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ANATOMIC BASES OF MEDICAL, RADIOLOGICAL AND SURGICAL TECHNIQUES

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Anatomic bases of graciloplasty using end-to-side nerve pudendal anastomosis

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Abstract The objective of this study was to evaluate the possibilities of reinnervation of the gracilis muscle, transposed around the anus, by the pudendal nerve using an end-to-side nerve anastomosis. This study was carried out in 14 cases (7 adult human cadavers bilaterally). The gracilis muscle and its vascular-nervous bundle have been dissected and the nerve innervating the gracilis muscle has been cut at its origin. The gracilis muscle, accompanied by its nerve, has then been transposed around the anus. The pudendal nerve has been dissected from its extrapelvic part. The reinnervation using an end-to-side nerve anastomosis has been considered as feasible when the proximal ending of the nerve of the gracilis was put into a tension-free contact with the extrapelvic part of the pudendal nerve. The extrapelvic part of the pudendal nerve has a common trunk in 12 cases. The width of the extrapelvic part of the pudendal nerve was 2.6 ± 0.7 mm, range 1–3.5. The width of the proximal endings of the nerve innervating the gracilis muscle was 2.3 ± 0.5 mm, range 2–3. The reinnervation of the gracilis muscle by the pudendal nerve has been possible in 14 cases. An average supplementary length of 17.4 ± 15.4 mm was available (range 5–52). These results suggest an eventual practical aspect of this technique for the reconstruction of a functional sphincter using the gracilis muscle transposed around the anus.

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Introduction

Many procedures of reconstruction with skeletal muscle draped around the anal canal have been developed for refractory anal incontinence. However, the results were unsatisfactory. The reasons for these disappointing results are absence of tonic contraction [3] and reflex mechanisms in the reconstructed sphincter [23]. The stimulation by chronic low-frequency electrical stimulation allows the muscle plasty to support a permanent contraction involuntarily and to improve the results. The defecation is obtained by stopping the electrical stimulation without relaxation during straining.

Recently, Sato [21] reported a procedure of sphincter reconstruction in dogs using end-to-side pudendal nerve anastomosis. In this study, the reconstructed sphincter was capable of contracting in co-ordination with the original external anal sphincter. The concept of end-to-side neurorrhaphy was revived by Viterbo [27] for nerve repair when the proximal stump is not available. This procedure could allow a muscular reinnervation without loss of donor nerve function [10, 11].

The possibility of reinnervating the gracilis muscle by the pudendal nerve was not reported. This anatomic study aims at evaluating the anatomic possibility to reinnervate the gracilis muscle using the pudendal nerve by an end-to-side nerve anastomosis, when the gracilis muscle is draped around the anal canal.

Materials and methods

During this study, seven human adult cadavers preserved in formalin ($n = 3$) or in Winckler's liquid ($n = 4$) were explored bilaterally. The mean age and the mean weight of cadavers were 76.1 ± 2.5 years (range 72–80) and 60.7 ± 7.3 kg (range 48–70). The human cadavers were installed in supine position. The gracilis muscle was dissected entirely from his insertion at the pubis to the medial condyle. The total number of neurovascular bundles was noted down. Only the principal neurovascular bundle was preserved. The nerve of the gracilis muscle was divided to its origin (Fig. 1) and was transected at this level. The diameter of the nerve has been measured at this level as well as its distal length. The distal tendon of the gracilis muscle was transected at its osseous insertion. The distal stump of the nerve of the gracilis muscle was attached to the muscle to be transposed with it.

The pudendal bundle was dissected by gluteal approach, as described by Robert [17]. The gluteus maximus muscle was dissected in the axis of the fibres. The sacrotuberal ligament was stripped free of its muscular attachment and was transected at the ischial spine level. The pudendal neurovascular bundle was dissected at its beginning in the pudendal canal. The length of the extrapelvic part of the pudendal nerve was measured between inferior border of the pyramidal muscle and the pudendal canal. The width of the pudendal nerve has been measured at the ischial spine level.

Bilateral radial perianal incisions were performed 2 cm from the anal verge. These two incisions communicate through a wide tunnel. The muscular portion of the gracilis muscle was wrapped around the anal canal.

A subcutaneous tunnelling allowed to approach the proximal stump of the nerve of the gracilis muscle and the extrapelvic part of the pudendal nerve. The end-to-side reinnervation of the gracilis muscle using the pudendal nerve was considered feasible when it was possible to put the nervous end of the gracilis muscle and the extrapelvic part of the pudendal nerve into tension-free contact (Fig. 2). The proximal stump of the nerve of the gracilis muscle was attached at this level. The length of the nerve of the gracilis muscle necessary for reinnervation was the length between this level and the penetration point into the muscle (Fig. 3).

