

Computational macroscopical patterning of the medullary striae of fourth ventricle

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Abstract

The aim of this study was to pattern macroscopically, by use of computational tools, the number and distribution of the medullary striae (MS) of fourth ventricle. After removing 71 fresh human brain stems, each respective rhomboid fossa was photographed. The MS were carefully identified to be shaped and fulfilled by means of a digital pen, using the Adobe Photoshop CS3® program. For absolute and relative analyses of number and distribution, it was considered the maximum and minimum numbers of striae; striae that reached the ipsilateral lateral recess; presence of horizontal or oblique striae, with or without parallelism; and striae located at pontine or bulbar part of the rhomboid fossa. At least two MS per side were macroscopically detectable in 90.6% of cases; they were bilaterally absent in 5.3% of pieces; and at least one medullary stria was present in both sides of the rhomboid fossa in 92% of cases. As on the right side (36% of cases) as on the left (26.6%), two MS were frequently more present. In 60% of cases, striae reached ipsilateral lateral recess on the left, and in 40% of cases on the right. It was detected horizontal, (non-parallel) oblique and parallel striae in 50.7, 86.7 and 26.7% of cases, respectively. Medial medullary striae were observed in the bulbar part of rhomboid fossa in 80% of pieces, and in 36% of cases in the pontine part. The MS of fourth ventricle show high morphological variability degree in relation to number and distribution.

Keywords: medullary striae, fourth ventricle, rhomboid fossa, gross anatomy, morphology.

1 Introduction

The first description of medullary striae of fourth ventricle (or *striae medullares ventriculi quarti*) dates from the 16th century by the anatomist Arcangelo Piccolomini (1526-1586 A.D.), the reason why it has been denominated at first, “Piccolomini’s stria” (UNIVERSITY OF CALIFORNIA, 2008). Along the centuries, the medullary striae of fourth ventricle, a currently adopted terminology (SBA, 2001; IFAA, 1998), presented a vast synonymia, such as “acoustic striae”, “auditory striae”, “medullary taeniae” and “acoustic taeniae” (TEIXEIRA, 1979; CANCER WEB PROJECT, 2008). They were also known as “Bergmann’s cords” or “Bergmann’s fibers”, paying homage to the German anatomist and neurologist Gottlieb H. Bergmann (1781-1861) (MEDICAL DICTIONARY, 2008).

The medullary striae of fourth ventricle are located inside the floor of the fourth ventricle or rhomboid fossa, which has a lozenge shape and it is formed by the posteroinferior part of the pons (superior position) and by the open portion of the oblong medulla (inferior position). The rhomboid fossa is limited, in an inferolateral position, by the inferior

cerebellar peduncles and by the tubercula of the gracil and cuneiform nuclei; above and in a lateral position, it is delimited by the upper cerebellar peduncles (or conjunctive brains). On each side, the limiting furrow enlarges itself to constitute two depressions, the upper and lower foveae, located respectively in the upper and lower halves of the rhomboid fossa (MACHADO, 2004).

There are two lateral furrows, named limiting furrows, which are delimited between the upper and lower foveae on each side. In the lateral position to the limiting furrow, and having its extension directed towards the lateral recesses, there is the vestibular area, a triangular region that corresponds to the vestibular nuclei of the vestibulocochlear nerve. From the medium furrow towards the vestibular area, thin nervous fibers, occasionally, may be observed, which constitute the medullary striae of fourth ventricle (MACHADO, 2004), and which are constituted of delicate glial filamentary fibers that touch the cerebellar cortex, perpendicularly to its surface (BARTOLUCCI, 2004). In mammals, the posterior cochlear nucleus (or dorsal) and its respective medullary stria (or “dorsal acoustic

stria”) seem to be essentially important in the perception and discrimination of high-tonality sounds (YOUNG, SHOFNER, WHITE et al., 1988; SUTHERLAND, MASTERTON and GLENDENNING, 1998).

Macroscopically, the medullary striae of fourth ventricle arise from the medium furrow and are, in a much variable way, visible or not in the rhomboid fossa. In general, they head transversally in a lateral direction to the level of the lower half of the pons, towards the lateral recess and to the medium or inferior cerebellar peduncles, to reach the posterior cochlear nucleus (or dorsal) (ROUVIÈRE, DELMAS, A. and DELMAS, V., 2005). Diagrammatic illustrations of the medullary striae from text books for medical board exams, may evidence them in a visible pattern of up to three parallel bilateral filaments (BLUMENFELD, 2002; KHALE, 1987). However, the macroscopical estimation related to number and direction of the medullary striae of fourth ventricle is not yet definitely established (ROUVIÈRE, DELMAS, A. and DELMAS, V., 2005).

