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Preoperative Diffusion Tensor Imaging for Facial Nerve Identification and Treatment Outcome in Vestibular Schwannoma: A systematic review

Uso de Imagem do Tensor de Difusão no Pré-Operatório para Identificar o Nervo Facial e o Resultado do Tratamento do Schwannoma Vestibular: Revisão Sistemática

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ABSTRACT

Preservation of the facial nerve (FN) and vestibulocochlear nerve is essential to keep the quality of life of patients during surgery for the treatment of vestibular schwannoma (VS). One of the great challenges for neurosurgeons is to make a good surgical planning, to identify a tumor location, as well as its relationship with anatomical and nervous structures to facilitate the surgeon's work and avoid inappropriate conducts. Currently, many studies have reported the effectiveness of the diffusion tensor and tractography imaging (DTI) technique. We conducted a systematic review of studies that report the use of this technique.The PubMed and Embase databases were used to search, according to pre-established inclusion and exclusion criteria. Twelve articles were selected for this study, with a total of 255 patients who underwent a DTI preoperatively. The location and path of the facial nerve were verified intraoperatively, and 226 (89%) correlated the DTI result with the intraoperative finding, which met our inclusion criteria. The results of this research pointed to the excellent result of the DTI to predict the location of the FN in the preoperative period, allowing greater surgical planning and improvement in the outcome of the facial nerve function.

Keywords: *Facial nerve; Vestibular Schwannoma; Acoustic neuroma; Diffusion Tensor Imaging; Diffusion Tensor Tractography.*

RESUMO

A preservação do nervo facial (NF) e vestibulococlear é fundamental para manter a qualidade de vida dos pacientes durante a cirurgia para o tratamento do schwannoma vestibular (SV), um dos grandes desafios do neurocirurgião é fazer um bom planejamento cirúrgico, identificar a localização do tumor, assim como sua relação com estruturas anatômicas e nervosas auxiliando no planejamento cirúrgico e evitando condutas inadequadas. Atualmente, muitos estudos relatam a eficácia da técnica do tensor de difusão e da tractografia (DTI). Realizamos uma revisão sistemática dos estudos que relatam o uso desta técnica. Para a busca foram utilizados o PubMed e o Embase, para isso filtramos os artigos com critérios de inclusão e exclusão pré-estabelecidos. Doze artigos foram selecionados para este estudo, um total de 255 pacientes foram submetidos a um DTI no pré-operatório. A localização e o trajeto do nervo facial foram verificados no intraoperatório. Nestes pacientes, 226 (89%) correlacionaram o resultado do DTI com o achado intraoperatório, que atendeu aos nossos critérios de inclusão. Os resultados desta pesquisa apontam para o excelente resultado do DTI em predizer a localização do NF no pré-operatório, permitindo maior planejamento cirúrgico e melhora no resultado da função do nervo facial.

Palavras-Chave: *Nervo Facial; Schwannoma Vestibular; Neuroma acústico; Imagem do tensor de difusão; Tractografia do tensor de difusão.*

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INTRODUCTION

Vestibular schwannoma (VS) is a benign tumor that stands out among the tumors present in the cerebellopontine angle (CPA). The presence of this neoplasm can present symptoms such as deafness, tinnitus, facial paralysis, ataxia and headache[1].

Precise anatomical visualization of the cranial nerves is of paramount importance in surgery for CPA tumors. Accordingly, it is essential to highlight the importance of the tumor's relationship with nearby structures and its location, which may differ depending on its size. Large and giant tumors can eventually cause distortion and compression of structures including the facial nerve (FN) and brainstem [2,3]. Reliable preoperative visualization of the location of brain structures in relation to VS would allow surgeons to plan tumor removal accordingly and may increase surgery safety[1].

VS surgery aims to remove all tumors, preserving as many structures as possible in order to maintain the patient's neurological functions and consequent quality of life. According to this statement, we emphasize that the preservation of the vestibulocochlear and FN is extremely important for the success of the surgery. However, this is not always possible. Postoperative FN injury is one of the most important causes of morbidity after resection of large VS. FN paresis is a devastating complication and has an adverse psychosocial impact. Other complications involve conjunctivitis and corneal ulceration, besides cosmetic disfigurement [1,2].

In view of this, we analyze the importance to understand the relationship between the tumor and structures, such as the FN in the period prior to surgery. In order for tumor resection in the safest way, aiming better outcomes, the Diffusion Tensor Imaging (DTI) can be used to determine the position of the FN more accurately in relation to the tumor [2].

