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Research article

Determination of the radioanatomical factors related to the position of facial nerve in accessing jugular foramen and carotid artery in temporal bone

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ABSTRACT

Introduction: Preservation of the facial nerve is of great importance in temporal bone surgeries. We intend to investigate the measurements of the radioanatomical factors related to the position of the facial nerve in accessing jugular foramen and internal carotid artery (ICA) in temporal bone of patients who were candidates for temporal high resolution computed tomography (HRCT) scan.
Methods: In this correlation cross-sectional study, samples were selected from patients referred to Amir Alam Hospital who were previously candidates for temporal HRCT. Radioanatomic factors were evaluated in three axial, coronal and sagittal views. Analyzes were performed using descriptive statistics, correlation analysis and factor analysis.
Results: A total of 173 samples were investigated. The most reliable radioanatomical factor based on coefficient of variation (CV) was the distance of the 7th nerve to the temporomandibular joint (TMJ) in the inferior to the cochlea in the sagittal view (variable name S2) (CV = 8.1%) and then the distance from the 7th nerve to the TMJ in the inferior section of the cochlea in the axial view (variable name AI3) (CV = 8.4%). Based on correlation analysis and then confirmatory factor analysis, three common latent factors were identified (overall $R^2 = 0.999$).
Conclusion: The results of this study can be used for two purposes. First, the direct use of the estimated measures in surgical operations, and the second is more advanced modeling to choose the approach in the surgical operation and how to implement that approach. For the first aim, the two factors AI3 and S2 were the most reliable radioanatomical factors in different people. For the second aim, the three-dimensional understanding of the obtained measurements and the further identification of the anatomical nature of the latent factors can help in choosing the approach in surgery.

1. Introduction

Due to the progress of medical science and the spread of surgical interventions and minimally invasive interventions, identifying the anatomy of patients with the help of imaging methods became very important, and thus the studies in this field were called as

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radioanatomical studies. Radioanatomical studies have been common since the very beginning of the emergence of this term about the anatomical elements of the head and neck. For instance, radioanatomical elements related to round window [1] and internal auditory canal [2] can be pointed out. In this way, many opportunities were created in radioanatomical studies of the head and neck, and the investigation of radioanatomical factors with practical purposes related to the choice of approach in surgical operations was promoted.

Temporal bone surgery is one of the surgeries performed by head and neck surgeons for cases such as fractures, acute and chronic infections of the middle ear and mastoid process, otosclerosis [3] and some cancers [4]. These surgeries, like other surgeries, are associated with various complications. Among the complications that exist in these surgeries is damage to the facial nerve (*i.e.* 7th cranial nerve). Because, in some cases it is necessary to remove the facial nerve to reach the desired anatomical location and sometimes it is necessary to cut it. Surgeons are trying to find the location and path of the facial nerve, first of all, to enter from other paths, and then, if it is not possible to enter the desired location from another path, they can gently bypass it. Therefore, imaging techniques are used to identify the anatomical position of this nerve before surgery and also to investigate possible damage to it after surgery [5].

This type of surgery requires a lot of experience, and on the other hand, due to the importance of complications, there is no possibility of trial and error during training. Virtual reality simulation is also used in the surgical process for teaching and practicing temporal bone surgery. This model helps to determine the preoperative surgical approach, especially to protect the facial nerve [6]. Radioanatomical landmarks are used to predict the exact condition of the facial nerve, internal auditory canal and generally the temporal bone [7,8]. Also, determining the surgical approaches including retrosigmoid, *trans*-labyrinth, subtemporal, infratemporal, etc. [9] may contribute to a better surgical outcome and radioanatomical landmarks can also be used to determine the best approach. In the infratemporal approach, the access is through the jugular foramen and the carotid artery is located nearby [9]. Another technology used in temporal bone surgeries is LandmarX navigation technology. The use of this technology increases the diagnostic accuracy in lateral skull base surgeries [10]. In general, these landmarks can be used for practicing on corpses, moulages, and computer models, and for planning surgical procedures.

Access to the jugular foramen is always limited by the presence of the facial nerve. In classical surgical methods, it is necessary to move the facial nerve from its anatomical location. This issue can lead to partial or complete paralysis of the face temporarily or sometimes permanently. Although there have been studies on the identification of radioanatomical factors and landmarks in determining the operation approach, facial nerve protection, and the result of temporal bone surgery, there is no study based on the radioanatomical intervals regarding the position of facial nerve in comparison to jugular foramen. Considering this gap, we intend to measure the radioanatomical distances related to the location of the facial nerve to anatomical elements including the temporomandibular joint (TMJ), the posterior fossa, the jugular bulb and the internal carotid artery (ICA) in patients who are candidates for high resolution computed tomography (HRCT) scan of temporal bone.

2. Material and methods

2.1. Study design

This study was carried out as a correlation cross-sectional study on HRCT scan samples. The study population was all patients who were candidates for temporal HRCT scan in Iran (although as a practical aim, the results will be generalized to patients who are candidates for temporal bone surgery and access to the jugular foramen).

