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Positional relationship between the facial nerve and other structures of the temporal bone

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Abstract
The quantitative relationships between the position of the mastoid segment of the facial nerve, mastoid pneumatization and the positions of neighbouring structures are undetermined. Using high resolution computed tomography (HRCT), the positions of these structures were measured in 66 normal temporal bones. A new method for measuring the volume of pneumatization in the temporal bone based on the serial digital images of CT was designed. The method of partial correlation analysis was used to find the real relationship of the two variables. The results suggest that the factors that influence the position of the mastoid segment of the facial nerve are complicated and multiple. The development of the cranium including the temporal bone, the temporal bone pneumatization and the variable position of the jugular bulb are considered to be important factors.

Key words: Facial Nerve; Temporal Bone; Anatomy; Tomography, X-ray Computed

Introduction

The structures in the temporal bone vary widely in shape and position, and sometimes are vulnerable to surgical injury.[1] In ear surgery, facial nerve injury due to surgical trauma is a devastating complication. The main reason is a surgeon's lack of familiarity with surgical anatomy of the facial nerve.[2] Many studies have described the anatomical features of the facial nerve,[3–7] but few articles have analysed facial nerve displacement in the temporal bone. As far as we know, the relationship between mastoid pneumatization and the position of the facial nerve has not been studied. The present study was undertaken to examine quantitatively the relationships between the position of the mastoid segment of the facial nerve, mastoid pneumatization and the positions of neighbouring structures.

Materials and methods

The present study was carried out on 33 healthy adults (66 normal ears). There were 14 males and 19 females. Subjects ranged in age between 23 and 73 years (mean 43.3 years).

Axial CT images were taken in 2 mm-thick sections. The window centre was 350, and window width 3000. Sections were parallel to the orbitomeatal line. Every ear was scanned at eight to 10 layers. The image was automatically changed to a digital image which was a bitmap file of 256 grey scale with an array of 1280×1024 pixels. All image manipulation, measures and statistical analysis were done using a computer.

A new method for measuring the volume of pneumatization in the temporal bone based on the serial digital images of high-resolution computed tomography (HRCT) was explored. The contours of the temporal bones within the serial digital images were outlined using Photoshop® software and the portions of non-pneumatization such as the intrapetrosal carotid artery, internal auditory canal, external auditory canal, labyrinth, jugular bulb and non-pneumatized petrous apex were excluded. Their histograms of grey scale were shown (Figure 1). Because a HRCT image was acquired when a layer of some tissues were irradiated by X-rays, on HRCT image, the cross-connecting area between bone substance and air cell behaved gradually changed the grey scale. The grey scale of the pixel representing bone substance was near or equal to 256, while the grey scale of the pixel representing air cell was near or equal to 0. Those pixels were considered to represent air cells if their grey scale was not more than 128, that is, the middle value of 256 and 0 (Figure 2). The volume of air cells (VAIR) was acquired by multiplying the sum of areas of pneumatization by the thickness of the layer.

The axial section passing through the central section of the external auditory canal was used for morphometric measurements. The longitudinal dis-

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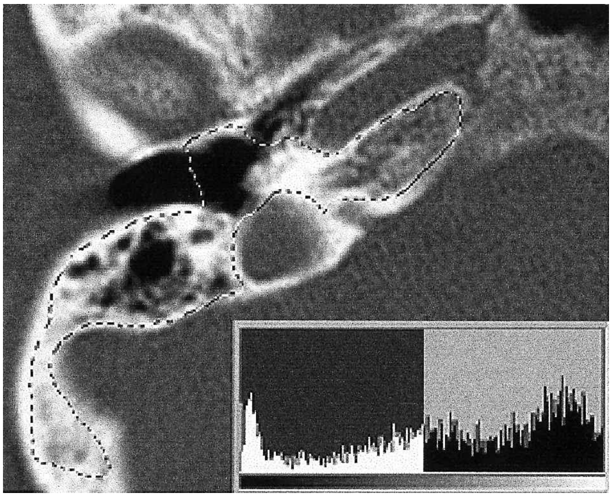

FIG. 1

The contour of the temporal bones including air cells within an axial CT section is shown, and the histogram of grey scale is shown.

tance (SS/EAC) between the posterior wall of the external auditory canal and the anterior edge of the sigmoid sinus was determined on the CT image with the widest external auditory canal. The transverse distance (SS-MC) between the lateral edge of the sigmoid sinus and the midline of cranium and the transverse distance (SS-MP) between the lateral edge of the sigmoid sinus and the lateral edge of the mastoid process were also measured (Figure 3).