DTI is based on the principle that water diffusion is anisotropic in organized tissues such as brain white matter. This type of imaging provides information on two fundamental aspects: the extent and orientation of diffusion anisotropy. It is a fact that the different structures of the biological environment offer different conditions for the displacement of particles. The direction of orientation (or displacement) is favored for the path parallel to the fibers and the perpendicular direction is restricted by the physical barrier of the clustered neurons. In this way, with the understanding that the orientation of water diffusion is aligned with the predominant fiber direction, DTI-based fiber tracking allows for a 3D reconstruction of the white matter architecture[1].

The DTI image is generated by the difference between the Fractional Anisotropy (FA) values of the FN and the tumor, which allows us to distinguish between the nerve and the VS. Using the FA values, the FN can be traced from the brainstem to the inner ear. Therefore, structures can be better analyzed for effective surgical planning, benefiting not only the patient but also the medical team [1,4].

The aim of this article is to carry out a systematic review to confirm the DTI as a viable tool for visualizing the FN in the preoperative period and to minimize possible damage to the facial innervation.

MATERIAL AND METHODS

This systematic review was carried out in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [5].

Literature search

For our study, only articles published in English were selected. The PubMed and Embase databases were used to search studies that reported the representation of the FN in the DTI and the real intraoperative correlation of the FN. We selected the MeSH terms of the most relevant publications to conduct a new search in order to obtain more articles that could potentially be included in this review. The keywords used were: ((facial nerve) AND ((vestibular schwannoma) OR

(acoustic neuroma))) AND ((diffusion tensor imaging) OR (diffusion tensor tractography)).

Among the inclusion criteria we included: (1) original articles that reported patients with diagnosis of VS; (2) articles from january 2000 to june 2021; (3) men and women of any age diagnosed with VS (4) related location of the preoperative FN using DTI or fiber tractography and the intraoperatively observed FN position. Among the exclusion criteria, we excluded (1) letters, review studies; (2) studies that did not use the DTI in the preoperative period to assess the location of the FN; (3) studies not written in English.

Data Extraction

The data for each study were extracted independently by three authors. Disagreements were resolved by consensus. If no consensus was reached, a fourth author was consulted. All studies were analyzed according to their titles and abstracts, according to inclusion and exclusion criteria. If the eligibility criteria were met, the full text was extracted. Missing data were clarified by contacting the authors directly.

DISCUSSION AND RESULTS

We found 64 articles, of which 10 were found in PubMed and 54 in Embase databases. To select the articles, we used the Rayyan System for Systematic Review. Of these articles, 23 were excluded because they were duplicates and systematic reviews. Other 28 articles were excluded based on the inclusion and exclusion criteria. According to the eligibility criteria, 12 articles were selected and the full texts were carefully analyzed for this review (Figure 1).

Randomized prospective article written by Samala et al (2019)[6] containing a total of 94 patients, with these being divided into study and control groups, and the use of preoperative DTI coincided with the same intraoperative location of the FN in 39 patients (97.5%). Out of the 47 patients in whom DTI was carried out, it was not possible to preoperatively identify FN in 5 patients (technical failure). It was possible to preserve the FN anatomically and functionally in 36 out of 40 cases in this group (90%). In comparison, the group who didn't use the DTI in the preoperative was able to preserve the function of the FN in 29 of 46 patients (63%).

