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HEAD AND NECK

Lateral pharyngoplasty techniques for obstructive sleep apnea syndrome: a comparative experimental stress test of two different techniques

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Abstract

Purpose To show the different effects of expansion sphincter pharyngoplasty (ESP) and barbed reposition pharyngoplasty (BRP) on muscle tension and muscle fiber tearing using a comparative experimental stress test with a frog thigh muscle model.

Methods Frog thigh muscle was used for this experimental study. A Barbed suture was used to simulate the BRP pharyngoplasty whereas a Vicryl 3-0 suture was used to simulate the ESP technique. The other extremity of the suture was attached to traction scales. The traction scales were used to measure the weight relative to the amount of force required to obtain muscle breaking. Both surgical techniques were simulated on the frog muscle. Traction was performed until muscle breaking was observed, measuring the value of force needed to obtain muscle rupture.

Results Specimen muscle breakdown in the ESP simulation occurred with an average value of 0.7 kg of traction force. Contrarily, specimen muscle breakdown in the BRP simulation with Barbed suture occurred with an average value of 1.5 kg of traction force

Conclusion During simulation of the ESP technique, specimen muscle breakdown occurred with an average value of traction force lower than in the BRP technique. During traction the multiple lateral sustaining suture loops of BRP could ensure greater stability then the single pulling tip suture of ESP with minor risk of muscle fiber damage.

Keywords Obstructive sleep apnea · Pharyngoplasty · Expansion sphincter pharyngoplasty · Barbed reposition pharyngoplasty · OSA surgery · Experimental test

Introduction

The velopharyngeal region is one of the most common sites of collapse and obstruction in patients suffering from obstructive sleep apnea syndrome (OSAS) [1, 2]. Over the years, a variety of surgical procedures have been proposed for reducing vibration and collapse of the palatal region [3, 4]. Uvulopalatopharyngoplasty (UPPP) was first described in the early 1950s by Ikematsu for snoring and later proposed in 1981 by Fujita for treating OSAS: to date it has been the most widely employed technique for soft palate collapse [4–6]. However, the long-term results and the risk of velopharyngeal insufficiency have often discouraged the use of this surgical procedure, leading to the development of alternative techniques [6–8]. Taking into account the import role of the lateral pharyngeal wall and, above all, the increased tendency to collapse in patients with OSA,

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Pang and Woodson [9] introduced a new technique for the treatment of OSA that they called expansion sphincter pharyngoplasty (ESP) (Fig. 1a).

The initial steps of ESP are tonsillectomy and identification and isolation of the palatopharyngeus muscle. The inferior portion of the muscle is transected horizontally and anchored using a Vicryl 3-0 round body needle and delineating a Fig. 8 suture. Then, it is rotated supero-laterally by traction of the lower extremity of the muscle bulk itself, leaving its posterior surface partially attached to the posterior horizontal superior pharyngeal constrictor muscles (Fig. 1b). Muscle mobilization should be sufficient for executing an adequate suture (Fig. 1c). Finally, the muscle is anteriorly attached to the arching fibers of the soft palate applying a vector of traction with a longitudinal direction with respect the muscle fibers (Fig. 1d). In their original paper, Pang and Woodson [9] reported an improvement of the apnea–hypopnea index after ESP from 44.2 ± 10.2 to 12.0 ± 6.6 ($p > 0.005$) in 23 patients with velopharyngeal collapse.

In 2015 Vicini et al. [10] introduced a new lateral pharyngoplasty technique for OSAS called Barbed Reposition pharyngoplasty (BRP) based on the relocation pharyngoplasty proposed by Li et al. [11]. This technique involves the use of barbed sutures that are knotless bidirectional reabsorbable sutures introduced into oropharyngeal surgery by Salamanca et al. [12]. The term ''Reposition pharyngoplasty'' was adopted because the technique requires suspension of the posterior pillar to the pterygomandibular raphe, displacing the palatopharyngeal muscle to a more lateral and anterior position. This results in an enlargement of the oropharyngeal inlet as well as of the retropalatal space with the only weakening of the palatopharyngeal muscle [13–15]. BRP pharyngoplasty is depicted in Fig. 2a. After the initial tonsillectomy, there are four steps: 1, introduction of a barbed thread at the level of the palatal spine; 2, intramucosal passage inside the palate; 3, rotation around the pterygomandibular raphe; 4, passage from the palate to the tonsil loggia. Subsequently, the barbed suture is passed through the upper part of the palatopharyngeus muscle emerging near the mucosa of the posterior pillar (Fig. 2b). The needle is passed back through the post-tonsillectomy muscle area and the resulting suture is again suspended around the raphe (Fig. 2c). Muscle traction is applied with a perpendicular direction to the palatopharyngeal muscle fibers (Fig. 2d). The raphe anchoring in an analogous way can be repeated several times both on the same and the opposite sides [10].