2.2. Patients

The samples were selected from among all patients over 18 years of age referred to Amir Alam Hospital who were candidates for temporal HRCT scan based on previous indications using convenient sampling. Exclusion criteria were abnormal anatomy of the study site for example due to trauma, history of surgery or known disease in the temporal bone, and lack of consent to use the patient's information for research purposes. The information was collected by observation and the tool for studying the electronic radiology record was the picture archiving and communication system (PACS).

The skull HRCT scan samples of the selected patients using a 16-slice multi-detector CT-Scanner (Somatom Emotion, SIEMENS; collimation, 0.625 mm; 110 kV; 100 mAs; matrix, 512*512) were analyzed in PACS. By default, the left temporal bone of the patients was considered. But in some patients, due to the mentioned exclusion criteria, the right side was chosen. Of course, if we consider a practical purpose of the study in the surgery of glomus jugular tumors, these tumors are mainly on the left side. Finally, only one side was examined in each patient, and in cases where both sides were intact, the left side was selected. Radioanatomic factors were investigated in axial, coronal and sagittal views. In order to check in the sagittal view, the images were reconstructed by the radiology department.

2.3. Radioanatomical factors

The radioanatomical factors of the axial view were investigated in three axial sections of the inferior of cochlea, stylomastoid and neck. The investigated factors in the inferior section of the cochlea were the distance of the 7th nerve to the dura, corresponding to the endolymphatic sac (with variable name AI1, *i.e.* the factor number 1 in the inferior section of the cochlea in the axial view), the distance of the 7th nerve to the internal carotid artery (ICA) (variable name AI2) and the distance of the 7th nerve to the temporomandibular joint (TMJ) (variable name AI3). The two factors examined in the stylomastoid section were the distance of the 7th nerve to the dura, corresponding to the sigmoid sinus (variable name AS1) and the 7th nerve to the jugular bulb (variable name AS2). The two factors investigated in the cervical section were the distance of the mandible to the apex of the transverse process of the C1 vertebra (variable name AC1) and the minimum distance of the mandible to the transverse process of the C1 vertebra (variable name AC2) (Figs. 1–3).

In the coronal view, two radioanatomical factors include the distance of the 7th nerve to the ICA in the axial section of the inferior of cochlea (variable name C1, *i.e.* factor number 1 in the coronal view) and the distance of the 7th nerve to the jugular bulb in the axial section of the stylomastoid (named variable C2) were measured. All the measurements were checked in the section where the 7th nerve can be seen in the clearest possible way (Fig. 4).

In the sagittal view, the radioanatomical factors include the distance from the 7th nerve to the dura in the axial section of the inferior of cochlea (with the variable name S1, *i.e.* factor number 1 in the sagittal view), the distance from the 7th nerve to the TMJ in the inferior axial section of the cochlea (variable name S2) and the distance from the 7th nerve to the dura in the axial section of the stylomastoid (variable name S3) were investigated. All the measurements were checked in the section where the 7th nerve can be seen in the clearest possible way (Fig. 5).

2.4. Statistical analysis

In order to describe the radioanatomical factors, the mean, standard deviation (SD), and coefficient of variation (CV) were reported (in necessary cases, the median, minimum, maximum, and some quantiles and percentiles were reported). The Shapiro-Wilk normality test was used to check the normal distribution of the data only to describe the distribution of radioanatomical factors. The relationship between radioanatomical factors and background variables was investigated using independent t-tests and Pearson's correlation analysis at a significance level of 0.05. Pearson correlation analysis and confirmatory factor analysis were used to compare and categorize radioanatomical factors. In order to compare the amount of individual data of each participant with the estimated averages, Z score was used and the obtained Z scores were used as the depth axis of the heat map. The selected levels of Z score were ± 1.64 (90% confidence interval), ± 1.96 (95% confidence interval) and ± 2.58 (99% confidence interval). By using such graphs, it was possible to check and compare the dispersion of data (depth axis with the help of color) at the individual level (horizontal axis including ID of the participants) for different variables (vertical axis). Considering that different radioanatomical measurements were not equal in the same person, using Z score helps to compare these measurements in an aligned manner. All the analyses of this study were done in Stata 14 (Stata Corp. LLC, TX, US) software.

2.5. Ethical considerations

The present study was approved by the ethics committee of Tehran University of Medical Sciences, Amir Alam hospital local ethics committee, with registration number IR.TUMS.AMIRALAM.REC.1399.011. All the participants had given written informed consent for research use of their information. All the HRCT scans were taken by routine indications and there was no force or suggestion by the researchers.

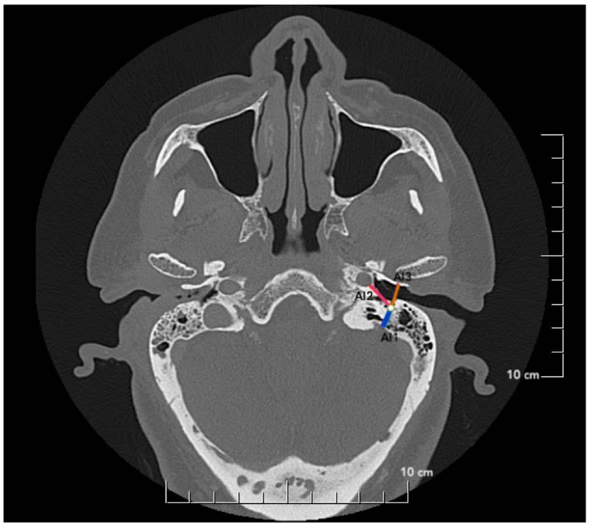

Fig. 1. Facial nerve (FN) distances in axial view (section: inferior level of cochlea); AI1: FN to dura (sigmoid sinus); AI2: FN to internal carotid artery; AI3: FN to temporomandibular joint.