Most part of the pontomedullary or pontine injuries are surgically approached by means of the rhomboid fossa. As for tumours restricted to the oblong medulla, the medullary striae of fourth ventricle may be a plausible option as a peri-surgery anatomical reference, and surgical incisions of 1 cm in length in the superoinferior direction, and of about 5 mm distally to the medium furrow, may be considered safe for interventions at the rhomboid fossa (HEFFEZ, ZINREICH and LONG, 1990). However, due to the macroscopical variability of the medullary striae in the pontine and bulbar parts of fourth ventricle, their use as an anatomosurgical referential is still debatable (LANG, 1993; LANG Jr., OHMACHI, LANG-SEN, 1991).

Once the medullary striae of fourth ventricle show high morphological variability degree in relation to number and distribution (BOGUCKI, GIELECKI and CZERNICKI, 1997), and due to the fact of their increasing importance as anatomical reference in neurosurgeries (KYOSHIMA, KOBAYASHI, GIBO et al., 1993) or in otosurgeries (MONSELL, MCELVEEN Jr., HITSELBERGER et al., 1987), the objective of the present work has been to pattern macroscopically, by the use of computational tools, the number and distribution of the medullary striae of fourth ventricle.

2 Materials and method

2.1 Material

After a consent, 71 human brain stems were removed as well as their respective cerebellums from fresh corpses (from natural death) deriving from the - Setec Funerary Division (General Technical Service), which is responsible for the Death Verification Sector from the city of Campinas-SP.

2.2 Technical utilized

The usual technical procedures of autopsy from the Sector, for dissection and subsequent surgical extirpation of the pieces, were adopted. Right after the removal of the brain stems, all the cerebella were disconnected from the correspondent brain stems by means of incisions in the medium cerebellar peduncles, at 3 cm from each ipsilateral lateral recess. Inferiorly, each piece was cut at 3 cm below

the inferior medullary velum, and superiorly, 3 cm above the superior medullary velum.

After each removal, all the pieces were consecutively identified in a cardinal numerical sequence by pins (fixed on the mesencephalo ceiling), and placed in a 10% solution of formaldehyde. Afterwards, each piece was positioned on flat surface (inclined 15 degrees from the horizontal plane and lined with blue film liners) and were photographed in conventional natural light by a Nikon Coolpix 8700® digital camera, placed on a tripod. The inclination angle of each picture was kept by the (unchanged) standard position of the camera on the tripod, while taking each picture. Each piece was photographed twice, at a distance of 30 cm (for a panoramic identification of the fourth ventricle – Figure 1) and at 10 cm (for a detailed analysis of the rhomboid fossa – Figure 2), using a millimeter ruler in the vertical and horizontal positions (Figure 1).

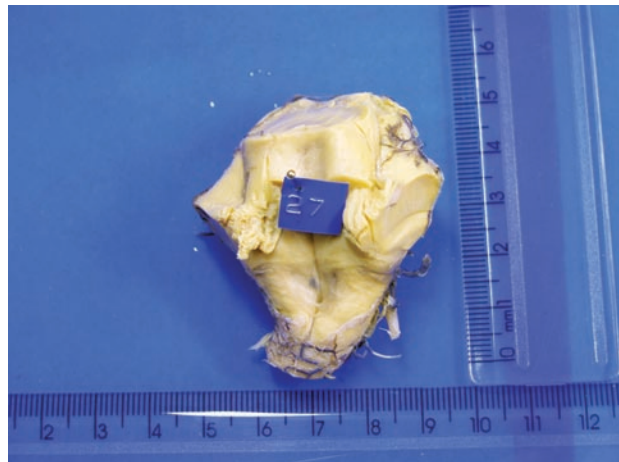


Figure 1. Picture of the rhomboid fossa at a distance of 30 cm (for panoramic identification of the fourth ventricle) and standardization of dimensions using millimeter ruler in the vertical and horizontal positions.

