Novel Radiographic Measurement Algorithm Demonstrating a Link between Obesity and Lateral Skull Base Attenuation

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Abstract

Objectives. (1) To describe a validated algorithm for measuring tegmen thickness on computed tomography scans. (2) To compare the tegmen thickness in 3 groups: patients with spontaneous cerebrospinal fluid (CSF) leaks, obese controls, and nonobese controls.

Study Design. Retrospective review.

Setting. Patients with spontaneous CSF otorrhea often have highly attenuated tegmen plates. This is associated with obesity and/or idiopathic intracranial hypertension (IIH). No evidence exists, however, that objectively links obesity and/or IIH with skull base attenuation.

Subjects and Methods. This was a retrospective review from 2004 to the present. Patients with spontaneous CSF otorrhea and matched obese (body mass index [BMI] >30 kg/m²) and nonobese (BMI <30 kg/m²) controls were selected. Tegmen thickness was measured radiographically. Interrater validity was assessed.

Results. Ninety-eight patients were measured: 37 in the CSF group (BMI, 36.6 kg/m²), 30 in the obese group (BMI, 34.6 kg/m²), and 31 in the nonobese group (BMI, 24.2 kg/m²). The CSF group had a significantly thinner tegmen compared to both the obese control (P <.01) and nonobese control (P = .0004) groups. Obese controls had a thinner tegmen than nonobese controls (P < .00001). A significant inverse correlation was detected between skull base thickness and BMI. Signs/symptoms of IIH were most commonly found in the CSF group. Good to very good strength of agreement was detected for measures between raters.

Conclusion. This is the first study to (1) quantify lateral skull base thickness and (2) significantly correlate obesity with lateral skull base attenuation. Patients who are obese with spontaneous CSF leaks have greater attenuation of their skull base than matched obese controls. This finding supports theories that an additional process, possibly congenital, has a pathoetiological role in skull base dehiscence.

Keywords

spontaneous, CSF leak, obesity, idiopathic intracranial hypertension, tegmen, dehiscence

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Spontaneous cerebrospinal fluid (CSF) otorrhea is a relatively rare phenomenon in which CSF enters the confines of the temporal bone in a manner unrelated to other causes. Spontaneous CSF otorrhea occurs in 2 populations: young children and middle-aged adults. Children typically present after episodes of recurrent meningitis, and the leak is often associated with congenital anomalies.1-6 In adults, a diagnosis is often made after myringotomy for a persistent effusion in obese, middle-aged females.7,8 Two major theories predominate regarding the pathophysiology in adults. The first posits that skull base attenuation occurs chronically secondary to increased intracranial pressure, which in turn is closely linked to obesity and idiopathic intracranial hypertension (IIH).9-18 The second theory, suggested by Gacek et al19 and corroborated by others, suggests that aberrant arachnoid granulations may instigate skull base erosion.18-21 A congenital predisposition may exist in either process.18-24

The radiographic appearance of the skull base in obese individuals is often one of broad attenuation.18 Quantifiable evidence correlating obesity, CSF leaks, and skull base attenuation would be beneficial for all otolaryngologists.
attenuation is lacking, however. In the present study, we sought to overcome this by developing a novel radiographic measurement algorithm for the lateral skull base. Using temporal bone computed tomography (CT) scans from patients with spontaneous leaks, obese controls, and nonobese controls, we sought to address 3 hypotheses: (1) current CT imaging/formatting technology can now achieve precise and reproducible measurements of lateral skull base thickness, (2) obese patients will have a quantifiably thinner skull base than nonobese patients, and (3) patients with spontaneous CSF otorrhea will have more skull base attenuation than obese patients without leaks. The aims of the study were to validate the algorithm for interrater reliability and to correlate radiographic findings with demographic, clinical, and body mass index (BMI) data.

Methods

Study Approval

Approval was obtained from the Medical University of South Carolina (MUSC) Institutional Review Board (Pro00023289).

Group Selection

This retrospective chart review from 2004 to 2013 utilized ICD-9 codes and operative notes. Inclusion criteria for the primary study group were the following: diagnosis of spontaneous CSF otorrhea, surgical intervention performed, age >18 years, and dedicated high-resolution temporal bone CT scans available. Demographic data recorded were age, sex, and race. Moreover, BMI (kg/m²) was calculated based on height and weight at the time of surgery. Clinical variables documented included hypertension, diabetes mellitus, osteopenia/osteoporosis, IHH, and smoking status. Exclusion criteria were the following: history of temporal bone trauma, cholesteatoma, neoplasm, prior lateral skull base and/or mastoid surgery, congenital ear anomaly, and age <18 years.

