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RELIABILITY AND AGREEMENT IN THE CEREBELLAR TONSIL TIP LOCALIZATION: TWO METHODS USING THE MCRAE'S LINE CONCEPT IN MRI

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Manuscript submitted to Centro de Ciências Médicas as a partial requirement for obtaining a bachelor's degree in Medicine from the Federal University of Paraíba.

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Abbreviations list

CI = confidence interval

CM = Chiari malformation type I

ICC = intraclass correlation coefficient

IQR = interquartile range

KS = Kolmogorov-Smirnov test

Met = method

ML = McRae's line

MPR = three-dimensional multiplanar reconstruction

MRI = magnetic resonance imaging

O = operator

R = round

Sag = sagittal

SD = standard deviation

TP = tonsil tip position

Table of contents

Abstract

Background: The cerebellar tonsil tip position (TP) is a common parameter used for the radiological diagnosis of Chiari malformation type I (CM). However, this paramedian structures is usually not properly visualized in the midsagittal section. Such mismatch may be a source of bias in TP measurements based on the McRae's line traced between median craniometric points. This study aims to evaluate the intra and interoperator reliability and agreement of two protocols to trace the McRae's line in MRI for the cerebellar tonsil tip localization, adding a three-dimensional multiplanar reconstruction (MPR) approach to the midsagittal plane. **Methods:** Sixty-two T1-weighted head MRIs were obtained for 32 CM patients and 30 controls. Two operators independently applied two TP measurement protocols, one considering only the visualization of the sagittal plane and the other using MPR. The intraclass correlation coefficient was used to assess intra and interoperator reliability, and the Bland-Altman graphical method to evaluate the agreement between the measurement protocols. **Results:** The sagittal method significantly underestimated McRae's line and tonsillar herniation when compared to the MPR method. The MPR method provided better reliability of the McRae's line measurement when compared to the sagittal method, but this did not influence the reliability of the TP. Analysis of the Bland-Altman plot showed that the limits of agreement were close to acceptable for the McRae's line, but not for measures of TP. **Conclusion:** It is possible that the greater precision in tracing the McRae's line by the MPR method provides a better standardized measurement of the TP.

Keywords: Chiari malformation. Agreement. Reliability. Magnetic Resonance.

Introduction

The Chiari malformation type I (CM) is a caudal displacement of the cerebellar tonsils tip towards the cervical spinal canal, what is commonly defined on magnetic resonance imaging (MRI) as a tonsil herniation greater than 5 mm through the foramen magnum.[1–3] This evaluation is performed based on the McRae's line, traced between basion and opisthion, the most anterior and posterior midsagittal points of the foramen magnum margin, respectively.[4]

Originally, the opisthion-basion line was proposed to assist in the diagnosis of bone malformations of the skull base, such as basilar invagination, being measured manually on lateral skull radiographs, a single two-dimensional image that results in superposition of structures located in different anatomical planes.[5] Despite not having been designed to be used in exams that allow three-dimensional navigation and having presented relatively low intra and interoperator reliability, the McRae's line is the classic parameter for the odontoid process evaluation (median structure) with best agreement between the radiography and tomography measurements.[6]

Likewise, the use of the McRae's line as a landmark for measuring tonsil tip position (TP) on MRI showed poor interoperator reliability.[7] In fact, the cerebellar tonsil tip is usually located in paramedian planes and it is not properly visualized in the midsagittal section where the McRae's line should be drawn, which may be a source of bias in the TP measurement. In radiological routine, a pragmatic solution to this problem is to adopt an approximation of the McRae's line, drawing it from the anterior to the posterior margins of the foramen magnum in the paramedian sagittal section, in which the tip of each tonsil is visualized.