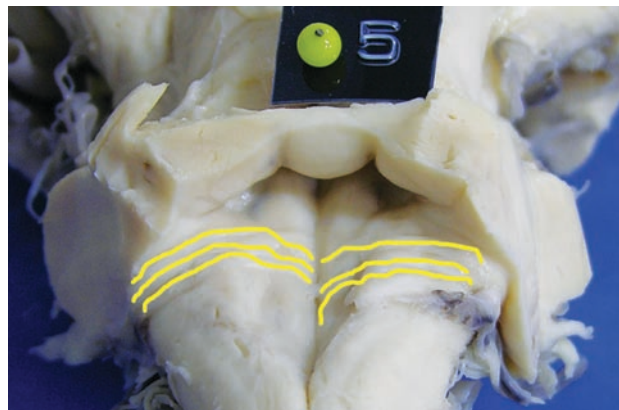


Figure 2. Picture of the rhomboid fossa at the distance of 10 cm (for panoramic identification of fourth ventricle) and careful manual contour of the medullary striae in the yellow-gold color.

2.3 Method

Afterwards, the digitalized pictures were transferred to an Intel Pentium 4[®] microcomputer, and the medullary striae were carefully identified for delineation and contour, at the thickness of 14 *pixels*, in the yellow-gold R239[®] color (Figure 2) using a digital pen (GUTIERREZ, 2008), at the Adobe Photoshop CS3[®] (ADOBE, 2008; MX STUDIO, 2008) computer program (graphical edition software).

For the analysis of macroscopical number and distribution of the medullary striae of fourth ventricle, it was considered the following criteria: maximum and minimum numbers of striae on the right and left halves of the rhomboid fossa; number of striae that reach the ipsilateral lateral recess; number of horizontal or oblique striae, with or without parallelism, on the right or left half of the rhomboid fossa; number of striae located at the bulbar part of the rhomboid fossa (delimited from an imaginary line between the inferior surface of both medium cerebellar peduncles) and number of striae located at the pontine part of the rhomboid fossa (above the bipeduncular imaginary line).

The obtained data were compiled at the Microsoft Office Excel[®] program for the attainment of a descriptive statistics (adopting a decimal) referring to the event frequencies (percentages), followed by the attainment of arithmetical averages for each adopted criterion (from the maximum number of striae found on each side of the rhomboid fossa, per piece). At the end, the macroscopical pattern (regarding number and distribution) most frequently found for the medullary striae was elaborated, by means of digital drawing over a picture of the rhomboid fossa, which was randomly chosen.

3 Results

In the 71 photographed brain stems, there was not any detection of tumoral, ischemic or hemorrhagic injuries, or malformations that could contraindicate the availability of the pieces for a macroscopical study of the medullary striae of fourth ventricle.

At least two medullary striae were macroscopically detectable, in both sides of the rhomboid fossa, in 90.6% of the cases (Table 1 and Figure 3). They were bilaterally absent in 5.3% of the pieces (Table 1). At least one medullary stria was present, as in the right half as in the left half of the rhomboid fossa, in 92% of the cases (Table 1). To the right, medullary striae were not macroscopically detectable in 8% of the cases, being two striae more frequently present (36% of the cases), having a maximum number of seven striae (1.3% of the cases). To the left, medullary striae were not macroscopically detectable in 8% of the cases, being two striae more frequently present (26.6% of the cases) having a maximum number of five striae (9.3% of the cases).

In 60% of the observed cases, the medullary striae on the left reached the ipsilateral lateral recess, and in 40% of the cases on the right (Table 1). It was detected horizontal (non-parallel) oblique and parallel medullary striae in 50.7, 86.7 and 26.7% of the cases, respectively, on the right or left half of the rhomboid fossa (Table 1). Medullary striae – in particular those of medial localization – were noticeable at the bulbar part of the rhomboid fossa in 80% of the pieces, and in 30% of the cases at the pontine part (Table 1). From the last obtained arithmetical averages and through digital

Table 1. Arithmetical averages of the morphological variables considered for medullary striae of fourth ventricle.

