared to 2021, which confirms the increasing trend in the last few years. Of the total, 18% correspond to a traumatic cause such as traffic accident [7].

The out-of-hospital approach to a person injured in a traffic accident, considering an initial suspicion of SCI, is adequate for optimizing care, in order to reduce the morbidity and mortality associated with the situation [5,6,8], Helmets are the most efficient protection for decreasing the morbi-mortality of motorcyclists [9–12]. They protect motorcycle users from cranial, cerebral, jaw and facial injuries; and this is a key aspect, as head injuries are classified as being the most common [9]. However, although they reduce cervical injuries [9], they also offer little protection to the neck [10,13], so that a possible lesion needs to be discarded.

The alarming figures presented suggest the need for good knowledge for the optimum health care of injured motorcyclists. It must be considered that the kinematics of the collision, and the safety elements, are determining factors in the related injuries [10,13,14].

Addressing an injured motorcyclist implies a series of steps and techniques which could aggravate the initial injury. One of the first steps is to remove the full-face helmet of the rider, which is defined as a fundamental act for an optimal initial assessment of the patient, an adequate access to the lungs, the assessment of lesions, and the placement of immobilization devices [10,13–16]. Almost all of the helmet-removal procedures previously described are centered on the technique with the patient in the supine position (SP), and it requires two rescuers to perform the technique: one rescuer who takes control of the head with the bimanual cervical stabilization, and a second rescuer who removes the helmet [14–16]. Thus, in the practice of care, when the hurt motorist is found in the prone position (PP), they are usually turned over, to afterward remove the helmet [14–16]. The most common helmet removal techniques are the Saw Technique (ST), widely described in the literature [10] and the Continuous Traction Technique (CTT), which implies the traction and widening of the angle in a posterior manner to overcome the tip of the nose [13–17].

Some studies seem to point out that the large volume of the motorcycle helmet on the floor results in the victim being in a cervical flexion position [10,13]. The hypothesis of this study is that the SP provokes a lever effect against a flat plane such as the floor, leading to a greater misalignment of the spine. Therefore, it is perhaps better to remove the helmet in the position in which we find the motorist, to afterward continue with the alignment as needed. The main objective of the present study is to analyze the cervical misalignment (CM) produced during the removal of a helmet of a motorcyclist after an accident, to compare the supine position (SP) with the prone position (PP). The secondary objective is to assess if the SP produces some degree of alteration as compared with the