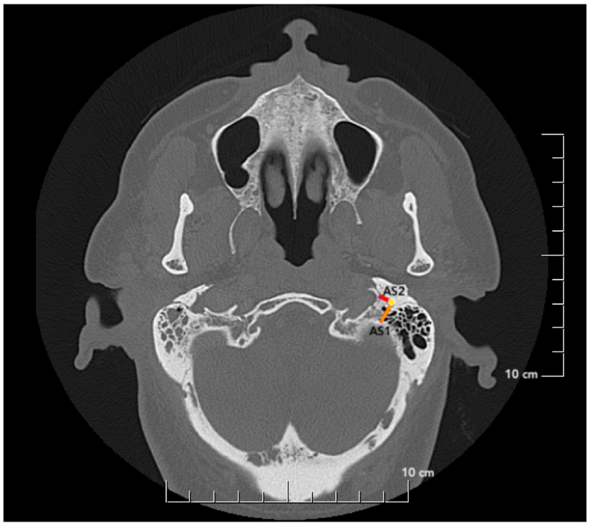

Fig. 2. Facial nerve (FN) distances in axial view (section: level of stylomastoid foramen); AS1: FN to dura (sigmoid sinus); AS2: FN to jugular bulb.

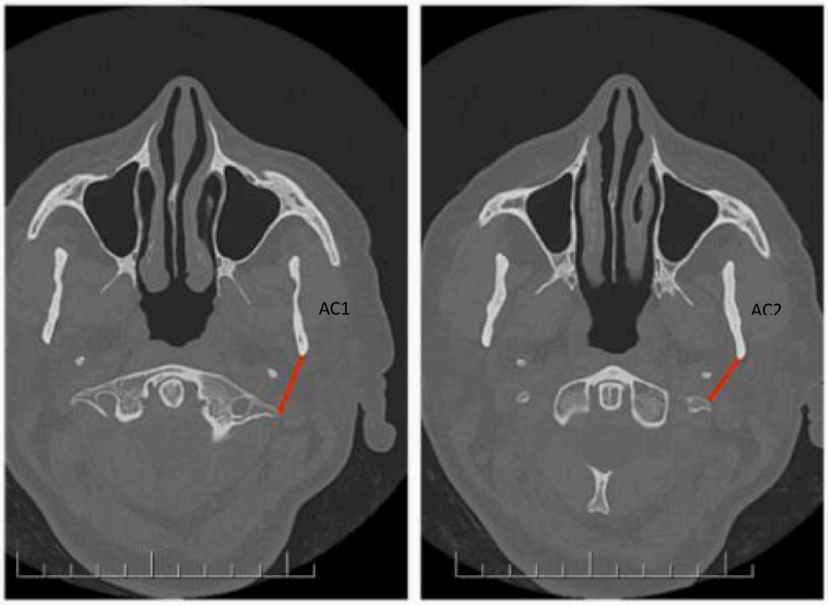

Fig. 3. The distance between the C1 transverse process and the mandibular ramus in the axial view (representing the bony window for infratemporal access to the jugular foramen) is measured at two specific points: AC1, at the most lateral level, and AC2, at the narrowest level.

3. Results

3.1. Baseline characteristics

Based on the inclusion and exclusion criteria, 173 patients from the reference population were included in the study by convenient sampling from Amir Alam Ear, Nose and Throat and Head and Neck Surgery Center, Tehran University of Medical Sciences. The average age of the participants was 46.50 years (±15.09), the youngest participant was 18 years old and the oldest participant was 84 years old. In terms of gender distribution, 77 participants (44.51%) were women and 96 participants (55.49%) were men. Based on the criteria mentioned in the selection of the examined side, the left side was examined in 107 patients (61.75%) and the right side was examined in 66 patients (38.15%).

The relationships between radioanatomical factors and underlying characteristics were investigated. The age variable was only related to C1 ($P = 0.037$); However, the magnitude of this relationship was not significant ($r = 0.159$). Gender was associated with AI2

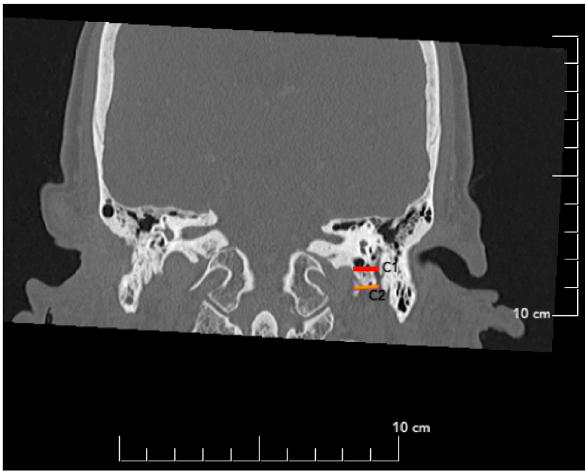

Fig. 4. Facial nerve (FN) distances in coronal view (section: facial nerve); C1: FN to jugular bulb at inferior level of cochlea; C2: FN to jugular bulb at level of stylomastoid foramen.

