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ORIGINAL RESEARCH

Adaptation and validation of a pediatric simulator to study the movement of the cervical spine

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Abstract

This study focused on adapting and evaluating the reliability of a pediatric simulator to assess the mobility of the spinal cord in its cervical segment. A comparative analysis was conducted on cervical mobility of 4 adapted pediatric simulators followed by a reliability study of the simulator that demonstrated ideal mobility characteristics. The simulator with the type of movement that was most similar to real-life physiological movement was "Simulator 1", with degrees of movement of: flexion 30° ± 4°, extension 43° ± 2°, left lateral movement 30° ± 2°, right lateral movement 32° ± 3°, left rotation 27° ± 2°, and right rotation 25° ± 2°. The reliability of this simulator was analyzed using the intraclass correlation coefficient, with a high reliability result. The results according to the axes were as follows: flexion-extension movement (0.937; $p < 0.001$), left-right lateral movement (0.893; $p < 0.006$), and left-right rotation (0.845; $p = 0.006$). Consequently, the pediatric simulator that we have adapted, allows us to determine the movement of the spinal cord in its cervical segment, with a very good degree of reliability.

Keywords

Pediatric simulator; Traumatic spinal cord injury; Reliability; Adaptation

1. Introduction

A pediatric spinal cord injury (SCI) represents around 2.5%–5% of the total annual incidence of traumatic spinal cord injuries (TSCI) [1, 2], with falls being the most common cause [1] in a sports context, according to some studies [3, 4]. Cervical injuries are the most common type of TSCI, with the incidence being double in children (80%) than adults (30%–40%) [1, 2]. Due to their anatomy, the risk of a SCI of children is smaller, although the consequences are not always or necessarily less devastating [5]. Children have a more flexible spinal cord, due to increased ligamentous laxity and less densely packed spinal ligaments, to their muscles being still under development, and underdeveloped spinous processes. Therefore, the pediatric spine is considered hypermobile as compared to the adult spine [6]. Until the age of 8, differences are observed in their spinal cord with respect adults, as well as an imbalance between their head and torso, with the craniocervical junction being the most vulnerable [1, 6–8].

In general, there are three main mechanisms that can lead to pediatric SCI (flexion/extension, acceleration/deceleration and rotational injury) [2]. Forces, impacts and injuries have different effects, and at this age, the injuries provoked by the acceleration and deceleration forces in a traffic accident tend to be more common [9]. We thus find ourselves with the complex diagnosis at this age, given that in the evolution of the development of the spinal cord, we can find parts that are not ossified yet, or cartilage undergoing processes of development, which can be confused with non-existing injuries, and *vice-versa* [6–8].

Health professionals consider that the restriction of movement (RM) is necessary for children when faced with a strong impact, a response that is not always reliable, although it is performed due to the fear of a possible misdiagnosis that could result in TSCI [10, 11]. The available evidence regarding protocols and management of pediatric patients, as well as their outcomes following trauma, is limited, and there is a prevalent reliance on pragmatism due to the absence of standardized techniques. However, this may heighten the risk of potential spinal cord injuries (SCI) [12, 13]. The creation of new protocols based on studies with real patients would imply a high risk for the victims, although for major trauma patients, time is critical, and any delay or mistake could result in fatal repercussions [14, 15].

Medical learning through simulation has become an increasingly important tool in recent years [16]. It is considered reliable, as there are numerous studies available in the literature that are based on simulation-based learning [15, 17–19].

Thus, a study was planned for choosing, preparing, adapting and validating a simulator that could comply with the anthropometric characteristics of a pediatric patient, which could allow for the continuous monitoring of the movement of the spinal column, in its cervical segment, in order to evaluate the quality of the mobilization maneuvers and RM. It is believed that having a highly reliable pediatric simulator creates a wide range of possibilities for conducting, to the highest degree of reliability possible, research in the care of pediatric patients with suspected spinal cord injury.