Knowing that these are millimetric distances, greater methodological rigor is necessary in clinical measurements and research protocols that seek to understand the pathophysiology of CM. Navigation techniques among multiplanar reconstruction images in volumetric acquisition MRI sequences should be considered to allow visualization of other planes that contain the longest longitudinal axis of each tonsil. Nonetheless, it seems important to keep median plane structures as landmarks to comply with McRae's line parameters as formerly proposed in x-rays plan films. Thus, this study aims to evaluate the intra and interoperator reliability and agreement of two protocols to trace the McRae's line in MRI for the cerebellar tonsil tip localization, adding a three-dimensional multiplanar reconstruction approach to the midsagittal plane.

Material and methods

Study design and ethics statement

A retrospective observational study was conducted based on the Guidelines for Reporting Reliability and Agreement Studies.[8] The research was approved by the institutional ethics committee with waiver of the informed consent, under protocol number 31235220.4.0000.8069.

Participants

This study used a database of head MRI of patients older than 18 years, performed on spontaneous demand in a private diagnostic imaging service, whose requests was due to their own specific clinical indications, unrelated to the protocol of this research. Thirty MRI of patients without craniovertebral transition disorders, performed from December 2011 to March 2013, were consecutively and randomly added to the sample. To evaluate the entire range of measurements in tonsils with distinct positions, 156 MRIs of patients with abnormalities in the craniovertebral transition were retrospectively selected for the sampling of CM cases through an electronic search for the terms “Chiari”, “basilar invagination/basilar impression” and “platybasia” in the exam report filed in the Radiology Information System, from January 2011 to December 2020. This sample was reassessed and classified prospectively according to the presence of CM (tip of the cerebellar tonsil extending more than 5 mm beyond the foramen magnum)[2,3], basilar invagination (tip of the odontoid process of axis extending more than 7 mm beyond Chamberlain's line)[9] and platybasia (Welcker basal angle greater than 140°)[10]. One hundred and fourteen patients who met the diagnostic criteria for CM were included. Of these, eighty-two who had association with basilar invagination and/or platybasia were subsequently excluded, resulting in a total of thirty-two patients with isolated CM.

Exam technique

MRI exams were acquired in a Magnetom C! 0.35 T (Siemens Medical

Solutions, Erlangen, Germany) and stored in DICOM (Digital Imaging and Communications in Medicine) format. Isotropic volumetric images were obtained in sagittal section, in the T1-weighted magnetization-prepared rapid gradient-echo (MP-RAGE) sequence (One acquisition; slice thickness 0.9-1.1 mm; TE 6.5 s; TR 18 s; field of view (FOV) 270 mm; FOV phase 81.3%; base resolution 256; phase and slice resolution 100%; and flip angle 30º). Most of the exams had been performed without the use of intravenous contrast. In contrasted exams, only the pre-contrast phase was used. Technical parameters of the exam were applied to reach signal-to-noise ratio and resolution similar of those from high-field equipment (1.5 T), at expenses of time resolution, resulting in acquisition time of approximately 7-8 minutes.

Operators

It is known that there is no methodological or statistical compromise in the measurements performed by non-radiologist researchers who received the proper training prior to data collection.[11] Thus, two non-radiologist operators (A and B) were previously trained to assess the McRae's line and the cerebellar tonsil tip position, as recommended in the literature, under the supervision of a radiologist with more than 20 years of experience in neuroimaging. Both performed the measurements of the 62 MRI independently and blinded to the data from the sampling stage. After an interval of two months, the operator A replicated the measurements, following a randomized sequence, blinded to the data from the sampling group (CM or non-CM) and from the previous measurements.

Measurements

MRI analysis was performed using OsiriX software (Pixmeo SARL, Bernex, Switzerland). Both operators performed two different protocols to assess the position of the greatest herniation of the cerebellar tonsil based on the margins of the foramen magnum. Each protocol was performed at separate times, temporally separated by at least two weeks.