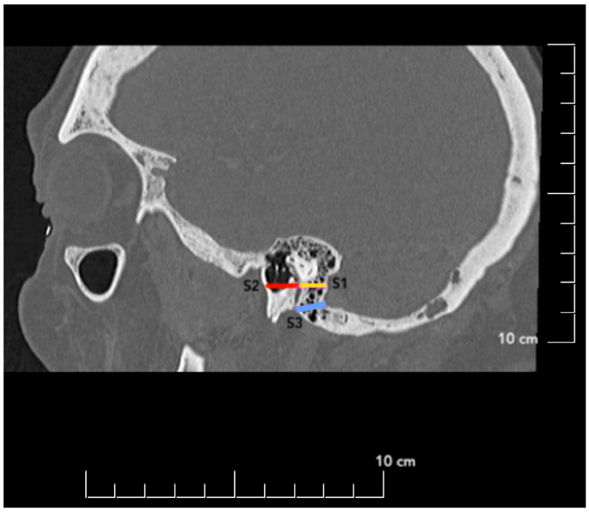

Fig. 5. Facial nerve (FN) distances in sagittal view (section: facial nerve); S1: FN to dura at inferior level of cochlea; S2: FN to temporomandibular joint at inferior level of cochlea; S3: FN to dura at level of stylomastoid foramen.

Table 1
Descriptive statistics for the radioanatomical factors (mm).

Radioanatomical Factors	Mean (median)	SD	Min	Percentile 5	Max	CV	Normality (P value)*
AI1	7.724 (7.73)	1.565	3.2	5.52	12.54	20.3%	0.292
AI2	13.502 (13.35)	1.539	8.5	11.43	17.54	11.4%	0.069
AI3	9.415 (9.53)	0.79	5.59	8.21	11.13	8.4%	<0.001
AS1	8.008 (8.15)	2.117	0.66	4.04	14.73	26.4%	0.012
AS2	5.580 (5.53)	1.564	2.05	3.21	10.45	28.0%	0.132
AC1	22.045 (21.83)	3.39	9.81	15.8	31.65	17.2%	0.05
AC2	18.337 (18.41)	3.826	7.42	12.96	33.6	20.9%	0.103
C1	6.582 (6.72)	2.09	2.19	3.06	12.1	31.8%	0.071
C2	7.148 (7)	2.408	2.05	3.6	14.58	33.7%	0.292
S1	8.180 (8.15)	1.669	3.33	5.7	13.82	20.4%	0.006
S2	9.408 (9.42)	0.762	4.48	8.3	11.01	8.1%	<0.001
S3	8.257 (8.02)	2.316	2.42	4.07	15.15	28.1%	0.198

* Shapiro-Wilk test. $P < 0.05$ was considered as normality rejection.

(P = 0.007), AS1 (P = 0.034) and S1 (P = 0.040). The investigated side was related to AI1 (P = 0.010) and AS2 (P = 0.020), where the average of AI1 was 0.632 mm lower and the average of AS2 was 0.572 mm higher on the left side (tables not shown). None of the above associations had enough magnitude of effect.

3.2. Radioanatomical factors

Summary of the descriptive study of the radioanatomical factors are shown in detail (Table 1, Fig. 6). In order to align the radioanatomical factors, Z score was calculated for each factor in each participant and these Z scores were displayed as a heat map (Fig. 7).

3.3. Correlation and factor analysis

Pearson correlation analysis was used to investigate the relationship between radioanatomical factors. All radioanatomical factors were compared pairwise. Thus, the correlations above 0.6 were correlation between AC1 and AC2 (r = 0.738), correlation between C1 and C2 (r = 0.644) and correlation between S1 and S3 (r = 0.641). AI3 and S2 – the two factors that had the lowest coefficient of variation – were only correlated with each other (r = 0.378) and no correlation they showed with other factors. The correlation matrix is shown (Table 2).

Radioanatomical factors were classified based on significant correlations in the range of 0.3 < r < 0.7. The first category included AI1, S1, S3 and AS1, and the common concept (latent variable) among them was called "Dura factor". The second category included AI3 and S2, and the common concept between them was called "TMJ factor". The third category included AS2, C1 and C2, and due to the lack of thematic connection between AS2 and the other two cases, AS2 was removed from the model and the common concept between C1 and C2 was named "jugular bulb factor".

Then, a confirmatory factor analysis was performed on the above categories (Fig. 8). Based on the obtained model, the three identified factors were able to predict the radioanatomical factors investigated in the model with a very small error (overall R^2 = 0.999) (Table 3).

