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Original Article

A new device to treat ping-pong skull fractures: The hammer puller technique. A comparative analysis using a realistic simulation model

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ABSTRACT

Background: This study aims to describe a new surgical technique for the treatment of ping-pong skull fractures and to evaluate its efficacy in a realistic simulation model compared to the dissector elevation technique.

Methods: A total of 64 fractures were obtained using 16 model units, each with four fractures (two frontal and two parietal). The hammer puller technique was applied for left-sided fractures and the dissector technique for right-sided fractures. The variables evaluated were fracture repair time, fracture volume, fracture corrected volume, and fracture correction percentage. Fractures were separated into groups according to the surgical technique used (hammer or dissector) and the bone fractured (frontal or parietal). Statistical analysis was performed with Jamovi® software (version 2.3) using Student's *t*-test.

Results: A complete degree of fracture correction was achieved with both techniques, demonstrating a sufficient performance in the correction of the deformity. The hammer technique was shown to be faster in correcting frontal bone depressions with 20.1 ± 7.8 s compared to 31.3 ± 4.7 s for the dissector technique, $P < 0.001$. There was no statistically significant difference for parietal applications ($P = 0.405$).

Conclusion: This study describes a new minimally invasive surgical technique for the treatment of ping-pong fractures. Comparative analysis showed that both techniques were equally effective but that the hammer puller technique was more efficient than the dissector elevation technique, especially for frontal bone fractures.

Keywords: Depressed skull fracture, Hammer puller, Pediatric skull fracture, Ping-pong fracture, Traumatic brain injury

INTRODUCTION

First described by Luckett in 1910, the ping-pong fracture is so named because of the three-sided pyramidal shape of the closed skull fracture, which is similar to the impact deformation of ping-pong balls.[14] It is typical of children under 1 year of age who have suffered head trauma and can occur at birth in neonates or due to other mechanisms of head trauma. It is associated with incomplete bone mineralization of the skull.[5,6]

Initially treated surgically with various correction techniques, they were later managed more conservatively. The observation that some ping-pong fractures resolved spontaneously led to longer periods of observation. It is now generally accepted that most fractures will resolve spontaneously over time. One potential concern is cortical compression by deep fractures, the threshold of which has been hypothesized to be 0.5–1 cm.[5,6,23]

There are a few surgical techniques described in the literature that use instruments to reduce the fracture, such as elevation with a periosteal elevator, acute hook and percutaneous screw, as well as craniotomy and bone remodelling.[3,8,11,19,28,29] Surgical treatment can cause complications, but the risk of anesthesia has been identified as the main limiting factor for urgent and immediate surgery.[1,5,6,20,23]

Successful elevation of fractures using suction techniques has been reported as well. The instruments used include a variety of vacuum suction devices such as extractors, breast pumps, and even a neonatal face mask attached to a 50 cc syringe.[1,2,13,15,16,21,22,24,27] Reports have been published documenting the complications associated with such automated aspiration reduction systems, including skin lacerations, subgaleal, subdural, and epidural hematomas.[4,9,10,17,18,26]

Several techniques are currently used to treat ping-pong fractures. There is no consensus in the literature about the best approach. In this scenario, new techniques and materials must be developed to treat this condition effectively. This study aims to describe a new surgical technique for the treatment of ping-pong fractures and to evaluate its effectiveness in a realistic simulation model compared to the dissector elevation technique.

MATERIALS AND METHODS

The research was developed as a doctoral thesis at the Department of Neurosurgery of the Faculty of Medicine of the University of São Paulo, with the approval of the Research Ethics Committee.

This is an analytical, experimental, and comparative study developed by applying the hammer puller technique in a realistic simulation model, compared to the technique of elevation with a dissector. The model is made of plastic, has a thickness of 1.6 mm, and is manufactured by Brasilflex®. It was chosen against other options because it allowed permanent deformation without losing the continuity of the material and showed the possibility of three-dimensional reconstruction on computed tomography (CT) scans [Figure 1].

