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Spatial hearing after auricular resection for non-melanoma skin Cancer

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ABSTRACT

Objective: To explore spatial hearing outcomes in patients undergoing auricular resection and reconstruction for non-melanoma skin cancer (NMSC) of the external ear.
Study design: Consecutive case series.
Methods: Twenty-three patients treated surgically for NMSC of the auricle between December 2023 and January 2026 were evaluated. Postoperative functional assessment included pure-tone audiometry (PTA) and the 12-item Speech, Spatial and Qualities of Hearing Scale (SSQ-12). Associations between spatial hearing performance and demographic, clinical, and surgical variables were analyzed using Spearman correlation and nonparametric group comparisons.
Results: The mean age was 77.0 ± 9.2 years. Mean bilateral PTA was 40.2 ± 9.7 dB HL, consistent with mild-to-moderate hearing loss. The mean SSQ-12 total score was 3.9 ± 1.6, indicating mild-to-moderate self-reported spatial hearing difficulty. SSQ-12 total score demonstrated a strong correlation with PTA ($\rho = -0.767$, $p < 0.001$), whereas no significant association was observed with age, lesion size, or surgical duration. Comparison between patients undergoing reconstruction and those managed by primary/secondary intention revealed no significant difference in overall SSQ-12 scores.
Conclusions: In this exploratory series, spatial hearing outcomes following auricular resection for NMSC were primarily associated with baseline auditory thresholds rather than lesion size or reconstructive strategy. While restoration of auricular morphology did not significantly affect global spatial hearing scores, task-dependent differences in challenging listening environments suggest a potential functional role of restoring auricular contour. These preliminary findings highlight the need to integrate functional hearing considerations into auricular oncologic surgery and support further prospective studies incorporating objective localization measures.

1. Introduction

When managing non-melanoma skin cancer (NMSC) of the external ear, surgeons are frequently required to perform partial or total auricular resections. Surgical planning traditionally prioritizes oncologic safety and aesthetic restoration of auricular form, while functional consequences are infrequently considered [1]. Unlike hearing preservation in middle- and inner-ear surgery, the functional role of the auricular pinna has received limited attention in surgical literature. Auricular reconstruction is primarily evaluated in terms of symmetry, contour, and patient-reported aesthetic satisfaction, while potential effects on spatial hearing are seldom assessed in clinical practice [2,3]. Despite this, the auricle is anatomically and acoustically integral to sound collection and spectral shaping, suggesting that its surgical alteration may have functional consequences that remain largely unquantified.

Spatial hearing, the ability to localize sounds in space, is a crucial component of human auditory perception. It enables individuals to detect, identify, and react to environmental sounds, thereby playing a fundamental role in communication, navigation, and safety. The auditory system integrates binaural cues—interaural time differences (ITDs) and interaural level differences (ILDs)—alongside monaural spectral

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cues shaped by the external ear, or pinna, to construct a spatial auditory scene [4]. While binaural cues account for the majority of horizontal plane localization, experimental studies showed that altering pinna morphology with molds disrupted vertical and front–back localization [5]. However, the auditory system could partially relearn spectral cues over time when the auricular shape alteration was sufficiently relevant to be detected by the central nervous system. In contrast, mild alterations failed to trigger adaptation, suggesting that sensory recalibration occurred only when the spectral mismatch exceeded a critical threshold [6].

However, these studies used reversible ear molds to simulate pinna deformation, an artificial model that does not reproduce the anatomical and acoustic consequences of real auricular defects. Therefore, clinical evidence remains lacking on the functional changes of the auricular pinna in patients who underwent auricular surgery. In this study we report preliminary exploratory data on spatial hearing outcomes following different excision and reconstructive strategies for NMSC of the external ear.

2. Materials and methods

This observational case series was conducted between December 2023 and January 2026 in accordance with the STROBE guidelines. The study complied with the Declaration of Helsinki and was approved by the Clinical Ethics Committee of Siena University Hospital (approval date: 21/01/2026; protocol no. 1).