Control subjects were culled from adult cochlear implant patients. The subjects were separated according to BMI into obese (BMI >30 kg/m²) and nonobese (BMI <30 kg/m²) groups. Inclusion criteria included age >18 years and dedicated high-definition CT scans available. Demographic data, clinical data, and exclusion criteria were identical to those of the primary study group.

Imaging and Hardware

Dedicated temporal bone CT scans were obtained with a standard collimation of 0.625 mm. Images were reconstructed in axial, coronal, and sagittal planes. The majority of scans were obtained at MUSC on either a Siemens Somatom Sensation 16 or Siemens Definition 128 (Siemens Medical Solutions, Malvern, Pennsylvania). Spatial resolution was rated as accurate to 0.1 to 0.2 mm using this protocol.

All images were analyzed on standardized personal computing stations equipped with Intel Core 2 Duo CPUs (Intel Corporation, Santa Clara, California). Processing speed was 2.3 GHz with 4 GB of available random-access memory (RAM). Stations were all equipped with Lenovo Think Vision 19-inch, square, backlit light-emitting diode (LED) and flat panel liquid-crystal display (LCD) monitors (Lenovo, Raleigh, North Carolina) set to a maximum resolution of 1280 × 1024 dpi.

Software

Reformatted images were analyzed via the proprietary digital radiology imaging system AGFA Impax 6 (AGFA Impax, Mortsel, Belgium). Temporal bone thickness was measured via the partial volume averaging formula (measurement caliper) in this software. Accuracy was rated to 0.1 mm.

CT Measurement Algorithm: Tegmen Tympani

Skull base measurements were made at predefined points. Measurements of the tegmen tympani (TT) were conducted within a coronal cut best depicting the malleus, the incus, and at least 2 turns of the cochlea (Figure 1). Measurements were made at the thickest and thinnest visible points of the tegmen plate as well as at a fixed point directly cephalad to the ossicles. All measurements were made on both sides of the skull base. Due to software limitations of the Impax measurement calipers and the quoted CT spatial resolution, we set an absolute minimum limit for thickness of 0.4 mm. This limit applied to dehiscent areas with no measurable bone density.

CT Measurement Algorithm: Tegmen Mastoideum

Measurements were made of the tegmen mastoideum (TM) in a coronal cut best demonstrating the most lateral curvature of the posterior semicircular canal (Figure 1). Measurements included the thickest and thinnest visible points along with a fixed point at the center of the tegmen plate between the cortical bone and posterior semicircular canal medially. Measurements were repeated on both sides of the skull base. The minimum thickness limit was applied.

Additional Calculations for Statistics

Using the above protocol, a total of 12 measurements were made for each patient (6 of the TT/TM on each side). To facilitate statistical comparisons, mean aggregate thickness values were calculated by averaging the data for the TT and TM on each side of the skull base. The overall mean skull base thickness was also calculated by averaging the mean aggregate TT and TM thicknesses of both sides. This value was statistically correlated with BMI and other demographic/clinical factors.

Validation Measures

The intraclass correlation coefficient (K) was calculated for the purpose of assessing interrater reliability among 3 raters at staggered levels of training in otolaryngology–head and neck surgery. This included a medical student, a fourth-year resident, and a second-year neurotology fellow. For the assessment, a total of 39 scans were randomly selected from the overall study cohort including 13 from each of the 3 study groups. The clinical diagnosis, group allocation, demographic data, operative notes, and clinical information were withheld from the raters. Over a period of 2 weeks, each rater independently performed a full set of measurements as described above on each of the 39 scans (468...
measurements per rater). The raters were blinded to each other’s measurements. Results were expressed as the intra-class correlation coefficient (K) and 95% confidence interval. Strength of agreement relative to K can be interpreted as the following: <0.20 = poor; 0.21-0.40 = fair; 0.41-0.60 = moderate; 0.61-0.80 = good; and 0.81-1.00 = very good.25

Statistics
All analyses and graphs were performed with Sigma Plot 12.5 (Systat Software Inc, San Jose, California) and MedCalc 13.3.0.0 (MedCalc Software bvba, Ostend, Belgium). Disease information and demographic variables were summarized by means of summary statistics. Continuous variables were summarized by the mean ± standard deviation. Nominal variables were summarized by the frequency and percentage. All continuous variables were tested for normal distribution as determined by the Kolmogorov-Smirnov test. Comparisons of outcomes (nominal variables) were performed using the Fisher exact test or χ² test with Yates correction. For continuous variables, comparisons were made using an independent t test. A correlation model was used to determine the relationship among variables such as skull base thickness, age, and sex. A value of P < .05 was considered indicative of statistical significance.