A total of 64 fractures were obtained using 16 model units, each with four fractures (two frontal and two parietal). Each simulator model was handled in the following sequence: (1) first CT scan (initial); (2) fractures (two frontal and two parietal); (3) second CT scan (after fracture); (4) treatment with hammer technique on the left side and dissector technique on the right side; and (5) third CT scan (after treatment). The following variables were evaluated: (1) fracture repair time (FRT), (2) fracture volume (FV), (3) fracture corrected volume (FCV), and (4) fracture correction percentage (FCP). Figure 2 shows a flowchart of the study design.

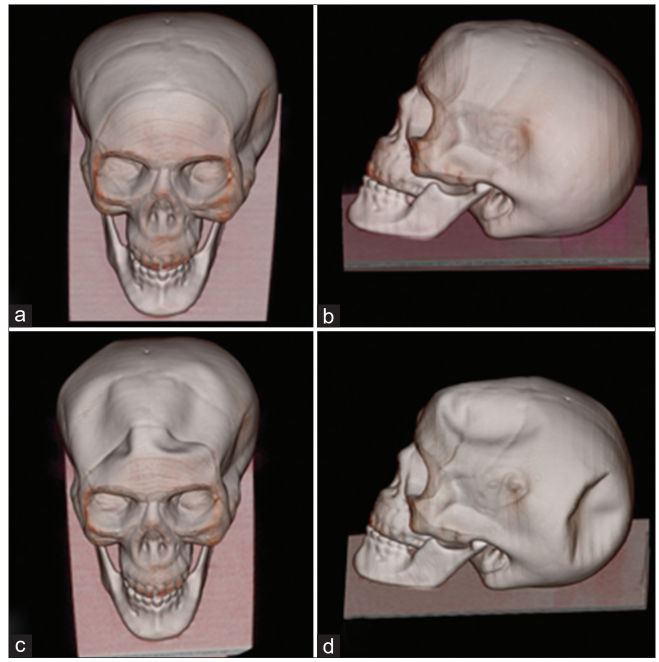


Figure 1: Three-dimensional reconstruction of the simulator model. (a and b) Before fracture simulation. (c and d) After the fractures.

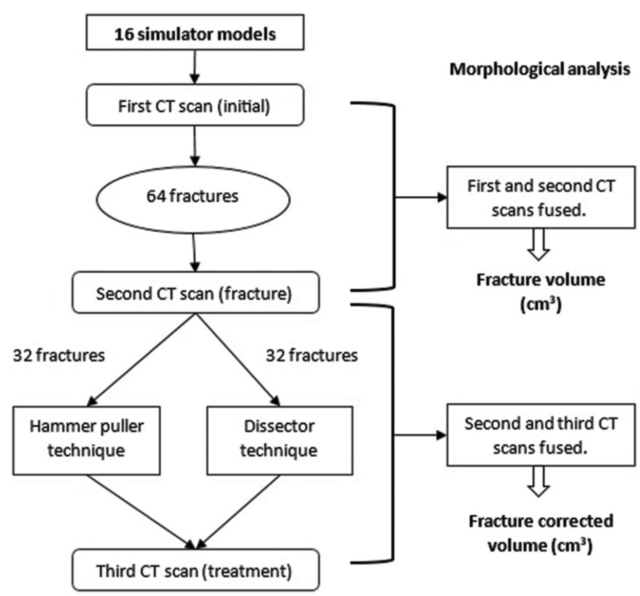


Figure 2: Study design and morphological analysis of the fracture and correction.

For comparative analysis, fractures were separated into groups according to the surgical technique used (hammer or dissector) and the bone fractured (frontal or parietal). Statistical analysis was performed with Jamovi® software (version 2.3) using Student's t-test.[25] Final results with a $P < 0.05$ were considered statistically significant. For descriptive purposes, data were presented as mean and standard deviation.