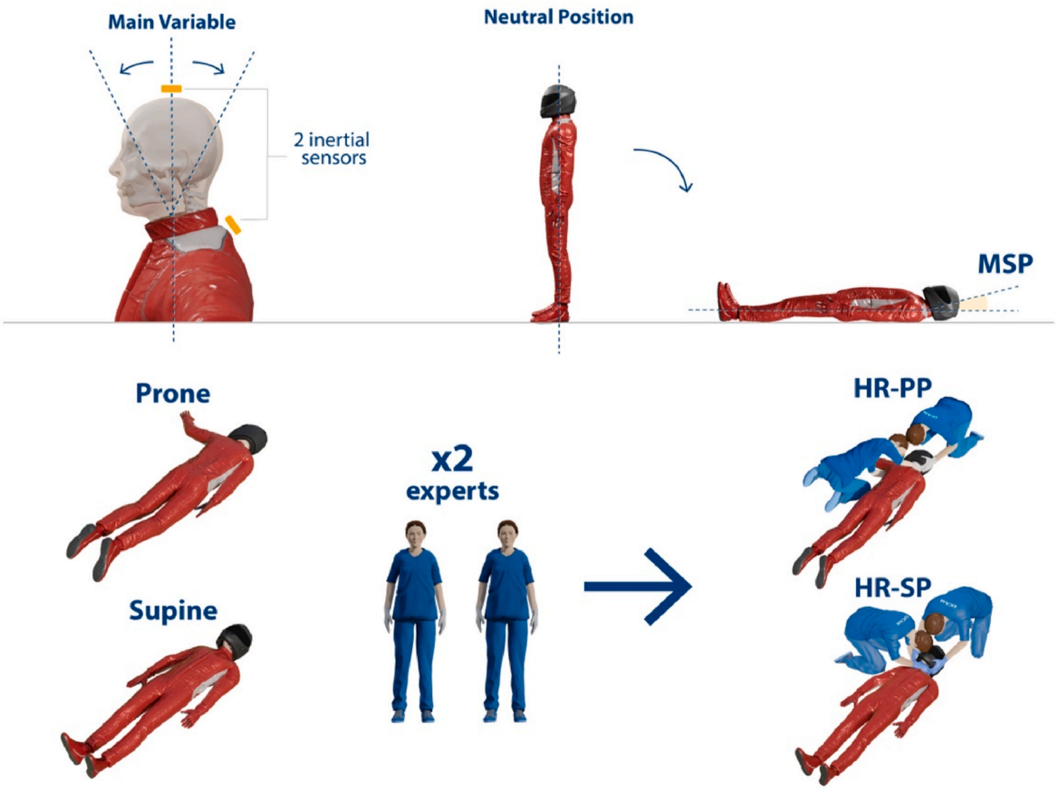

Fig. 1. Flow diagram of the study procedures and variables.
MSP: misalignment supine position; HR-PP: helmet removal prone position; HR-SP: helmet removal supine position.

neutral position (NP) of the patient.

2. Material and method

A comparative cross-sectional study with a clinical simulation was conducted. The movement of the cervical spine was analyzed during the removal of a motorcycle helmet, via a biomechanical analysis through the use of inertial sensors (IS) (Fig. 1). This work was approved by the Ethics Committee from the Catholic University of San Antonio (UCAM), with registration number 6.118. All the participants signed an informed consent form, and the Declaration of Helsinki guidelines were followed.

2.1. Sample selection

An open call was made, which obtained a sample of 30 participants, considered sufficient for performing the study, according to the Central Limit Theorem [18,19].

For the selection of the volunteers, the following inclusion criteria were applied:

- Being older than 18 years old.
- Signing the informed consent form.
- Completing the basic personal data form.

The exclusion criteria applied were the following:

- Having a physical injury making experimental steps impossible.
- Lack of attitudes or aptitudes to follow the indications given.
- Appearance of discomfort or pain during the study.

Each volunteer assumed the role of an unconscious victim wearing a helmet. The volunteers completed the personal data sheet: sex, age, weight (Kg), and height (cm). Each participant was subjected to a measurement of the head circumference (cm); the adequate helmet size was calculated, and they were offered an adequate size model. Following the recommendations from the manufacturer, the available sizes were S (for perimeters from 55 to 56 cm), M (perimeters from 57 to 58 cm), L (perimeters from 59 to 60 cm), and XL (for perimeters from 61 to 62 cm).

2.2. Helmet removal techniques

The helmet removal was performed by two P.H.T.L.S. (*Prehospital Trauma Life* Support) instructors, with one performing the manual cervical control, while the other removed the helmet from the simulated victim, utilizing the CTT in all cases. The team