Patients undergoing surgical treatment for NMSC of the external ear were eligible for inclusion. Exclusion criteria comprised bilateral auricular disease, previous ear surgery, and cognitive impairment precluding reliable questionnaire completion. Demographic, clinical, and surgical variables were prospectively collected. Postoperative functional assessment included pure-tone audiometry (PTA) and the 12-item Speech, Spatial and Qualities of Hearing Scale (SSQ-12) [7,8], which was administered using an Italian translation derived from the original version. The questionnaire was scored 0–10, where higher scores indicated greater difficulty. Air- and bone-conduction audiometry was performed using an Amplaid A137 audiometer (Amplaid, Italy) in a sound-attenuated booth, in accordance with IEC 60645–1 and ISO 389 standards. The reported pure-tone average represents the bilateral PTA, calculated as the mean of air-conduction thresholds from both ears across 0.5, 1, 2, and 4 kHz.

Statistical analyses were conducted using Jamovi (version 2.3). Associations between continuous variables were explored using Spearman's rank correlation, correlation strength was interpreted as weak (<0.40), moderate (0.40–0.69), and strong (≥0.70). Between-group comparisons were performed using the Mann–Whitney *U* test. A two-sided *p* value <0.05 was considered statistically significant, effect size (ES) was reported.

3. Results

A total of 23 patients who underwent surgical treatment for NMSC of the external ear were included; details of the series have been reported in Table 1. The mean age was 77.0 ± 9.2 years (range 55–92 years); the cohort was found to be predominantly made up of male subjects (95.7%). Most patients reported at least one comorbidity (84.2%), and 50% self-reported subjective hearing loss, although only 8.7% were hearing-aid users. Lesion size averaged 1.75 ± 0.73 cm, and mean surgical time was 129.5 ± 31.5 min. Anatomical reconstruction using local flaps was equally divided between healing by primary or secondary intention. Histology included basal cell carcinoma (38.1%), squamous cell carcinoma (38.1%), and other benign lesions (23.8%). PTA was available for 23 patients, with a mean bilateral PTA of 40.2 ± 9.7 dB HL, consistent with mild-to-moderate hearing loss in this cohort characterized mainly by elderly patients.

The mean SSQ-12 total score was 3.94 ± 1.60 (range 1.58–7.07),

Table 1
Demographic, clinical, and outcome characteristics of the study cohort (23 subjects).

Variable	Mean ± SD or n (%)	Median (range)
Age (years)	76.95 ± 9.24	77 (55–92)
Male sex	22 (95.7%)	–
Smoking (current/former)	17 (85.0%)	–
Any comorbidity	16 (84.2%)	–
Subjective hearing loss	11 (50.0%)	–
Hearing-aid use	2 (8.7%)	–
Lesion size (cm)	1.75 ± 0.73	1.55 (0.7–4.0)
Surgical time (min)	129.5 ± 31.5	122.5 (75–190)
Histology (BCC / SCC / Other)	8 (38.1%) / 8 (38.1%) / 5 (23.8%)	–
Reconstruction (local flap)	11 (50%)	–
Pure-tone average, dB HL	40.2 ± 9.7	45 (23.75–55)
SSQ total score (0–10)	3.9 ± 1.6	4.1 (1.6–7.1)

consistent with an overall mild-to-moderate self-reported spatial hearing handicap in this cohort. At the item level, the highest mean scores were observed for movement discrimination (Q8: 7.61 ± 3.01) and sound localization (Q6: 7.57 ± 2.76). Conversely, the lowest mean score was recorded for clarity of everyday sounds (Q11: 4.74 ± 3.51). Items addressing speech understanding in complex communicative environments showed intermediate-to-high handicap levels, for example conversation in competing speech (Q3: 6.83 ± 2.74).

Spearman correlation analysis demonstrated a strong negative association between SSQ-12 total score and bilateral PTA ($\rho = -0.767$, $p < 0.001$). Age showed no significant association with SSQ-12 total score ($\rho = 0.358$, $p = 0.111$). SSQ-12 total score was not significantly related with lesion size ($\rho = 0.303$, $p = 0.170$) or surgical duration ($\rho = -0.433$, $p = 0.056$). Lesion size was moderately associated with age ($\rho = 0.562$, $p = 0.008$), but not with SSQ-12 outcomes ($\rho = 0.303$, $p = 0.170$). Surgical time was moderately associated with lesion size ($\rho = -0.428$, $p = 0.048$) but not with SSQ total score ($\rho = -0.433$, $p = 0.056$). Analysing reconstructive strategy, the correlation between lesion size and surgical time remained moderately negative but did not reach statistical significance (partial Spearman $\rho = -0.426$, $p = 0.054$).