Preliminary study published on this technique confirmed good clinical results of BRP and the significant decrease in mean AHI from 43.65 ± 26.83 to 13.57 ± 15.41 [11]. In their comparative study of single-level palatal surgeries, Rashwan et al. [15] showed that the mean values of pre- and postoperative differences in the apnoea-hypopnoea index (AHI) were higher in the BRP group than in the ESP one, namely 15.76 ± 14.5 Vs 10.13 ± 5.3 ($p < 0.05$). However, no differences in oxygen desaturation index values emerged between the two techniques examined.

However, one negative aspect of lateral pharyngoplasty should be borne in mind: these techniques may lead to an excessive weakening of the palatopharyngeus muscle fibers due to excessive traction during relocation [13–17]. In our experience, comprising more than 300 ESP and 600 BRP

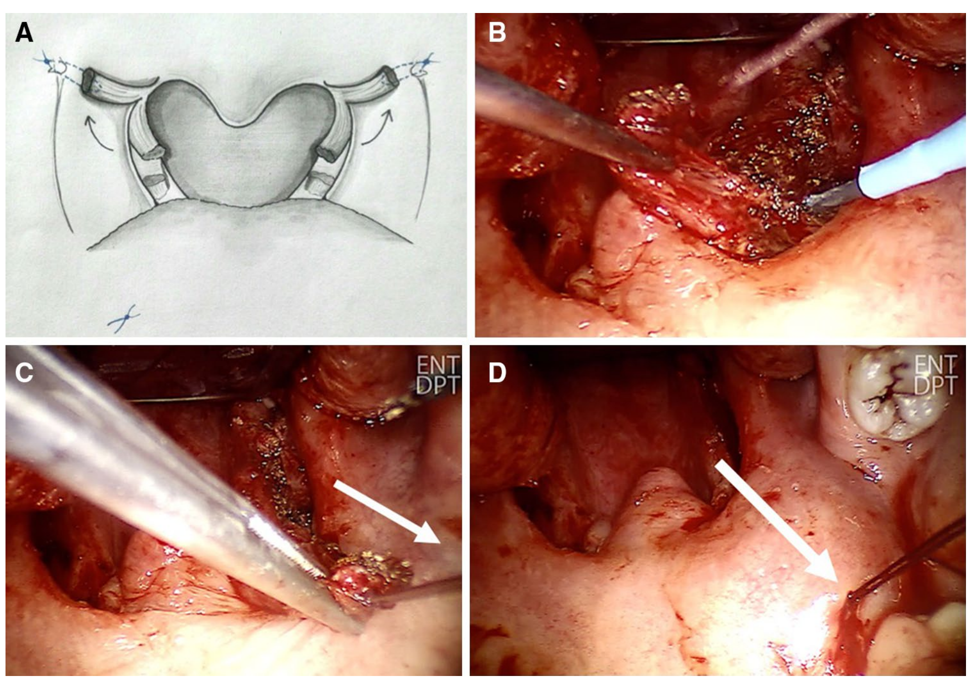

Fig. 1 **a** ESP surgical technique; **b–d** intraoperative surgical steps; palatopharyngeus muscle is isolated and left with its posterior surface partially attached to the posterior horizontal superior pharyngeal constrictor muscles (**b**); muscle is mobilized and its extremity is sutured using a 3-0 Vicryl (**c**); muscle traction with a vector having a longitudinal direction to the muscle fibers and suture to the arching fibers of the soft palate (**d**) (white arrow = traction vector)