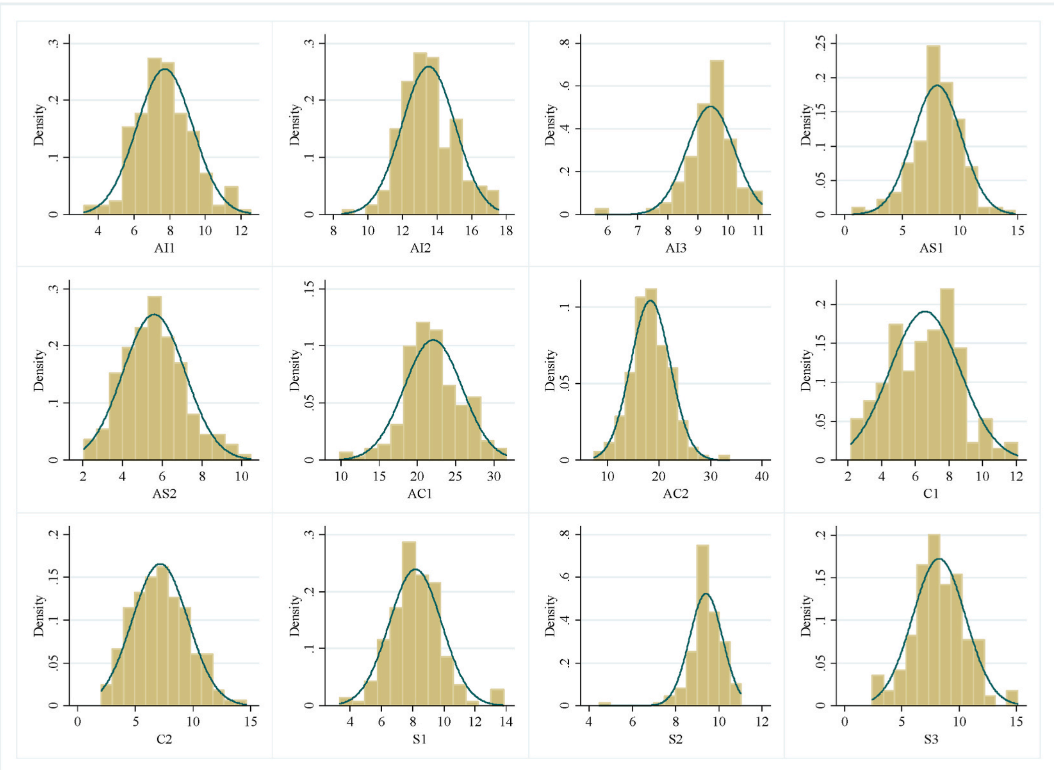

Fig. 6. Histogram of the measured distances between the facial nerve (FN) and other key landmarks: ***Axial***- AI1: FN to dura (sigmoid sinus); AI2: FN to internal carotid artery; AI3: FN to temporomandibular joint; AS1: FN to dura (sigmoid sinus); AS2: FN to jugular bulb; AC1: C1 transverse process to the mandibular ramus at the most lateral level; AC2: C1 transverse process to the mandibular ramus at the narrowest level. ***Coronal***- C1: FN to jugular bulb at inferior level of cochlea; C2: FN to jugular bulb at level of stylomastoid. ***Sagittal***- FN to dura at inferior level of cochlea; S2: FN to temporomandibular joint at inferior level of cochlea; S3: FN to dura at level of stylomastoid foramen.

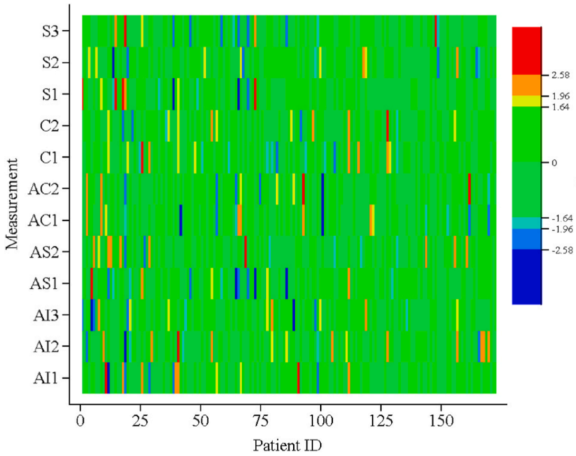

Fig. 7. Heat plot to show Z score (z axis) of radioanatomic factors (y axis) in all participants in the study (x axis).

Table 2
Correlation matrix of the radioanatomical factors.

Variables	AI1	AI2	AI3	AS1	AS2	AC1	AC2	C1	C2	S1	S2	S3
AI1	1											
AI2	0.123	1										
AI3	−0.109	0.193	1									
AS1	0.405[a]	0.135	−0.001	1								
AS2	−0.011	0.106	−0.035	0.041	1							
AC1	0.014	−0.053	−0.055	−0.017	−0.067	1						
AC2	0.033	−0.048	−0.053	−0.046	−0.090	0.738[a]	1					
C1	0.103	0.209	−0.049	0.062	0.509[a]	−0.104	−0.065	1				
C2	−0.057	0.167	0.058	−0.014	0.511[a]	−0.075	−0.122	0.644[a]	1			
S1	0.560[a]	0.028	−0.075	0.331[a]	−0.049	−0.076	−0.085	−0.004	−0.156	1		
S2	0.113	0.121	0.378[a]	0.172	0.046	−0.035	−0.097	0.014	0.070	0.077	1	
S3	0.355[a]	−0.009	0.056	0.584[a]	0.040	−0.119	−0.132	0.036	−0.052	0.641[a]	0.164	1

[a] Significant at level 0.05 after Bonferroni correction.

