Neurosurgery Simulators Developed for Neurosurgical Training in Brazil: A Systematic Review

Simuladores de neurocirurgia desenvolvidos para o treinamento neurocirúrgico no Brasil: Revisão sistemática da literatura

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Abstract

Introduction Simulation in neurosurgery is a growing trend in medical residency programs around the world due to the concerns there are about patient safety and the advancement of surgical technology. Simulation training can improve motor skills in a safe environment before the actual setting is initiated in the operating room. The aim of this review is to identify articles that describe Brazilian simulators, their validation status and the level of evidence (LoE).

Methodology This study was conducted using the Preferred Reported Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. A search was performed in the Medline, Scielo, and Cochrane Library databases. The studies were evaluated according to the Medical Education Research Quality Instrument (MERSQI), and the LoE of the study was established according to the classification system of the Oxford Centre for Evidence-Based Medicine (OCEBM), which has been adapted by the European Association of Endoscopic Surgery.

Results Of all the studies included in this review, seven referred to validated simulators. These 7 studies were assigned an average MERSQI score of 8.57 from 18 possible points. None of the studies was randomized or conducted in a high-fidelity environment. The best evidence was provided by the studies with the human placenta model, which received a score of 2b and a degree of recommendation of 3.

Keywords ► simulation training ► neurosurgery ► spine ► education ► Brazil


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Introduction

The reduction of the working hours of residents in the United States and Europe has made simulation training a reality in all surgical specialties. Simulation allows residents to acquire a skill quicker and more safely before they go into the real scenario of the operating room. A recent meta-analysis has shown the benefits of simulation for motivated individuals who receive feedback for their performance. While simulation training has just started in Brazil and is taking its first steps, simulators in other countries are developing as new technologies are now emerging. Simulations are being done on synthetic models, using virtual reality and 3D printing, rather than human cadavers and live animals. There is now the possibility of pathology-specific training with an educational purpose and preoperative planning.

Simulation training in neurosurgery has become even more important because one error can lead to devastating consequences for the patient. Kirkman et al demonstrated the benefits of simulation in the first systematic review of simulation in neurosurgery. However, most of the simulators demonstrated were expensive and so would be costly if they were used in Brazilian neurosurgery simulation laboratories.

The objectives of this systematic review are: 1. To identify studies that describe simulation methods developed by Brazilian neurosurgeons. 2. To determine the quality of the study, the validation status, the level of evidence (LoE) and the degree of recommendation.

Material and Methods

This study was conducted by using the approved guidelines of the Preferred Reported Items for Systematic Reviews and Meta-Analysis (PRISMA). Inclusion and Exclusion Criteria

Articles describing validated and non-validated simulators for neurosurgical training were included in this review, while studies describing simulators for lumbar puncture, central venous access and rhizotomy procedures were excluded. Articles that were not written in either English or Portuguese were also excluded.

Information Sources and Search

A search in the databases at Medline, Scielo and Cochrane Library was performed and the studies took place between January 1, 1998, and September 29, 2018. The search terms...
used were “neurosurgery,” “spine surgery” and “simulation training” as these were found to provide the largest number of articles. A more specific search was then performed afterwards using the terms “skill transfer,” “skill retention,” “motor performance” and “haptics.” This allowed the researcher to find other supplementary studies.

Studies Selection and Data Collection
Articles approved in the inclusion criteria were submitted to evaluation of their abstracts, according to the PRISMA protocol. Duplicate papers, conference publications and articles that were not related to neurosurgery or surgery simulation were all excluded. The selected studies were submitted to a full-text evaluation. Articles that did not describe or validate simulators were also excluded. Studies with patient-specific planning simulators were considered simulators. Only studies by the main Brazilian authors were selected. The relevance tests were performed by two authors, and the study inclusion was done when consent had been obtained from both of them. When there was any disagreement, a third author defined the selection.

Collected Data
The data extracted from each study was categorized according to the type of simulator, the neurosurgical subspecialty addressed, the type of procedure, the validation of the simulator, the Medical Education Research Study Quality Instrument (MERSQI)11, 12 (¬Table 1), and the (LoE) of the study, according to the classification system of the Oxford Centre for Evidence-Based Medicine (OCEBM), adapted by the European Association of Endoscopic Surgery13, 14 (¬Table 2 and 3).