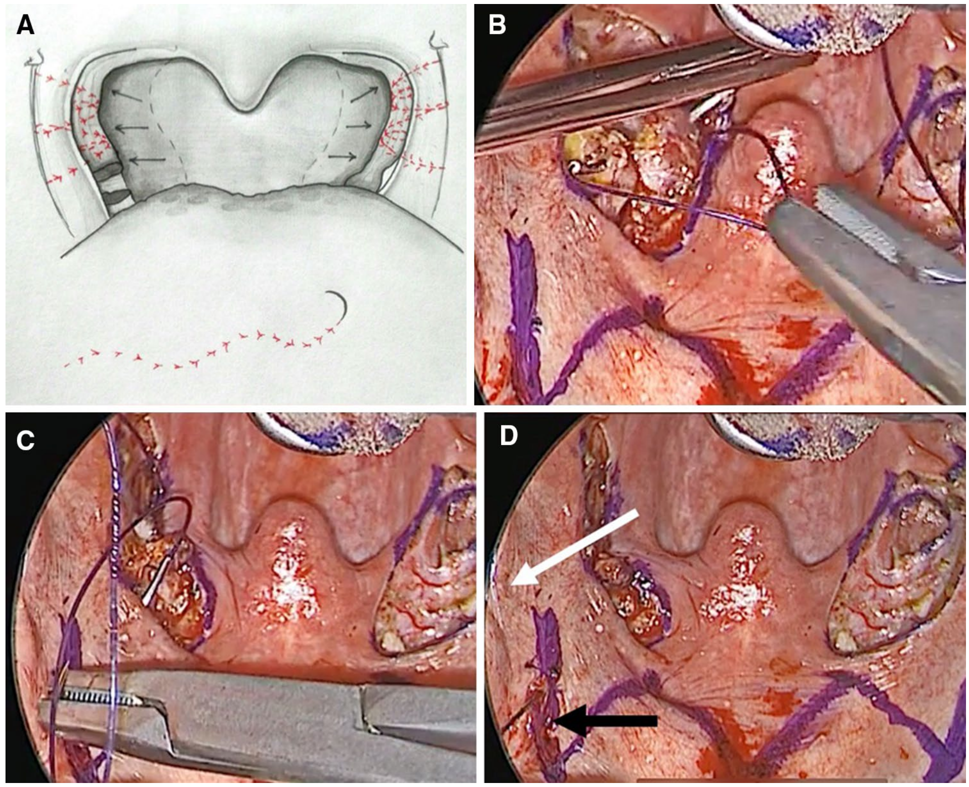

Fig. 2 **a** BRP surgical technique; **b**–**d** intraoperative surgical steps; barbed suture is passed through the upper part of the palatopharyngeus muscle (**b**); suture is suspended around the raphe (**c**); muscle traction with a direction perpendicular to the palatopharyngeal muscle fibers (**d**) (white arrow = traction vector; black arrow = barbed suture)

procedures, this muscle fiber damage was observed following 18 ESP and 15 BRP procedures and resulted in the complete loss of pulling force.

In the light of the above clinical findings the present experimental study was designed with the aim of showing the different effects of ESP and BRP on muscle tension and muscle fiber tearing. To do this a comparative experimental stress test of these two surgical techniques was carried out employing a frog thigh muscle model.

Materials and methods

Experimental study protocol

For this experimental study thigh muscle of dead frog was used since it was considered by us an excellent specimen for simulating the two surgical techniques rather than using the palatopharyngeal muscle. In fact, its length, size and muscular consistency is very similar to those of the palatopharyngeal muscle.

All the frog muscle specimens employed in the experimental study had a similar length and thickness (length 1.8 ± 0.2 cm. thick 0.8 cm ± 0.2 cm thick). The muscle was anchored using a small hook to a wooden tablet (Fig. 3a).

A Barbed suture was used to simulate the BRP pharyngoplasty (Fig. 3b), whereas a Vicryl 3-0 suture was used to simulate the ESP technique. The other extremity of the suture was attached to a traction scales. The traction scales were used to measure the weight relative to the force that had to be exerted to cause muscle damage/breakage for both surgical techniques (Fig. 3c, d).

The simulation of the ESP technique was achieved using a figure 8 3-0 Vicryl suture at one of the muscle extremities (Fig. 4a). As is normally done in the ESP technique, traction was performed with a vector having a longitudinal direction to the muscle fibers until muscle breakage was observed (Fig. 4b).