Comparison between reconstructive strategies (primary/secondary healing vs local flap reconstruction) revealed no significant difference in overall SSQ-12 total score (Mann–Whitney $U = 40.0$, $p = 0.189$; ES = 0.34). Mean SSQ-12 score was 4.41 ± 1.63 in the non-reconstruction group and 3.52 ± 1.58 in the reconstruction group. No significant difference was observed in bilateral PTA ($U = 42.5$, $p = 0.248$; ES = 0.30), with mean PTA values of 37.8 ± 9.9 dB HL and 42.0 ± 9.8 dB HL, respectively. However, two individual SSQ-12 items demonstrated significant between-group differences. For Q3 (conversation in competing speech), the reconstruction group reported higher handicap scores (7.82 ± 2.82 vs 5.73 ± 2.45; $U = 28.5$, $p = 0.036$; ES = 0.53). For Q4 (conversation in a busy restaurant), reconstructed patients likewise reported higher scores (7.91 ± 1.87 vs 4.91 ± 2.51; $U = 19.5$, $p = 0.007$; ES = 0.68). These differences did not survive correction for multiple comparisons. As expected, surgical time was significantly longer in the reconstruction group (154.1 ± 23.6 min vs 105.0 ± 14.0 min; $U = 6.0$, $p < 0.001$; ES = 0.90). No significant differences were observed in age ($U = 36.5$, $p = 0.204$; 79.18 ± 7.60 vs 74.50 ± 11.05 years) or lesion size ($U = 45.5$, $p = 0.338$; 2.01 ± 0.87 vs 1.49 ± 0.47 cm) between the non-reconstruction and reconstruction groups, respectively.

4. Discussion

To our knowledge, this is the first surgical case series to explore spatial hearing outcomes in patients undergoing auricular resection for NMSC, adopting a functional perspective alongside traditional oncologic and reconstructive considerations. In this cohort, patients exhibited a mild-to-moderate self-reported spatial hearing difficulty, which was strongly associated with audiometric hearing thresholds, while age and tumor size showed only weak and non-significant relationships. In this preliminary exploratory clinical setting, overall spatial hearing scores did not differ significantly between reconstructive strategies after multiple comparison adjustments, suggesting that restoration of auricular morphology alone may not substantially influence perceived spatial hearing at a global level.

Defects of the middle third were most commonly addressed using retroauricular tissue advancement, reshaping the auricle into a slightly reduced but anatomically coherent contour [9], as shown in Fig. 1. It is worth noting that, although this was not a predefined analytic variable, certain reconstructive patterns emerged from this retrospective series. Preauricular flaps were more frequently employed for reconstruction of upper-third defects [10], whereas split-thickness skin grafts (STSG) were preferentially used for lesions exceeding approximately 1.5–2 cm, particularly in elderly patients with significant comorbidities who were considered less suitable candidates for longer or more complex flap procedures [11]. However, STSG reconstruction may result in reduced structural support and less stable auricular projection, occasionally leading to mild ptosis; these reconstructive tendencies are illustrated in Fig. 2. Our clinical experience showed a potential functional impact of resection involving the upper third of the auricle, particularly with respect to hearing-aid coupling and retention, as illustrated in Fig. 3.

4.1. Previous experimental studies altering pinna morphology with molds: From alteration effects to recalibration and rehabilitation

Various experimental studies have shown that alterations in pinna morphology impair sound localization. In a seminal experiment, Hofman et al. demonstrated that modifying spectral filtering properties of the concha using custom molds produced marked deficits in elevation and front–back localization, while horizontal localization remained largely preserved [5]. However, over several weeks of continuous wear, subjects gradually recovered their spatial hearing performance and immediately reverted to baseline accuracy after mold removal, suggesting the development of parallel neural representations for altered and original spectral maps [5].