2. Materials and methods

A comparative analysis was conducted to assess the spinal cord mobility of 4 distinct pediatric simulators. The objective was to identify the most suitable simulator among the four candidates. Subsequently, a reliability study was undertaken on the chosen simulator to evaluate the precision and consistency of measurements pertaining to spinal cord movement within the cervical segment.

The study was conducted in Spain, at the Catholic University of Murcia (UCAM). The sample was comprised of 4 pediatric simulators (Simulator 1: Pediatric Hal® S3005, from Gaumar/Simulator 2: SimJunior®, from Laerdal/Simulator 3: Kyle®, from Simulaids/Simulator 4: Child Rescue®, from More Than Simulators), with different characteristics and weights (Fig. 1). The simulators that were available, had a non-rigid structure allowing joint movement, and followed the growth percentiles of the World Health Organization (WHO) [20] were utilized. The anthropometric data corresponding to the WHO percentiles for a 5-year-old child are the following: a weight of 18.3 kg and a height of 110.0 cm. Weight was added to the head of each simulator to reach a total of 1 kg, and the mobility of the neck was modified to reach the maximum ranges of movement (Fig. 2). Afterwards, a total of 30 repetitions, which each simulator, were executed for each of the following movements: flexion, extension, lateral bending to the left and right, as well as left and right rotations.

In a pediatric unstable column, the range of movement is very high [5, 21]; thus, a decision was made to choose the simulator with the largest mean range of movement. After the simulator was chosen, a reliability analysis was conducted by executing 100 repetitions of each of the movements while applying a 1 kg force.

2.1 Inertial sensor

The analysis of movement was determined through the use of inertial sensors (IS) (STT Systems Group, San Sebastián, Spain), model STT-IBS iSen 3D Motion Analyser®. These IS have been used in other, similar studies [18, 19]. These IS were composed by an accelerometer, a gyroscope, and a magnetometer, wrapped by a rigid case (36 mm × 15 mm × 46.5 mm) with a total weigh of 29 g, a transmission frequency of 250 Hz, static precision (roll, pitch, yaw) $<0.5°$, dynamic precision (roll, pitch, yaw) $<1.5°$, and a latency of less than 0.004 s. The IS determines the angular orientation, thus providing values in the 3 axes of space (X, Y and Z). Two IS were placed on the simulator: one inside the head (upper area), and one on the inside of the thorax (retrosternal).

2.2 Statistical analysis

The data were collected with the EXCEL Microsoft program (EXCELL v2019. Microsoft Corporation, Redmond, WA, United States) and analyzed with the SPSS statistics v26 program (IBM, Armonk, NY, United States). The data are shown as means and standard deviations (SD). The Intraclass Correlation Coefficient (ICC) was utilized to determine reliability. To interpret the ICC, which determines the level of reliability or agreement of the results obtained, the classification by Prieto *et al.* [22] was followed. Thus, an ICC <0.3 indicated a low reliability, an ICC between 0.3–0.5 indicated to a moderate correlation, and an ICC >0.5 indicated a high reliability. The differences were defined as statistically significant if $p < 0.05$.

3. Results

The initial phase of the study involved the selection of the most appropriate simulator. Table 1 displays the averages of the maximum range of movements recorded during the simulations with the 4 devices chosen for the initial tests. After analyzing the results of the recorded cervical movements, "Simulator 1" (Pediatric Hal® S3005, from Gaumar) was chosen as the most suitable for our study, due to its wider range of forced mobility, as it was the closet to the pediatric patient with an unstable spine. The degrees of movement of the simulator selected were flexion 30° ± 4°, extension 43° ± 2°, left lateral movement 30° ± 2°, right lateral movement 32° ± 3°, left rotation 27° ± 2°, and right rotation 25° ± 2°.