The hammer puller

The hammer puller is a surgical instrument developed for use by neurosurgeons in the treatment of ping-pong fractures [Figure 3a]. It is made from stainless steel and aluminum. The parts were manufactured separately, allowing disassembly for sterilization. It has an atraumatic blunt tip screw that is inserted into the trepanation hole. The tip is 5 mm long to provide adequate grip, considering the thickness of the bone and skin when performing minimal incisions. Before use, trepanning with the initiator is required [Figure 3b]. It is currently in the final stages of obtaining an invention patent.

Technical description

Through a small skin incision of approximately 1 cm in the center of the deformity, the initiator is applied [Figure 4a] and a small trepanation is achieved by clockwise rotation. The tip of the hammer puller is then coupled to the burr hole by clockwise rotation [Figure 4b]. Fracture reduction is achieved by applying counterforce with gentle hammering [Figure 4c]. Finally, the skin is closed with nylon thread.

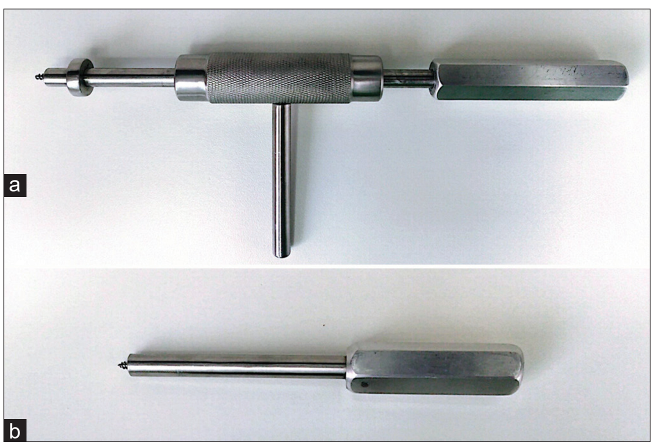


Figure 3: New device developed to treat ping-pong fractures. (a) Hammer puller. (b) Initiator.

Realistic simulation

A plane surface was used as the base for the model to allow comparative fusion of the tomographic images [Figure 5a]. The fractures were made using a carpenter's C-clamp by applying a force to the surface of the model [Figure 5b]. The hammer technique was applied to the center of the deformity, only for the fractures on the left side [Figure 5c and Video 1], while the dissector elevation technique was applied to the edge of the deformity, only for the fractures on the right side [Figure 5d]. The dissector technique required a 3-mm carbon drill combined with a Hall® Ultrapower high-speed pneumatic drill system and a Penfield number 3 dissector. FRT was measured by filming the correction of each fracture.

Morphological analysis

A Toshiba CT scanner (Asteion model) was used with a slice thickness of 2 mm and a setting of 80 kV and 50 mA. The same professional radiologist performed all CT scans. The fractures were analyzed individually with Radiant® DICOM Viewer software (version 2022.1.1) through a fusion technique between the overlaid tomographic images. Volume was calculated using the A × B × C/2 method, where A is the largest coronal diameter, B is the largest sagittal diameter, and C is the depth.[12] First, the FV was calculated from measurements obtained by fusing the first and second CT scans [Figures 6a and b]. Second, the FCV was calculated from measurements obtained by fusing the second and third CT scans [Figures 6c and d]. The FCP was calculated using the FCV/FV × 100 formula.