4. Discussion

4.1. Summary of evidence

This study was designed as a descriptive investigation of radioanatomical factors related to facial nerve position in our samples, inferential generalizing of the measurements to the reference population and analytical classification of these factors in order to identify more reliable approaches in temporal bone surgery. Thus, the HRCT scan of 173 patients in a head and neck surgery referral center was examined.

Among the 12 radioanatomical factors examined, two factors AI3 and S2 had a CV less than 10%. Both mentioned factors had no normal distribution. According to the histogram, it seems that the cause of rejecting the normality is the positive kurtosis and the presence of two patients with very low values. In any case, by ignoring abnormally low values – which were very few in this study based on the heat map – these two factors provide the surgeon with the safest estimate due to the very small dispersion. This means that you can rely on their average to access deeper areas during surgery. In other words, the possibility of anatomical damage caused by individual differences during the passage of surgical equipment seems to be less. Roughly, each distance can be estimated to be around 9–10 mm (according to the percentiles, only less than 5% of people were less than 8 mm). The common aspect of these two factors is the distance from nerve 7 to TMJ in the inferior section of the cochlea (with this difference that AI3 is in the axial view and S2 is in the sagittal view).

Among the radioanatomical factors, the factors examined in the coronal view have the most dispersion, the CVs were more than 30% and the range of their variation was relatively wide. It seems that in order to access deeper areas during surgery, these distances cannot be relied on based on guesswork, and the possibility of anatomical damage seems to be higher. The rest of the radioanatomical factors were in an intermediate condition CV-wise. With the help of heat map, individual differences could be observed in all participants. Of course, in this map, the blue items were more important; because they were very small amounts of anatomical distances that could be associated with the risk of injury during surgery. In terms of the relationship between radioanatomical factors and underlying factors, although age was related to C1, the intensity of this relationship was not clinically valuable. Also, the correlations of some radioanatomical factors with gender and side were not clinically important and the differences between the averages were less

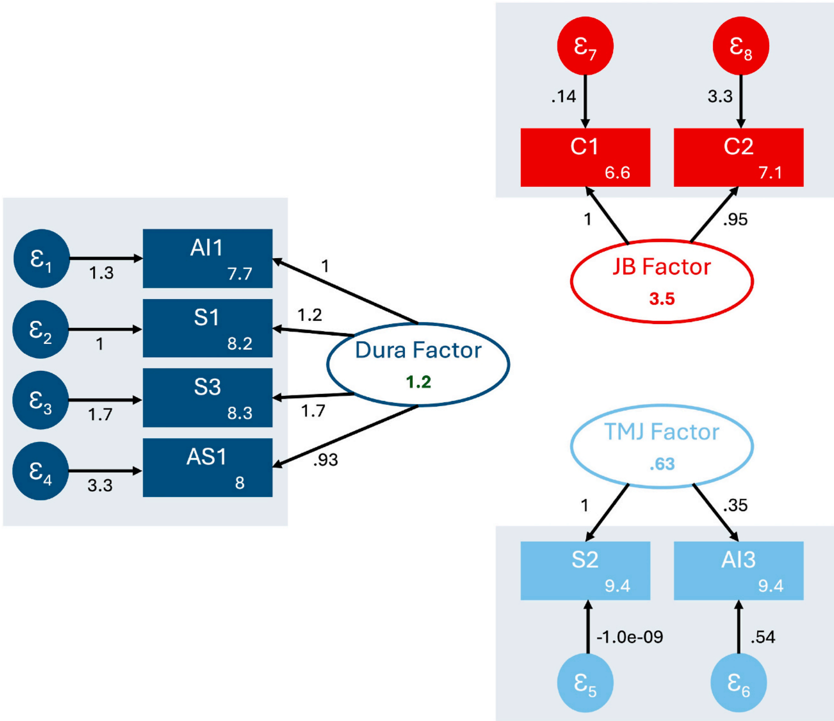

Fig. 8. Confirmatory factor analysis using the maximum likelihood method. The covariance links between the three central factors were removed from the model because they were not significant. JB: jugular bulb; TMJ: temporomandibular joint.

Table 3
Confirmatory factor analysis for prediction of latent factors.

Latent Factors (Variance)	Radioanatomical Factors	Pathway Coefficient (Intercept)	P value	Factor Load	R^2	AVE
Dura factor (-1.245)	AI1	1 (7.724)	Constrained	0.706	0.499	0.509
	S1	1.176 (8.180)	<0.001	0.789	0.622	
	S3	1.692 (8.257)	<0.001	0.819	0.671	
	AS1	0.930 (8.008)	<0.001	0.495	0.245	
TMJ factor (-0.633)	S2	1 (9.408)	Constrained	0.999	0.999	0.561
	AI3	0.346 (9.415)	0.016	0.35	0.122	
Jugular bulb factor (-3.483)	C1	1 (6.582)	Constrained	0.981	0.962	0.725
	C2	0.948 (7.148)	<0.001	0.698	0.487	

AVE: average variance extracted (the mean of R^2s calculated as equation-level goodness of fit). Factor loads were calculated based on equation-level goodness of fit. Overall $R^2 = 0.999$.

than 1 mm.