Data obtained were subjected to statistical analysis by calculation of average, mean, standard deviation, extremes values, and P value using Student's t test (unpaired). The results were considered significant for a value $P < 0.05$.

Results

The average number of vascular bundles was 2.6 ± 0.7 (range 2–4). The main bundle was always the more proximal. The gracilis muscle nerve originated from the anterior branch of the obturator nerve ($n = 14$) and ran anteriorly between the pectineus muscle and the adductor longus , and posteriorly between the obturator externus muscle and the adductor brevis. The end was always situated at the level of the anterior-medial side of the gracilis muscle. The length of the nerve was

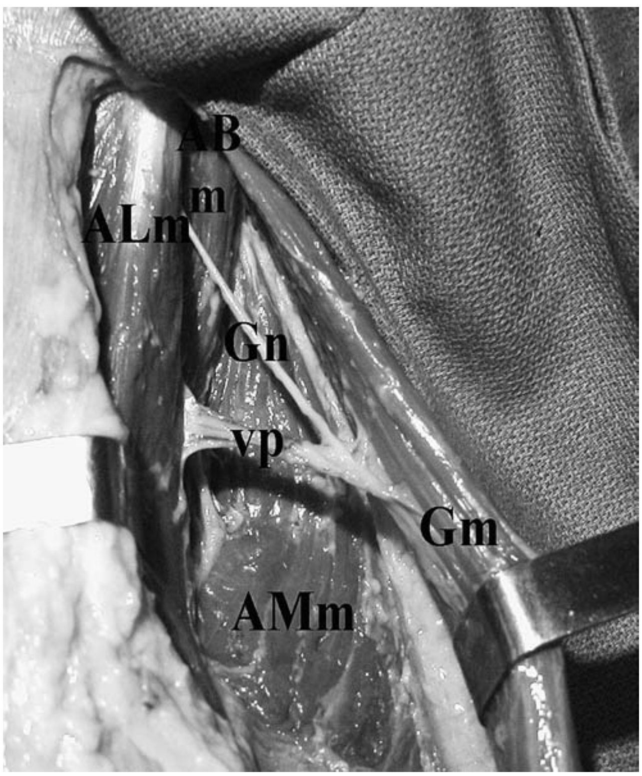

Fig. 1 Anterior view of neurovascular bundle of the gracilis muscle. *Right side*. *Gm* gracilis muscle; *Gn* nerve of the gracilis muscle; *ABm* adductor brevis muscle; *ALm* adductor longus muscle; *AMm* adductor magnus muscle; *vp* main vascular bundle of the gracilis muscle

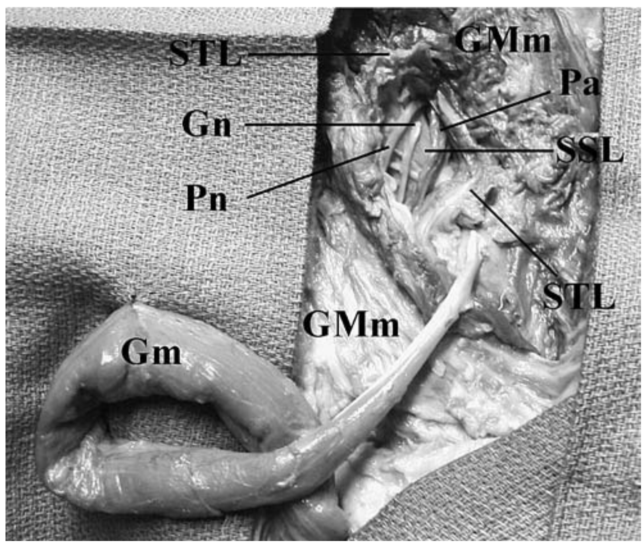

Fig. 2 Posterior view of the right gluteal area after transposition of the gracilis muscle in the anal area. The proximal end of the nerve of the gracilis was transposed on contact with the extrapelvic par of the pudendal nerve. *STL* sacro-tuberous ligament; *SSL* sacro-spinous ligament; *Gn* proximal end of the nerve of the gracilis muscle; *Pn* pudendal nerve; *GMm* gluteus maximus muscle; *Gm* gracilis muscle; *Pa* pudendal artery