The simulators were categorized according to their neurosurgical subspecialty: vascular, functional, pediatric, spine, skull base, oncology, trauma, and basic neurosurgery. The results were then tabulated, and the simulators from each neurosurgical field grouped. The type of validation of the simulator was classified, according to the definitions of McDougall and Van Nortwick et al1 (¬Fig. 1). All the studies were evaluated for the LoE, and the studies’ quantitative analysis also received a MERSQI score.

Results

Selected Articles
Our search strategy found 512 articles. After the duplicates and articles that were not published in either English or Portuguese had been excluded, 494 remained for the screening of the title. After this stage, 191 articles were submitted to the abstract evaluation. Two authors agreed on the selection of 19 papers for a review of the full text version, out of which 15 were selected for inclusion in this systematic review (¬Fig. 2).

Characteristics of the Selected Studies
The neurosurgery fields that had the largest number of simulation studies were the vascular and pediatric, with 4 (26.66%) studies each. The most described simulator type was the human placenta (33.33%), followed by 3D printed simulators (26.66%), and the synthetic simulators (20%). Only one study (6.66%) reported the use of virtual or mixed reality. Eleven studies (73.33%) had the resident’s skill training as their main purpose and 4 (26.66%) had patient-specific simulation. The most simulated neurological procedure was ventricular neuroendoscopy (20%). ¬Table 4 shows the relationship between the type of simulator that was used for each simulated procedure.

Study Quality and Level of Evidence
Of all the studies included in this review, 7 (46.66%) referred to simulators that were validated. These studies were evaluated according to the MERSQI score and they presented an average score of 8.57 from 18 possible points (¬Table 1). The studies with the highest scores were the models in the human placenta (MERSQI 12 to 8.5). No study was randomized to the control group. No studies were conducted in a high-fidelity environment. Only one study demonstrated the skill transfer from the simulator to the surgical center15. The studies with the best evidence were the models in the human placenta, which received a score of 2b and a degree of recommendation of 3 (¬Table 5).

Data Synthesis

Validated Simulation Models
Of the 15 studies included in this systematic review, 7 (46.66%) had at least 1 type of validation. The most used of these were construct and face validity, which occurred in 4 studies (57.14%). Three studies (42.85%) showed content validity, 2 (28.57%) concurrent validity, and 1 (14.28%) presented predictive validity. Vascular neurosurgery was the area that had the highest number of validated studies.

Non-Validated Simulation Models
Eight studies (53.33%) were not validated. Four of them (50%) were related to patient-specific simulation. A descriptive study using the placenta was subsequently validated in further studies. The area of pediatric neurosurgery was the one that presented the most non-validated studies (¬Table 6).

Vascular Neurosurgery
Four studies were presented, with three of them being validated and one descriptive. The human placenta was the only type of simulator that was described for vascular neurosurgery simulation. It was used in the four mentioned studies. These studies received the highest scientific evidence and the highest MERSQI score. The descriptive study demonstrated the potential of the placenta for simulation in vascular neurosurgery16 (LoE=3, level of recommendation [LoR]=4). The study with the highest MERSQI score (12) used the placenta to demonstrate the transfer of skills that are acquired in the simulator to help with the neurological procedure15 (LoE 2b, LoR 3). The validated intracranial—intracranial (IC-IC) bypass model presented the possibility
of performing several different bypass techniques (MERSQI 8.5, LoE 2b, LoR 3). The placenta was also used to demonstrate how useful it is in simulating endovascular procedures (MERSQI 9.5, LoE 3, LoR 4).

