



The utility of acoustic pharyngometry in treatment of obstructive sleep apnea patients with expansion sphincter pharyngoplasty surgery

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Abstract

Purpose Expansion sphincter pharyngoplasty (ESP) is a common surgery for patients with obstructive sleep apnea (OSA) which aims to correct the obstruction at the palatal level. The effectiveness of ESP has been widely shown in the literature using surgical success rates, but to our knowledge, there is no research which documents the changes in the upper airway anatomy objectively. We aimed to demonstrate the effectiveness of expansion sphincter pharyngoplasty using acoustic pharyngometry. We also aimed to study the possible utility of acoustic pharyngometry in predicting surgical outcomes.

Methods Pre- and post-operative acoustic pharyngometry and polysomnography data of patients who underwent expansion sphincter pharyngoplasty were compared prospectively. Minimum cross-sectional area (MCA) and total volume of the pharynx (TPV), apnea–hypopnea index (AHI), and surgical success rates were evaluated.

Results Fifty-two patients with OSA were invited to this study, and 35 patients who agreed to participate were enrolled. All patients underwent ESP surgery. Surgical success rate was 63% according to Sher’s criteria. The mean AHI of the patients decreased from 29.6 ± 16.3 to 18.3 ± 18.1 . MCA increased from 1.1 ± 0.4 to 2.3 ± 0.4 cm², and TPV increased from 21.1 ± 6.9 to 31.7 ± 5.5 cm³. Comparative analysis of the successful and unsuccessful groups yielded no significant differences between the groups concerning pre- and post-operative MCA and TPV or in mean changes in MCA and TPV achieved with the surgery.

Conclusion Improvement in the upper airway anatomy by expansion sphincter pharyngoplasty can be clearly demonstrated using acoustic pharyngometry. Acoustic pharyngometry findings are quite similar in patients with successful and unsuccessful outcomes; therefore, pharyngometry findings cannot be used to predict surgical success; and surgical success cannot be solely attributed to the changes in MCA and TPV.

Keywords Sleep apnea, Obstructive · Treatment outcome · Otorhinolaryngologic surgical procedures · Palate · Pharynx · Pharyngometry, Acoustic

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Introduction

Obstructive sleep apnea (OSA) is a sleep disorder characterized by recurrent episodes of either partial or complete upper airway obstruction [1]. It is a common disorder with serious detrimental effects on both the individual and the public health [2]. Many factors contribute to the development of OSA. The main factors causing OSA are anatomical narrowing and tendency of the upper airway structures to collapse along with insufficiency of the neuromuscular compensatory mechanisms [3–5]. OSA is usually more severe in the elderly population because of the increase in anatomical collapsibility and the worsening neuromuscular compensation with age [6].

Surgery is a treatment option in OSA which can be effective when patient selection is made carefully. A myriad of surgical modalities are defined for different anatomical regions [7]. Expansion sphincter pharyngoplasty (ESP) is one available technique, first described by Pang and Woodson in 2007 and later modified by many others, targeting the narrowing at the level of the soft palate [8–10]. The main limitation of the surgery in OSA is the unpredictability of results. While excellent clinical outcomes are achieved in some patients, the response may be limited in others [11]. Therefore, it is of critical importance to discover methods that can determine the patients who are good surgical candidates. Several methods have been proposed in the literature to predict the surgical outcome in patients with OSA. Evaluation of the airway during drug-induced sleep is used to determine the level of upper airway collapse and can be helpful for guiding the surgical approach, and its findings have claimed to predict the surgical outcome, though not all studies support this claim [12, 13]. Determining the contributions of non-anatomical traits (high loop-gain, low arousal threshold) in patients with OSA for predicting the surgical outcome is gaining popularity and shows promise; but further study is needed on this topic [14, 15].

Acoustic pharyngometry (AP) is a rapid and non-invasive diagnostic test that can be used in patients with OSA. AP calculates the cross-sectional area of the upper airway segments using the reflection of sound waves and gives valuable information about the anatomical narrowing of the airway [16]. Many studies have shown the effectiveness, safety and reproducibility of AP in the diagnostic process of patients with OSA [17–20]. Its results are compared with computed tomography calculations and are found to be correlated [21]. Also, significant changes in AP results after CPAP or mandibular advancement device treatments have been demonstrated in the literature [22, 23].