Results
A total of 42 patients were identified with a diagnosis of spontaneous CSF otorrhea. Of these, 5 patients were excluded for inadequate temporal bone CT scans, leaving 37 patients for the CSF group. Only 31 total patients were identified from the control cohort who were obese. As the number of nonobese controls was relatively large, 31 consecutive patients were selected to numerically match the obese controls. Of these, only 1 obese control failed to meet inclusion criteria, leaving 30 patients for the obese control group and 31 patients for the nonobese control group.

The demographic and clinical information of each group is summarized in Table 1. The mean ages of the CSF group, obese control group, and nonobese control group were 60.9 years, 57.0 years, and 62.2 years, respectively. The mean

Table 1. Group Demographics and Clinical Data.

<table>
<thead>
<tr>
<th></th>
<th>Spontaneous CSF Leak</th>
<th>Obese Control Group (BMI &gt; 30 kg/m²)</th>
<th>Nonobese Control Group (BMI &lt; 30 kg/m²)</th>
<th>Statistical Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total (N = 98), n</td>
<td>37</td>
<td>30</td>
<td>31</td>
<td>N/A</td>
</tr>
<tr>
<td>Mean age, y</td>
<td>60.9</td>
<td>57.0</td>
<td>62.2</td>
<td>—</td>
</tr>
<tr>
<td>Mean BMI, kg/m²</td>
<td>36.6</td>
<td>34.6</td>
<td>23.7</td>
<td>—</td>
</tr>
<tr>
<td>Sex, n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>7</td>
<td>13</td>
<td>17</td>
<td>—</td>
</tr>
<tr>
<td>Female</td>
<td>30a</td>
<td>17</td>
<td>14</td>
<td>P = .028a</td>
</tr>
<tr>
<td>Race, n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>21</td>
<td>22</td>
<td>24</td>
<td>—</td>
</tr>
<tr>
<td>Black</td>
<td>16</td>
<td>8</td>
<td>7</td>
<td>—</td>
</tr>
<tr>
<td>Hypertension, n</td>
<td>29a</td>
<td>18</td>
<td>12</td>
<td>P = .023a</td>
</tr>
<tr>
<td>Diabetes mellitus, n</td>
<td>12</td>
<td>7</td>
<td>7</td>
<td>—</td>
</tr>
<tr>
<td>Osteopenia/osteoporosis, n</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>Current/former smoker, n</td>
<td>11</td>
<td>8</td>
<td>9</td>
<td>—</td>
</tr>
<tr>
<td>Idiopathic intracranial hypertension, n</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>—</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index; CSF, cerebrospinal fluid; N/A, not applicable.

aAll 3 groups were similar for all measures except for the CSF group in which female sex and hypertension were significantly more common.
BMIs of the groups were 36.6 kg/m², 34.6 kg/m², and 23.7 kg/m², respectively. The CSF group and obese control group did not significantly differ from each other in terms of BMI. The CSF group had a significantly higher proportion of both women and patients with hypertension. All diagnoses of IIH were in the CSF group, but the relatively small number was not enough to reach statistical significance. The groups did not differ in any other clinical factor.

When reviewing temporal bone scans, the lateral skull base of patients in both the CSF group and obese control group had a similar, broadly attenuated appearance with a moth-eaten quality to the bone (Figure 2). There was generally a paucity of pneumatized bone cephalad to the otic capsule structures and ossicles. Findings were usually bilateral and involved both the TT and TM. Scans in nonobese controls typically demonstrated thick and well-defined tegmen plates with a notable amount of pneumatized bone buffering the inner ear.