### Table 1 Medical Education Research Quality Instrument score for validated simulators

<table>
<thead>
<tr>
<th>Items of the scale (possible points)</th>
<th>Sub items of the scale (points if present)</th>
<th>Number of studies (%)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study design (3)</td>
<td>Single group cross-sectional or single group posttest only (1)</td>
<td>4 (57)</td>
<td>1.28</td>
</tr>
<tr>
<td></td>
<td>Single group pretest and posttest (1.5)</td>
<td>2 (28)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nonrandomized, 2 groups (2)</td>
<td>1 (14)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Randomized controlled trial (3)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Sampling (3)</td>
<td>Number of institutions studied:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 (0.5)</td>
<td>4 (57)</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>2 (1)</td>
<td>2 (28)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 (1.5)</td>
<td>1 (14)</td>
<td></td>
</tr>
<tr>
<td>Response rate, %:</td>
<td>Not applicable</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt; 50 or not reported (0.5)</td>
<td>7 (100)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50–74 (1)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 75 (1.5)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Type of data (3)</td>
<td>Assessment by study participant (1)</td>
<td>4 (57)</td>
<td>1.85</td>
</tr>
<tr>
<td></td>
<td>Objective measurement (3)</td>
<td>3 (42)</td>
<td></td>
</tr>
<tr>
<td>Validity of evaluation instrument (3)</td>
<td>Internal structure:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not applicable</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not reported (0)</td>
<td>3 (42)</td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td>Reported (1)</td>
<td>4 (57)</td>
<td></td>
</tr>
<tr>
<td>Content:</td>
<td>Not applicable</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not reported (0)</td>
<td>3 (42)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reported (1)</td>
<td>4 (57)</td>
<td></td>
</tr>
<tr>
<td>Relationships to other variables:</td>
<td>Not applicable</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not reported (0)</td>
<td>3 (42)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reported (1)</td>
<td>4 (57)</td>
<td></td>
</tr>
<tr>
<td>Data analysis (3)</td>
<td>Appropriateness of analysis:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Data analysis inappropriate for study design or type of data (0)</td>
<td>3 (42)</td>
<td>2.57</td>
</tr>
<tr>
<td></td>
<td>Data analysis appropriate for study design or type of data (1)</td>
<td>4 (57)</td>
<td></td>
</tr>
<tr>
<td>Complexity of analysis:</td>
<td>Descriptive analysis only (1)</td>
<td>3 (42)</td>
<td></td>
</tr>
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<td></td>
<td>Beyond descriptive analysis (2)</td>
<td>4 (57)</td>
<td></td>
</tr>
<tr>
<td>Outcomes (3)</td>
<td>Satisfaction, attitudes, perceptions, opinions, general facts (1)</td>
<td>4 (57)</td>
<td>1.21</td>
</tr>
<tr>
<td></td>
<td>Knowledge, skills (1,5)</td>
<td>3 (42)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Behaviors (2)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Patient/health care outcome (3)</td>
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<td>0.00</td>
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<tr>
<td>Total score</td>
<td></td>
<td></td>
<td>8.57</td>
</tr>
</tbody>
</table>

### Pediatric Neurosurgery

Four studies were presented for simulation in pediatric neurosurgery, but none of them were validated. Two studies were used for patient-specific simulation. Ghizoni et al.
demonstrated the use of 3D printing in both planning and preoperative simulation in three cases of craniosynostosis. Coelho et al performed the patient-specific simulation for an encephalocele on the face using a multimaterial 3D print. This was later replicated in surgery.

Coelho et al presented two studies with the same simulator (ASPER) that was developed for the simulation of craniosynostosis and ventricular neuroendoscopy. The studies of pediatric neurosurgery were evaluated with a LoE of 3 and a LoR of 4.

Neurosurgical Oncology
Two studies were included with simulators to remove brain tumors. Both of these simulators were validated. Oliveira et al described the use of the human placenta to simulate microsurgery for an intracranial tumor. Filho et al described and validated a synthetic simulator called Sinus Model Otro-Rhino NeuroTrainer (S.I.M.O.N.T.) for the simulation of neuroendoscopy for the resection of a ventricular tumor and access to the base of the skull.

Spine
Two simulators were described for the spine. One simulator underwent validation and the other was a patient-specific simulation description. Coelho et al described and validated a simulator to perform lumbar spine procedures, such as arthrodesis and laminectomy. They used the mixed reality that combines virtual reality with the synthetic model called Sinus Model Otro-Rhino NeuroTrainer (S.I.M.O.N.T.) for the simulation of neuroendoscopy for the resection of a ventricular tumor and access to the base of the skull.

Basic Neurosurgery
There was no validation for any of the three studies that were related to the basic procedures of neurosurgery. Drummond-Braga et al described the use of a coconut fruit as a simulator for cerebrospinal fluid leak avoidance during craniotomy for residents of the first year. Ferreira et al described a method that is used for dilation of the ventricular system in cadavers to simulate ventricular endoscopy.