The reliability of Simulator 1 obtained ICC results for the flexion-extension movement of 0.937 ($p < 0.001$), 0.893 ($p < 0.006$) for the left-right lateral movement, and for the left-right rotation, 0.845 ($p = 0.006$). The results showed an ICC with a "high" reliability for the three movement axes analyzed.

4. Discussion

The available literature on the management of pediatric spinal cord injury is limited, and there is no specific pediatric simulator on the market for analyzing cervical misalignment. The information gathered from the management of spinal cord injury in adults is not applicable to children under the age of eight due, to numerous differences in the spine between the two populations. In these children, the greater number of vertebrae in the spine, the higher center of rotation (COR) at the cervical level (C2–C3), increased cerebrospinal fluid (CSF) volume, greater spinal flexibility, increased muscle weakness, and a larger head size relative to body surface area, all contribute to these differences [6].

We have not found studies on cervical movement in children with traumatic spinal cord injuries (TSCI). Some authors have studied cervical instability by inducing injuries in adult cadavers, and have demonstrated that after an injury, an unstable spinal column results, leading to wide ranges of motion due to section, distention or injuries to different ligaments [21]. Del Rossi *et al.* [21], for instance, conducted studies based on previously prepared cadavers, inducing injuries at the cervical level (C5–C6) of the spinal cord in each cadaver, obtaining movement results of more than 11° [21]. In our study, the simulator achieved values greater than 30° ± 2°. Given the

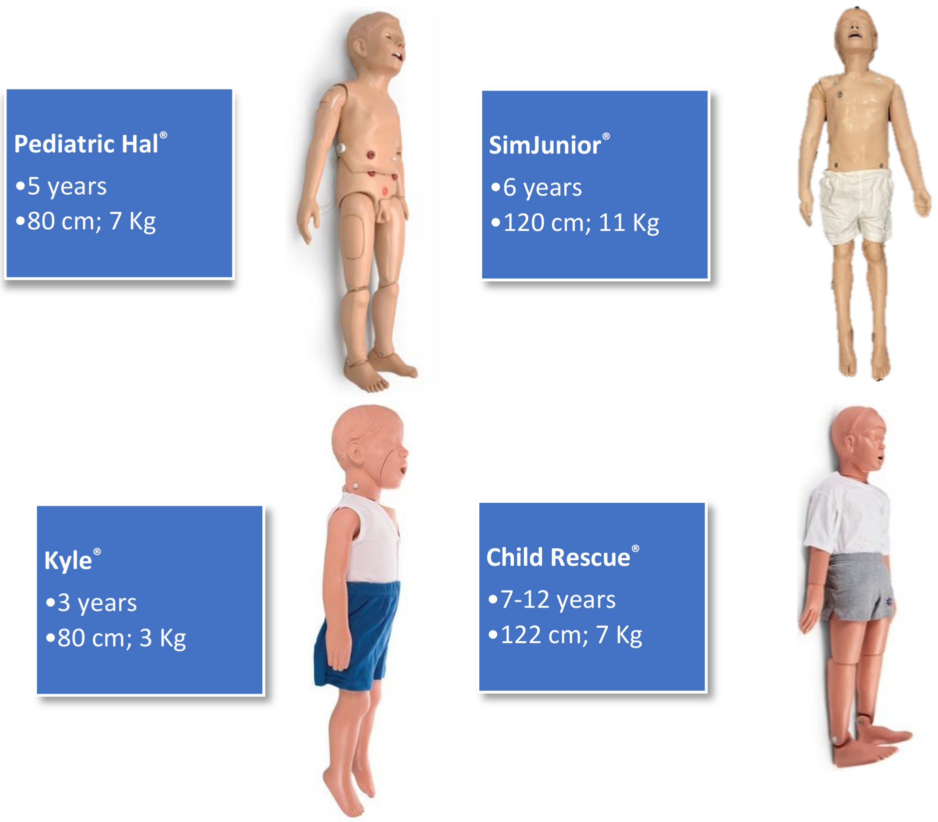

FIGURE 1. Name and technical characteristics of each of the 4 simulators.