Objectively, skull base thickness differed significantly between each of the groups bilaterally (Figure 3). The nonobese controls had the thickest skull bases, with a mean of 1.204 ± 0.047 mm and 1.337 ± 0.048 mm on the left and right sides, respectively. This was significantly thicker than skull base measurements in both the obese control group (left: 0.981 ± 0.037 mm; right: 1.008 ± 0.038 mm; P < .0001) and CSF group (left: 0.862 ± 0.040 mm; right: 0.811 ± 0.033 mm; P < .0004).

A comparison of skull base thickness controlling for obesity was also made between the obese control group and CSF group (Figure 4). This was accomplished by removing all nonobese patients with CSF leaks (6 excluded; n = 31 obese patients with CSF leaks). Between the 2 groups, patients with CSF leaks had significantly thinner skull bases (left: 0.833 ± 0.038 mm; right: 0.814 ± 0.036 mm) than controls (left: 0.981 ± 0.037 mm; right: 1.008 ± 0.038 mm; P < .01). The mean BMI of this “obese only” CSF group was 37.7 kg/m². There remained no significant difference in BMI, however, between the obese CSF and obese control groups.

When correlation modeling was performed, a significant inverse correlation was detected between skull base thickness and BMI (r = −0.466, P = .00001) (Figure 5). No significant correlation was demonstrated between skull base thickness and age (r = 0.065, P = .644) or any of the other demographic/clinical parameters from Table 1 (data not shown).

Figure 2. Subjective attenuation: Coronal computed tomography scans depicting tegmen tympani from the 3 groups. The nonobese control (NOC) group was normal, the obese control (OC) group was attenuated, and the cerebrospinal fluid (CSF) leak group was dehiscent.

Figure 3. Mean aggregate thickness comparisons: significant differences (P < .001) were detected between nonobese/obese controls (*), nonobese controls/patients with cerebrospinal fluid (CSF) leaks (†), and obese controls/patients with CSF leaks (‡). Black, left; gray, right. Error bars are the standard error of the mean.

Figure 4. Obese controls versus obese patients with cerebrospinal fluid leaks: mean aggregate thickness comparison. Thickness differed significantly (P < .01) on both sides of the skull base (‡). Black, left; gray, right. Error bars are the standard error of the mean.
When the intraclass correlation coefficient ($K$) was used to assess interrater reliability, the results were “good” to “very good” among all 3 raters when measuring both obese and nonobese groups. The results were “poor” to “good” among all 3 raters when measuring individual segments of the tegmen for the CSF group. Results were “good” to “very good” when comparing mean aggregate measures for this group (Table 2).

**Discussion**

In developing the measurement algorithm described above, consideration was given to the limitations of the Impax software package and scanner technology. As the resolution of CT formatting and the Impax caliper is rated to 0.1 mm, precision was felt to be adequate for detecting submillimeter differences between groups. To this end, the absolute minimum measurement convention of 0.4 mm requires additional discussion. The application of this convention was considered necessary to overcome software limitations preventing reliable measures <0.4 mm (the calipers cannot be drawn this small). As nearly all subjects in the CSF group and some obese controls had skull base dehiscences, use of this convention rather than 0.0 mm likely masks a more pronounced difference in thickness than that reported. In turn, the minimum thickness value also likely prevents unnecessary skewing of the data toward an attenuated state by preventing 0.0 mm being entered for any measurement between 0.1 to 0.3 mm. Detection of a significant difference between groups using our more conservative approach may lend more support to the hypotheses than the use of a 0.0-mm minimum value.