Table 2 Modified levels of evidence classification for validation studies, adapted from the Oxford Centre for Evidence-Based Medicine classification by the European Association of Endoscopic Surgeons (Carter et al, 2005)

<table>
<thead>
<tr>
<th>Level of evidence</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Systematic reviews (meta-analysis) containing at least some trial of level 1b evidence, in which results of separate, independently controlled trials are consistent</td>
</tr>
<tr>
<td>1b</td>
<td>Randomized controlled trial of good quality and of adequate sample size (power calculations)</td>
</tr>
<tr>
<td>2a</td>
<td>Randomized trials of reasonable quality and/or of inadequate sample size</td>
</tr>
<tr>
<td>2b</td>
<td>Nonrandomized trials, comparative research (parallel cohort)</td>
</tr>
<tr>
<td>2c</td>
<td>Nonrandomized trials, comparative research (historical cohort, literature controls)</td>
</tr>
<tr>
<td>3</td>
<td>Nonrandomized, non-comparative trials, descriptive research</td>
</tr>
<tr>
<td>4</td>
<td>Expert opinions, including the opinion of Work Group members</td>
</tr>
</tbody>
</table>

Table 3 Levels of recommendation for training models, adapted from the Oxford Centre for Evidence-Based Medicine Classification by the European Association of Endoscopic Surgeons (Carter et al, 2005)

<table>
<thead>
<tr>
<th>Level of evidence</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Based on one systematic review (1a) or at least two independently conducted research projects classified as 1b</td>
</tr>
<tr>
<td>2</td>
<td>Based on at least two independently conducted research projects classified as level 2a or 2b, within concordance</td>
</tr>
<tr>
<td>3</td>
<td>Based on one independently conducted research project level 2b, or at least two trials of level 3, within concordance</td>
</tr>
<tr>
<td>4</td>
<td>Based on one trial at level 3 or multiple expert opinions, including the opinions of Work Group members (e.g., level 4)</td>
</tr>
</tbody>
</table>

Fig. 1 Types of validity. Definitions from McDougall et al; van Nortwick et al. Translated by Aydin et al. Current Status of Simulation and Training Models in Urological Surgery: A Systematic Review. DOI: 10.1016/j.juro.2016.01.131.
Fig. 2 Preferred Reported Items for Systematic Reviews and Meta-Analysis flow diagram.

Table 4 Type of simulator used for training in each neurosurgical procedure

<table>
<thead>
<tr>
<th>Subspeciality</th>
<th>Procedure</th>
<th>Human Placenta</th>
<th>Synthetic Model</th>
<th>3D Printing</th>
<th>Mixed Reality</th>
<th>Corpse</th>
<th>Fruit</th>
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<tbody>
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<td>Neurovascular</td>
<td>Vascular microsurgery</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intracranial bypass</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Angiography/Endovascular</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Microsurgery aneurysm</td>
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<td></td>
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<tr>
<td>Neuropediatric</td>
<td>Neuroendoscopy</td>
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<td></td>
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<td></td>
<td></td>
<td>x</td>
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<tr>
<td></td>
<td>Craniosynostosis</td>
<td>x</td>
<td>x</td>
<td></td>
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<td></td>
<td>Meningocele</td>
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<tr>
<td>Neuroncology</td>
<td>Microsurgery for tumor</td>
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<td></td>
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<tr>
<td></td>
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<td>Spine</td>
<td>Arthrodesis</td>
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<td></td>
<td>Corpectomy</td>
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<td>Basic Neurosurgery</td>
<td>Craniotomy</td>
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<td></td>
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<td>x</td>
<td>x</td>
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<td>Anatomy</td>
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<td></td>
<td>External ventricular drain/</td>
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<tr>
<td></td>
<td>neuroendoscopy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>
for neurosurgical training and preoperative planning. All the studies in this area were classified according to their LoE, which was 3, and the LoR, which was 4. Table 7 shows a summary of each study’s main characteristics.

**Discussion**

The Brazilian studies that underwent validation presented an average score of 8.56 points in the MERSQI. This value approximates the score described in the systematic review by Kirkman et al in 2014 (9.21 points). The worst scores were received by validation topics that related to study design and the number of institutions involved.