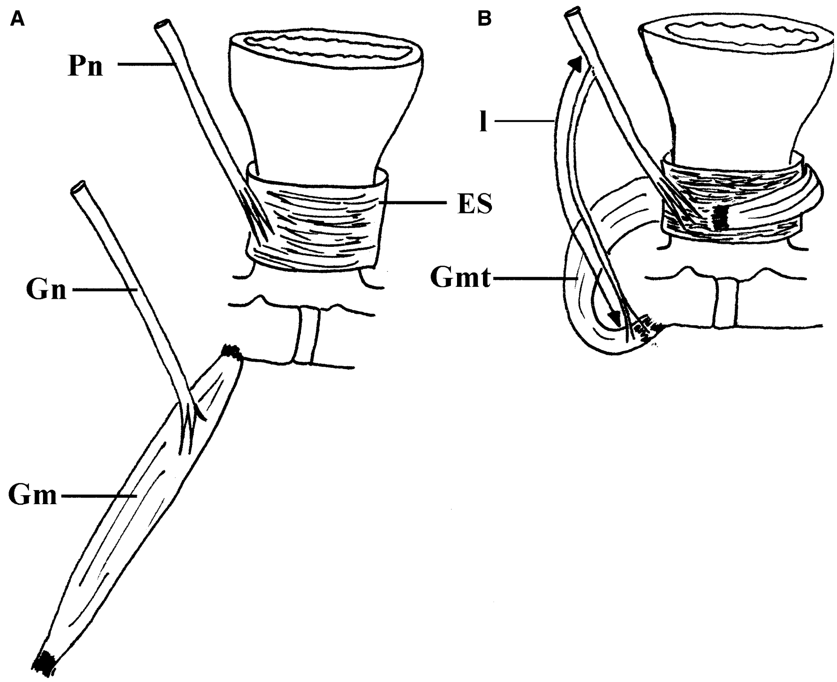

Fig. 3 Drawings of transposition of the gracilis muscle and of anal sphincter reconstruction (**a** before transposition, **b** after transposition). The gracilis muscle (*Gm*) was dissected. The nerve of the gracilis muscle (*Gn*) is transected at its origin. The gracilis muscle is transposed (*Gmt*) around the anal sphincter (*ES*). The proximal end of the gracilis muscle is transposed on contact with the extrapelvic par of the pudendal nerve. The length necessary for reinnervation of the gracilis muscle is the length (*l*)

118.9 ± 15.4 mm (range 95–148). The mean diameter of the nerve was 2.3 ± 0.5 mm (range 2–3). The trunk of the pudendal nerve in the extrapelvic part was single ($n = 12$) or double ($n = 2$). The mean width of the main trunk was 2.8 mm ± 0.8 (range 1–3.5) facing the ischial spine. The length of the extrapelvic part was 34.6 ± 7.1 mm (range 24–51), on the right side as well as on the left side (34.9 ± 6.2 vs. 34.3 ± 8.3 mm, $P > 0.05$). In one case the rectal inferior nerve originated off the extrapelvic part of the nerve.

The reinnervation of the gracilis muscle by the pudendal nerve was possible in all the cases. The surplus of length was 17.4 ± 15.4 mm (range 1–52). The length of the gracilis muscle necessary for reinnervation was 101.6 mm ± 15.4 (80–132).

Discussion

Few studies have demonstrated the feasibility for the construction of perineal colostomy using a transposed skeletal muscle with a pudendal nerve anastomosis [4, 20]. The reconstructed sphincter could achieve the physiologic and histological characteristics of the external anal sphincter [4, 22]. Anal sphincter reconstruction using the end-to-end pudendal nerve anastomosis procedure requires transecting the donor pudendal nerve, thereby losing the original functioning anal sphincter. This procedure should only be performed in the case of patients after abdominoperineal resection. A recent experimental study has proved the feasibility of transposition of skeletal muscle reinnervated by end-to-side pudendal nerve [21]. This procedure allows innervating the neosphincter without losing the donor pudendal nerve function of the original anal sphincter [10]. It is expected to increase the pressure of the anal canal with contraction of the neo-sphincter in co-ordination with the original anal sphincter. This procedure could allow to integrate intact sensory mechanisms [4, 22], and thus to obtain a spontaneous relaxation with a better muscular co-ordination during defecation.

The concept that end-to-side nerve neurorrhaphy can induce collateral sprouting was initially introduced by Ballance et al. [2] at the beginning of the twentieth century. Despite experimental evidence supporting its potential usefulness, the technique was abandoned, and end-to-end neurorrhaphy increased in popularity. In the early 1990s, Viterbo et al. [27] revived interest in end-to-side neurorrhaphy when he demonstrated successful nerve regeneration and muscle reinnervation with end-to-side neurorrhaphy in a rat model.