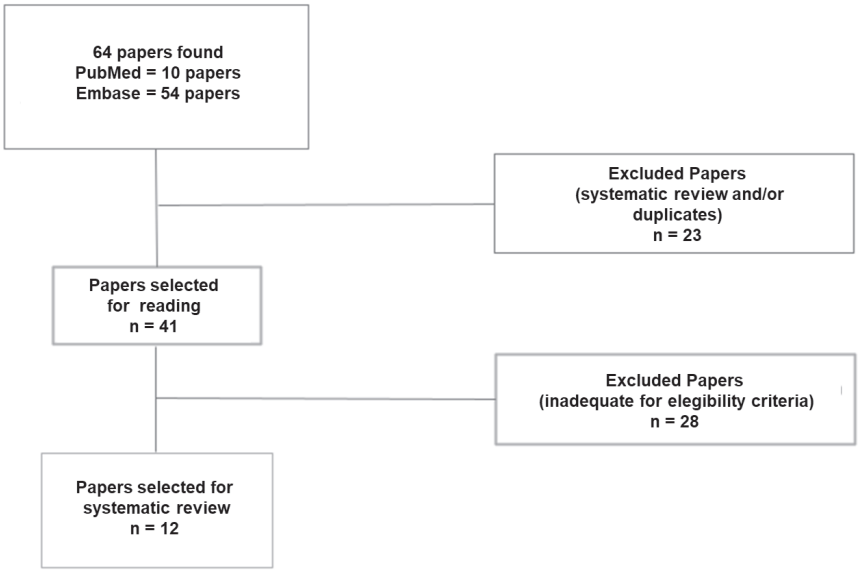

Figure 1. PRISMA flow diagram of systematic review of neurosurgical studies about the DTI use on Vestibular Schwannoma, outlining the number of initial non duplicate citations screened, the articles excluded, and the final 12 included articles.

In another article written by Churi et al. (2019)[1], containing 40 patients, 31 of whom had VS, DTI was also performed in the preoperative period to analyze the relationship of the FN with the tumor. Correlation between DTI and intraoperative findings for the FN was 85% (34 of 40). It was correlated in 8 of 9 non-VS tumors (88.8%) and 26 of 31 VSs (83.8%).

Gerganov et al. (2011)[3] performed a prospective study and analyzed the relationship of the FN with the VS in 22 patients. The location of the CPA segment of the FN, in relation to the VS determined during surgery corresponded to the location of the fibers, predicted by the DT imaging–based fiber tracking, in 20 (90.9%) of the 22 patients. The anatomical integrity of the FN could be preserved in all 22 patients. Two weeks after surgery 63.7% (14/22) of the patients had excellent FN function (House-Brackmann (HB) Grade I in 36.4% and Grade II in 27.3%), 9.1% had good function (HB Grade III), and 27.3% (6/22) had fair function (HB Grade IV).

A study written by Song et al. (2016)[7] also sought to analyze the relationship of the FN with VSs through the DTI and compared the examination result with the surgical finding in 15 patients. As a result they found that preoperative visualization of the FN using DTI-FT was observed in 93.3% of the patients. However, in 92.9% of the patients, the FN visualization results were consistent with the actual surgery. FN electric stimulation, after tumor resection, showed a good nerve response. The patients' postoperative FN function was evaluated according to their HB. In the preoperative 13 patients were HB Grade I, one patient was Grade II e one patient was Grade III. In the postoperative, five patients were Grade I, six were Grade II e four were Grade III.

A prospective cohort study written by Szmuda et al. (2020)[8], sought to compare the result of the DTI with the surgical finding in 38 patients who had a tumor in the CPA, of which 32 had VSs. Regarding the framework involving the VS, DTI-FT was correct in simulating the FN position in 26 out of 30 patients (86.7%). Following surgery, 86.5% of the patients presented with useful facial function (HB grades I-III).

Li et al. (2017)[9] reported in his study the realization of preoperative tractography of the FN was demonstrated and guided by the tractography-integrated navigation system. In this study 19 patients were included. The patients were correlated with the real location of the FN in 17/18 patients (94.4%), 18 patients in grade I and one patient in grade II according to the HB FN grading system preoperatively. In the twelve-month follow-up, FN function was classified as grade I in ten patients, grade II in eight patients and grade III in one patient.

A prospective study written by Zhang et al. (2016)[14] also used DTI in the preoperative period to analyze the FN and its reaction with large VS in 30 patients. In this study, the intraoperative finding coincided with that presented in the DTI in 29 cases (96.7%). In this study, 70.0% (21/30) of the patients had excellent FN function (Grade I in 13.3% and Grade II in 56.7%), 16.7% (5/30) had good function (Grade III), and 10.0% (3/30) had fair function (Grade IV). Patient 27 had Grade VI in tthe FN function, postoperatively.

Zolal et al. (2017)[11] conducted a prospective cohort study with twenty-one patients having unilateral large VS (Hannover Grades 3 e 4) with mean age of 54.6 years. In this study the representation corresponded to the FN (as seen intraoperatively) in 17 of the 21 cases (81%) and to the cochlear nerve in six of the 18 cases (33%). In three cases, the position of cochlear nerve not could be discover intraoperatively, for tumors where the results was correctly on representation of FN, the mean postoperative HB score (8th postoperative day) was 1.9 in patients with correct FN depiction and 2.8 in cases where such depiction was not correct.