Variable	%
Bilateral presence (at least two striae)	90.6
Presence on the left (at least one striae)	92.0
Presence on the right (at least one striae)	92.0
Bilateral absence	5.3
Two striae at the bulbar part of the rhomboid fossa	80.0
Two striae at the pontine part of the rhomboid fossa	36.0
Two horizontal striae in both sides of the rhomboid fossa	50.7
Two non-parallel oblique striae in both sides of the rhomboid fossa	86.7
Two parallel striae in both sides of the rhomboid fossa	26.7
Two striae reach the lateral recess on the left	60.0
Two striae reach the lateral recess on the right	40.0

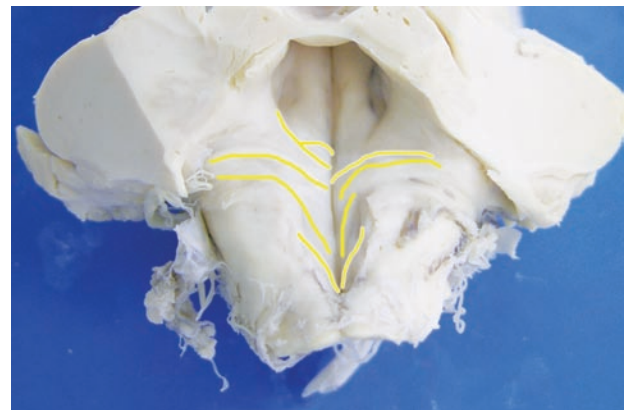


Figure 3. Detection of medullary striae of fourth ventricle in both sides of the rhomboid fossa.

drawing over a picture of rhomboid fossa randomly chosen, the macroscopical pattern more frequently found of the medullary striae of fourth ventricle, was the presence of two striae on each side, both having a non-parallel oblique direction; on the right, the medial stria ascends until the pontine part of the rhomboid fossa, and on the left, both striae reach the ipsilateral lateral recess (Figure 4).

4 Discussion

In mammals, the axons of the neurons of second order, related to the cochlear nuclei, get to organize themselves to constitute three groups of main fibers: the anterior medullary striae (or ventral, located in the trapezoid body), intermediate (or “Helde’s striae”) and the posterior ones (or dorsal, also known as “Monakow’s striae”). The anterior medullary striae have their origin from globular and spherical cells from the anterior cochlear nucleus, and course, medially or distally, towards the oblong medulla to reach the lateral and medial superior olivary nuclei, as well as the medial nucleus of the trapezoid

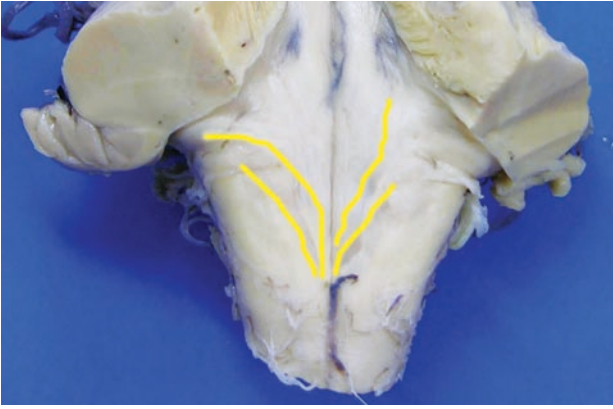


Figure 4. Computational elaboration of the macroscopical pattern of the medullary striae of fourth ventricle: two striae on each side, both having oblique direction; on the right, the medial stria ascends until the pontine part of the rhomboid fossa, and on the left, both striae reach the ipsilateral lateral recess.

body and the inferior colliculus nuclei (OLIVER, 1987; NEELY and KIM, 1986). The intermediate medullary striae derive, mainly from the posterior ventral cochlear nuclei cells, and they are projected ipsilaterally, bilaterally or contralaterally towards the ventral nuclei of the trapezoid body, to the lateral superior olivary nuclei, and also to the periolivary region, in which the olivocochlear fibers originate from (OSEN, 1969; THOMPSON, AM. and THOMPSON, GC., 1986).

The posterior medullary striae are, essentially, a crossed group of fibers for the projection of the posterior cochlear nucleus (or dorsal) cells, towards the lateral lemniscus nuclei and the central nuclei of the inferior colliculus (KHALE, 1987; OSEN, 1969), and the periolivary nuclei receive afferents from the cochlear nuclei through three groups of medullary striae of fourth ventricle (WARR, 1969, 1972). However, in human beings, the macroscopical standardization concerning, as much as for the medial or distal course of the anterior medullary striae, as for the (ipsilateral, bilateral or contralateral) projections of the intermediate striae and to the crossed projections of the posterior striae is not consensually established (SANTI and MANCINI, 2008).