Few of the studies on simulation were able to demonstrate the transfer of skills from the simulator to the surgical room. However, in 2018, Oliveira et al were able to demonstrate the transfer of an acquired ability in simulations of vascular microsurgery in the placenta to the real scenario in aneurysm surgeries. It was the only Brazilian study that described predictive validity.

The highest LoE found was 2b and the best grade of recommendation was 3. This demonstrates the lack of a randomized blind study in Brazilian simulators. When analyzed in conjunction with the MERSQI score, the indication is that further Brazilian studies in simulation should be performed that search for randomization with control groups and multicentric studies.

The majority of the studies were of vascular and pediatric subspecialties. The most simulated procedures had the greatest demand for manual skills, such as vascular microsurgery and recent technological evolution, such as ventricular endoscopy. The least frequently simulated were functional neurosurgery and neurotrauma.

Among the non-validated simulators, the use of patient-specific or pathology-specific simulators is noteworthy. These simulations were used to provide education about specific conditions found in neurosurgery, as well as preoperative planning and rehearsal in complex cases. Three-dimensional printing was the most described type of simulation used for this purpose. Craniosynostosis surgery was the most simulated patient-specific procedure described.

This systematic review had its limitations. The main ones being the different forms of methodology of each study, and the different groups of evaluated participants and heterogeneous simulators. Perhaps the greatest limitation was the difference in the quality of the studies and the fact that most simulators lack a validation instrument.

Future research should focus on the creation of high-fidelity simulators that are accessible to the resident physician and could be introduced to neurosurgical training.
<table>
<thead>
<tr>
<th>Author</th>
<th>Type of validation</th>
<th>Neurosurgery field</th>
<th>Procedure type</th>
<th>Simulator type</th>
<th>Objective</th>
<th>Participants (n)</th>
<th>Function</th>
<th>Main results</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grillo F. W., 2018</td>
<td>Yes</td>
<td>Neurosurgery</td>
<td>Craniotomy</td>
<td>3D print</td>
<td>Creation of a realistic phantom for reproduction of the cerebral cortex, cerebrospinal fluid, meninges and scalp.</td>
<td>17 residents</td>
<td>Skill training</td>
<td>The fresh human patient can be used for training. After this time, the vessel walls become weaker, more difficult to dissect and suture.</td>
<td>Most neurosurgeons rated the model as very good for realism and educational purpose.</td>
</tr>
<tr>
<td>Oliveira M. M. R., 2018</td>
<td>Yes</td>
<td>Vascular</td>
<td>Vascular</td>
<td>Human placenta</td>
<td>Assess both the quality of the model and the development of surgical skills by residents and neurosurgeons.</td>
<td>22 residents</td>
<td>Synthetic</td>
<td>Residents trained in the human placenta simulator had the highest overall performance scores when compared with those who had trained in the cadaver model and those who had simply watched operative videos.</td>
<td>Residents trained in the human placenta simulator consistently had the highest overall performance scores when compared with those who had trained in the cadaver model and those who had simply watched operative videos (p &lt; 0.001).</td>
</tr>
<tr>
<td>Filho F. V., 2011</td>
<td>Yes</td>
<td>Oncology</td>
<td>Synthetic</td>
<td>Human placenta</td>
<td>The experts considered the model capable of replicating surgical situations as if they were real and presenting great similarity with the human brain.</td>
<td>16 residents</td>
<td>Synthetic</td>
<td>The experts considered the model capable of replicating surgical situations as if they were real and presenting great similarity with the human brain.</td>
<td>The experts considered the model capable of replicating surgical situations as if they were real and presenting great similarity with the human brain.</td>
</tr>
<tr>
<td>Oliveira M. M. R., 2016</td>
<td>Yes</td>
<td>Tumor microsurgery</td>
<td>Human placenta</td>
<td>Synthetic</td>
<td>To describe and assess the quality and development of surgical skills by residents and neurosurgeons.</td>
<td>10 residents</td>
<td>Synthetic</td>
<td>To describe and assess the quality and development of surgical skills by residents and neurosurgeons.</td>
<td>The tumor microsurgical resection model is a high-fidelity training model that may have significant potential in the assessment and training of neurosurgical residents.</td>
</tr>
<tr>
<td>Oliveira M. M. R., 2018</td>
<td>Yes</td>
<td>Vascular</td>
<td>Vascular</td>
<td>Human placenta</td>
<td>To describe the human placenta vascular anatomy to guide IC-IC bypass apprenticeship.</td>
<td>9 residents</td>
<td>Synthetic</td>
<td>To describe the human placenta vascular anatomy to guide IC-IC bypass apprenticeship.</td>
<td>Biological risks, patient consent issues, placenta need to be fresh.</td>
</tr>
<tr>
<td>Oliveira M. M. R., 2018</td>
<td>Yes</td>
<td>Oncology</td>
<td>Synthetic</td>
<td>Human placenta</td>
<td>To describe the human placenta vascular anatomy to guide IC-IC bypass apprenticeship.</td>
<td>9 residents</td>
<td>Synthetic</td>
<td>To describe the human placenta vascular anatomy to guide IC-IC bypass apprenticeship.</td>
<td>Biological risks, patient consent issues, placenta need to be fresh.</td>
</tr>
</tbody>
</table>