Various studies reported histological [8, 27] and electrophysiological [9, 10] evidence of both sensory and motor axon regeneration after end-to-side anastomosis. Muscular reinnervation is observed when using end-to-side neurorrhaphy with donor and recipient nerves from the same spinal cord level [7, 12, 29] or from various levels [6, 14, 18, 28, 30] (Table 1). Otherwise, the transfer using two nerves with a different spinal cord level was used in a clinical practice [11, 25]. This collateral sprouting is induced by neurotrophic factors such as gangliosides, antiproteases, nerve growth factor, neurotrophins [1]. Such factors released from the end-to-side implanted nerve stump cause the uninjured donor-nerve axons to give rise to a sprout which emerges from its side [1, 9] and passes down to the attached distal segment while the original homonymous nerve still carries on its original target organ [11]. The use of epineurial win-

Table 1

Authors	Type of study	Donor/recipient nerves
Lutz et al. [12]	Experimental[a] ($n=16$)	Median/radial or ulnar
Giovanoli et al. [7]	Experimental[a] ($n=24$)	Motor branch to vastus medialis muscle/nerve to rectis femoris muscle
Sananpanich et al. [18]	Experimental[b] ($n=24$)	Ulnar/musculocutaneous
Viterbo et al. [28]	Clinical[b] ($n=1$)	Phrenic/brachial plexus (C5 and C6 roots)
Loy et al. [11]	Clinical[b] ($n=18$)	Ulnar/biceps muscle nerve
Pellat et al. [14]	Clinical[c] ($n=60$)	Facial/hypoglosseal nerves
Franciosi et al. [6]	Clinical[b] ($n=5$)	Ulnar/musculocutaneous
Zheng et al. [30]	Clinical[c] ($n=6$)	Phrenic/recurrent laryngeal nerve

[a]End-to-side neurorrhaphy using donor and recipient nerves originate from the same spinal cord level
[b]End-to-side neurorrhaphy using donor and recipient nerves originate from various spinal cord levels
[c]End-to-side neurorrhaphy using spinal nerve and branchial nerve

dows, which is discussed [1], probably increases the rate of reinnervation of end-to-side nerve anastomosis [9, 27]. Perineurial sutures are more likely to induce collateral sprouting rather than epineural sutures [1].

Many muscles were used for anal sphincter reconstruction. Anal sphincter reconstruction by using a gluteus maximus muscle, with a pudendal nerve anastomosis, has been reported [20, 22]. A plasty with only the lower part of the gluteus maximus muscle is possible [5, 20] without dysfunction [16]. The anatomy of the gluteus maximus muscle is different. It is composed of two parts with different nutrient vessels. The upper and the lower part of the gluteus maximus muscle are supplied by the superior gluteus artery and vein, and by the inferior gluteus artery and vein, respectively. The inferior gluteus nerve innervates both muscles. Many variations of the inferior gluteus nerve were reported. For 50% of the cases, the peripheral ends of the inferior gluteal nerve to the lower gluteus maximus muscle are split into three or four bundles of nerves [20]. The nerve anastomosis is impossible directly.

The extrapelvic part of the pudendal nerve is generally a single trunk. Sometimes a venous plexus surrounding the pudendal nerve complicates its gluteal approach [17].

Gracilis muscle has been used frequently as a transposed neosphincter since Pickrell et al. [15] first reported using this muscle. The reinnervation of the gracilis muscle using the pudendal nerve has not been studied. The gracilis muscle is the most suitable one to perform a sphincteroplasty. The use of the gracilis muscle does not lead to dysfunction of the inferior limb. Since it is a long muscle, its proximal insertion as well as the neurovascular bundle is situated close to the perineum. The muscle is superficial on the inside of the leg. The approach is easy and may be done by minimal invasive surgery. The neurovascular anatomy of the gracilis muscle is found to be remarkably consistent from a specimen to another one, varying only in the length of the muscle and tendon, and the number of minor bundles supplying the distal portion of the muscle [13, 26]. The motor nerve arises from the obturator nerve and enters the muscle in association with the major vascular bundle. The main arterial supply to the muscle enters around 10 cm from the attachment to the body and inferior ramus of the pubis [19]. The nerve then splits within the muscle into two or three major branches that run alongside the arterial branches and muscle fibres [13, 19]. The distal portion of the muscle was supplied by one to three small arterial branches of the superficial femoral artery [13]. Venous drainage was noted to be carried out through paired venae comitantes [19].

Whereas the rate of nerve regeneration is reported to be about 1–2 mm/day [24], the period necessary for the reinnervation of the gracilis muscle by the pudendal nerve would be about 4–18 weeks. An electrical stimulation could prevent the muscle atrophy during the reinnervation period [4].

Conclusion

Anal sphincter reconstruction using the gracilis muscle transposed around the anal canal with end-to-side pudendal nerve neurorrhaphy is anatomically achievable. This procedure could be used for faecal incontinence to reinforce the original anal sphincter. It could allow to transpose the gracilis muscle to achieve the characteristics of the external anal sphincter and to contract in co-ordination with the original sphincter.

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