In the simulation of the BRP technique the 3-0 Vicryl suture was achieved by repeatedly passing the needle through the middle of the muscle as is normally done in the BRP technique (Fig. 5a, b). Traction was performed with a vector perpendicular to the direction of the muscle fibers, until muscle breakage was observed (Fig. 5c).

In both simulations, traction of the suture and muscle was continued until muscle rupture was observed (Figs. 4c, d; 5c, d). Subsequently, the weight relative to the force exerted to obtain muscle breakage in both surgical techniques was evaluated and analyzed.

These stress tests were performed several times for each procedure. Only the tests executed as described above were taken into consideration for evaluation of study results. The procedures that did not correctly simulate the surgical technique were excluded from the study.

The simulation of BRP technique was also performed using 3-0 Vicryl thread. This was done for evaluating the

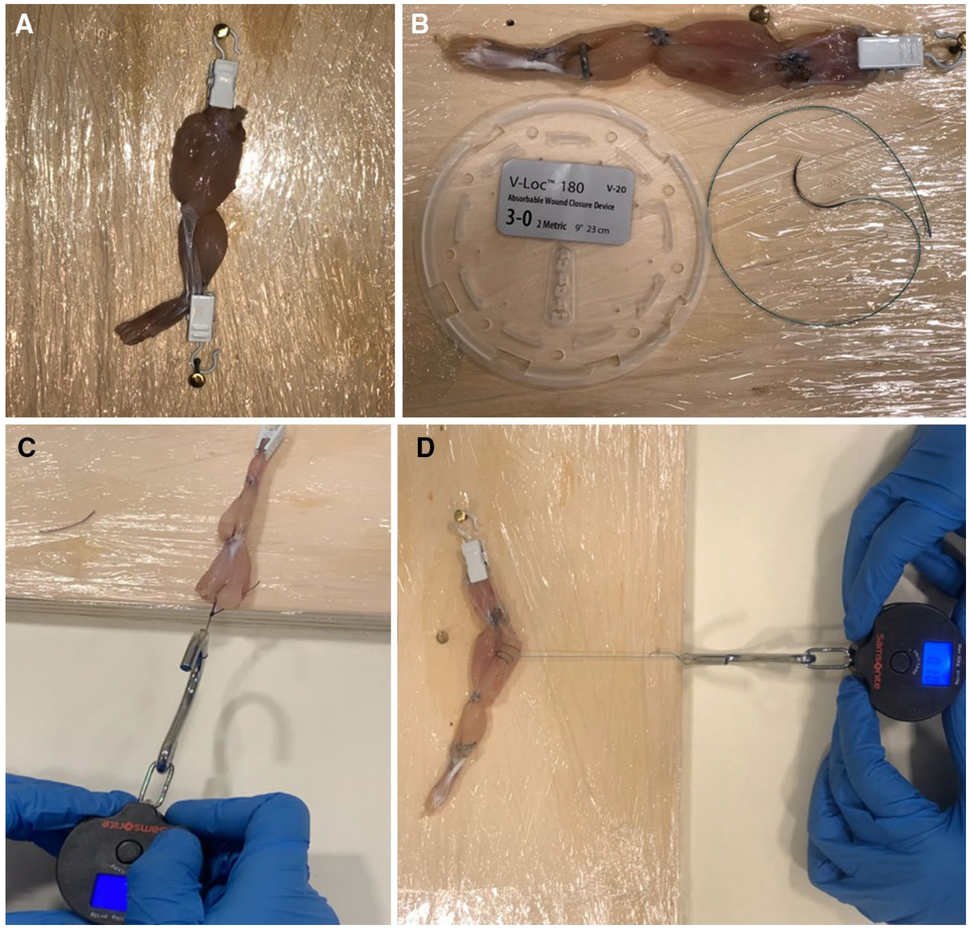

Fig. 3 Experimental stress test steps: **a** the muscle is anchored through a small hook to a wooden tablet; **b** Barbed suture (V-Loc) are used to simulate BRP technique; **c**, **d** a traction scales is used to measure the weight relative to the force that had to be exercised to obtain the muscle breaking in both simulations of the two techniques

potential impact on the muscle breakdown of the different types of suture or of the tension vector.