The axial section passing through the superior portion of the vertical segment of the intrapetrous carotid artery was also used for morphometric measurements. The transverse distance (FN-MC) between the centre of the facial nerve and the midline of the cranium and the transverse distance (FN-MP) between the centre of the facial nerve and the lateral edge of the mastoid process were

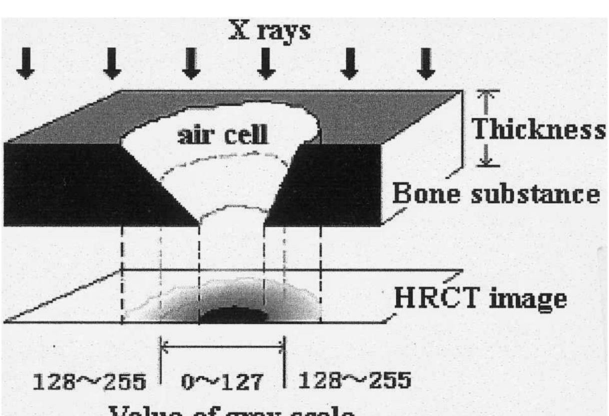

FIG. 2

Schematic drawing for calculation of area of air cells. A HRCT image was acquired when a layer of some tissues were irradiated by X-rays. On HRCT image, the cross-connecting area between bone substance and air cell behaved gradually changed grey scale. Those pixels were considered to represent air cell if their grey scale were not more than 128.

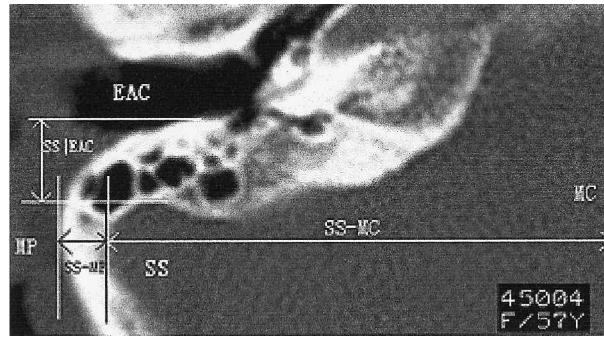

FIG. 3

Schematic representation of the measuring for the distances of SS-MC, SS-MP, SS/EAC in the right axial CT section. SS = sigmoid sinus; EAC = posterior wall of the external auditory canal; MC = midline of cranium; MP= lateral edge of mastoid process.

measured. The transverse distance (JB-MC) between the centre of the jugular bulb and the midline of the cranium and the transverse distance (JB-MP) between the centre of the jugular bulb and the lateral edge of the mastoid process were measured. The longitudinal distance (FN/FS) between the centre of the facial nerve and the foramen spinosum and the longitudinal distance (JB/FS) between the centre of the jugular bulb and the foramen spinosum were also measured (Figure 4). At this layer, the regional area of air cells RAIR in the mastoid process was also calculated. Meanwhile the average of the measured transverse and longitudinal diameter of the jugular bulb was calculated to represent the jugular bulb size. The transverse distance (JB-FN) between the centre of the jugular bulb and the centre of the facial nerve were also measured.

If the jugular bulb appeared in the axial section passing through the basal turn of the cochlea, this jugular bulb was considered as a high jugular bulb.

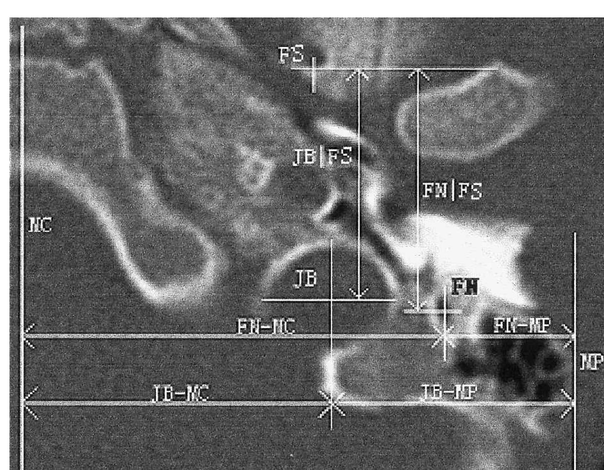

FIG. 4

Schematic representation of the measuring for the distances of JB-MC, JB-MP, JB/FS, FN-MC, FN-MP, FN/FS in the left axial CT section. JB = jugular bulb; FN = facial nerve, MC = midline of cranium; MP= lateral edge of mastoid process; FS = foramen spinosum.