The cochlear nuclei in mammals have been considered a structural pattern for the study of the morphological and physiological relations among groups of cells. However, several debates still persist, especially which concerns the morphological patterns of the dorsal, intermediate or commissural projections of the medullary striae of fourth ventricle (SMITH, MASSIE and JORIS, 2005). Therefore, in spite of the relatively large size of the human cochlear nuclei, their medullary striae are small and hard to be identified, what has caused some drawbacks to clearly identify and define the intrinsic and descending anatomical routes (fibers), related to the cochlear nuclei (MOORE and OSEN, 1979).

The auditory fibers (afferent) related to the cochlear nuclei are visible, bilaterally, in the rhomboid fossa, at the lateral recesses level or pontocerebellar junction, when the cerebellar hemispheres are removed (MOORE and OSEN, 1979). Immunohistochemical studies of the superior olivary complex (by the use of anti-calcium antibodies linked to the

parvalbumin, calbindin, calretinin proteins and to the non-phosphorized filaments HSMI-32) have turned possible the elaboration of details of the morphological organization (tridimensional reconstructions of axonal terminals) related to the cochlear nuclei. Nevertheless, even through the combination of these markers, a consistent nuclear structure concerning the medial nucleus of the trapezoid body was not stipulated yet (BAZWINSKY, HILBIG, BIDMON et al., 2003). Reports of some cases suggest that the former projections of the medullary striae of fourth ventricle (in their decussation areas) are probably responsible for most of the neural signs necessary to hearing, moreover all the required signs to promote the language perception (EGAN, DAVIES and HALMAGYI, 1996).

Surgeries on intra-axial focal brain lesions are considered a risky procedure, whose morbidity (in varied degrees) cannot be avoided, even in cases of partial removal of lesions or of biopsy. Main complications are related to direct damages during the removal of tumours, the choosing of surgical *locus* (place) and retraction direction or tumoral diversions of the brain stem (KYOSHIMA, KOBAYASHI, GIBO et al., 1993). This way, the best surgical accesses considered are those where important neural structures are less prominent. One of these ways refers to the “infra-facial triangle”, medially delimited by the medial longitudinal fascicle, distally by the medullary striae of fourth ventricle, and laterally by the facial nerve. Aiming to minimize secondary damages to the tumoral retraction of the brain stem, it is necessary to promote lateral traction from the “intra-facial triangle” limits. This way, to identify and to delimit macroscopically the medullary striae of fourth ventricle, allows using the “infra-facial triangle” to surgically remove unilateral brain injuries (posterior to the medial lemniscus and located at the oblong medulla or at the pons), effect biopsy or aspirate hemorrhagic contents (KYOSHIMA, KOBAYASHI, GIBO et al., 1993), what has justified the accomplishment of the present study.

Once operating procedures in the fourth ventricle may cause potential injury to the brain stem, cerebellum, and cranial nerves or to cerebellar blood vessels, macroscopical dissections associated to microscopical examination, with magnifications between 03 and 25 times, have been useful to avoid accidental surgical injuries (MATSUSHIMA, 1982). By this means, the pre-operative knowledge on Radiological and Microsurgical Anatomy (through magnetic resonance) of fourth ventricle may provide important routes for less invasive surgical interventions, especially in cases of tumors (MATSUSHIMA, 1982). For such, neuroendoscopy techniques have been used in the fourth ventricle of fresh corpses, in order to determine anatomical details, which are important to surgical procedures (STRAUSS and FAHLBUSCH, 1997). However, medullary striae may be macroscopically invisible up to 14% of the cases, mainly at the superior half (or pontine) of the rhomboid fossa (LANG, 1993). At the present study, the medullary striae have been macroscopically absent in the fourth ventricle, in bilateral means, in 5, 3% of the cases (Table 1 and Figure 4).