Statistical analysis

Mann–Whitney *U* test, ideal for small number of samples, was used to compare the analyzed factors ups. A *p* value of < 0.05 was considered statistically significant. Regression analysis was employed to correlate the length of the muscle with the value of muscle breakage.

This research study was approved by the local Ethics Committee. This study was performed in respect of the animal ethical standards.

Results

In 10 specimens an ESP simulation was performed whereas in other 10 specimens a BRP simulation using Barbed was done. In other 10 specimens the simulation of BRP using Vicryl suture was tested.

Table 1 shows the values of the weight-related to the force exerted to obtain breakage of the frog muscle in the experimental simulation, divided into the three sub-groups.

Specimen muscle breakdown in the ESP simulation occurred with exertion of an average value of 0.7 kg of traction force (Hi value = 1.2, Low value = 0.4 Median = 0.6 Average Absolute Deviation from Median = 0.2). In contrast, BRP simulation with Barbed suture gave an average value of 1.5 kg of traction force (Hi value = 2.1 Low value = 0.9, Median = 1.5 Average Absolute Deviation from Median = 0.3). There was a statistically significant difference in the force necessary for muscle breakdown between the two groups of tests (z score = − 3.36, $p = 0.007$; Fig. 6).

BRP simulation with Vicryl 3-0 gave an average value of 1.3 kg of traction force. There was no statistical difference between these two groups (z score = 0.64, p value 0.52).

Regression analysis did not show any correlation between the muscle length and the value observed for muscle breakage in either of the two study groups ($p > 0.5$ in both groups of study).