In this study, we aimed to investigate the utility of AP in patients with OSA who underwent ESP by comparing the pre-operative and post-operative AP data and apnea–hypopnea index (AHI) values. We also aimed to investigate the possible use of AP in predicting surgical success.

Materials and methods

Study design and patients

This prospective study was conducted in Hacettepe University, Faculty of Medicine, Department of Otorhinolaryngology Head and Neck Surgery, between October 2015 and June 2020. Subjects were patients with OSA who either had tried and failed CPAP therapy or did not want to try CPAP and sought surgical treatment. All patients were evaluated

by a clinical team experienced in evaluating patients with OSA. Evaluation included demographic data, history of the disorder, Epworth sleepiness scale (ESS), and thorough upper airway examination, including flexible nasopharyngoscopy. Inclusion criteria were as follows: (1) age between 18 and 55 years, (2) presence of velopharyngeal obstruction detected with flexible nasopharyngoscopy, (3) no history of previous surgery of the oropharyngeal region, and (4) Friedman tongue position score 2 or 3. Patients who had large palatine tonsils (Friedman tonsil grade 3 or 4) were not included in this study, because significant improvement in the airway volume with the tonsillectomy alone is to be expected in these patients, and it would be hard to differentiate the contribution of the ESP to the change in the airway volume. Patients with a body mass index (BMI) over 35 were also not included in this study because of the reported low success rates in obese individuals [24]. The tongue base was evaluated with flexible nasopharyngoscopy, while the patient was sitting and was graded according to Cormack-Lehane (CL) grading system [25, 26]. Patients with significant narrowing at the tongue base (CL 3 or 4) were not included in this study as single-step palatal surgery would not be enough to achieve clinical improvement in these patients and multilevel surgery involving the tongue base would affect the results of the post-operative upper airway evaluation, creating a possible bias. Also, patients with malocclusion of teeth, clinically evident maxillomandibular retrusion, or severe orthodontic anomalies were not included in this study. All patients who were treated within the time period of the study and fulfilled the inclusion criteria were invited to participate in the study. Fifty-two patients who fulfilled the inclusion criteria were invited and thirty-five patients who agreed to participate were included.

Polysomnography

Full-night polysomnography (PSG) was used to evaluate the patients' sleep before and after surgery. PSG included the following parameters: electroencephalography, electrooculography, sub-mental electromyography, intercostal electromyography, plethysmography, chest and abdominal movements, snoring, nasal airflow, oxygen saturation, lower limb movement, and electrocardiographic activity. All of the pre- and post-operative PSGs were carried out in the same sleep laboratory. Post-operative polysomnography was performed 3–4 months after the operation. Evaluation and scoring of the PSGs were performed by the same technician according to the criteria defined by the American Academy of Sleep Medicine (AASM) in 2017 [27]. To differentiate between central sleep apnea and obstructive sleep apnea, the respiratory effort was recorded, and apnea with increased but ineffective respiratory effort was considered obstructive apnea. The frequency of apneas and hypopneas per hour of

sleep was expressed as the AHI. Acquired data included AHI, apnea index (AI), hypopnea index (HI), oxygen desaturation index (ODI), mean, and minimum O₂ saturation levels.

Acoustic pharyngometry

All patients were evaluated with AP pre- and post-operatively by the same clinician. AP was performed using the EccoVision Acoustic Pharyngometer (Sleep Group Solutions®, Miami, USA). Test was performed with patients sitting upright with their backs resting on a straight-back chair, their heads in a natural position, and during tidal breathing. For each patient, the test was repeated four times, and results with the least in-test variability were accepted (Fig. 1). Minimum cross-sectional area (MCA) and total pharyngeal volume (TPV) values were calculated according to AP results. Post-operative AP was performed on the day of post-operative polysomnography.