Building on this, Van Wanrooij and Van Opstal studied unilateral pinna mold manipulation and identified two distinct patterns of neural adaptation. In participants with strongly altered spectral cues, localization accuracy improved progressively over days, indicating recalibration at the spectral-to-spatial mapping stage of auditory processing. In contrast, subjects with milder cue perturbations failed to develop stable localization strategies, supporting the hypothesis that a sufficiently strong mismatch is required to trigger top-down plasticity [6].

Further evidence of active recalibration processes—both spontaneous and training-related—has been provided by Carlile and Blackman, who investigated relearning of monaural spectral cues in visually accessible and visually inaccessible spatial regions [12]. Their results showed progressive but incomplete reacquisition of localization ability despite substantial initial degradation, including increased front–back confusions and elevation errors. Importantly, adaptation occurred even without visual feedback, suggesting that sensorimotor or proprioceptive mechanisms may support auditory spatial plasticity across the entire spatial field [12].

Similarly, Rabini et al. demonstrated that short multisensory training following unilateral ear plugging improved horizontal localization performance but did not significantly affect vertical localization accuracy, suggesting that brief training paradigms may be insufficient to induce plasticity in elevation-dependent spectral processing [13].

Additional insights into adaptive auditory plasticity were provided by Kumpik et al., who explored chronic unilateral earplugging as a model of asymmetric auditory input. Their findings showed progressive recovery of horizontal spatial hearing accuracy only when broadband spectral cues were preserved and training occurred over multiple days. No adaptation was observed when spectral information varied unpredictably between trials, supporting the hypothesis that recovery depended on reweighting monaural spectral cues rather than recalibration of interaural timing or level cues [14].

4.2. Strengths and limitations of our case series

Our preliminary study addressed an underexplored functional dimension of auricular surgery, shifting the focus from aesthetic outcomes toward patient-perceived spatial hearing performance following

Fig. 1. Representative cases of reconstruction of large middle-third auricular defects achieved by primary intention closure combined with retroauricular tissue transposition, resulting in reduction and reshaping of the auricular framework.

Fig. 2. Upper-third auricular defect reconstruction. The upper row demonstrates a staged preauricular flap providing structural support and contour preservation; the lower row shows split-thickness skin graft reconstruction, which may result in reduced projection and stability of the auricle.