Measurement method in sagittal orientation

Using sagittal images, the operator was instructed to identify the parasagittal section containing the cerebellar tonsil with the greatest caudal extent. In this section, an approximation of McRae's line was drawn, connecting the anterior and posterior margins of the foramen magnum. The length of this segment was computed as an estimate of the real size of the McRae’s line. The perpendicular distance between the McRae’s line approximation and the point of greatest caudal projection of the cerebellar tonsil was computed, adopting negative values when above and positive when below the foramen magnum.[7]

Measurement method in three-dimensional multiplanar reconstruction

A protocol using three-dimensional multiplanar reconstruction (MPR) was adopted to ensure greater accuracy and adequate delimitation of the real McRae’s line, usually defined as the segment connecting the anterior (basion) and posterior (opisthion) margins of the foramen magnum in the midsagittal plane.[4] Using the MPR, the laterolateral and craniocaudal axes were normalized so that the sagittal plane divided the head into symmetrical sides, thus representing the midsagittal plane. The axial plane of the MPR was then angled to be tangent to the basion and opisthion at the lower margin of the foramen magnum (Fig. 1). After that, the operator turned to the coronal plane of the MPR, tangent to that previous axial plane, projecting it on the posterior half of the foramen magnum, to demonstrate both tonsils, side by side. On the same image, a straight-line indicates to the operator the axial plane of the MPR, just previously adjusted to the McRae’s line in the midsagittal image, as described above. Even though McRae's reference points are eminently median, now the laterolateral extent of his level/plane can be rigorously marked by this line. It is finally in this single image in the parasagittal or coronal plane (the “mouse position” tool allows visualizing the equivalence between the position of the marking in both slices) that the distance from the tip of each of the tonsils to the McRae’s line plane is measured. Distance from the cerebellar tonsil tip located over McRae's line was considered as zero, being negative if above and positive if below McRae's line. This is an operationally simple procedure, which timed takes no more than 8 to 10 seconds in the hands of the trained operator (Fig. 2). Only the position of the largest tonsil was used in the statistical analysis. The length of McRae's line was also measured and is a representation of the anteroposterior diameter of the foramen magnum.

Statistical analysis

Descriptive statistical analysis was performed considering the CM and control groups. The Kolmogorov-Smirnov test was used to assess normality. The sociodemographic characteristics of the groups were compared using the Chi-Square and Mann-Whitney tests. The comparison between the measurement methods performed by the same operator was performed using the paired T test. Intraclass correlation coefficient (ICC) was used to assess the intraoperator and interoperator reliability of measurements of cerebellar tonsil tip position and reference line size (real McRae's line or its approximation), which was interpreted as poor (<0.40), moderate (0.40-0.59), good (0.60-0.74) or excellent (>0.74).[12] To calculate the ICC, a two-way mixed model was adopted, based on the average measurements for analysis of absolute agreement.[13] Intraoperator reliability was evaluated considering both sets of operator A measurements. Interoperator reliability was evaluated considering the first set of operator A measurements and operator B measurements. The agreement between the measurement protocols (Sagittal and MPR) was evaluated using the Bland-Altman graphical method, based on the first set of measurements by operator A.[14] An agreement interval of ±1 mm was considered acceptable. Statistical analysis was performed using the Statistical Package for Social Science (SPSS) version 20.0 software (IBM, Armonk, USA). The graphs were produced using the GraphPad Prism software (version 9). All tests were applied considering a confidence interval of 95%.

Results

Sample characterization

The percentage of women in the control and CM groups was 13/30 (43.3%) and 26/32 (81.2%), respectively. The median age was 44.5 (IQR 22.0) years and there was no significant difference between the groups.

Paired analysis of measurements

The sagittal method significantly underestimated the McRae's line measurements, when compared to the MPR method, both in the CM and control group. The same happened in the measurements of the tonsil tip position, except for the data set of operator B in the evaluation of the CM group. Tables 1 and 2 describe the distribution of McRae's line measurements and tonsil tip position, respectively.