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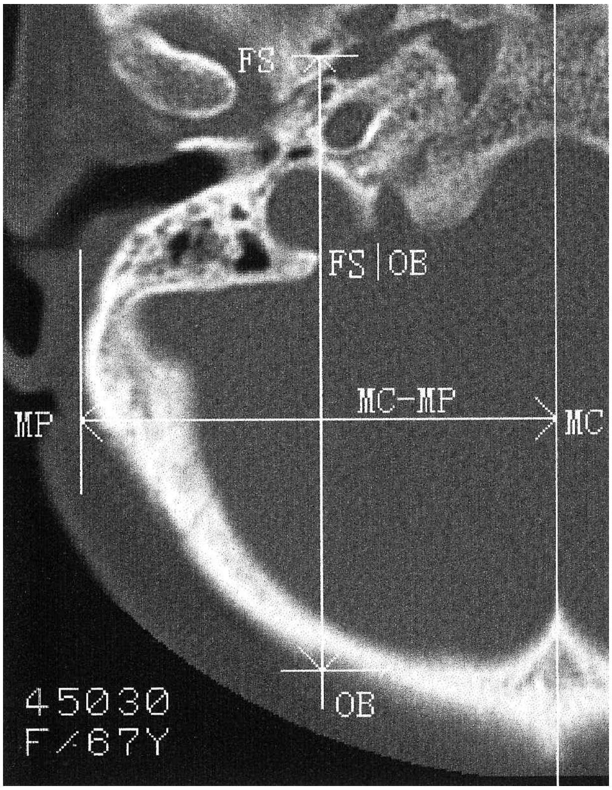

FIG. 5

Schematic representation of the measuring for the distances of MC-MP, FS/OB in the right axial CT section. MC = midline of cranium; MP = lateral edge of mastoid process; FS = foramen spinosum; OB = the point at which the extension line of midpoint of posterior edge of FS and occipital bone intersect.

Because of possible influence of cranial shape on the results, the transverse distance (MC-MP) between the midline of the cranium and lateral edge of the mastoid process was determined to represent the cranial width. The longitudinal distance (FS/OB) represents the cranial length between the midpoint of the posterior edge of the foramen spinosum and the point at which the extension line of the midpoint of posterior edge of the foramen spinosum and the occipital bone intersect (Figure 5). In linear correlation analysis, including partial correlation analysis, the influences of the cranial length and width on results were excluded. For example, FN-MC/MC-MP represented the relative transverse position according to the cranial width.

We assumed no correlation between paired data on the same individual and, therefore, assumed that the 66 measurements were independent. The resulting data were analysed using SPSS8.0. Student's *t*-test was used to compare FN-MC, FN-MP, FN/FS, and so on between the various groups (sides, sex, high jugular bulb and low jugular bulb, etc). The partial correlation analysis was used to find the real relationship between two variables by excluding the influence of other variables, and all the significance tests for the correlation coefficients were two-tailed.

Results and analysis

Influence of sex

Mean values of the measured parameters with respect to sex are shown in Table I(a). The FN-MC and FN-MP were found to be longer in the male temporal bone ($p<0.001$, and $p<0.02$, respectively). After influence of the cranial shape was excluded, the relative positions of the facial nerve are shown in Table I(b). There were no differences between the sexes.

Influence of sides

Side differences for measured values are shown in Table II(a). The FN-MC was found to be longer in

TABLE I(a)

MORPHOMETRIC ANALYSIS OF THE FACIAL NERVE POSITION AND CRANIAL SHAPE WITH REGARD TO SEX (MM)

	FN-MC	FN-MP	FN|FS	MC-MP	FS|OB	Diameter of FN
All subjects (n = 66)	43.08 ± 2.80	19.07 ± 2.97	20.93 ± 1.54	62.14 ± 3.89	61.79 ± 7.65	1.74 ± 0.35
Female (n = 38)	41.94 ± 2.66	18.30 ± 2.24	20.95 ± 1.27	60.24 ± 2.80	60.03 ± 7.02	1.68 ± 0.29
Male (n = 28)	44.62 ± 2.21	20.11 ± 3.51	20.91 ± 1.87	64.73 ± 3.69	64.18 ± 7.94	1.83 ± 0.42
p	p<0.001	*p*<0.02	*p*>0.05	*p*<0.001	*p*<0.05	*p*>0.05