Table 7: Summary of the main characteristics of each study.
<table>
<thead>
<tr>
<th>Author</th>
<th>Validity</th>
<th>Type of validation</th>
<th>Neurosurgery field</th>
<th>Procedure</th>
<th>Simulator type</th>
<th>Function</th>
<th>Participants</th>
<th>Objective</th>
<th>Main results</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coelho, G., 2018</td>
<td>Yes</td>
<td>Contend and face</td>
<td>Spine</td>
<td>Arthrodesis</td>
<td>Mixed reality</td>
<td>Skill training</td>
<td>(n = 16) Spinal surgeons</td>
<td>To propose and validate a new tool for neurosurgical education, associating virtual and realistic simulation (mixed reality), for spine surgery</td>
<td>The surgery team considered that this virtual simulation provides a highly effective training environment, and it significantly enhances teaching of surgical anatomy and operative strategies.</td>
<td>Expensive, not largely available.</td>
</tr>
<tr>
<td>Oliveira M. M. R., 2015</td>
<td>Yes</td>
<td>Construct, contend and face</td>
<td>Vascular</td>
<td>Neurointerventional</td>
<td>Human placenta</td>
<td>Skill training</td>
<td>(n = 12) Residents and neurosurgeons</td>
<td>To describe and assess face, contend and construct validity of the model</td>
<td>Excellent haptics, low startup costs, and ready availability for any institution with interventional capabilities.</td>
<td>Biological risks, patient consent issues.</td>
</tr>
<tr>
<td>Ghizoni E., 2018</td>
<td>No</td>
<td>N/A</td>
<td>Pediatrics</td>
<td>Craniosynostosis</td>
<td>3D print</td>
<td>Patient- specific simulator</td>
<td>(n = 2) Residents and neurosurgeons</td>
<td>Describe the use of three models for craniosynostosis practice made with a 3D printer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drummond-Braga B., 2016</td>
<td>No</td>
<td>N/A</td>
<td>Basics</td>
<td>Craniotomy</td>
<td>Fruit-Coconut</td>
<td>Skill training</td>
<td>N/A</td>
<td>To describe an original model for learning craniotomy first steps with CSF leak avoidance using a coconut.</td>
<td>Its main advantages are that coconuts are affordable and widely available and simulate CSF leaks. It has a potential pedagogic neurosurgical application for freshman residents, and further validity is necessary to confirm this hypothesis.</td>
<td>Complete absence of anatomic landmarks and the consistency of the coconut layers.</td>
</tr>
<tr>
<td>Paiva W. S., 2007</td>
<td>No</td>
<td>N/A</td>
<td>Spine</td>
<td>Corpectomy</td>
<td>3D print</td>
<td>Patient- specific simulator</td>
<td>N/A</td>
<td>The purpose of this work is to demonstrate the practical use of the stereolithography an auxiliary method for training and surgical simulation</td>
<td>It is easier for the surgeon to understand the complexity of the case and plan the approach before any surgical procedure. Careful planning and previous rehearsal reduce the risk of surprises during an operation.</td>
<td>High cost involved in prototyping process.</td>
</tr>
<tr>
<td>Author</td>
<td>Validity</td>
<td>Type of validation</td>
<td>Neurosurgery field</td>
<td>Procedure</td>
<td>Simulator type</td>
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<td>Participants</td>
<td>Objective</td>
<td>Main results</td>
<td>Limitations</td>
</tr>
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</tr>
<tr>
<td>Coelho G., 2014</td>
<td>No</td>
<td>N/A</td>
<td>Pediatrics</td>
<td>Craniosynostosis</td>
<td>Synthetic</td>
<td>Skill training</td>
<td>N/A</td>
<td>To describe a synthetic simulator for the practice of craniosynostosis</td>