Intraoperator reliability

Considering the total sample, McRae’s line measurement by sagittal and MPR methods indicated good and excellent intraoperator reliability, respectively. While the sagittal method showed good performance in the CM group and excellent performance in the control group, the MPR method was excellent in both groups. The measurement of tonsil position revealed excellent intraoperator reliability in both methods, regardless of the study groups (Table 3).

Interoperator reliability

The McRae’s line measurement by sagittal and MPR methods showed moderate and excellent interoperator reliability, respectively, in the total sample and in group analysis. Measurement of tonsil tip position indicated excellent intraoperator reliability in both methods and in all group analyses (Table 4).

Agreement

The difference between the sagittal and MPR methods for evaluating the McRae’s line was normally distributed ($p = 0.903$), with a significant bias of 0.46 (0.38:0.55) mm and a limit of agreement from -0.19 (-0.34:-0.04) mm to 1.12 (0.97:1.27) mm (Fig. 3). Likewise, the difference between the two methods of assessing the tonsil tip position showed a normal distribution ($p = 0.400$), with a significant bias of 0.77 (0.27:1.28) mm and a limit of agreement from -3.11 (-3.99:-2.24) mm to 4.66 (3.79:5.54) mm (Fig. 4).

Discussion

The cerebellar tonsil tip is a paramedian structure that is usually not properly visualized in the midsagittal section, which may be a source of bias in TP measurements based on the McRae’s line traced between median craniometric points (basion and opisthion). Eventually, the radiological routine can adopt an approximation of the McRae’s line as a landmark for measuring TP, tracing it from the anterior to the posterior margin of the foramen magnum in the paramedian sagittal section containing the tonsil tip. As a result of these and other factors, the traditional method using only the sagittal visualization has shown low interoperator reproducibility.[7] Our study evaluated the intra and interoperator reliability and the agreement in the location of the cerebellar tonsil tip in MRI, having as landmark the real McRae’s line (MPR method) and its approximation (sagittal method). The sagittal method significantly underestimated McRae's line and tonsillar herniation when compared to the MPR method. The MPR method provided better reliability of the McRae’s line measurement when compared to the sagittal method, but this did not influence the reliability of the tonsil position. Analysis of the Bland-Altman plot showed that the limits of agreement were close to acceptable for the McRae’s line, but not for measures of tonsil tip position. Therefore, it is possible that the greater precision in tracing the McRae’s line by the MPR method provides a better standardized measurement of the tonsil position.

The McRae’s line traced on the midsagittal section is a conceptually simple landmark that is easy to apply in routine radiology. Arguments in favor of tracing this reference line in sagittal sections are based both on anatomical aspects and on technical issues of MRI interpretation. In addition to the undulations and presence of small foramina in the lateral region of the foramen magnum, the absence of the diploic bone layer, which confers a pattern of high signal intensity on MRI, does not create the necessary contrast to highlight the lack of signal from the cortical layers of the occipital bone.[3] Our results indicate that the intra and interoperator reliability of the MPR method in tracing the McRae’s line is superior to that of the sagittal method, without being a time-consuming task. Thus, the use of this multiplanar navigation method is justified to trace the McRae’s line in the midsagittal plane and measure tonsillar herniations with the complement of coronal visualization positioned in the greater craniocaudal axis of the tonsil.

Measuring tonsil position based on McRae's line remains the most practical protocol to perform, but it can still be improved to provide better reliability. In fact, previous analyzes using the sagittal method demonstrated an unsatisfactory interoperator reliability, as it presents a wide average range of operator measurements, characterizing a parameter that alone is questionable to provide the diagnosis of CM and assess the need for surgical interventions.[7] Other less conventional landmarks have been proposed to define the TP, such as the arch of the C1 vertebra, showing even better interobserver reliability than the protocol based on the foramen magnum border (McRae's line approximation).[15] On the other hand, our data indicate satisfactory intra and interoperator reliability for both TP assessment methods based on the McRae’s line (sagittal and MPR), which may be due to the standardization of measurement techniques performed prior to the execution of our study protocol. We believe that the McRae’s line can be a good landmark for TP measurement, provided that its tracing is performed in a standardized way, as in the MPR method. In addition, the better visualization of the herniation anatomy, the possibility of distinguishing the laterality of the tonsil and the guarantee of the real tracing of the McRae’s line are themselves arguments that justify the use of the MPR method to the detriment of visualization by the sagittal method alone.