Yoshino et al (2015a)[12] the study included 22 in their study, the mean age was 44 years old, the function preoperative of FN for all patients was HB Grade I. The average tumor size was 29.6 mm (range 8.6–51.8 mm), The DTI was performed in all patients, and the identification of the nerves was registered intraoperatively. Yoshiro patients. and the identification of the nerves was registered intraoperative, in your outcome, Yoshiro found the postoperative FN functions as HB Grade I for 15 patients, Grade II for six patients, and Grade III for one

patient. As it were, HB Grade I–III function was achieved in all 22 patients. Functional hearing was preserved in 9 (69.2%) of 13 patients. The representation of fibers on DTI was verified with the intraoperative findings, there was agreement in 17 of 18 patients, and for all 22 patients, the coincidence rate of fibers depicted by DTT and the FN was 13.6% (3/22). The fibers corresponding to the cochlear nerve identified by DTT were 63.6% of the sample (14/22). Furthermore, the sensitivity of DTT for the FN was 100%.

Yoshino et al. (2015b)[13] conducted a study in order to observe whether only the FN was seen during the visualization procedure with the DTT. Postoperative FN function according to HB Classification was Grade I in seven patients, grade II in four patients. That is, all patients achieved HB Classification Grade I–III (100 %). The visualized fiber tract in six patients (6/11; 54.5%) in whom fiber tracts were visualized corresponded to the pathway area of the cochlear nerve, while in three patients (27.3%) it corresponded to the pathway area of the FN. Thus, in this study, the visualization rate was higher for the vestibulocochlear nerve than for the FN.

Choi et al. (2014)[2] prospectively studied 11 patients who underwent VS surgery, with mean age of 51 years, Asymmetric sensorineural hearing loss was evident in seven preoperative patients (64%), the FN function on preoperative period of all patients was normal, the mean size tumor was 18-38 mm, all patients did DTI preoperative, the function was clinically evaluated according to the HB. In this study, the FN course on preoperative tractography was entirely correlated with intraoperative findings in all patients (100%). For the outcomes of FN function, on immediate postoperative 1 day, two patients were grade II, two patients were grade III, five patients were grade IV, and one patient was grade V, after one year. Two patients recovered to HB grade III, seven patients recovered to HB grade II, and two other patients recovered HB grade I, FN preservation was evident in ten of the 11 patients.

Zhang et al. (2013)[14] included eight patients, with mean age of 51 years, All his cases underwent DTT for visualization of FN preoperatively, and had hearing deficits. Among them one case had complete loss. FN function was normal in six, HB Grade II in one, and HB Grade III in one. Four manifested hypesthesia, two had tinnitus, four had dizziness, and three had ataxia or disequilibrium. Two cases exhibited syndromes of increased intracranial pressure. Pyramidal signs were disclosed in 2 cases. Hydrocephalus was disclosed in 2 cases. The DTI was obtained in 7 out of 8 cases (87.5%), the course of each FN was consistent with the surgical findings in all the seven cases. Only the distal part of the FN could be mapped in one patient who had a VS of 48 mm in diameter.

Our results confirm the premise that DTI presents excellent results regarding its use to predict the location of the FN, allowing for a more accurate surgical planning and reduction of problems in the postoperative period.

Most of the analyzed studies have been inconclusive and mainly unclear, due to numerous and substantial factors that may affect the results presented and, consequently, their interpretation and comparison, such as: the unit of measure used to analyze the size of the tumor, which varied between the studies, some used it in "cm", others in "mm", others still in "cm^3". In addition, another identified limiting factor refers to the use of different software and different image acquisition methods, considering that several bibliographies have improved the DTI protocols. Another factor identified was related to the surgeon's non-blinding of the DTI result, which may bias the study result; the low number of articles found by the group also becomes a limiting factor for conducting the research. Despite all the limitations, the excellent use of the HB scale to assess FN function was observed, as all articles are based on this same scale.

Table 1. Main characteristics of the 12 articles analyzed.