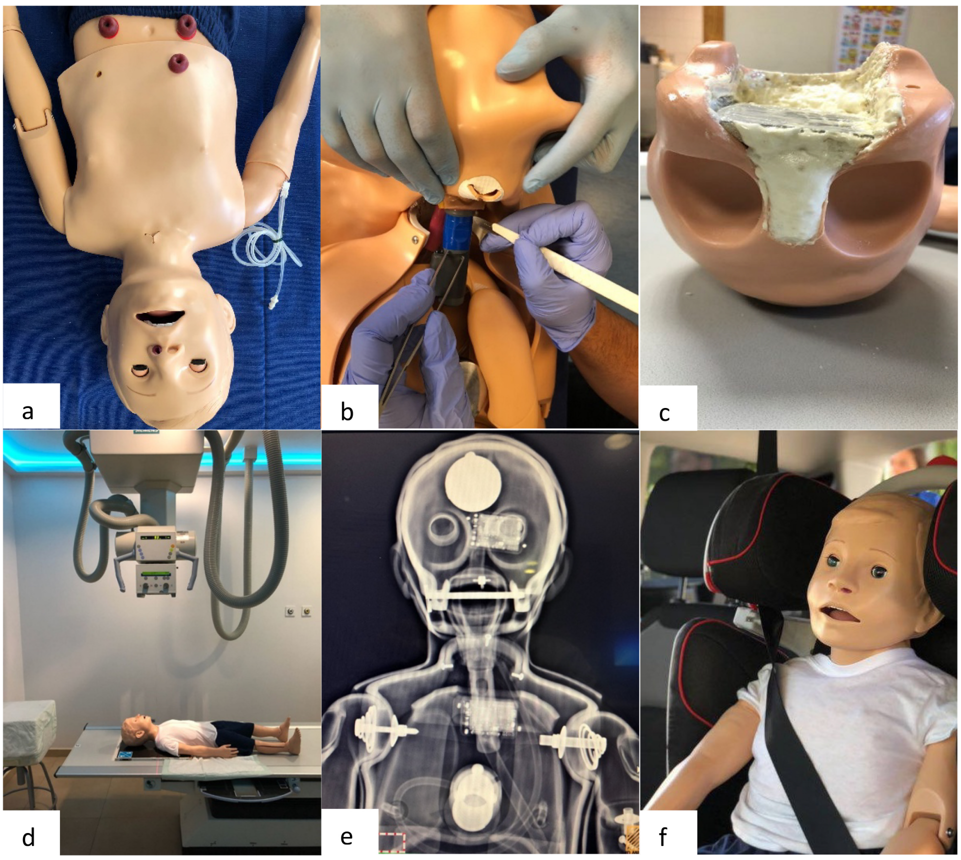

FIGURE 2. Process of modification and adaptation of the simulator. (a) simulator selection; (b) modification of neck mobility; (c) adaptation of the head to 1 kg in weight; (d) anteroposterior radiograph of the device; (e) result of the adaptation of the device; (f) final result of the adapted simulator.

TABLE 1. Means of the degrees of maximum misalignment of each simulator. The data are presented in degrees as: mean ± standard deviation.

	Flexion	Extension	Left Lateral Movement	Right Lateral Movement	Left Rotation	Right Rotation	Mean
Simulator 1 (Pediatric Hal®)	30° ± 4°	43° ± 2°	30° ± 2°	32° ± 3°	27° ± 2°	25° ± 2°	31° ± 2°
Simulator 2 (SimJunior®)	38° ± 4°	34° ± 3°	12° ± 2°	11° ± 2°	13° ± 2°	12° ± 2°	18° ± 2°
Simulator 3 (Kyle®)	18° ± 4°	42° ± 5°	27° ± 4°	30° ± 3°	25° ± 3°	27° ± 3°	28° ± 4°
Simulator 4 (Child Rescue®)	12° ± 2°	23° ± 4°	24° ± 3°	25° ± 3°	24° ± 4°	26° ± 3°	22° ± 3°

inherent hypermobility of the pediatric spine as compared to the adult spine, it is believed that cervical instability may result in even greater ranges of motion in children, and the ideal simulator would allow for a greater range of movement [6].