The standardization of the McRae’s line tracing by the MPR method can provide a more accurate measurement of TP. Our data indicate that the sagittal method significantly underestimates ML and TP measurements when compared to the MPR method. Regarding the ML measures, the bias of 0.46 mm is compatible with what was expected, especially when we observe a narrow agreement interval (-0.19:1.12) close to what we defined as acceptable (±1 mm). This finding can be interpreted as an indication that the anteroposterior diameter of the foramen magnum shows little variation in relation to the plane in which it is measured, since the measurement in the sagittal plane (real McRae’s line in the MPR method) is relatively close to those performed in imminently parasagittal planes (approximation of McRae's line in the sagittal method). However, we know that the size of the ML alone does not influence the TP measurements, having been measured in this study only to estimate the quality of the standardization of the measurements of this landmark. In fact, the characteristic of the ML that can influence the TP measurements is its angulation in relation to the cervical canal since the TP measurement is performed perpendicularly to the baseline tracing. Even with similarly sized ML, it is possible that different methods provide baselines with different angulations. This is reflected in the results of agreement between the methods in the TP measurements, with a bias of 0.77 mm and a wide agreement interval (-3.11:4.66), much higher than what we consider acceptable (±1 mm) in this context. Knowing that TP is numerically defined as the perpendicular distance from the tonsil tip to the baseline and, since the tonsil tip is a static and fixed parameter for both methods, the difference found can only reflect the difference in angulation of ML in the assessment methods evaluated. The interval of agreement between the methods estimated for TP is relatively large, as its upper limit is very close to the cut-off point adopted to define the presence of the disease. As only the MPR method can guarantee the real tracing of the McRae’s line, the TP measurements performed by this method may be less influenced by variables that we do not have full control over, such as the angulation of the basal tracing.

The cisterna magna topography presents several structures delimited in a relatively small space, which can be even more complex in patients with alterations in the craniovertebral transition. As it is a millimeter scale measure, small changes in the way of measuring TP can impact the screening and categorization for group analysis, showing the need for standardization in future research protocols. Our data indicate that navigation techniques between the anatomical planes in MRIs should be considered to continue having the McRae’s line as a parameter, allowing the visualization of other planes that contain the longest longitudinal axis of each tonsil.

This study has some limitations. First, the CM group was predominantly female compared to the control group. In fact, female sex is associated with the presence of lower tonsils, which may have influenced the composition of the CM group.[16] This disparity could generate a confounding factor in any eventual comparison of anthropometric variables between the groups. Fortunately, such comparisons were not the purpose of our study. Second, the measurements were performed by only two operators, given that the focus was to assess whether the methods agreed with each other. It is recommended that future studies assess the consistency of our reliability findings in a larger sample of operators.

Conclusion

The MPR method provides better reliability of the McRae’s line measurement when compared to the sagittal method, but this does not influence the reliability of the measurement of the tonsil tip position. Although the sagittal method significantly underestimates McRae's line and tonsillar herniation when compared to the MPR method, the limits of agreement were close to acceptable for McRae's line, but not for measures of tonsil position. Thus, we believe that the greater precision in tracing the

McRae's line using the MPR method provides a more standardized measure of the tonsil position.

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Tables

Table 1. McRae's line measurements.