Surgical intervention and post-operative follow-up

All patients were operated under general anesthesia, with transoral intubation and by the same surgical team experienced in the procedure. For all patients, expansion sphincter pharyngoplasty surgery was applied. The palatopharyngeus muscle flap was rotated and sutured through a submucosal tunnel, as described by Woodson et al. [8]. Uvulectomy was not performed routinely but rather performed only in patients with excess uvula length (i.e., if uvula is in contact with the tongue base in natural position). When deemed necessary, the uvula was resected distally by 5 mm at most, and mucosal ends were sutured by a braided absorbable suture. Patients were followed up for 2–3 days after the surgery on the in-patient ward. Change in AHI was calculated by subtracting the post-operative AHI from pre-operative AHI. Changes in MCA and TPV were calculated by subtracting the pre-operative values from post-operative values. As the most commonly used method in the literature, the criteria

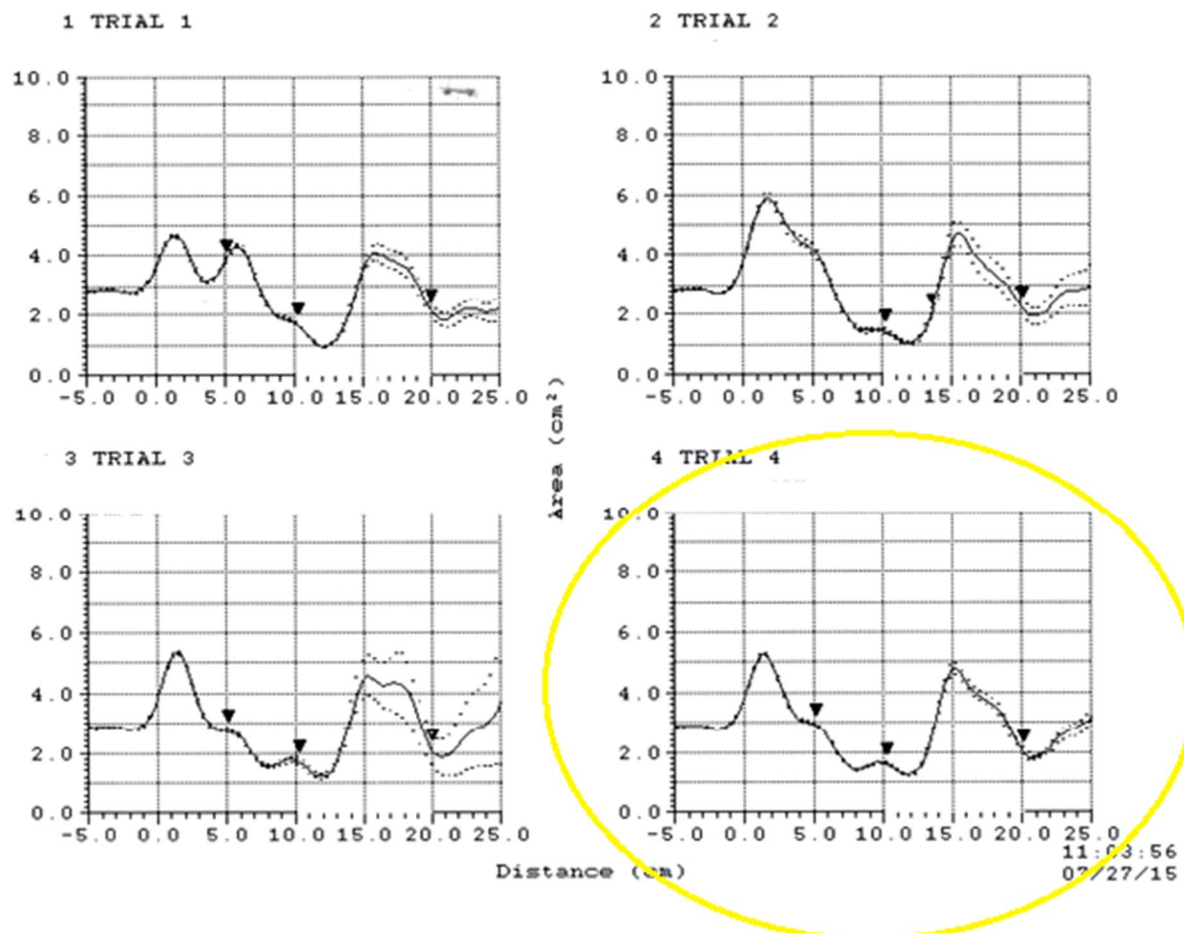


Fig. 1 Acoustic pharyngometry results of a patient are presented. Among the four results, trial 4 is used for the study, because of lower in-test variability

proposed by Sher et al. was used to evaluate the surgical success (> 50% decrease in AHI with a post-operative AHI < 20) [28].