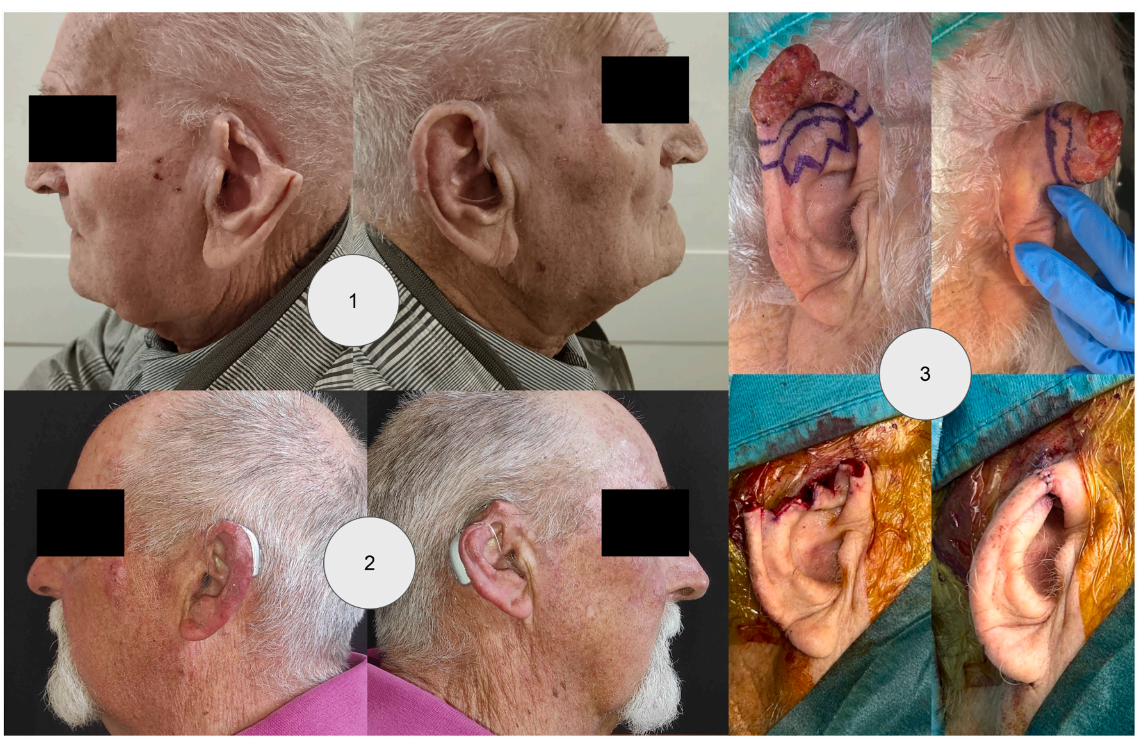

Fig. 3. Functional implications of upper-third auricular reconstruction on hearing-aid (HA) use. Case 1: absence of adequate auricular support preventing HA placement. Case 2: compromised upper-third contour resulting in unstable HA retention. Case 3: anatomically appropriate reconstruction of the upper third providing secure HA coupling and stable retention.

real-world auricular resection and reconstruction, thus extending previous experimental pinna-mold models into a clinical surgical setting. The integration of subjective SSQ-12 data with objective pure-tone audiometry strengthens internal coherence and supports construct validity of the findings.

Nonetheless, several limitations warrant consideration. First, the small sample size and exploratory design limited statistical power and precluded causal inference. Second, the heterogeneity of auricular defects and reconstructive approaches, inherent to oncologic surgery of the external ear, might have attenuated potential functional differences attributable to specific morphological changes. Third, spatial hearing was assessed using self-reported outcomes rather than objective localization tasks, limiting fine-grained analysis of directional accuracy.

Importantly, the Italian version of the SSQ-12 used in this study has not undergone formal psychometric validation, whereas the extended SSQ has been validated in Italian [15]. Although the SSQ-12 has demonstrated robust reliability and cross-cultural applicability in other languages [7,8], the absence of a validated Italian SSQ-12 introduces potential measurement uncertainty and this should be considered when interpreting absolute score values. For this reason, analyses were interpreted comparatively rather than against predefined thresholds.

Future research should move beyond subjective assessment alone and leverage emerging computer-aided design and manufacturing (CAD/CAM) technologies (see Fig. 4) to investigate the functional consequences of auricular morphology in a controlled and reproducible manner [16,17]. Advances in CAD/CAM now allow precise replication and systematic manipulation of auricular structures, offering a unique opportunity to study how specific variations in pinna shape influence spectral filtering properties underlying vertical localization and front–-back discrimination. Coupling patient-specific 3D auricular models with acoustic simulations [18] and functional hearing assessments could help disentangle the relative contribution of different auricular subunits and guide function-oriented reconstructive strategies. In this context, standardized digital auricular modelling may also facilitate longitudinal within-subject comparisons and improve integration of functional outcomes into surgical planning.

5. Conclusions

Auricular resection for NMSC is associated with a mild-to-moderate self-reported spatial hearing handicap which, in our cohort, was strongly related to overall hearing thresholds rather than to lesion size or reconstructive strategy. While restoration of auricular morphology did not significantly modify global spatial hearing scores, subjective differences were reported in specific real-world listening conditions, suggesting a task-dependent functional role of auricular shape. These preliminary findings highlight that functional hearing considerations - particularly spatial hearing and hearing-aid usability - remain underrecognized in auricular oncologic surgery. Larger, prospective studies integrating objective localization measures [19] and patient-specific anatomical modelling are mandatory to better define the functional implications of auricular reconstruction and to support, when this is oncologically possible, function-oriented surgical planning.