Additionally, safe approaches of the rhomboid fossa for surgical interventions of intrinsic injuries of the brain stem, have been based in a detailed knowledge on the Morphometrical Anatomy of the motor structures, superficially located in the fourth ventricle. For such, morphometrical data must consider the shrinking degree

of each piece histologically elaborated. Another option to avoid surgical morbidity to the rhomboid fossa structures includes elaborating a neurophysiological mapping of the fibers and superficial motor nuclei, mainly in cases of intrinsic or pontomedullary pontine injuries (STRAUSS, LÜTJEN-DRECOLL and FAHLBUSCH, 1997). This way, the intra-operative neurophysiological monitorization has provided good surgical results with a minimum morbidity, from the application of mapping techniques, electroneuromiography and of muscular evoked potential. Specially, the neurophysiological mapping techniques allow the determination of surgical anatomical references and prognostic data, once efferent reflex arcs may be evaluated in an intra-operative way (SALA, MANGANOTTI, TRAMONTANO et al., 2007).

Morphometrical studies of brain stems (using a digital image analyzer) from patients having a *causa mortis* not related to diseases from the nervous system, have indicated that the medullary striae of fourth ventricle may present visibility difficulty, in up to 30% of the cases (BOGUCKI, GIELECKI and CZERNICKI, 1997). However, even the most completed colored atlas available in the market, elaborated with advanced digital technology (having accurate images generated by computers) for Functional Neuroanatomy, it does not show details of the medullary striae of fourth ventricle (KRETSCHMANN, WEINRICH, RAMSEY et al., 1998). In the present study, the use of the Photoshop CS3® computer program has allowed to, carefully, delimit and delineate the medullary striae of fourth ventricle, from a digital marker pen (Figure 2). This way, the digital pen (having a thickness of 14 pixels) allowed to control shape and thickness of the images, because of its conventional use for obtaining a high performance on creation softwares (GUTIERREZ, 2008) as, for instance, Adobe Photoshop CS3®, which has been chosen for this study. This way, during the digital edition of the images, such computer program was able to provide a proper graphic interface, control of environmental light, increase of saturation in areas with saturated images, sensible adjustments for the control of all the tonalities and tests of digital filters (GUTIERREZ, 2008; PHOTOSHOP CS3, 2008).

Histological studies with colloidal carbon in corpses have suggested that the understanding of the medullary striae of fourth ventricle topography (and of other structures), may provide a trans-labyrinth surgical access, as well as chances of an auditory rehabilitation from the electrical stimulation of the cochlear nuclei located in the lateral recesses, in patients who are not candidates to cochlear implants, without causing any harm to the adjacent neurovascular structures (MCELVEEN Jr., HITSELBERGER and HOUSE, 1987; JACOB, 1991). This way, electroauditory prosthesis have been implanted in fixed corpses, for identification of anatomosurgical references of positioning to be used in patients having bilateral transection of the cochlear nerves after tumoral removal, to provide auditory perception (TERR, FAYAD, HITSELBERGER et al., 1990). In this context, the medullary striae of fourth ventricle (especially those that reach the lateral recesses), with other anatomic references, may be useful to identify the best surgical access at the pontomedullary junction (MONSELL, MCELVEEN Jr., HITSELBERGER et al., 1987). In the present study, the macroscopical pattern of the medullary striae of fourth

ventricle most commonly found was the presence of two non-parallel oblique striae per side, where, on the right, the medial stria reaches up to the pontine part of the rhomboid fossa and, on the left, both striae reach the ipsilateral lateral recess (Table 1 and Figure 4).

5 Conclusion

The medullary striae of fourth ventricle show high morphological variability degree in relation to number and distribution. Their most common macroscopical pattern found is correlated to the presence of two non-parallel oblique striae per side. On the right, the medial stria reaches the pontine part of rhomboid fossa and, on the left both striae reach the ipsilateral lateral recess. Computational tools that can illustrate medullary striae of fourth ventricle are useful in providing assistance to surgical approaches of the rhomboid fossa.