AUTHOR AND YEAR	NUMBER OF PATIENTS	AGE	SEX	MEAN TUMOR SIZE	ANISOTROPY	RESULTS IN RELATION TO THE FACIAL NERVE FUNCTION AND INTEGRATED	FACIAL NERVE POSITION IN RELATION TO SCHWANNOMA VESTIBULAR	INTRAOPERATIVE CONCORDANCE
Szmuda et *al.*, 2020	32	54.4 years	both (19 male and 19 female)	28.8 mm	Yes	Following surgery, 86.5% of the patients presented with useful facial function (House Brackmann grades I-III).	Anterosuperior (17/38) and anterior (9/38) were the most common positions of the FN	86.7%
Churi *et al*., 2019	31	41.15 a ± 13.96 years	both (18 female and 22 male)	45.13 ± 29.89 cm³	Yes	Not mentioned	Anterosuperior in 13 patients, anterior in 12 patients, anteroinferior in 5 patients and inferior in 4 patients	83,80%
Samala *et al.*, 2019	47	39.12 ± 13.6 years	both (not discriminated)	27.14 ± 14.3 ml	No	70.9% patients had grade II facial nerve paralysis at presentation followed by grade I (19.7%) paresis.	Anterosuperior in 24 patients, antero-middle in 10 patients, anteroinferior in 5 patients and posterior in 1 patient	97.5%
Zolal *et al.*, 2017	21	54.5 years old (range 28-75 years)	both (7 male and 14 female)	5.1 cm³	No	Grade I in 8 patients, grade II in 8 patients, grade III in 1 patient, grade IV in 3 and grade V in 1 patient	Not mentioned	81%
Li *et al.*, 2017	19	31.4 years old (range:19-62)	both (11 female and 8 male)	41.3 mm in diameter (ranging from 25.0-53.4 mm).	Yes	Grade I in 10 patients, grade II in 8 patients, grade III in 1 patient.	Anterior middle third portion of the tumor surface in 9 cases, anterior inferior third in 5 cases, anterior superior third in 4 cases, and posterior inferior portion in 1 case	94.4%
Zhang *et al.*, 2016	30	46.8 years (range:	both (11 males and 19	33.4 mm (range: 20.4–54.0	Yes	Grade I in 28 patients, Grade II in 1 patient, and Grade III	upper side (n = 5), anterior middle side (n = 15), anterior lower	96.7%
Song *et al.*, 2016	15	43.5 ± 10.3 years	both (6 male and 9 female)	31.9 ± 8.5 mm (range 9–45 mm)	Yes	Grade I in 5 patients, grade II in 6 patients and grade III in 4 patients	anterior upper side (n = 7), anterior middle portion (n =1), anterior lower portion (n= 3), or inferior polar side (n= 2)	93.3%
Yoshino *et al*., 2015a	22	44 years (range 18–64 years)	Both (10 male and 12 female)	29.6 mm (range 8.6–51.8 mm)	Yes	Grade I for 15 patients, Grade II for 6 patients, and Grade III for 1 patient.	superior tumor surface in 2 patients, anterior superior one-third of the tumor surface in 13 patients, and anterior middle one-third of the tumor surface in 7 patients.	27.3%
Choi *et al.*, 2014	11	51 years (range, 40-74)	Both (3 male and 8 female)	range 18-38 mm	Yes	Facial nerve preservation was evident in 10 of the 11 patients.	anterior of the tumor surface in 5 cases, anteroinferior in 3 cases, anterosuperior in 2 cases, and posteroinferior in 1 case.	100%
Zhang *et al*., 2013	8	51 years (range from 40 to 63 years).	both (2 male and 6 female)	38.1 mm	Yes	FN function was normal in 6, House – Brackmann (HB) Grade II in 1, and HB Grade III in 1.	Anterior middle portion to the VS in 4 cases, on the anteroinferior third in 2 cases, and on the inferior pole in 1 case	87.5%
Gerganov *et al.*, 2011	22	43.6 years old (range 19–62 years old)	both (13 male and 9 female)	Range 1,6 - 5 cm	No	Grade I in 36.4% and Grade II in 27.3%, 9.1% in Grade III and 27.3% Grade IV.	anterior middle third of the tumor surface in 10 cases (45.5%), anterior lower third in 6 cases (27.3%), anterior upper third in 2 cases (9.1%), inferior surface in 2 cases (9.1%), and superior surface in 1 case (4.5%).	91%
Yoshino *et al*., 2015b	11	40.0 years (range 18–58 years).	both (6 male and 5 female)	29.7 mm (range, 20.1–40.4 mm).	Yes	All patients achieved House & Brackmann Classification grade I–III (100 %).	On the superior tumor surface in 1 patient, anterosuperior one-third of the tumor surface in 7 patients, and anterior middle one-third ofthe tumor surface in 3 patients.	81.8%

CONCLUSION

The use of DTI proved to be effective. Circumstances such as the difference in the software used, the size of the tumor, technique and protocol are of significant importance for the FN to be correctly visualized preoperatively. Given the limitations of the DTI, it is highly recommended that electrophysiological monitoring of the FN be performed intraoperatively in order to protect the FN functions.

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