The part of the results of this study that could open a window towards the practical goals of the study was correlation analysis and factor analysis. The common feature of all significant correlations in the correlation matrix (except AC1 and AC2) was that their correlation coefficients were in the range of 0.3–0.7. This means that these radioanatomical factors had an effective relationship with each other ($r > 0.3$) and on the other hand, they have maintained their independence from each other ($r < 0.7$). But the high correlation between AC1 and AC2 indicated their collinearity with each other. It meant that they could be used interchangeably. Both of these variables showed the distance of the mandible to the transverse process of the C1 vertebra (maximum and minimum distance).

Factor analysis showed that there was a latent variable behind the four variables AI1, S1, S3 and AS1. Since the common factor of these four variables was the distance of nerve 7 to dura, this latent variable was called "dura factor". Behind the two variables AI3 and S2 was a latent factor, which was named as "TMJ factor" due to the measurement of the distance from nerve 7 to TMJ as a common concept. Behind the three variables AS2, C1 and C2 there was a latent variable, and due to the lack of thematic connection between AS2 and the other two cases, AS2 was removed from the model and the common concept between C1 and C2 was named "jugular bulb factor".

Apart from the statistical discussions, the measurements examined in this study each have their own clinical importance. For example, coronal measurements of the distance of the 7th nerve to the jugular bulb could be used in medial facial nerve surgeries in cases such as cholesteatoma expansion and some glomus cases (if the distance does not match). The average of C1 and C2 were 6.582

and 7.148 mm, respectively, and their median was 6.72 and 7 mm, respectively. Also, their minimum was 2.19 and 2.05 mm. As mentioned, the measurements of the coronal view showed the highest CVs which indicated their high diversity among the participants.

In the continuation of the discussion of clinical importance, the variables related to dura include AI1, AS1, S1 and S3, which were the variables related to the retrofacial window. Considering that the main clinical goal of this study was to access the jugular foramen through the retrofacial window, perhaps the findings of these four variables could be considered the most useful findings of this study. The minimums of these four measurements were very important considering the thickness of surgical instruments and were 3.2, 0.66, 3.33 and 2.42 mm, respectively. As its seen, these minima were at the end of the spectrum and had been obtained under the influence of exceptions. Therefore, it was necessary to use the smallest size obtained in the majority of people. For this purpose, 2.5% of normal distribution ($Z = -1.96$) could be used, thus the considered minima were 4.657, 3.858, 4.909 and 3.717 mm, respectively. According to the histograms, it seemed that the distribution of all variables in the parameter (reference community) was normal.

Regarding the clinical application of variables related to TMJ, including AI3 and S2, these variables were used in the prefacial path, which showed the safe space in front of the facial nerve. For example, in canal wall down surgeries, it is necessary to estimate these distances. The minimum values of these two measurements were 5.59 and 4.48 mm, respectively, and their 2.5% normal values are 7.867 and 7.915 mm, respectively. As mentioned, these two measurements had the lowest CVs, which showed that it is almost fixed and reliable in the general population.

Accessing the jugular foramen surgically involves navigating through the distal intratemporal segment of the facial nerve. In the original approach to the infratemporal fossa (Fisch type A) [11], it is necessary to redirect this portion of the nerve anteriorly. To mitigate the risk of facial nerve paresis/paralysis associated with rerouting, subsequent modifications have been suggested that allow access without rerouting and entail minimal alterations [12]. In such cases, the dimensions of the pathway anterior to the facial nerve are determined by its proximity to the temporomandibular joint (such as AI3 and S2). Furthermore, in situations where minimal access to the jugular foramen is adequate—such as for tissue biopsy to confirm meningioma or other non-paraganglioma pathologies—the dimensions of this window become crucial.

Finally, regarding the clinical applications of transverse process measurements including AC1 and AC2, it should be said that these measurements were used to access the jugular foramen from the neck view. Thus, their minimum values were 9.81 and 7.42 mm, respectively, and their 2.5% normal values were 14.617 and 10.837 mm, respectively.

Some past radioanatomical studies were conducted in order to achieve the best surgical approach, and the ultimate goal of choosing the best approach was to reduce the possibility of anatomical injuries during surgery. For example, Zador and de Carpentier (2015) in England investigated a three-dimensional radioanatomical model in the transpetrosal approach to the internal acoustic meatus (IAM). In this way, they found that the angle of access to the IAM in the translabyrinth approach decreased significantly. Their aim of this study, which was conducted on 50 samples, was to find a safe way to expose the internal auditory canal [7]. In our study, more number of patients were examined and the finding approach was not directly examined; Rather, the radioanatomical factors were examined in two-dimensional form to identify possible latent factors among them and visualize them in three-dimensional form for further research.