<td>This training model may represent a very useful method to simulate the steps of surgery for scaphocephaly. This training provides an alternative to the use of human cadavers and animal models.</td>
<td>High cost for maintenance.</td>
</tr>
<tr>
<td>Ferreira C. D., 2014</td>
<td>No</td>
<td>N/A</td>
<td>Basics</td>
<td>Neuroendoscopy</td>
<td>Cadaver</td>
<td>Patient-specific simulator</td>
<td>N/A</td>
<td>Create an anatomical model that simulates hydrocephalus and can be used in training in neuroendoscopy techniques.</td>
<td>The adequate use of the anomalous chemical-physical characteristics of the water molecule may provide a good mechanism to expand the ventricular cavity, to create an experimental model of hydrocephalus.</td>
<td>Biological risk. Difficulty of availability of cadavers.</td>
</tr>
<tr>
<td>Coelho, G. 2014</td>
<td>No</td>
<td>N/A</td>
<td>Pediatrics</td>
<td>Neuroendoscopy</td>
<td>Synthetic</td>
<td>Skill training</td>
<td>N/A</td>
<td>In this study, we present a new pediatric neuroendoscopic simulator that facilitates training. Description</td>
<td>Description of the simulator. This realistic simulator was built with a synthetic thermo-retractile and thermo-sensible rubber called Neoderma®.</td>
<td>High cost for maintenance.</td>
</tr>
<tr>
<td>Coelho, G. 2017</td>
<td>No</td>
<td>N/A</td>
<td>Pediatrics</td>
<td>Encephalocele</td>
<td>3d print</td>
<td>Patient-specific simulator</td>
<td>N/A</td>
<td>To describe a case of frontoethmoidal encephalocele, (nasofrontal subtype) of a 19-month-old girl, whose surgical correction was planned using 3D printing modeling.</td>
<td>The 3D model allowed predicting with millimetric precision the bilateral orbitotomy measurements, reducing the time of surgery, and precontouring the osteosynthesis material.</td>
<td>Demand computer design expert, high cost.</td>
</tr>
<tr>
<td>Oliveira, M. M. R. 2014</td>
<td>No</td>
<td>N/A</td>
<td>Vascular microsurgery</td>
<td>Human placenta</td>
<td>Skill training</td>
<td>Human placenta</td>
<td>N/A</td>
<td>To describe an aneurysm surgical model that recreates the acquisition and maintenance of the specific microsurgical skills used in clipping cerebral aneurysms</td>
<td>The human placenta provides an inexpensive, convenient biological model for modeling cerebral aneurysms with high fidelity to neural tissue. In addition, it can be used to create aneurysms of various morphologies.</td>
<td>The fresh human placenta can be used for only 1 to 2 weeks. After this time, the vessel walls become weaker, more difficult to dissect and suture.</td>
</tr>
</tbody>
</table>

Abbreviations: CSF, cerebrospinal fluid; IC, intracranial.
laboratories throughout Brazil. Further validated and randomized studies should be performed to define the ideal simulators that could truly fit in every level of Brazil’s residency skill training program.

Conclusion

The MERSQI score of the Brazilian studies resembles the international average. The LoE and the degree of recommendation of most of the published articles is still low. New studies should pursue a further validation of the simulators and hold randomized trials with a control group. There is a lot of creativity, simplicity and technology involved in Brazilian simulators. Most of them can be reproduced at the skill training laboratories that are available in the country.

Conflict of Interest

None declared.

References

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28 Ferreira CD, Matushita H, Silva BR, et al. Proposal of a new method to induce ventricular system dilation to simulate the features of hydrocephalus and provide an anatomical model for neuroendoscopy training. Childs Nerv Syst 2014;30(07):1209–1215