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References

- UNIVERSITY OF CALIFORNIA. Department of molecular and cell biology: glossary. California, 2008. Available from: <http://mcb.berkeley.edu/courses/mcb160L/Handouts_2006/Glossary.doc>. Access in: 08/04/2008.
- COMISSÃO DE TERMINOLOGIA. Anatomia da Sociedade Brasileira de Anatomia: terminologia anatômica. São Paulo: Manole, 2001. p. 136-138.
- INTERNATIONAL FEDERATION OF ASSOCIATIONS OF ANATOMISTS - IFAA. International anatomical terminology. 1 ed. Stuttgart: Thieme, 1998. p. 113,115.
- TEIXEIRA, SA. Stedman: dicionário médico. 23 ed. Rio de Janeiro: Guanabara Koogan, 1979. p. 1304. (vol. 2)
- CANCER WEB PROJECT. Medical dictionary. Available from: <<http://cancerweb.ncl.ac.uk/cgi-bin/omd?query=medullary+teniae>>. Access in: 15/02/2008.
- MEDILEXICON. Medical dictionary. Available from: <www.medilexicon.com/medicaldictionary.php?t=20353>. Access in: 04/04/2008.
- MACHADO, ABM. Neuroanatomia funcional. 2 ed. Rio de Janeiro: Atheneu, 2004. p. 43-48.
- BARTOLUCCI, SL. Stedman's medical eponyms. 2 ed. Baltimore: Lippincott Williams & Wilkins, 2004. p. 65.
- YOUNG, ED., SHOFNER, WP., WHITE, JA. et al. Response properties of cochlear nucleus neurons in relationship to physiological mechanisms. In EDELMAN, GM., GALL, WE. and COWAN, WM. (Eds.). Auditory function: neurobiological bases of hearing. New York: Wiley, 1988. p. 277-312.
- SUTHERLAND, DP., MASTERTON, RB. and GLENDENNING, KK. Role of acoustic striae in hearing: reflexive responses to elevated sound-sources. Behavioural Brain Research. 1998, vol. 97, no. 1-2, p. 1-12.
- ROUVIÈRE, H., DELMAS, A. and DELMAS, V. Anatomia humana: descriptiva, topográfica y funcional. 11 ed. Madrid: Elsevier, 2005. p. 31-40.
- BLUMENFELD, H. Neuroanatomy through clinical cases. 1 ed. Sunderland: Sinauer, 2002. p. 459-489.