The aim of some studies has been to find anatomical landmarks. For example, Gupta et al. (2013) in India investigated radio-anatomical landmark identification to localize the foramen ovale during surgery. They used 117 dry skull samples and measured 6 different radioanatomical distances. In this way, they identified a number of reliable landmarks [13]. In our study, radioanatomical factors were examined crudely; although, it was possible to design a landmark using the measurements.

Considering the importance of preserving the facial nerve in head and neck surgeries, some radioanatomical studies have been carried out for this purpose. Gupta et al. (2017) in India investigated radioanatomical tympanomastoid fragments of facial trauma on cadavers. For this purpose, 30 wet samples of temporal bone were used. They descriptively measured the length of the nerve fragments and the angle of the second genu [14]. In this study, we intended to use the investigated radioanatomical factors to safely access the deeper areas without bypassing the 7th nerve. For example, in this study, the distance from the 7th nerve to the TMJ was identified as the most reliable distance based on the obtained dispersion indices, which had the least variation (in the axial and sagittal view, on average were 9.415 and 9.408 mm, respectively) and it seemed that the selection of approaches related to this distance was associated with less possibility of damage.

In the most recent study, Butzer et al. (2022) in Switzerland designed a three-dimensional model to preserve hearing in access to the internal auditory canal. They investigated two hearing preservation approaches including infracochlear, exclusively endoscopic *trans*-canal and *trans*-mastoid retrolabyrinthine with endoscopic assistance. For this purpose, three-dimensional reconstruction of HRCT scans of 53 temporal bone samples was used. They measured the surgical access window between anatomical landmarks. Finally, they came to the conclusion that in more than 80% of the samples, the width of the access window in both approaches was more than 3 mm [15]. In our study, a larger number of patients were examined and the examinations were performed on two-dimensional images. Our goal was to access the jugular foramen and the internal carotid artery.

4.2. Strengths and limitations

Compared to the previous studies, this study was conducted in a larger sample size. The large sample size made the indices of dispersion more realistic and provided a more accurate estimate of the parameter (reference population). Since these measurements were supposed to be trusted in the future, their indices of dispersion played a very important role for surgeons. From a surgical perspective, employing the lateromedial approach from the surface to the deep, the jugular foramen is situated medial to the distal mastoid segment and the stylomastoid part of the facial nerve. Understanding the spatial dimensions on either side of the facial nerve can enhance the visibility within the corridor. This is especially crucial when approaching the jugular foramen while preserving the integrity of the facial nerve and enhance the assessment of nerve risk. This includes considering the option of an approach without rerouting, working anterior to the nerve, and consequently delivering more precise information to the patients. Also, in this study, for the first time, factor analysis method was used in radioanatomical studies. Nevertheless, one of the limitations of this study was the lack of sufficient identification of the extracted latent factors. Another limitation of this study was the lack of three-dimensional examination of the measurements. Based on the findings and existing gaps, it is suggested: 1- More radioanatomical factors should be investigated in accordance with other surgical procedures. 2- In a multidisciplinary and interdisciplinary manner, the nature of latent factors should be investigated. 3- In this context, a database of information from different ethnic groups should be prepared and computer modeling and artificial intelligence should be used to interpret the findings. 4- The data obtained should be used in simulation educational technologies. 5- Considering the relevant ethical issues, the clinical conclusions obtained from this project can be evaluated on patients in operating room. Diverse two-dimensional measurements derived from temporal bone imaging can offer an illuminating three-dimensional perspective of the target anatomical area. This, in turn, may facilitate a more directed and secure surgical approach.

5. Conclusion

The results of this study can be used for two purposes. First, the direct use of the estimated sizes in surgical operations, and the second is more advanced modeling to choose the approach in the surgical operation and how to implement that approach. In the first aim, the two factors AI3 and S2 were the most stable radioanatomical factors in different people. Among these two factors, AI3 seemed to be more practical due to the more difficult access to the sagittal view; In addition, it had a higher correlation with the latent factor related to itself. This radioanatomical factor indicates the safe distance of the facial nerve to the TMJ, which is more than 8 mm in more than 95% of the study subjects. For the second aim, the three-dimensional understanding of the obtained measurements and the further identification of the anatomical nature of the latent factors can help in choosing the approach in surgery.

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Ethical considerations

The present study was approved by the ethics committee of Tehran University of Medical Sciences, Amir Alam hospital local ethics committee, with registration number IR.TUMS.AMIRALAM.REC.1399.011. All the participants had given written informed consent for research use of their information. All the HRCTs were taken by routine indications. All the HRCT scans were taken by routine indications and there was no force or suggestion by the researchers.

Data availability

Data are available through the authors upon request.

CRediT authorship contribution statement

Parisadat Ahmadi: Writing – original draft, Validation, Investigation, Formal analysis, Data curation. **Mohammad Ali Kazemi:** Writing – review & editing, Visualization, Software, Project administration, Methodology, Data curation. **Nasrin Yazdani:** Writing – review & editing, Supervision, Project administration. **Sasan Dabiri:** Writing – review & editing, Visualization, Supervision, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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