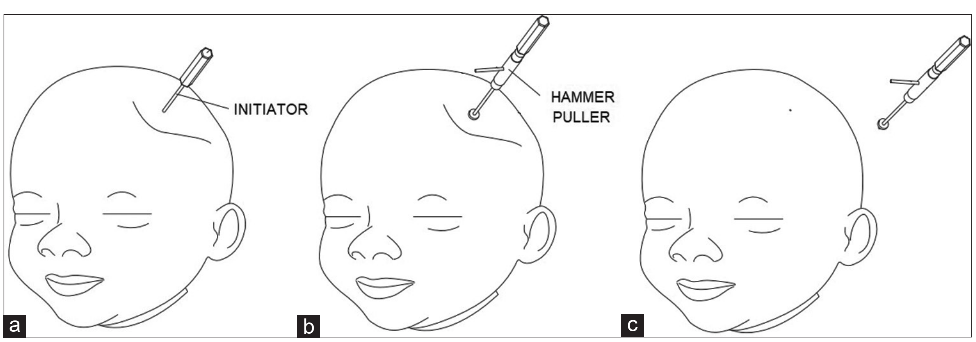


Figure 4: Technical illustration of the use of the hammer puller in a ping-pong skull fracture. (a) Trepanation with the initiator. (b) Deformity correction by gentle hammering. (c) Final result.

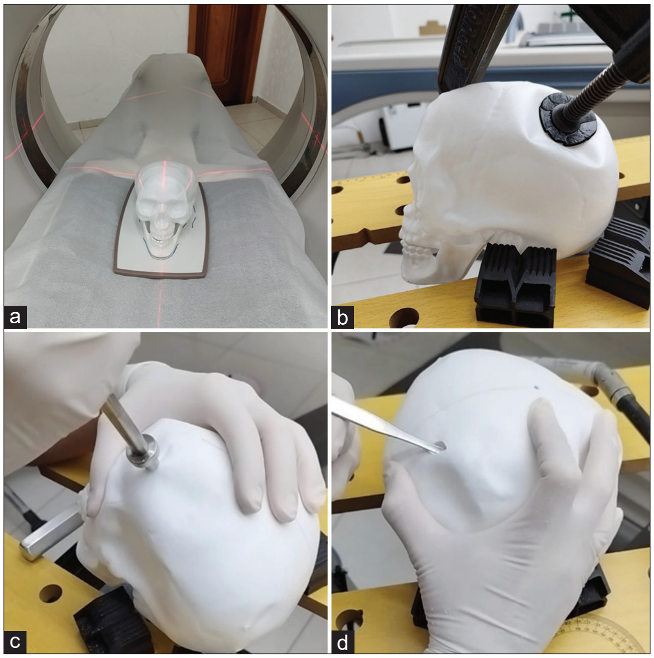


Figure 5: (a) Tomographic acquisition of the simulator model. Note the fixed flat surface on the tomograph table for fine adjustment of the model. (b) Production of the ping-pong fracture. (c) Application of the hammer technique to a left frontal fracture. (d) Application of the dissector elevation technique to a right parietal fracture.

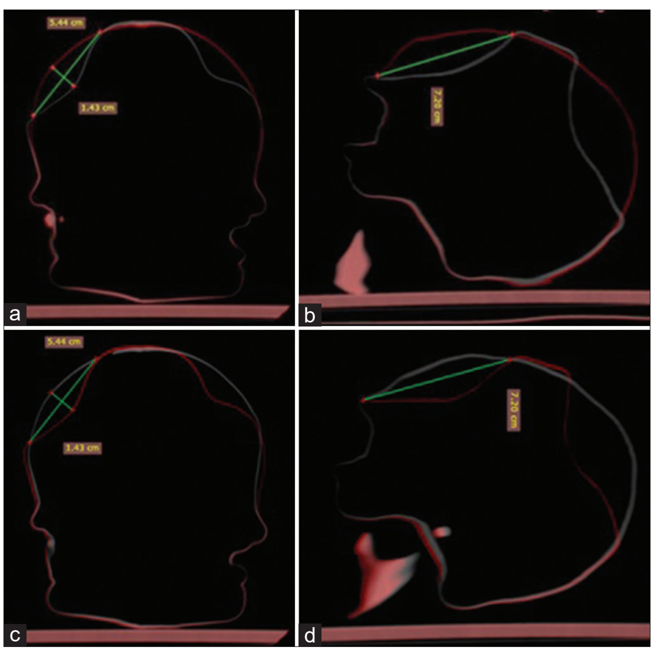
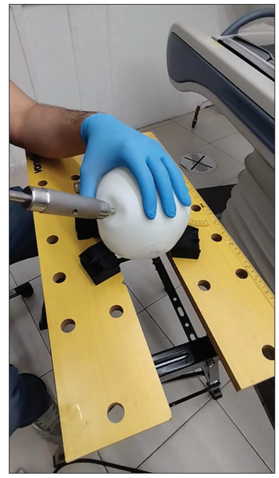