O	R	Met	Chiari (n = 32)				Control (n = 30)				Total (n = 62)			
			Mean	SD	KS	p*	Mean	SD	KS	p*	Mean	SD	KS	p*
A	1	Sag	3.07	0.35	0.99	<0.001	3.10	0.29	0.96	<0.001	3.09	0.32	0.99	<0.001
A	1	MPR	3.57	0.29	0.75		3.53	0.22	0.57		3.55	0.26	0.33	
A	2	Sag	3.16	0.37	0.31	<0.001	3.11	0.37	0.83	<0.001	3.13	0.37	0.52	<0.001
A	2	MPR	3.57	0.26	0.68		3.60	0.23	0.84		3.59	0.24	0.80	
B	1	Sag	3.43	0.42	0.76	0.010	3.34	0.22	0.83	<0.001	3.38	0.34	0.93	<0.001
B	1	MPR	3.58	0.29	0.71		3.64	0.19	0.55		3.61	0.25	0.96	

O = operator; R = round; Met = method; Sag = sagittal; MPR = 3D multiplanar reconstruction; SD = standard deviation; KS = p value of the Kolmogorov-Smirnov test; * Paired T test.

Table 2. Cerebellar tonsil tip position measurements.

O	R	Met	Chiari (n = 32)				Control (n = 30)				Total (n = 62)			
			Mean	SD	KS	p*	Mean	SD	KS	p*	Mean	SD	KS	p*
A	1	Sag	10.27	5.00	0.33	0.044	-0.23	2.33	0.72	0.034	5.19	6.58	0.47	0.003
A	1	MPR	10.93	5.06	0.35		0.66	2.11	0.88		5.96	6.47	0.36	
A	2	Sag	10.18	5.27	0.14	0.012	0.14	2.05	0.96	<0.001	5.32	6.46	0.37	<0.001
A	2	MPR	10.81	4.95	0.22		1.11	2.12	0.89		6.12	6.21	0.46	
B	1	Sag	10.75	5.51	0.29	0.053	0.60	2.55	0.12	0.023	5.84	6.68	0.32	0.003
B	1	MPR	11.37	5.05	0.59		1.54	2.14	0.39		6.62	6.30	0.51	

O = operator; R = round; Met = method; Sag = sagittal; MPR = 3D multiplanar reconstruction; SD = standard deviation; KS = p value of the Kolmogorov-Smirnov test; * Paired T test.

Table 3. Intraoperator reliability of McRae's line and tonsil tip position.

Variable	Method	Chiari (n = 32)		Control (n = 30)		Total (n = 62)	
		ICC	95% CI	ICC	95% CI	ICC	95% CI
ML	Sagittal	0.697	0.388-0.851	0.749	0.467-0.881	0.716	0.530-0.828
	MPR	0.923	0.842-0.962	0.796	0.568-0.904	0.873	0.789-0.923
TP	Sagittal	0.977	0.953-0.989	0.885	0.759-0.945	0.987	0.978-0.992
	MPR	0.962	0.921-0.981	0.878	0.741-0.942	0.982	0.970-0.989

ML = McRae's line; TP = tonsil tip position; ICC = intraclass correlation coefficient; CI = confidence interval.

Table 4. Interoperator reliability of McRae's line and tonsil tip position

Variable	Method	Chiari (n = 32)		Control (n = 30)		Total (n = 62)	
		ICC	95% CI	ICC	95% CI	ICC	95% CI
ML	Sagittal	0.599	-0.121-0.839	0.471	-0.115-0.752	0.557	-0.048-0.789
	MPR	0.796	0.579-0.901	0.766	0.361-0.902	0.780	0.633-0.868
TP	Sagittal	0.979	0.955-0.990	0.769	0.508-0.891	0.980	0.963-0.989
	MPR	0.962	0.922-0.981	0.827	0.549-0.926	0.979	0.962-0.988

ML = McRae's line; TP = tonsil tip position; ICC = intraclass correlation coefficient; CI = confidence interval.