Statistical analysis

Statistical analysis was performed using SPSS 17 (SPSS Inc, Chicago, IL). As the sample size was small, the “Wilcoxon signed ranks test” was used to compare the variables. To evaluate the relationship between surgical success and AP parameters, patients were divided into two groups according to their surgical success, and groups were compared concerning their mean pre- and post-operative MCA and mean pre- and post-operative TPV. The relationship between the change in AHI and the change in MCA and TPV was also analyzed, using “Pearson correlation analysis.” For all analyses, a *p* value below 0.05 was considered significant.

Results

In this study, 35 patients (26 men) were included.

The mean age of the patients was 41 (range 22–56). The mean pre-operative BMI of the patients was 28.6, the mean post-operative BMI was 28.9, and the difference was not significant (*p* = 0.17).

Mean pre-operative and post-operative AHIs are shown in Table 1. According to Sher’s criteria, 22 patients had a successful surgical result (63%). Mean AHI reduction was found to be 56% in the successful group and 9% in the unsuccessful group (5 patients in the unsuccessful group demonstrated minimal change in the AHI, decreasing the overall percentage of the group). Mean AHI of the successful group decreased from 29.4 ± 14.2 to 13 ± 17.3, while the mean AHI of the unsuccessful group decreased from 30 ± 19.2 to 27.2 ± 18.9. Mean MCA and mean TPV before and after the surgery are shown in Table 1. When compared to their pre-operative values, the relative increases in MCA and TPV were 100% and 50%, respectively. Comparison of pre-operative and post-operative results can be found in Table 1.

To evaluate the relationship between surgical success and AP parameters, successful and unsuccessful groups were compared. MCA increased from 1.2 ± 0.5 to 2.4 ± 0.4 in the successful group and from 1.1 ± 0.4 to 2.1 ± 0.4 in the unsuccessful group. Likewise, TPV increased from 22.0 ± 5.7 to 32.1 ± 4.9 in the successful group and from 19.5 ± 8.6 to 31 ± 6.5 in the unsuccessful group. No significant differences were found between the groups (Table 2).

For a more detailed analysis, changes in MCA and TPV values with the surgery were also compared. Mean change in MCA was 1.2 ± 0.5 cm² in the successful group and 1.1 ± 0.5 cm² in the non-successful group, and the difference was not significant (*p* = 0.694). Likewise, mean change in TPV was 10 ± 5.6 cm³ in the successful group and 11.5 ± 9.5 cm³ in the non-successful group, and the difference between the two groups was not significant. With the surgery, MCA increased 99.1% in the successful group and 99% in the unsuccessful group. Likewise, we achieved a relative TPV increase of 45.5% in the successful group and 59.1% in the unsuccessful group.

Correlation analysis between the change in AHI and the change in MCA and TPV yielded a significant strong positive correlation between the changes in MCA and TPV

Table 2 Comparison of variables in successful and unsuccessful groups in terms of AP parameters. *Pre-*: pre-operative, *Post-*: post-operative. MCA and TPV values are measured in cm² and cm³, respectively

| | | Mean ± SD | <i>p</i> value |
|---------------|--------------|------------|----------------|
| Pre-MCA | Successful | 1.2 ± 0.5 | 0.517 |
| | Unsuccessful | 1.1 ± 0.4 | |
| Post-MCA | Successful | 2.4 ± 0.4 | 0.147 |
| | Unsuccessful | 2.1 ± 0.4 | |
| Pre-TPV | Successful | 22 ± 5.7 | 0.322 |
| | Unsuccessful | 19.5 ± 8.6 | |
| Post-TPV | Successful | 32.1 ± 4.9 | 0.306 |
| | Unsuccessful | 31 ± 6.5 | |
| Change in MCA | Successful | 1.2 ± 0.5 | 0.694 |
| | Unsuccessful | 1.1 ± 0.5 | |
| Change in TPV | Successful | 10 ± 5.6 | 0.562 |
| | Unsuccessful | 11.5 ± 9.5 | |