CRediT authorship contribution statement

Andrea Frosolini: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft,

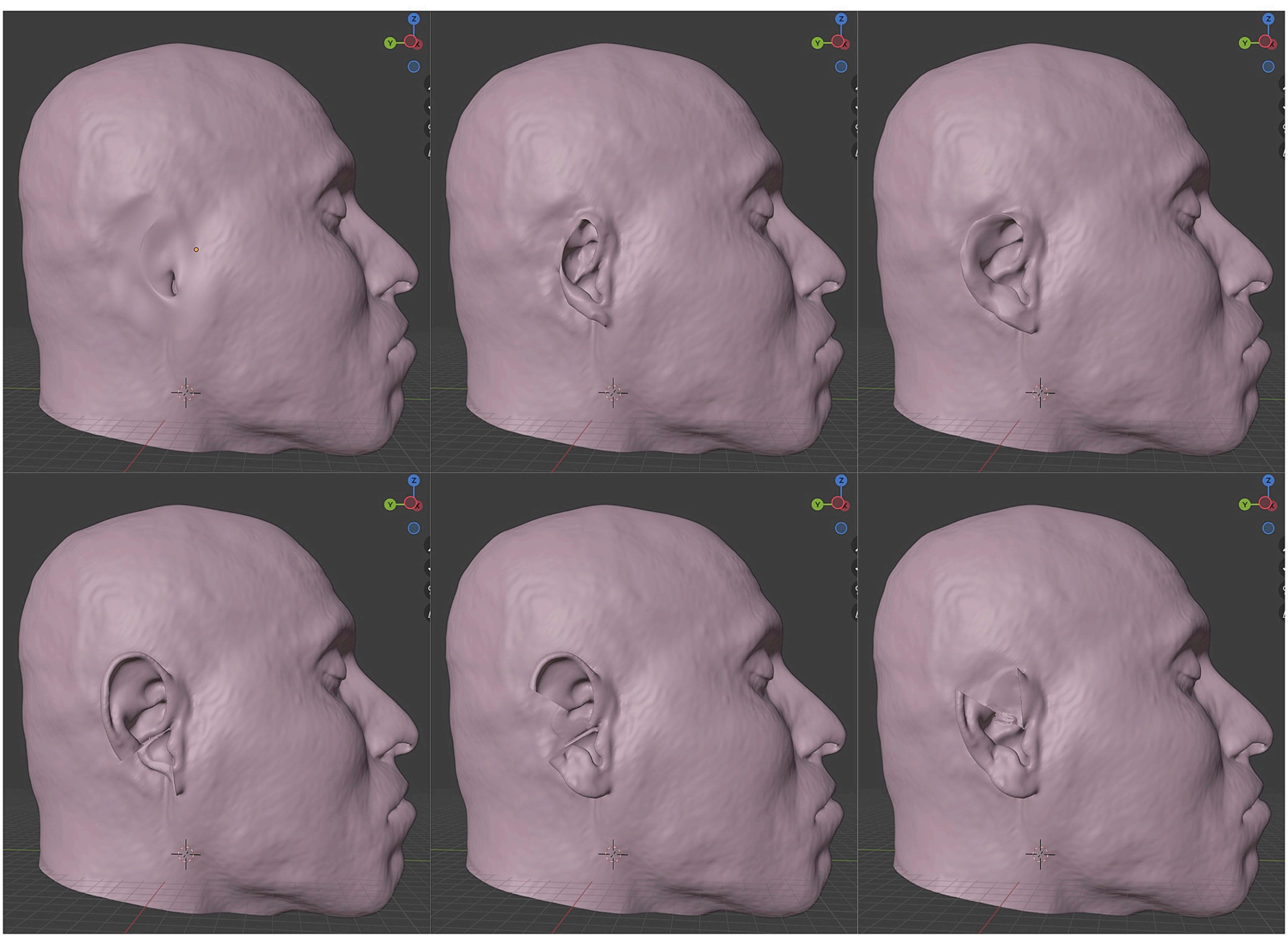

Fig. 4. A high-resolution craniofacial CT scan (slice thickness 0.6 mm) from a healthy adult was used as anatomical reference for 3D auricular modelling. DICOM data were imported into 3D Slicer (v5.2.2) for threshold-based and manual segmentation. The segmented auricle was exported in STL format and refined in MeshLab (v2023.02) for artefact removal and mesh optimization. Controlled geometric modifications of the helix, antihelix, concha, and lobule were then performed in Blender (v3.6). From left to right lower, middle, and upper third resections are shown.

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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.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request. Data are not publicly available due to privacy and ethical restrictions related to patient information.

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