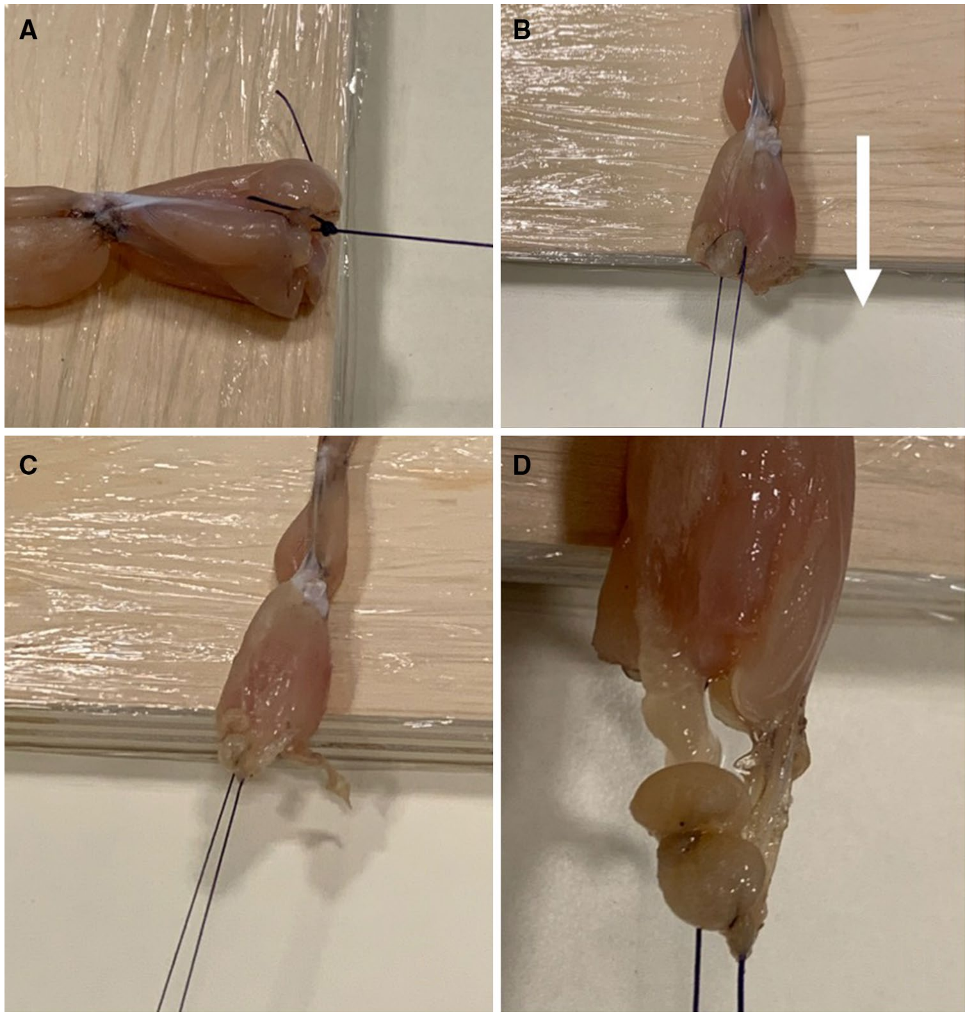

Fig. 4 **a**–**d** simulation of ESP; traction is performed with a vector having a longitudinal direction to the muscle fibers up to muscle breaking is observed (white arrow = traction vector);

Discussion

It has been demonstrated that lateral pharyngeal muscle wall collapse plays an important role in the pathogenesis of OSA. This aspect has been confirmed in various clinical studies by means of drug-induced sleep endoscopy (DISE) [1, 2, 18].

Authors concur that in surgical treatment it is difficult to create an adequate lateral pharyngeal wall tension to prevent its collapse [10–13, 19]. The ideal procedure would be one that is easy to perform, has low morbidity and minimal complications, and does not require any special equipment [10].

Over recent years, a number of surgical techniques, inspired by the lateral pharyngoplasty approach proposed by Cahali e et al. [17], have been proposed in order to obtain stabilization of this region and to prevent lateral wall collapse. Nowadays, two of the most widely used lateral pharyngoplasty techniques are expansion sphincter pharyngoplasty and barbed relocation pharyngoplasty [19–22]. Both these techniques are based on the relocation of the pharyngeal palate muscle in order to widen the transverse and antero-posterior pharyngeal space [9, 10].

The principle of the ESP technique is to isolate the palatopharyngeus muscle (the main part of the lateral pharyngeal wall bulk) and rotate this muscle supero-anterolaterally, thus creating lateral wall tension and removing the bulk of the lateral pharyngeal walls [9]. Some modifications of the expansion pharyngoplasty technique have been introduced, namely functional expansion pharyngoplasty [20] and modified expansion pharyngoplasty [21]: these techniques are fundamentally similar since their crucial point is palatopharyngeusmuscle muscle isolation and antero-supero-lateral rotation. Both techniques employ a tunnelling method for mobilizing the palatopharyngeus muscle antero-supero-laterally through an incision made on the anterior surface of the soft palate, just medial to the last upper molar on their respective sides.

The optimal results of this technique, in terms of postoperative AHI reduction, have been confirmed in several published papers. In fact, Sorrenti and Piccin performed functional expansion pharyngoplasty on 85 patients with obstructive sleep apnea and observed a reduction of the