Table 1 Comparison of pre-operative and post-operative mean values. *AHI* apnea–hypopnea index, *ODI* Oxygen desaturation index, *MCA* minimum cross-sectional area, *TPV* total pharyngeal volume, *ESS* Epworth sleepiness scale. *Statistically significant

| | Pre-operative mean | Post-operative mean | <i>p</i> value |
|-----------------------------------|--------------------|---------------------|----------------|
| AHI | 29.6 ± 16.3 | 18.3 ± 18.1 | < 0.001* |
| Mean O ₂ saturation | 93.9 ± 2.2 | 94.8 ± 2.3 | 0.06 |
| Minimum O ₂ saturation | 84.8 ± 6.3 | 87.3 ± 6.5 | 0.005* |
| ODI | 18.6 ± 17.1 | 10.9 ± 15.7 | 0.022* |
| MCA (cm ²) | 1.1 ± 0.4 | 2.3 ± 0.4 | < 0.001* |
| TPV (cm ³) | 21.1 ± 6.9 | 31.7 ± 5.5 | < 0.001* |
| ESS | 10.8 ± 4.1 | 3.8 ± 3.2 | < 0.001* |

($r=0.539$, $p=0.001$), but there was no significant correlation between changes in AHI and MCA or AHI and TPV. The findings are summarized in Table 3.

Although post-operative bleeding is a well-known complication of ESP, no patients in our study experienced it. Minor dysphagia was present in three patients, which resolved within one week post-operatively. There were no complaints of long-term taste disturbance, voice change, or pain.

Discussion

There are many different treatment methods for OSA, but an effective and widely accepted treatment algorithm is yet to be developed. The main treatment option, CPAP, is effective, but has low patient adherence [29]. Positional therapy, lifestyle changes, and oral appliances are also used in the management of OSA, but their effectiveness remains limited. Surgical treatments are promising but have lower-than-desired success rates. Patient selection is vital when surgery is considered, and any method which could contribute to the patient selection should be investigated.

ESP was first described by Pang and Woodson in 2007 and rapidly gained popularity over other palatal correction surgeries. Many studies showed the effectiveness of this surgical technique and a meta-analysis performed in 2016 revealed a success rate according to Sher's criteria of 86.3% [30]. In our study, the surgical success rate was 63% (22 of 35 successful), which is lower than but still relatable to the literature. As stated before, we excluded patients who had large palatine tonsils from our study, which could possible explain the slightly lower surgical success rate. After the exclusion of patients with Friedman grade 3 or 4 tonsils, our patient population only consisted of patients whose tonsils did not extend beyond tonsillar pillars. In this way, we were able to evaluate the effects of ESP more accurately at the cost of lower surgical success.

AP is easy to perform and non-invasive test, which gives an objective assessment of upper airway anatomy [17]. As ESP is a surgical procedure that remodels the upper airway

anatomy, one can assume that AP results change significantly after the surgery. We aimed to show the changes in AP results after the surgery and predict the surgical success using the AP parameters.

When the patients were analyzed as a whole, pre-operative mean MCA was 1.1 ± 0.4 cm², which increased to 2.3 ± 0.4 after the surgery. Likewise, mean TPV increased from 21.1 ± 6.9 to 31.7 ± 5.5 cm³ after the surgery. The differences were significant ($p < 0.001$ for both). These results objectively showed the improvement of upper airway anatomy by the surgery. With the surgery, 100% increase in mean MCA and 50.1% increase in mean TPV were achieved. Thus, we can say without a doubt that ESP is an effective surgical method for achieving a wider and larger airway in patients with OSA. Tearing of the palatopharyngeus muscle is a possible complication of the ESP, which may reduce the effectiveness of the surgery, but our AP findings showed that this was not a significant concern in our series [31]. Two studies have demonstrated the anatomical changes in upper airway after maxillomandibular advancement surgeries using the computed tomography [32, 33]. A study conducted by Zhang et al. demonstrated the improvement in upper airway anatomy after modified uvulopalatopharyngoplasty (UPPP) using computed tomography. However, no studies have shown the effectiveness of ESP using AP [34].

Separate analysis of successful and non-successful patients revealed no significant difference between these groups concerning mean pre- and post-operative MCA and TPV values. Therefore, we can assume that AP parameters cannot be used as predictors of surgical success, either pre- or post-operatively. This finding also shows us that successful and unsuccessful patients are quite similar in their pre- and post-operative anatomical structure. Changes in MCA and TPV were also compared between the successful and unsuccessful groups. The changes were significant for both groups, and there was no significant difference between successful and unsuccessful groups. None of the parameters were significantly different between successful and unsuccessful groups.