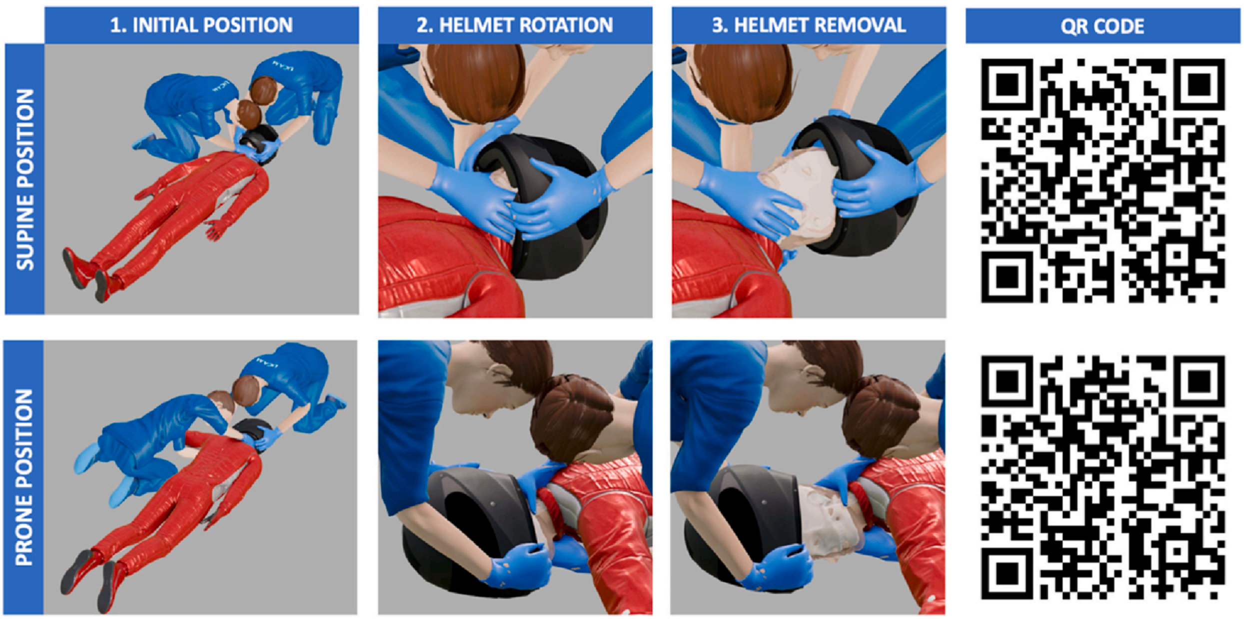

Fig. 2. Diagram of helmet removal in two positions (supine and prone) and QR codes with a digital reconstruction in augmented reality of both.

professionals were highly trained in out-of-hospital care (with more than 5 years of out-of-hospital work and in severe trauma training units), so that we could assume that they were highly skilled in these techniques.

Each of the participants was subjected to each intervention three times: a) helmet removal (HR) in the SP (HR-SP); b) helmet removal in the PP (HR-PP); and c) cervical misalignment in SP (MSP). For the calculation of MSP, the range of motion was determined as the change from the NP of the patient in a standing posture while wearing the motorcycle helmet to the support of the posterior part of the body in a standing position against a rigid plane (wall). The NP was determined in the standing position with the body and extremities relaxed, and the head looking straight. Also, a and c were added (HR-SP + MSP) to calculate the total misalignment a motorcyclist is subjected to when removing the helmet in this position, which was named SP Sum. The technique utilized, according to the position, as well as the measurements, are shown graphically with a 3D reconstruction of the process in Fig. 2.

2.3. 3D digital reconstruction

The 3D digital reconstruction of the helmet removal in SP and PP were designed with the program *Blender*, and exported in GLB format (Fig. 2). The anatomical models shown used the normal body proportions, through the use of basic objects that were modified by the 3D designers from the *VR Lab* at the UCAM. The files were uploaded to the *Skethfab* platform to be able to interact with them. Also, high-resolution screenshots renders were obtained. The instructions can also be used as augmented reality through the QR link (Fig. 2). This can be done by scanning the QR with a smartphone or tablet device > go to the QR link > authorize permissions of use > click on "*Tap here to place in your space* > follow the instruction). Once the object is positioned, it can be turned, its size can be changed, it can be moved around and a picture can be taken with a screenshot.

2.4. Biomechanical analysis

The analysis of the movement was performed through the use of an IS system STT-IWS (STT Systems). The data, was collected by wireless sensors (WiFi) at a frequency between 25 and 400 Hz, offers the information on screen and ready to export and analyze. These IS are composed by an accelerometer, a gyroscope, and a magnetometer, wrapped with a rigid case (56 mm × 38 mm × 18 mm), weighing a total of 46 g. Among their characteristics, we find a transmission frequency of 8 kHz/10-bit and a static Pitch precision of <0.5°, static Roll <2°, and static Heading <2°. The IS determines the angular orientation, with values obtained for the three spatial coordinates (X, Y, and Z).

The data on the degree of cervical misalignment are automatically generated during the acquisition of the movements in real time. The communication of the sensors is wireless, through the use of a local network (such as Wi-Fi). The biomechanical model of movement analysis of the cervical spine was chosen. Two IS were placed on the simulated victim who played the role of an unconscious accident victim: a cervical one (upper part of the head) and one on the back (between the C6 and C7 cervical vertebrae). For the analysis of movement of the cervical flexion-extension, the mean degree of movement was measured in degrees. The rotation and lateral movements were excluded from the results, as these ranges of movement are very small, and without significant differences or relations with other variables.