- FIX, JD. High-Yield Neuroanatomy. 3 ed. Philadelphia: Lippincott Williams & Wilkins, 2000. p. 73.
- KHALE, W. Sistema nervoso e organi di senso. 2 ed. Milano: Casa Editrice Ambrosiana, 1987. p. 93-112.
- HEFFEZ, DS., ZINREICH, SJ. and LONG, DM. Surgical resection of intrinsic brain stem lesions: an overview. *Neurosurgery*. 1990, vol. 27, no.5, p. 789-799.
- LANG, J. Surgical anatomy of the brain stem. *Neurosurgery Clinics of North America*. 1993, vol. 4, no. 3, p. 367-403.
- LANG JUNIOR, J., OHMACHI, N. and LANG-SEN, J. Anatomical landmarks of the rhomboid fossa (floor of the 4th ventricle), its length and its width. *Acta Neurochirurgica*. 1991, vol. 113, no. 1-2, p. 84-90.
- BOGUCKI, J., GIELECKI, J. and CZERNICKI, Z. The anatomical aspects of a surgical approach through the floor of the fourth ventricle. *Acta Neurochirurgica*. 1997, vol. 139, no. 11, p. 1014-1019.
- KYOSHIMA, K., KOBAYASHI, S., GIBO, H. et al. A study of safe entry zones via the floor of the fourth ventricle for brain stem lesions: report of three cases. *Journal of Neurosurgery*. 1993, vol. 78, no. 6, p. 987-993.
- MONSELL, EM., MCELVEEN JUNIOR, JT., HITSELBERGER, WE. et al. Surgical approaches to the human cochlear nuclear complex. *The American Journal of Otolaryngology*. 1987, vol. 8, no. 5, p. 450-455.
- GUTIERREZ, F. Canetas Digitais Wacom. Available from: <www.portalvp.com.br/producao/WebForms/wfrEspecialVPDetailhe.aspx?IdEspecialVP=29>. Access in: 04/02/2008.
- ADOBE. Adobe Photoshop CS4. Available from: <www.adobe.com/br/products/photoshop/photoshop/features/>. Access in: 25/02/2008.
- MX STUDIO. Conhecendo o Photoshop CS3. Available from: <http://www.mxstudio.com.br/photoshop/conhecendo_o_photoshop_cs3/>. Access in: 25/02/2008.
- OLIVER, DL. Projections to the inferior colliculus from the anteroventral cochlear nucleus in the cat: possible substrates for binaural interaction. *The Journal of Comparative Neurology*. 1987, vol. 264, no. 1, p. 24-46.
- NEELY, ST. and KIM, DO. A model for active elements in cochlear biomechanics. *The Journal of the Acoustical Society of America*. 1986, vol. 79, no. 5, p. 1472-1480.
- OSEN, KK. The intrinsic organization of the cochlear nuclei. *Acta Oto-laryngologica*. 1969, vol. 67, no. 2, p. 352-359.
- THOMPSON, AM. and THOMPSON, GC. Olivocochlear neurons in the squirrel monkey brainstem. *The Journal of Comparative Neurology*. 1986, vol. 254, no. 2, p. 246-258.
- WARR, WB. Fiber degeneration following lesions in the posteroventral cochlear nucleus of the cat. *Experimental Neurology*. 1969, vol. 23, no. 1, p. 140-155.
- WARR, WB. Fiber degeneration following lesions in the multipolar and globular cell areas in the ventral cochlear nucleus of the cat. *Brain Research*. 1972, vol. 40, no. 2, p. 247-70.
- SANTI, PA. and MANCINI, P. Cochlear anatomy and central auditory pathways. Sant Louis: Mosby, 2008. Available from: <http://famona.tripod.com/ent/cummings/cumml140.pdf>. Access in: 06/04/2008.
- SMITH, PH., MASSIE, A. and JORIS, PX. Acoustic stria: anatomy of physiologically characterized cells and their axonal projection patterns. *The Journal of Comparative Neurology*. 2005, vol. 482, no. 4, p. 349-371.
- MOORE, JK. and OSEN, KK. The cochlear nuclei in man. *The American Journal of Anatomy*. 1979, vol. 154, no. 3, p. 393-418.
- BAZWINSKY, I., HILBIG, H., BIDMON, HJ. et al. Characterization of the human superior olivary complex by calcium binding proteins and neurofilament H (SMI-32). *Journal of Comparative Neurology*. 2003, vol. 456, no. 3, p. 292-303.
- EGAN, CA., DAVIES, L. and HALMAGYI, GM. Bilateral total deafness due to pontine haematoma. *Journal of Neurology, Neurosurgery, and Psychiatry*. 1996, vol. 61, no. 6, p. 628-631.
- MATSUSHIMA, T., RHOTON JUNIOR, AL. and LENKEY, C. Microsurgery of the fourth ventricle: part 1. *Neurosurgery*. 1982, vol. 11, no. 5, p. 631-67.
- STRAUSS, C. and FAHLBUSCH, R. Anatomical aspects for surgery within the floor of the IVth ventricle. *Zentralblatt für Neurochirurgie*. 1997, vol. 58, no. 1, p. 7-12.
- MATULA, C., REINPRECHT, A., ROESSLER, K. et al. Endoscopic exploration of the IVth ventricle. *Minimally Invasive Neurosurgery*. 1996, vol. 39, no. 3, p. 86-92.
- STRAUSS, C., LÜTJEN-DRECOLL, E. and FAHLBUSCH, R. Pericolicular surgical approaches to the rhomboid fossa: part I. *Journal of Neurosurgery*. 1997, vol. 87, no. 6, p. 893-899.
- SALA, F., MANGANOTTI, P., TRAMONTANO, V. et al. Monitoring of motor pathways during brain stem surgery: what we have achieved and what we still miss? *Neurophysiologie Clinique*. 2007, vol. 37, no. 6, p. 399-406.
- KRETSCHMANN, H., WEINRICH, W., RAMSEY, RG. et al. *Neurofunctional Systems*. Stuttgart: Thieme, 1998. p. 55-148.
- MCELVEEN JUNIOR, JT., HITSELBERGER, WE. and HOUSE, WF. Surgical accessibility of the cochlear nuclear complex in man: surgical landmarks. nucleus anatomy related to central electroauditory prosthesis implantation. *Otolaryngology-Head and Neck Surgery*. 1987, vol. 96, no. 2, p. 135-140.
- JACOB, U., MROSACK, B., GERHARDT, HJ. et al. The surgical approach to the cochlear nucleus area. *Anatomischer Anzeiger*. 1991, vol. 173, no. 2, p. 93-100.
- TERR, LI., FAYAD, J., HITSELBERGER, WE. et al. Cochlear nucleus anatomy related to central electroauditory prosthesis implantation. *Otolaryngology-Head and Neck Surgery*. 1990, vol. 102, no. 6, p. 717-121.

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