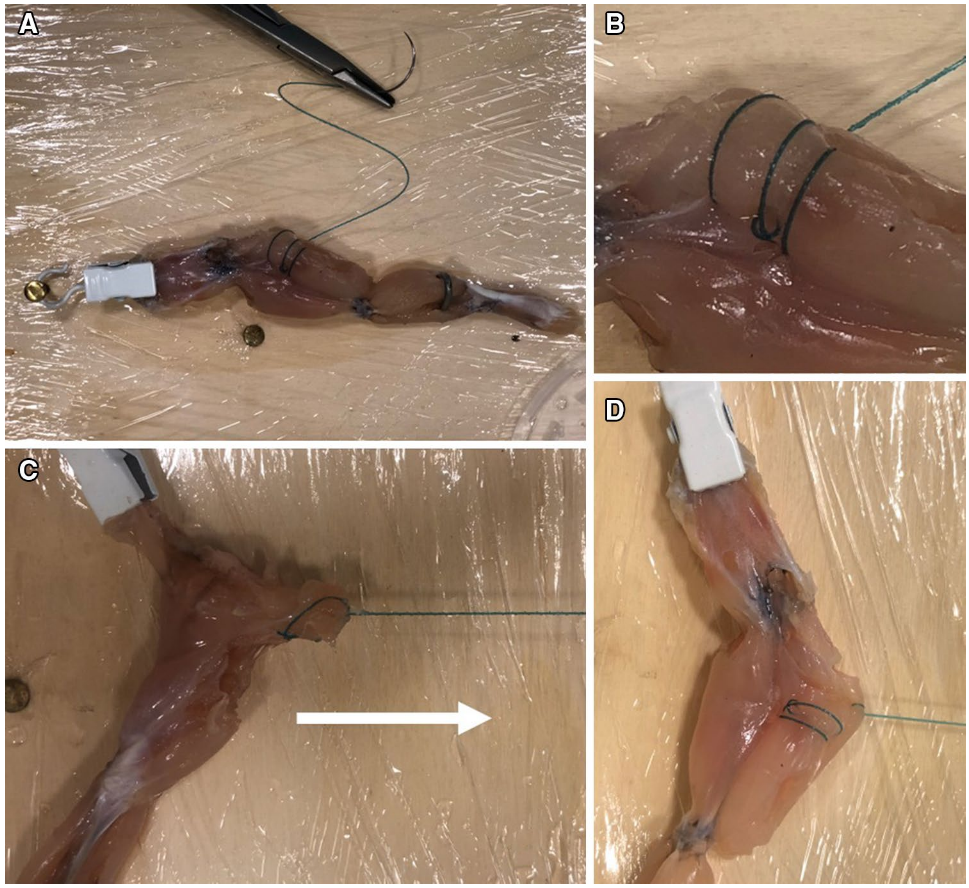

Fig. 5 **a**–**d** simulation of the BRP technique; traction is performed with a perpendicular vector to the muscle fibers' direction, up to muscle breaking is observed

Table 1 Weight relative to the force that had to be exercised

Cases	ESP Simulation longitudinal stretch vector (Vicryl 3-0 suture) breaking point kg	BRP simulation perpendicular stretch vector (Vicryl 3-0 suture) breaking point kg	BRP simulation perpendicular stretch vector (Barbed suture V-Loc) breaking point kg
1	0.4	1.3	1.8
2	0.8	1.5	1.4
3	0.6	1.6	0.9
4	1	1.3	1
5	0.7	1.8	2.1
6	0.4	1.5	1.8
7	1.2	0.8	1.7
8	0.5	1.6	1.2
9	0.6	1.4	1.1
10	0.8	1	1.9
Average value	0.7	1.3	1.5

ESP expansion sphincter pharyngoplasty, *BRP* barbed reposition pharyngoplasty

AHI from the pre-op average value of 33.3 to a post-operative average value of 11.7 [20].

A systemic review and meta-analysis of 5 papers and 143 patients showed the technique to be successful (50% reduction in pre-operative AHI and an AHI of less than 20) in 86.3% of patients [19].

Despite the fact that the ESP procedure has proved to be superior to UPPP in terms of AHI improvement and postoperative complications, in the last years surgeons have attempted to modify the approach to the lateral pharyngeal/retropalatal wall, suggesting alternative techniques to the ESP [10, 20, 21].

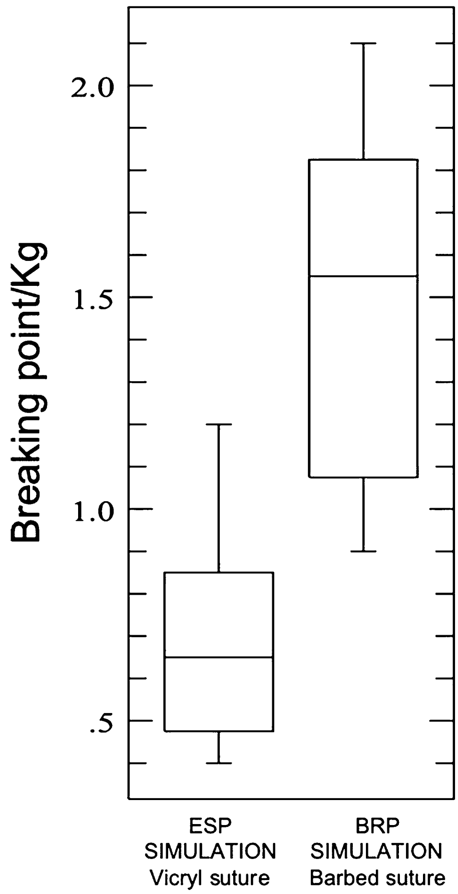

Fig. 6 Box plot, differences in force resulted for the muscle breakdown between ESP and BRP with barbed suture

Following its introduction in clinical practice, the BRP technique has been considered a valid alternative to ESP for the management of palatal/oropharyngeal obstruction [14, 15].