2.5. Statistical analysis

The data were exported to the Microsoft Excel®, and were examined with the IBM SPSS Statistics® version 24 program. Given that a new method is proposed, with respect to an already-established one for the removal of helmets, a quality-reliability measurement was performed with the Bland-Altman method. The data are presented as frequency, range, mean, standard deviation (SD), and confidence interval (CI) at 95%. The main variable was the comparison of the range of movement of the cervical spine during flexion-extension between HR-SP and HR-PP. The secondary variables were: age, sex, height, weight, head perimeter, helmet size, rotation to the right, rotation to the left, right lateral movement, and left lateral movement. A repeated measures ANOVA was used to compare the results, and a $p < 0.05$ was used to determine statistical differences.

3. Results

The descriptive variables considered were: sex, age, body mass index, and helmet size. The distribution of volunteers, with respect

Table 1
Results of the flexion-extension movement of the cervical spine for each of the helmet removal positions studied.

Technique	N	Mean	Standard deviation	Comparison	Significance
CMS	30	1.29°	±5.01°	–	–
HR-SP	30	17.51°	±6.49°	**HR-SP vs HR-PP**	**0.0003***
HR-PP	30	10.82°	±8.05°	**HR-PP vs PS Sum**	**0.0087***
PS Sum	30	18.72°	±10.23°		

*p values denoting statistical significance ($p < 0.05$); **MSP** (cervical misalignment in the supine position); **HR-SP** (helmet removal in the supine position); **HR-PP** (helmet removal in the prone position); **PS Sum** (sum of the helmet removal in the supine position and cervical misalignment in the supine position).

to sex, were: 43% women and 57% men. The mean age was 29 ± 9 years old, and the volunteers were classified into 5 age groups: younger than 20 years old (y.o.) (3.3%), 21–29 y.o. (80%), 30–39 y.o. (3.3%), 40–49 y.o. (3.3%), and 50–59 y.o. (10%). The distribution of the groups, with respect to body mass index, with a mean of 24.74 (normal) ± 5.48, was: 3.3% underweight, 63.3% normal, 20% overweight, and 13.3% obese. As for the type of helmet, a mode of the M size was observed (30% S, 37% M, 33% L), verified to be adequate after the measurement of the head diameters, which obtained a mean of 57.13 ± 2.39 cm.

Initially, a quality-reliability measurement was performed of the helmet extractions through the Bland-Altman method, with adequate results obtained (Supplementary Material 1 and 2), which support the reproducibility of the techniques analyzed. The results from the simulation experiment are shown in Table 1. The main variable of the study is shown in Fig. 3, which compares the ranges of cervical flexion, with it being smaller for HR-PP, with a value of 10.82° ± 8.05°, as compared with HR-SP, with a value of 17.51° ± 6.49° ($p = 0.0003$). This implies that the removal of the helmet in the SP increases the flexion-extension by 66% as compared to the PP.

With respect to the patient who was turned over from the supine position to the prone position, we used a combination of the flexion produced by the helmet, 1.29° ± 5.01°, and that already described by the HR-SP. Their sum, defined as SP Sum, was found to be 18.72° ± 10.23°. Based on its comparison with the HR-PP, a greater cervical movement was observed ($p = 0.0087$). This implies an increase in the flexion-extension movement of 73% as compared to helmet removal in the PP.

4. Discussion

From the time an accident occurs and the SCI victim receives out-of-hospital care, until stabilization and admission to the hospital, successive transfers increase the risk of causing or aggravating the spinal cord injury [20]. In the study by Nicola et al., an adaptation to the transfer of SCI patients sequence created by Conrad et al. [17], is proposed, which includes the removal of equipment (helmet from the injured motorcyclist) as part of the cycle; in our case, this is considered a critical point.

Most of the manuals and protocols indicate performing a HR-SP [10,13–16]. The results obtained in our study show that all helmet removal techniques tested provoke a certain degree of movement, especially flexion-extension. It is not possible to determine, on an SCI patient, the exact point or degree of movement in which a greater injury or secondary injury is produced. Following the principle of *primum non nocere*, and having determined that all the positions will cause harm or movement, we must select the least harmful. In our case, this was the PP. With respect to HR-SP, a range of movement almost four times less was observed, as compared to the range found in another study from the literature, in which the removal of the helmet of the injured motorcyclist was measured with inertial sensors in the supine position [21]. A possible explanation for this difference was the use of the ST in their study, as compared to our use of the CTT. The results from a previous study conducted by the same authors, for comparing the ST and the CTT, indicated a greater range of movement in the SP with both techniques [17]. A possible explanation, also applicable to the study by Gordillo et al. [21], could be large sample of interventions in the present study, or the performance of the technique by two PHTLS experts.