Figure 6: Acquisition of the largest coronal diameter, largest sagittal diameter, and depth measurements by means of tomographic fusion technology. (a and b) Fused images of the first and second computed tomography (CT) scans in the coronal and sagittal planes. (c and d) Fused images of the second and third CT scans in the coronal and sagittal planes.



Video 1: Demonstration of the hammer puller technique on a left parietal fracture.

RESULTS

A complete degree of fracture correction was achieved with both techniques, demonstrating a sufficient performance in the correction of the deformity. The hammer puller showed sufficient grip without the tip coming off during applications. The mean FVs, FCVs, FCPs, and number of applications of the technique are shown in Table 1. The hammer technique was shown to be faster in correcting frontal bone depressions with 20.1 ± 7.8 s compared to 31.3 ± 4.7 s for the dissector technique, $P < 0.001$. There was no statistically significant difference for parietal bone applications ($P = 0.405$). The mean FRTs are shown in Table 1 and are represented in Graph 1.

DISCUSSION

Ping-pong fractures have been the subject of debate in terms of indications for treatment and techniques used. With the advent of vacuum techniques, there have been several studies in the literature showing reductions with different devices. The potential advantages of this technique are that it avoids open neurological surgery, is noninvasive, is performed under sedation, is quick to perform, and is low cost. However, the lack of control over the application of the vacuum can put intracranial structures, such as the brain parenchyma and vascular structures, at risk if the indication is not correct. In addition, the lack of standardization of the technique allows it to be used in very different ways in different parts of the world. The subgaleal edema caused by suction on the subcutaneous tissues can mask the result of the correction, which is considered complete but is often not achieved, giving a false-positive result.[4,9,26]

Table 1: Results obtained from the study.

Bone	Technique	Mean FV (cm^3)	Mean FCV (cm^3)	FCP	Mean NA	Mean FRT (s)	Minimum FRT (s)	Maximum FRT (s)	*P*-value (FRT)
Frontal	Hammer	15	15	100%	1.2	20.1±7.8	13	44	<0.001
	Dissector	17	17	100%	1	31.3±4.7	25	40	<0.001
Parietal	Hammer	33	33	100%	2	34.7±22.5	13	75	0.405
	Dissector	39	39	100%	1	39.9±9.9	27	56	0.405

FV: Fracture volume, FCV: Fracture corrected volume, FCP: Fracture corrected percentage, NA: Number of applications, FRT: Fracture repair time

The dissector elevation technique allows rapid correction of the fracture, but the risk of general anesthesia has been identified as the main disadvantage for urgent surgery, apart from the fact that the total treatment time is increased.[1,20] In this context, the hammer puller technique was developed as a minimally invasive surgical procedure that could be performed quickly and without general anesthesia. It was inspired by the method used to correct deformities in car bodies. In Brazil, it is popularly known as the "golden hammer." However, in the case of large fractures, more than one application of the technique may be necessary.