In the BRP technique a suspension of the posterior pillar to the pterygomandibular raphe is performed using barbed sutures, displacing the palatopharyngeal muscle to a more lateral and anterior position [10, 14].

In a prospective multicentric study to evaluate barbed reposition pharyngoplasty, a reduction of preoperative AHI values of 33.4 ± 19.5 to postoperative values of 13.5 ± 10.3 ($p < 0.001$) was observed [14]. Some clinical studies compared clinical outcomes of BRP and ESP. Rashwan et al. [15] found that the mean values of the pre- and postoperative differences in the apnoea-hypopnoea index (AHI) were higher in the BRP group than in the ESP one: 15.76 ± 14.5 vs 10.13 ± 5.3 ($p < 0.05$). However, no differences in oxygen desaturation index values was noted. On the other hand, Babademez et al. [22] compared barbed palatoplasty (BP) vs. expansion sphincter pharyngoplasty with anterior palatoplasty (ESPwAP) not observing statistically significant difference of the post-operative AHI scores. Successful rates were 86.6% in BP group and 84.9% in ESPwAP group.

The aim of the present experimental study was to assess the different effects of ESP and BRP on both palatopharyngeal muscle tension and tearing/breakage of muscular fibers using an experimental stress test employing a frog muscle model.

ESP is a simple surgical procedure; it is anatomically conservative and has minimal intra- and post-operative complications. However, in our experience of 300 ESP procedures, a risk of muscle fiber tearing (18 ESP cases) exists due to the possibility of excessive traction being exerted during muscle relocation. This muscle damage could be responsible for the loss of the entire pulling force and could be the effect of section of the lower portion of the muscle. Owing to the fact that there is a single anchorage suture at the muscle extremity and that muscular traction goes in the same direction (longitudinal vector) as the palatopharyngeal muscle fibers, during traction the entire force acts on the single point of the muscle where the suture is applied.

As shown by our stress test, muscle traction with a longitudinal vector (same direction as the muscle fibers) determines an elongation of the muscle fibers with the possibility of breakage even at low tensile forces (Fig. 4b–d, 6). Moreover, in all the specimens tested breakage occurred at the site of the suture (Figs. 4c, d, 5c, d). In the BRP technique the inferior portion of the palatopharyngeal muscle is only weakened and traction is performed with a vector having a perpendicular direction to that of the muscle fibers [10, 14]. Our experimental stress test showed that traction in a perpendicular direction to the muscle fibers required a greater force for muscle stretches/breaks (average value 1.5). The same higher force is required if simulation of BRP is performed using Vicryl suture. This seems to indicate that the vector of traction applied to the muscle and not the type of suture used is the cause of the different muscle stretches/breaks. However, due to the limited samples analyzed, more tests are needed in order to confirm this aspect.

Another aspect should be noted: in all specimen examined (both BRP and ESP simulations) breakdown of the muscle occurred at the anchorage point of the suture (Figs. 4c, d, 5c, d).

Finally, another consideration should be emphasized. ESP technique, may remarkably reduce the thickness of the lateral pharyngeal wall in case of bulky palatopharyngeus muscle anteriorly attached to the arching fibers of the soft palate. In contrast, BRP does not reduce the thickness of the pharyngeal wall only displacing laterally and anteriorly the palatopharyngeal muscle. This factor may have an important effect on the long-term outcomes meriting further study.

Conclusions

During simulation of the ESP technique, the average value of traction force necessary for muscle specimen breakdown was lower than in the BRP technique. The multiple lateral sustaining suture loops of BRP seem to ensure greater stability under traction than the single pulling tip suture of ESP with a consequent minor risk of muscle fiber damage.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies are in accordance with the animal ethical approval.

Ethical standards All procedures performed in studies are in accordance with the ethical standards of the Morgagni Pierantoni Hospital institutional committee.

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