**Table 2. Interrater Validation Measures.**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Intraclass Correlation Coefficient (95% Confidence Interval)</th>
<th>Strength of Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obese control group: left side</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean aggregate</td>
<td>0.8185 (0.5552 to 0.9368)</td>
<td>Very good</td>
</tr>
<tr>
<td>Tegmen mastoideum</td>
<td>0.7154 (0.3020 to 0.9009)</td>
<td>Good</td>
</tr>
<tr>
<td>Tegmen tympani</td>
<td>0.8505 (0.6334 to 0.9479)</td>
<td>Very good</td>
</tr>
<tr>
<td>Obese control group: right side</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean aggregate</td>
<td>0.7417 (0.3669 to 0.9101)</td>
<td>Good</td>
</tr>
<tr>
<td>Tegmen mastoideum</td>
<td>0.7922 (0.4907 to 0.9277)</td>
<td>Good</td>
</tr>
<tr>
<td>Tegmen tympani</td>
<td>0.6586 (0.1630 to 0.8811)</td>
<td>Good</td>
</tr>
<tr>
<td>Nonobese control group: left side</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean aggregate</td>
<td>0.8076 (0.5111 to 0.9363)</td>
<td>Very good</td>
</tr>
<tr>
<td>Tegmen mastoideum</td>
<td>0.8585 (0.6405 to 0.9531)</td>
<td>Very good</td>
</tr>
<tr>
<td>Tegmen tympani</td>
<td>0.7750 (0.4283 to 0.9255)</td>
<td>Good</td>
</tr>
<tr>
<td>Nonobese control group: right side</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean aggregate</td>
<td>0.8995 (0.7445 to 0.9667)</td>
<td>Very good</td>
</tr>
<tr>
<td>Tegmen mastoideum</td>
<td>0.7823 (0.4469 to 0.9279)</td>
<td>Good</td>
</tr>
<tr>
<td>Tegmen tympani</td>
<td>0.8207 (0.5445 to 0.9406)</td>
<td>Very good</td>
</tr>
<tr>
<td>CSF group: left side</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean aggregate</td>
<td>0.6775 (0.1804 to 0.8932)</td>
<td>Good</td>
</tr>
<tr>
<td>Tegmen mastoideum</td>
<td>0.1441 (–1.2654 to 0.7323)</td>
<td>Poor</td>
</tr>
<tr>
<td>Tegmen tympani</td>
<td>0.5584 (–0.1689 to 0.8619)</td>
<td>Moderate</td>
</tr>
<tr>
<td>CSF group: right side</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean aggregate</td>
<td>0.8139 (0.5270 to 0.9383)</td>
<td>Very good</td>
</tr>
<tr>
<td>Tegmen mastoideum</td>
<td>0.3316 (–0.7691 to 0.7909)</td>
<td>Fair</td>
</tr>
<tr>
<td>Tegmen tympani</td>
<td>0.7306 (0.2869 to 0.9157)</td>
<td>Good</td>
</tr>
</tbody>
</table>

Abbreviation: CSF, cerebrospinal fluid.
The total number of measurement samples per subject also was intentionally kept high (6 per side/12 per subject) to more accurately reflect aggregate thickness. The initial build of the algorithm incorporated a solitary measurement of the thinnest point on the tegmen. It was quickly discovered, however, that most subjects with CSF leaks and obese controls had at least 1 “thinnest point” at the minimum thickness limit. Detecting a difference between groups was therefore impossible. Additionally, as the leading pathoetiological theory for the development of spontaneous CSF otorrhea entails elevated intracranial pressure and broad skull base attenuation, a larger sampling of measurements was felt to more accurately reflect the underlying pathophysiology.

Using these methods, our interrater validation assessment revealed good to very good strength of agreement for aggregate thickness measures between observers at all levels of training (Table 2). The lower strength of agreement noted for CSF group measures was likely due in part to the software’s minimum thickness limitations and to the highly variable presentation of the thickest point in patients with CSF leaks. When aggregate measures were considered though, overall agreement was much better.

Although many studies have performed radiographic assessments of skull base attenuation, the vast majority of investigators have done so in a solely qualitative manner.9,11,23,26-30 Within the ear, nose, and throat literature, little quantitative, measurement-driven data exist to detect differences between groups.23,27,31,32 To our knowledge, only 1 prior study has made quantifiable radiographic measurements of the lateral skull base.23 The best precedent for objective radiographic investigations ultimately came from the oral-maxillofacial literature, which heavily utilizes cephalometric evaluations.33-43

Many such studies have used “smallest detectable difference” (SDD) calculations to further validate CT-based measurement algorithms.33,35-37 The SDD is a statistical estimate of the smallest significant amount of change that can be detected by a given measure regardless of how reliably that measure can be reproduced. When we applied SDD calculations to our data, it was found that the difference in skull base thickness between each study group was indeed larger than the calculated SDD. This finding strongly suggests that the significant differences detected herein are indeed real differences. Appendix A (available at www.otojournal.org) provides further detail on SDD calculations.

Although the pathophysiology underlying adult spontaneous CSF otorrhea is not fully understood, this condition is associated with obesity and IIH.9-18 Our data support these associations and are consistent with commonly cited demographic patterns. The mean BMI of our CSF group was 36.6 kg/m², and the mean age was 60.9 years. Eighty-one percent (30/37) of the patients were female. Five of 37 (13.5%) had a formal diagnosis of IIH. Because CSF opening pressure was not routinely measured, the number of individuals with IIH was likely higher than reported.