Figures

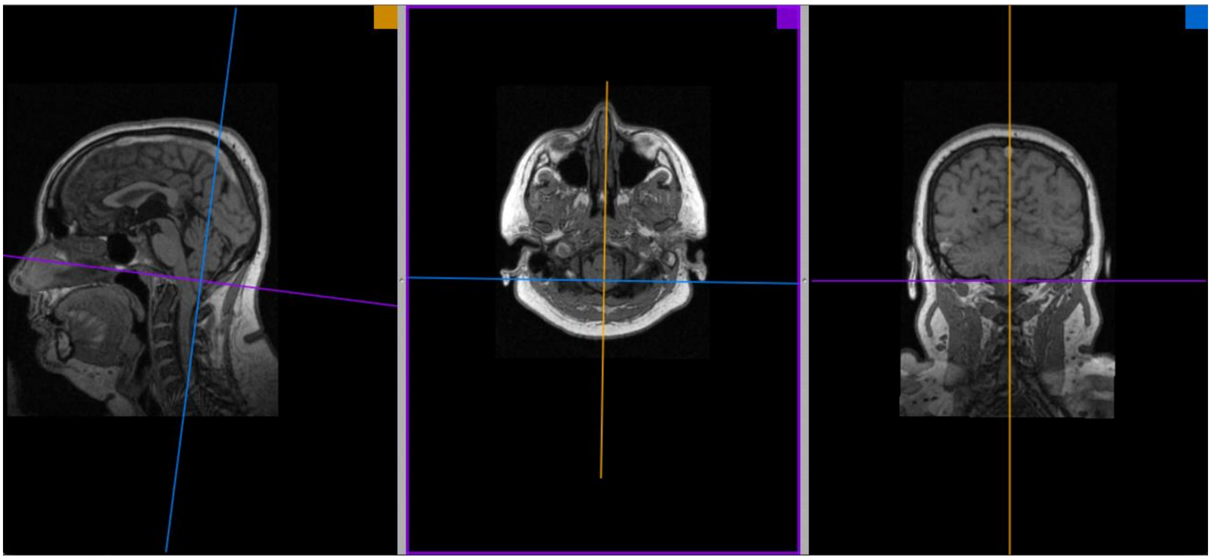

Figure 1. Situation of the midsagittal plane and angulation of the axial plane in an oblique position, perpendicular to the midsagittal plane and passing through the basion and the opisthion. Orange = midsagittal plane; Violet = axial plane; Blue = coronal plane.