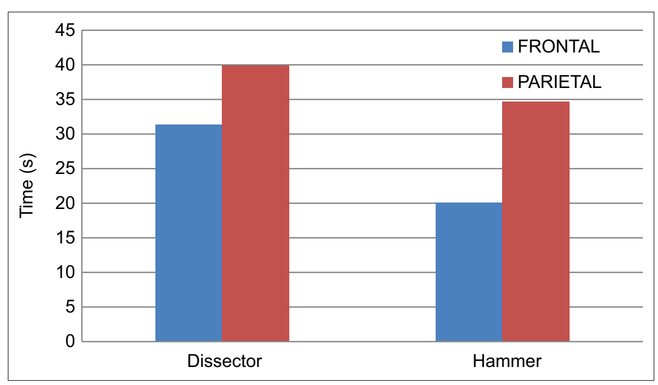
The hammer puller is a unique tool in the world and is currently being patented. It has been developed with the aim of providing an immediate and effective solution to ping-pong fractures, based on the observation of patients treated with the vacuum method without success (or with a false-positive result) and cases in which conservative management was chosen, but there was no improvement of the deformity during the outpatient follow-up period.

Analysis of volumetric correction established equal efficacy for both techniques, which achieved 100% correction. The new technique should, therefore, be considered as a minimally invasive and effective therapeutic option. In the practical context, its use without the need for intubation and general anesthesia may represent a reduction in risk and treatment time. Table 2 shows the main advantages and disadvantages of the treatment techniques.

Regarding FRT, the hammer technique proved to be faster than the dissector elevation technique. This superiority was more significant in frontal bone fractures (20.1 s ± 7.8 s vs. 31.3 s ± 4.7 s, $P < 0.001$), while there was no statistically significant difference between the two techniques in parietal bone fractures (34.7 s ± 22.5 s vs. 39.9 s ± 9.9 s, $P < 0.405$). Despite the result achieved, if we consider the time factor in isolation, the difference of a few seconds in FRT should not be of great relevance in the clinical setting. Considering the difference in the volume proportion of the fractures (smaller in the frontal bone and larger in the parietal bone), it is possible to establish a favorable outcome correlation for the new technique when it is used in fractures of smaller volume, as observed in frontal fractures. This may have occurred because, in the case of larger fractures, it was necessary to apply more than once to residual deformities until complete correction was achieved, impacting the total treatment time. In the case of smaller fractures, correction could be achieved in a single application.

Table 2: Main advantages and disadvantages of each technique.

Technique	Advantages	Disadvantages
Hammer puller	General anesthesia is not required Minimally invasive Quick application Low cost	More than one application may be required
Dissector	Single application Quick application	General anesthesia is required Increased anesthetic risk Longer treatment time Larger incision and burr hole High cost
Vacuum techniques	General anesthesia is not required Non-invasive Quick application Low cost Avoid surgical procedure	Can result in false positive Aspiration pressure is not controlled Many techniques described More than one application may be required



Graph 1: Fracture repair time per bone and technique used.

The use of physical simulators has become a promising method for training in neurosurgery, providing effective results at a reasonable cost, as well as a risk-free experience.[7] The use of cadaveric specimens was not possible due to the infant age group, as well as their high cost and difficult logistics. The simulated experience has some limitations, but it is necessary because the new technique cannot yet be tested on humans for ethical reasons. One limitation is that it is not possible to assess the risk of injury to intracranial structures below the fracture, such as the dura mater and brain tissue. An animal model study should be performed to assess these risks. In addition, it is not possible to evaluate the viability of the new technique in old fractures that are already ossified.

CONCLUSION

A new minimally invasive surgical technique for the treatment of ping-pong fractures has been described: the hammer puller technique. The hammer puller surgical tool was developed for this purpose and proved to be suitable for use with the new technique, achieving complete resolution of all fractures treated. A comparative analysis in a realistic simulation model concluded that both techniques were equally effective and that the hammer puller technique was more efficient, especially for frontal bone fractures, and corrected the deformity in a shorter time.

Ethical approval

The research/study was approved by the Institutional Review Board at the Faculty of Medicine of the University of Sao Paulo, number 461/19, dated 12/11/2019.

Declaration of patient consent

Patient's consent is not required as there are no patients in this study.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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