TABLE I(b)

MORPHOMETRIC ANALYSIS OF THE RELATIVE POSITION OF THE FACIAL NERVE WITH REGARD TO SEX

	FN-MC/MC-MP	FN-MP/MC-MP	FN|FS/FS|OB
Female (n = 38)	0.6964 ± 0.0338	0.3036 ± 0.0338	0.3529 ± 0.0397
Male (n = 28)	0.6907 ± 0.0401	0.3093 ± 0.0401	0.3318 ± 0.0573
p	*p*>0.05	*p*>0.05	*p*>0.05

TABLE II(a)

MORPHOMETRIC ANALYSIS OF THE FACIAL NERVE POSITION AND CRANIAL SHAPE WITH REGARD TO SIDE DIFFERENCES (MM)

	FN-MC	FN-MP	FN|FS	MC-MP	FS|OB	Diameter of FN
Right (n = 33)	43.39 ± 2.71	19.12 ± 3.07	20.82 ± 1.68	62.51 ± 4.05	61.68 ± 7.36	1.73 ± 0.42
Left (n = 33)	42.77 ± 2.89	19.01 ± 2.91	21.04 ± 1.41	61.78 ± 3.75	61.90 ± 8.04	1.75 ± 0.28
*p**	*p*<0.05	*p*>0.05	*p*>0.05	*p*<0.05	*p*>0.05	*p*>0.05

*paired *t*-tests

TABLE II(b)
MORPHOMETRIC ANALYSIS OF THE RELATIVE POSITION OF THE FACIAL NERVE WITH REGARD TO SIDE DIFFERENCES

	FN-MC/MC-MP	FN-MP/MC-MP	FN|FS/FS|OB
Right (n = 33)	0.6950 ± 0.0361	0.3050 ± 0.0361	0.3425 ± 0.0500
Left (n = 33)	0.6930 ± 0.0373	0.3070 ± 0.0373	0.3454 ± 0.0481
p*	$p>0.05$	$p>0.05$	$p>0.05$

*paired t-tests

TABLE III
THE CORRELATION COEFFICIENTS (R) BEWTEEN THE PNEUMATIZATION AND THE FACIAL NERVE POSITION

			Influences of MC-MP and FS|OB excluded	
	VAIR	RAIR	VAIR	RAIR
FN-MC	0.2509*	0.1998	–0.1290	–0.1515
FN-MP	0.3579***	0.3542***	0.1290	0.1515
FN|FS	0.2843*	0.2962**	0.3340**	0.3385**

*$p<0.05$, **$p<0.01$, ***$p<0.005$, ****$p<0.001$

TABLE IV(a)
MORPHOMETRIC ANALYSIS OF THE FACIAL NERVE AND CRANIAL SHAPE WITH REGARD TO THE HEIGHT OF THE JUGULAR BULB (MM)

	FN-MC	FN-MP	FN|FS	MC-MP	FS|OB
High JB (n = 37)	42.49 ± 3.08	18.98 ± 3.10	20.96 ± 1.20	61.47 ± 3.99	61.08 ± 8.10
Low JB (n = 29)	43.84 ± 2.23	19.17 ± 2.83	20.90 ± 1.91	63.01 ± 3.64	62.69 ± 7.06
p	$p>0.05$	$p>0.05$	$p>0.05$	$p>0.05$	$p>0.05$

JB = jugular bulb

the right temporal bone ($p<0.05$). After influence of the cranial shape was excluded, the relative positions of the facial nerve are shown in Table II(b). There were no differences between the right-side and the left-side.

Influence of the pneumatization

The volume of pneumatization (VAIR) of the temporal bone was 6.31 ± 3.71 ml, and the RAIR 187.54 ± 125.53 mm^2. The correlation coefficient between VAIR and RAIR was 0.9007 ($p<0.0001$). As seen in Table III, there were correlations between the pneumatization and the measured parameters of the facial nerve. But the positive correlations between the VAIR or RAIR and the FN/FS were actually significant ($p<0.01$, $p<0.01$, respectively) when influences of the cranial length and width were excluded using the method of partial correlation analysis.