The data also demonstrate a significant correlation between obesity and skull base attenuation. To our knowledge, this is the first report of a statistically significant inverse relationship between skull base thickness and BMI. It is also the first description of a significant difference in skull base attenuation between obese and nonobese subjects. As BMI is an indirect measure of obesity and not related to intracranial processes, the reasons for the above findings cannot be entirely explained by these data alone.

Some inferences are possible, however, when considering the physiology associated with the obese habitus. The latter causes elevated central venous pressure, leading in turn to elevated intracranial pressure. Also, IIH is known to be more prevalent in obese individuals.44,45 Over time, this steep pressure gradient across the entirety of the dura-bone interface likely causes gradual and broad bony skull base erosion. Subjectively, the majority of our obese subjects fit such a description. Other authors have noted similar findings, and the quantitative measures here support their prior reports.13-15,18,23,26-30 The lack of an inverse correlation between skull base thickness and age, however, does not fit the temporal aspect of the theory. This may be due to the fact that changes in skull base thickness over time may be too small to detect with currently available technology.

In addition to supporting a theory of pressure-induced erosion caused by obesity, our data also seem to suggest that subjects with CSF leaks were affected by an additional pathophysiological process. This was evidenced by that group having significantly thinner skull bases than obese patients without leaks. One potential explanation for this is bias introduced by our measurement algorithm. Given the preponderance toward skull base dehiscence in subjects with CSF leaks, the lack of measurable bone may have skewed the data relative to controls. As discussed previously, the inclusion of a minimum thickness measure does render this explanation somewhat less likely. An additional cause may be hormonal in nature, as female sex was significantly overrepresented in the CSF group. While it is difficult to assess this directly, other indicators of the influence of sex such as osteoporosis and osteopenia (more common in women) did not appear to differ significantly between groups.

One further explanation may be one of congenital predisposition. A growing conceptual trend in the literature holds that certain individuals may have a genetic predisposition to accelerated bone loss or perhaps an aberration in tegmen ossification. In 2 cadaveric studies, between 6% to 34% of all temporal bones had at least 1 tegmen dehiscence, while a smaller subset (1%-6%) had multiple dehiscences and poor bone quality.46,47 Another large cadaveric study, investigating the prevalence of superior semicircular canal dehiscence across age groups, found tegmen thickness to be uniformly thin in neonates/infants. Thickness gradually increased until 3 years of age and then plateaued. Interestingly, approximately 2% of adult subjects in this study had tegmen thicknesses that differed little from the neonatal period.22 This potential congenital predisposition to skull base attenuation has been corroborated in other studies and case reports.23,27,48-52 Newer
investigations linking superior semicircular canal dehiscence and spontaneous CSF otorrhea (rate of concomitance, 15%-55%) as well as the data reported here suggest that at least a portion of patients with spontaneous leaks may be susceptible to more accentuated skull base thinning than would be explained by the pathophysiology of an obese habitus alone.²⁶,²⁸

Conclusion

The data gathered in this study supported the hypothesis that our novel measurement algorithm and current imaging technology would allow for precise and reliable quantification of lateral skull base thickness. The data also indicated that a significant correlation between obesity and skull base thickness exists and that patients suffering from spontaneous CSF otorrhea have significantly thinner skull bases than do matched obese controls. While reasoning for the latter finding is not directly clarified by our data, indirect evidence may suggest the existence of a congenital pathoetiological process that augments tegmen thinning already known to occur in this cohort.

Acknowledgments

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Author Contributions

Shawn M. Stevens, conception of design, acquisition of data, analysis of data, interpretation of data, drafting article, and final approval; Paul R. Lambert, conception of design, analysis of data, interpretation of data, critical revision, and final approval; Habib Rizk, acquisition of data, analysis of data, critical revision, and final approval; Wesley R. Mcllwain, acquisition of data, interpretation of data, drafting article, and final approval; Shaun A. Nguyen, analysis of data, interpretation of data, critical revision, and final approval; Ted A. Meyer, conception of design, analysis of data, interpretation of data, critical revision, and final approval.

Disclosures

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Supplemental Material

Additional supporting information may be found at http://otojournal .org/supplemental.

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