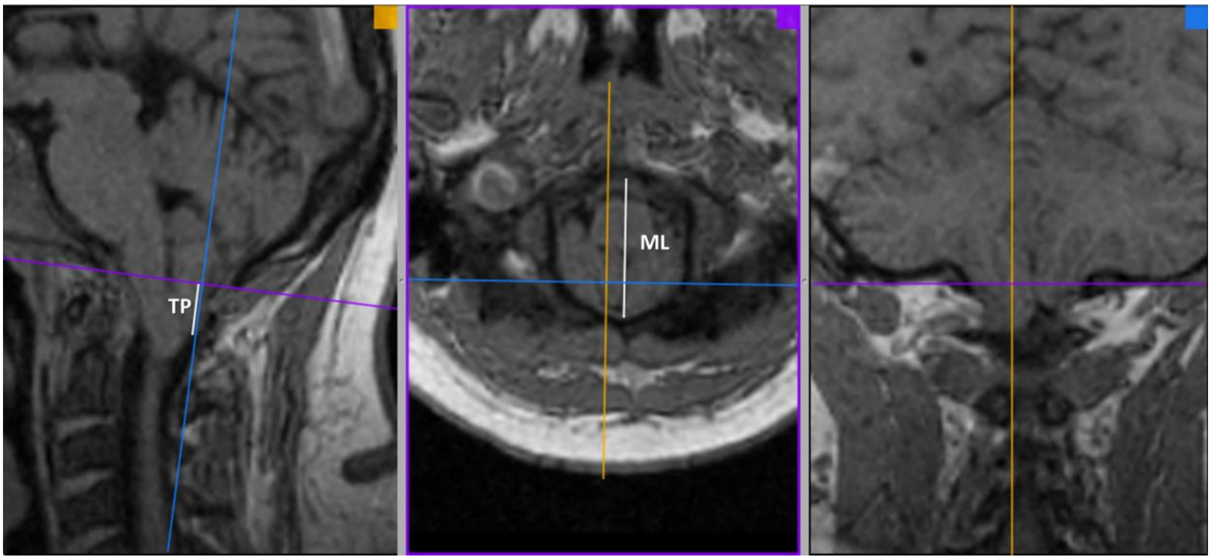

Figure 2. Method for measuring the size of the McRae line (ML) and the tonsil position tip (TP). Orange = parasagittal plane; Violet = axial plane; Blue = coronal plane.

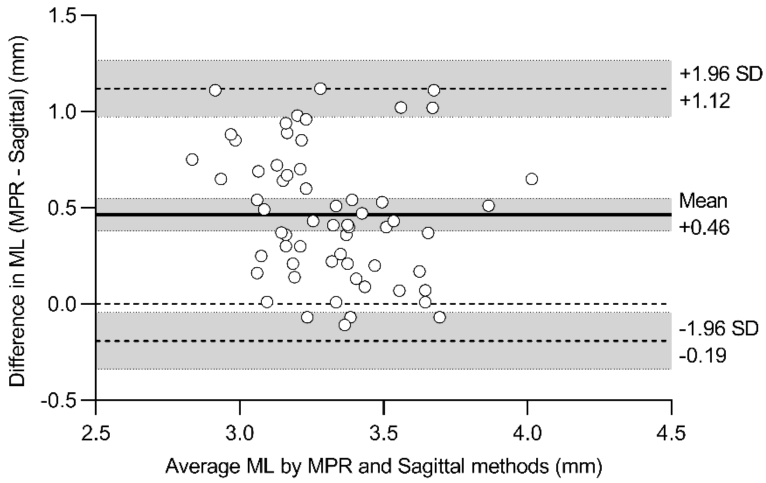

Figure 3. Difference vs. average: Bland-Altman of McRae's line measurements. Continuous line represents the mean of the difference between the sagittal and MPR methods (bias), the dotted line represents the limits of agreement, and the shaded region represents the confidence interval of the respective parameters.

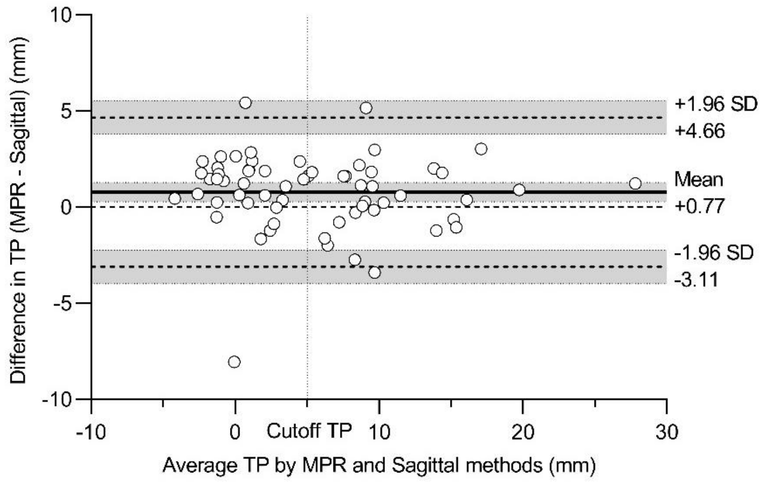

Figure 4. Difference vs. average: Bland-Altman of tonsil tip position measurements. Continuous line represents the mean of the difference between the sagittal and MPR methods (bias), the dotted line represents the limits of agreement, and the shaded region represents the confidence interval of the respective parameters.