Influence of height of the jugular bulb

Mean values of the measured parameters with respect to the height of the jugular bulb are shown in Table IV(a). There were no differences between the low jugular bulb and the high jugular bulb. After the influence of the cranial shape was excluded, the relative positions of the facial nerve are shown in Table IV(b). There were also no differences between the low jugular bulb and the high jugular bulb.

Influence of the position of the jugular bulb

As shown in Table V, there were significant correlations between the facial nerve position and the jugular bulb position (FN-MC and JB-MC, FN-MP and JB-MP, FN/FS and JB/FS), even though influences of the pneumatization, cranial length and width, and the sigmoid sinus position were excluded.

TABLE IV(b)
MORPHOMETRIC ANALYSIS OF RELATIVE POSITION OF THE FACIAL NERVE WITH REGARD TO THE HEIGHT OF THE JUGULAR BULB

	FN-MC/MC-MP	FN-MP/MC-MP	FN|FS/FS|OB
High JB (n = 37)	0.6918 ± 0.0395	0.3081 ± 0.0395	0.3483 ± 0.0440
Low JB (n = 29)	0.6967 ± 0.0325	0.3033 ± 0.0325	0.3384 ± 0.0549
p	$p>0.05$	$p>0.05$	$p>0.05$

JB = jugular bulb

TABLE V
THE CORRELATION COEFFICIENTS (R) BETWEEN THE FACIAL NERVE POSITION AND THE JUGULAR BULB POSITION

	FN-MC and JB-MC	FN-MP and JB-MP	FN|FS and JB|FS
	0.7431****	0.8265****	0.6153****
Influences of MC-MP and FS|OB excluded	0.6080****	0.6080****	0.6171****
Influences of MC-MP, FS|OB and VAIR excluded	0.5995****	0.5995****	0.5662****
Influences of MC-MP, FS|OB, VAIR, SS-MC, SS-MP, and SS|EAC excluded	0.5810****	0.5810****	0.5567****

*$p<0.05$, **$p<0.01$, ***$p<0.005$, ****$p<0.001$

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TABLE VI

THE CORRELATION COEFFICIENTS (R) BETWEEN THE JB-DIA AND FACIAL NERVE, JUGULAR BULB POSITION

	JB-DIA and						
	FN-MC	FN-MP	FN|FS	JB-MC	JB-MS	JB|FS	JB-FN
	–0.0454	0.0553	0.0024	0.2643*	–0.1766	–0.0442	–0.3987***
Influences of MC-MP and FS|OB excluded	–0.1066	0.1066	–0.0058	0.2863*	–0.2863*	–0.0536	–0.4415****
Influences of MC-MP, FS|OB and VAIR excluded	–0.1157	0.1157	0.0155	0.2805*	–0.2805*	–0.0344	–0.4381****

*$p<0.05$, **$p<0.01$, ***$p<0.005$, ****$p<0.001$

TABLE VII

THE CORRELATION COEFFICIENTS (R) BETWEEN THE FACIAL NERVE POSITION AND THE SIGMOID SINUS POSITION

	FN-MC and SS-MC	FN-MP and SS-MP	FN|FS and SS|EAC
	0.4452****	0.3653***	0.0506
Influences of MC-MP and FS|OB excluded	0.3347**	0.3123*	0.0835
Influences of MC-MP, FS|OB and VAIR excluded	0.3188*	0.2909*	–0.0405
Influences of MC-MP, FS|OB, VAIR, JB-MC, JB-MP, and JB|FS excluded	0.0405	–0.0255	–0.2278

*$p<0.05$, **$p<0.01$, ***$p<0.005$, ****$p<0.001$

- **In this paper the position of the mastoid segment of the facial nerve in relation to the degree of mastoid pneumatization was correlated from CT scans**
- **This together with the position of the jugular bulb and the development of the mastoid is important in localizing the position of the nerve**
- **The authors speculate that this information may be of help to surgeons**

Influence of the size of the jugular bulb

The transverse diameter of the jugular bulb was 8.43 ± 2.30 mm, and the longitudinal diameter 7.44 ± 2.29 mm. The jugular bulb diameter was 7.94 ± 2.24 mm. The transverse distance between the centres of the jugular bulb and the facial nerve (JB-FN) was 11.09 ± 1.90 mm. According to longitudinal orientation, the centres of the facial nerve of 52 cases (79 per cent) were posterior to the centres of the jugular bulb, and the longitudinal distance between the centres of the jugular bulb and the facial nerve of all 66 cases was 1.07 ± 1.82 mm. As seen in Table VI, there were no correlations between the jugular bulb diameter and FN-MC, FN-MP, FN/FS, respectively, but there were correlations between the jugular bulb diameter and JB-MC, JB-MP, JB-FN, respectively.