The chosen and adapted simulator allowed us to obtain extensive ranges of motion, with anthropometric measurements corresponding to those of a 5-year-old child according to WHO standards [20]. The results of the reliability test, assessed through the ICC, indicated a high level of agreement and excellent reliability, thereby providing a valid and reliable tool, as described by authors such as Prieto *et al.* [22].

In the biomechanical study conducted by Hontoria *et al.* [18], to analyze cervical misalignment during pediatric patient extrication using the RM SIPE Baby Rescuer® device, the simulator from our study was employed. The results obtained with the RM SIPE Baby Rescuer® device showed that it allows for the extrication of pediatric patients with high levels of spinal RM [18]. Such an analysis would be impossible to carry out on real patients due to legal and ethical constraints, as conducting experiments on actual patients would not be safe [2]. Hence, the RM SIPE Baby Rescuer® could not have been safely evaluated without the simulator. This is closely related to the primary limitation of our study, as it is a simulation, and the data does not originate from real patients. The life of an individual and the importance of timely action take precedence, preventing any delay in patient care due to an experiment. Therefore, simulation has emerged as the ideal solution for learning and providing new data without jeopardizing patient lives [23, 24]. This approach is currently widely practiced, and it is considered reliable [15, 17–19].

Managing major trauma patients, both adults and pediatrics, is extremely challenging. There is a notable lack of scientific evidence to determine the optimal choice of techniques and devices for spinal motion restriction (RM), and to support the development of protocols. The management of traumatic spinal cord injury cases in pediatrics is controversial, similar to that in adults [17, 25–28]. Survey results, such as those by Khetarpal *et al.* [29], conclude that even within the same state, recommendations for spinal clearance and pediatric immobilization are discrepant. In 2022, Nolte *et al.* [30] developed a new and interesting Emergency Medicine Spinal Immobilization Protocol for pediatric trauma patients. It was evaluated and shown to have a high level of compliance among professionals who performed the applicability test (82.9%), and a very high rate of professionals considered the protocol useful (97.8%) as well [30]. However, it should be noted that these professionals constituted a small group (44 participants) from the same location (Germany), so further research is needed to consider this protocol as applicable to broader trauma healthcare.

For all of these reasons, a simulation tool was adapted and validated to measure cervical misalignment in pediatric patients after a severe collision. This provides a valid and reliable tool for future studies and research. This opens the door to a vast realm of knowledge, as a reliable tool is now available to explore the care of pediatric patients with major trauma. This field of study is considered largely unexplored and of vital importance for finding reliable and adequate protocols for managing children with major trauma.

While various simulators are available on the market for techniques such as basic care, resuscitation and the development of skills in different medical and nursing areas, specific simulators for assessing spinal column movement in pediatric patients are not currently available. Our simulator is capable of providing a reliable measurement of simulator angulation when the same traction force, in the form of a 1 kg weight, is applied.

5. Conclusions

The main strength of this study is the adaptation of a pediatric simulator. Usually, these simulators are developed for training in other competencies such as cardiopulmonary resuscitation (CPR), care or trauma. With our results, we can now provide training on the management of a pediatric patient with a suspected SCI. The main conclusion of this study is that the selected, adapted, and validated pediatric simulator can determine spinal column movement in its cervical segment with a high degree of reliability.

AVAILABILITY OF DATA AND MATERIALS

The data are contained within this article.

AUTHOR CONTRIBUTIONS

MPR, LJR—designed the research study. RGM, MIHH and PRB—performed the research. JRC, ANC and MFP—analyzed the data. JRC and ANC—wrote the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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