In the data obtained in our study, the results were better for HR-PP as compared to HR-SP, which increased the cervical movement by about 66%. Perhaps this could be due to the lever effect of the posterior part of the helmet with the floor; when rotating the helmet to avoid touching the nose, the helmet pushes against the back of the head, bending the neck. This does not occur in the PP, given that in this position, the helmet does not act as a lever against the floor, as the helmet is rotated in an axis of movement parallel to the floor, and not perpendicular to it. It must be highlighted that turning the patient over from a SP position to a PP position is not recommended, as the maneuver creates more movement than the difference between both positions. To our knowledge, there are no scientific publications that have addressed the possibility of removing a helmet in the PP, therefore, there are no aviable studies that could be used which to compare our results.

The step from a NP to a SP provokes a slight cervical flexion due to the large volume of the posterior part of the helmet. These data

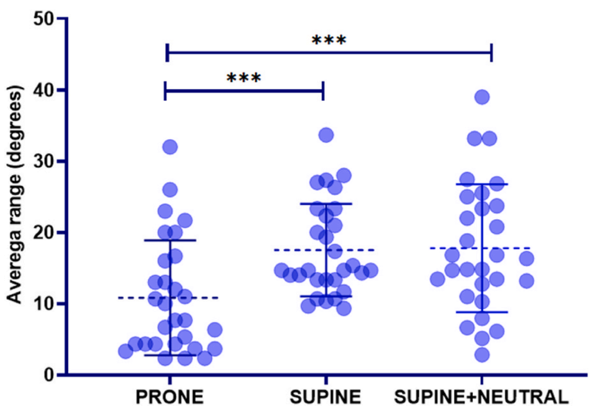

Fig. 3. Comparison of average range of cervical movement during helmet removal in a simulated injured motorcyclist in each of the positions studied.
Prone (helmet removal in the prone position); **Supine** (helmet removal in the supine position); **Supine + Neutral (**PS Sum; sum of the helmet removal in the supine position and cervical misalignment in the supine position).

are in agreement with previously-published articles with respect to this movement [10,13]. Given that the misalignment observed by the sum of HR-SP and the forced flexion from the NP to the SP increases the cervical flexion-extension by 73% with respect to HR-PP, the data obtained support the removal of the helmet in the PP when the patient is found in that position. We understand that this helmet removal proposal in the PP refutes what has been previously published about the technique in the SP [10,13–16]. However, to our knowledge, this is the first time that a biomechanical study has been conducted that ratifies this variation of the application of the helmet removal position.

Among the limitations of the present study, we must underline the stability of the spinal column of the volunteers, which practically limits the extrapolation of the results, as a certain degree of difference could exist with the real SCI victims and/or the instability of the column. Nevertheless, we must also consider the high reliability of the inertial sensors, in agreement with the results obtained in other studies that utilized similar systems [17,21–27]. In addition, the establishment of the maximum levels of acceptable cervical flexion prior to data analysis through the Bland-Altman method support the reliability of the data obtained in the simulation. Another limitation is the inability to compare the HR-PP results, as no similar studies were found in the literature. Consequently, the present work opens a line of research for the improvement of severe trauma care in the case of accidents that involve motorcycle riders.

In conclusion, the new HR-PP position provokes less movement of the spinal column as compared to the habitual HR-SP position. However, this does not justify the movement of the patient from a PP to a SP. Therefore, a recommendation is made to remove the helmet in whatever position the victim is found, and more specifically, if the victim is found in the PP, to not turn the patient to the SP before removing the helmet. Also, we support the conclusions from other authors, with respect to the spinal column of a patient in SP not being in a NP, but rather in a slight flexion.

Data availability statement

The data from the research conducted have been deposited in a publicly accessible repository: Institutional Repository of the Catholic University San Antonio of Murcia (RIUCAM), under access number 6.118.

CRediT authorship contribution statement

Ana Nicolás Carrillo: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Javier Ruiz Casquet:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Juan José Hernández Morante:** Writing – review & editing, Formal analysis, Data curation, Conceptualization. **Francisco Gallego España:** Writing – original draft, Validation, Methodology, Investigation, Formal analysis. **MaryBeth Horodyski:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Catalina Baez:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Manuel Pardo Ríos:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e27428.

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