There are a few studies in the literature that compare upper airway volume changes and surgical success. The

Table 3 Correlation matrix for AHI, MCA and TPV changes. “ r ”: correlation coefficient. “*”: correlation is statistically significant (Pearson correlation)

| | | Change in AHI | Change in MCA | Change in TPV |
|---------------|-----|---------------|---------------|---------------|
| Change in AHI | r | 1 | 0.091 | -0,082 |
| | p | . | 0.605 | 0.640 |
| Change in MCA | r | 0.091 | 1 | 0.539* |
| | p | 0.605 | . | 0.001 |
| Change in TPV | r | -0,082 | 0.539* | 1 |
| | p | 0.640 | 0.001 | . |

aforementioned study conducted by Zhang et al. divided patients into two groups according to their surgical response and showed that the MCA change was significantly higher in the successful group [34]. Another study conducted by Abramson et al. documented the changes in RDI and airway volume with the maxillomandibular advancement surgery [33]. The study showed a strong correlation between the increase in airway volume and changes in RDI. Our findings contradict these studies, as in the current study, responders and non-responders had rather similar changes in MCA and TPV. However, as both the surgical modalities and airway evaluation methods differ in all three studies, it is not easy nor rational to interpret these results together. New studies with larger patient groups are required to support both hypotheses.

In this study, we also compared the changes in MCA and TPV to the changes in AHI using correlation analysis and found no significant correlation between these parameters, indicating that like surgical success, changes in AHI are not related to the degree of anatomical improvements. A study conducted by Chiffer et al. used MRI to evaluate the airway and soft tissue volume changes in patients with OSA treated with transoral robotic surgery, which included posterior hemiglossectomy, limited pharyngectomy, and UPPP. The study found no significant correlation between changes in airway volume or airway cross-sectional area and changes in AHI [35]. Our findings support the results of this study.

The current study revealed an important result: successful and unsuccessful surgical patients are quite similar concerning pre-operative and post-operative anatomical structure and also the degree of anatomical improvement achieved by the surgery. Simple logic may lead us to think that greater enlargement in the upper airway would result in a better surgical outcome, but this is not always the case in patients with OSA as demonstrated by this study. OSA is a multifactorial disorder, and similar, objectively measured anatomical improvements may induce a good response in one patient while being less effective in another. Patients with better functioning neuromuscular mechanisms probably benefit significantly from anatomical improvements, while patients with worse neuromuscular compensation fail to improve with the same improvements. More studies on this topic are needed.

AP does not evaluate the airway in the sleeping patient, and the awake airway structure determined by AP may not accurately represent the asleep airway. But in this study, awake AP was also used to determine the anatomical improvement achieved by the surgery. As the changes apply to both the awake and the asleep airway, measurements should represent the changes of the airway during sleep. For evaluation of the airway volumes in a sleeping patient, radiological tests are necessary, but they are harder to perform and more expensive, and some have significant side

effects (radiation exposure). Further studies comparing the airway volumes before and after surgery in asleep patients may provide additional information on this topic.

Our study has limitations. We enrolled a relatively small number of cases. Larger study designs are needed to consolidate our findings. Another limitation is the lack of pre-operative drug-induced sleep endoscopic (DISE) evaluation. The addition of DISE to the pre-operative evaluation could give different results compared to nasopharyngoscopy as stated in the literature, which could change the decision to perform surgery [36]. Patients who had multilevel airway narrowing were excluded from this study, and awake nasopharyngoscopic examination was used to determine the level of anatomic obstruction. However, in some patients, a totally normal retroglottal airway may become obstructed during sleep, and DISE is the only way to demonstrate that [37]. Therefore, it is possible that some of our patients may have had multilevel obstruction, which may have hindered our surgical success.

Conclusion

ESP is an effective surgery for improvement of upper airway obstruction, and its effectiveness may be objectively demonstrated using AP findings. Neither surgical success nor the change in AHI can be predicted using the AP results.

Declarations

Ethics approval This study was approved by the ethics committee of Hacettepe University. This research study was conducted retrospectively from data obtained for clinical purposes and in accordance with the standards declared by the 1964 Helsinki Declaration.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication The authors affirm that human research participants provided informed consent for publication of their clinical data.

Conflict of interest The authors declare no competing interests.

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