Influence of the sigmoid sinus

As shown in Table VII, there were correlations between FN-MC and SS-MC, and between FN-MP and SS-MP, even though influences of the pneumatization, cranial length and width were excluded using the method of partial correlation analysis. But when the influences of the jugular bulb position were also excluded, there was no significant correlation between the sigmoid sinus position and the facial nerve position.

Discussion

For protection of the facial nerve in ear surgery, it is important to master its anatomy. The length and complexity of the anatomical course of the facial nerve explains the difficulty of its accurate morphological evaluation. It has been reported that the tympanic and mastoid segments of the facial nerve are damaged most frequently by ear surgery.[2] Some articles have described or measured the position and anatomical variation of the mastoid segment of the facial nerve,[4,8] but the factors that influence its position or displacement were rarely involved. In consideration of these reasons, it is necessary to study the factors that influence the position of the mastoid segment of the facial nerve.

The present study revealed that the cranial width and cranial length in the males were larger than those in females, and the cranial width on the right side was larger than that on the left side. There was a tendency for the facial nerve in the males to be situated more laterally when compared to the females, and the lateral bone wall of the facial nerve in the males tended to be thicker than that in the females (1.8 mm on average). This information should be kept in mind while operating on the ear. The cranial shape may cause this tendency, because there were no differences for the position of the facial nerve between the sexes when the influences of the cranial length and width were excluded. When compared to the left side, the facial nerve in the right side tended to be situated more laterally and the cranial shape may cause this tendency, too.

Some articles have indicated that the extent of temporal bone pneumatization correlated with position and shape of some structures in the temporal bone such as the sigmoid sinus,[9–11] but the relationship between the facial nerve position and pneumatization was not studied. The method of evaluating pneumatization in this study was precise and convenient, and differed from the previous studies.[11–18] The volume of pneumatization including air cells and tympanic cavity was calculated and found to be similar to other studies.[13–18] It was found

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that there were correlations between the pneumatization and all the measured parameters of the facial nerve. There was a tendency for the facial nerve to be situated more medially and backwards in well-pneumatized bones. We have failed to find any other study indicating this. This fact might help ear surgeons to identify the localization of the facial nerve during mastoidectomy. More analysis indicated that only a positive correlation between the pneumatization and the longitudinal position of the facial nerve was actually significant when the influence of the cranial shape was excluded. These results suggested that the facial nerve was located further back when the degree of temporal bone pneumatization was higher. A possible explanation might be as follows: pneumatization extends into peripheral regions mainly from the mastoid antrum which lies anteriorly and medially to the mastoid segment of the facial nerve during the postnatal stage. As the air-cell size tends to increase progressively, the facial nerve might be removed backwards.

The facial nerve is located in the neighbourhood of the jugular bulb. Because the shape and position of the jugular bulb may vary, the facial nerve position may be influenced by the jugular bulb position. Our study demonstrated that the facial nerve position and jugular bulb position changed synchronously in the same direction, but the height of the jugular bulb did not influence the position of the facial nerve. It was also found that the size of the jugular bulb did not affect the position of the facial nerve, but the jugular bulb tends to be situated more laterally when the jugular bulb is larger and then the jugular bulb is more adjacent to the facial nerve. The close relationships of the jugular bulb with the facial nerve are of great importance to the ear surgeon and must be kept in mind during mastoidectomy procedures.

Although the facial nerve position and the jugular bulb position changed synchronously in a transverse direction, more analysis suggests that the position of the sigmoid sinus did not influence the position of the facial nerve.

The method of partial correlation analysis was used in the present study to find the real relationship of two variables from the complicated, multiple dependence relations. This method has not been used in previous similar studies.

Limitations of the present study include that the possible influence of age on the facial nerve position was not considered, and a qualitative assessment rather than a quantitative assessment was applied to represent the jugular bulb height.

Conclusion

The factors that influence the position of the mastoid segment of the facial nerve are complicated and multiple. The development of the cranium including the temporal bone, the temporal bone pneumatization and varied position of the jugular bulb should be considered as important factors.

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