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Dynamic Myoplasty
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Introduction

Myoplasty encompasses a variety of clinical processes involving transfer of skeletal muscle for replacement or enhancement of body parts. Depending on whether the purpose of using the skeletal muscle flap is for filling a defect or restoration of contractile function, innervation is not, respectively is of major importance.

Muscle flaps are mainly used for bulk to cover defects of the upper and lower extremity caused by trauma1 and osteomyelitis,2,3 deformities of the face4 and to cover defects caused by oncological resections.5 For breast reconstruction the rectus abdominis muscle has been used extensively. For this application the muscle serves as a carrier for the vascular supply but nowadays can be omitted when the vessels are dissected out (perforator flaps).6 The result is an inferior epigastric artery skin flap without rectus abdominis muscle.

Restoration of upper and lower extremity function is made possible by transposition of tendons (local muscle flaps), transposition of distant pedicle muscle flaps and by microneurovascular reanastomoses in free muscle flaps. Restoration of function of the upper extremity by a gracilis muscle free flap for replacement of the flexor muscles of the forearm is an example.7,8 Restoration of function using a distant pedicle flap has been described by Mackinnon et al. They transposed the latissimus dorsi muscle to the upper arm to replace a non-functioning biceps femoris.9 As free revascularized muscle flaps the gracilis10,11 and pectoralis minor muscle12,13 have been used for dynamic reanimation in patients with facial paralysis. Restoration of function could be established after a microneurovascular anastomosis. In the given functional myoplasty examples the contraction characteristics of the transposed muscle flap are in close proximity to the original muscle (extremity musculature) or far from the normal function (face musculature) but no electrical stimulation is required because of reinnervation.

In the eighties there was felt to be a need for muscle flaps that could be more versatile in terms of performing a different function from its original one. This led to the development of dynamic myoplasty, in which the addition of electrical stimulation allows the transferred skeletal muscle to provide a function different from its original one. The two major applications presently under clinical investigation are dynamic cardiomyoplasty for the treatment of heart failure and dynamic myoplasty for the treatment of fecal or urinary incontinence (dynamic anal respectively urinary graciloplasty).
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Muscle Plasticity

The term muscle ‘plasticity’ refers to the ability of muscle tissue to undergo profound changes in its contractile speed and other properties long after the primary processes of differentiation and growth have been completed. The contractile properties of muscle can be changed by exercise and electrically induced exercise. The latter involves the placement of an electrode in a muscle or on a nerve followed by a conditioning period of electrically induced exercise. During this period the muscle is subjected to continuous or interrupted electrical stimulation in a graded incremental fashion until the desired properties are achieved. The effect of exercise is to convert the muscle from one that fatigues rapidly (fast-twitch glycolytic (type II) fibers) to one that can sustain a reasonable force for a protracted period of time (slow-twitch oxidative (type I) fibers).

From animal experimentation it is known that continuous stimulation, at a low frequency (5-10 Hz), can convert a muscle with a mixed fiber type population to a muscle with a uniform population of slow-twitch fibers, which have a high capacity for oxidative metabolism. It is also known that a muscle subjected to electrically induced exercise with a low frequency (10 Hz) paradigm will undergo a decrease in mass and a decrease in the magnitude of the maximum force the muscle can generate.

Muscle property changes can be predicted and fashioned for a particular purpose, depending on the stimulation paradigm involved. Hudlicka et al. found that a paradigm that allowed the muscle to generate greater sustained muscle tension was the 30 Hz pattern. Muscles adapted to a particular paradigm functioned more effectively in concert with that paradigm. However, histochemical, histological, and biochemical results did not explain the different effects of the stimulation paradigms. No difference was found in the extent of fiber conversion present for muscles stimulated at 10 and 30 Hz in the same animal despite the improvement in sustained and tetanic tension seen for muscles stimulated at 30 Hz. Changes in muscle properties have been mainly attributed to the total hours of stimulation per day and not the pattern of stimulation.

Dynamic Cardiomyoplasty

Dynamic Cardiomyoplasty is a technique that uses skeletal muscle to augment ventricular function. It is aimed at treating patients with chronic heart failure, refractory to medical therapy, that severely limits their daily life, a Class III or intermittent Class IV condition, according to the New York Heart Association (NYHA) classification. In dynamic cardiomyoplasty, the latissimus dorsi muscle is elevated as a flap based on its thoracodorsal
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neurovascular pedicle, transferred into the thorax, and wrapped around the ventricles of a failing heart. The most common form of the procedure involves wrapping the left latissimus dorsi muscle around the heart as a posterior wrap. Subsequently, the muscle is trained over an 8-12 week period to contract in synchrony with cardiac systole by means of a programmable, implantable nerve-muscle stimulator. In this way, cardiac function is augmented. The first procedure was performed in 1985 in Paris by Carpentier et al. and to date has been performed clinically in more than 600 patients worldwide.

Whilst many patients do well after cardiomyoplasty procedures in the literature there exists a large variability in the actual improvements in cardiac haemodynamic indices described. The reason for this variability is unclear. One of the possibilities could be related to the viability of the latissimus dorsi muscle used to wrap the heart. It is known that when the latissimus dorsi muscle is lifted in its entirety on its thoracodorsal pedicle the distal region of the flap will experience ischemia and often go on to necrosis. In experimental studies vascular delay has been found to improve latissimus dorsi muscle perfusion and contractile function. Another determining factor of the functional outcome could be the training protocol used. Different methods of electrical stimulation have been compared in their effectiveness of creating fatigue resistance and their effect on damaging the muscle. Chronic electrical training of the latissimus dorsi muscle prior to cardiomyoplasty has been studied in various experimental models. Mannion et al. examined chronic electrical stimulation and vascular delay as done before cardiomyoplasty. They demonstrated that, after mobilizing the latissimus dorsi, chronic electrical preconditioning of the latissimus dorsi muscle prior to cardiomyoplasty significantly increased, but did not totally restore, exercise-induced blood flow to the distal part of the muscle when compared to contralateral in situ latissimus dorsi muscle. Ali et al. found that preconditioning the latissimus dorsi muscle with vascular delay resulted in improving performance of the latissimus dorsi muscle with consistent increases in left ventricular hemodynamics. However, this was not observed after preconditioning with chronic electrical stimulation.

Dynamic Anal Graciloplasty

Fecal incontinence is an underreported condition that affects 2.5 percent of the population. It is a huge problem in human terms with high direct economic costs and indirect costs that result from the unwillingness of people to leave their homes. If anal sphincter repair or biofeedback training is not successful, dynamic graciloplasty is an effective option.
In the 1950s, surgeons developed a passive wrap of gracilis muscle around the anal canal.\textsuperscript{39,40} It failed because the patients were unable to maintain the necessary contraction of the muscle voluntarily because the muscle fatigued. The electrically stimulated, skeletal muscle neo-sphincter was developed later on. It adds to the passive muscle wrap a neural or intramuscular electrode that stimulates the muscle.\textsuperscript{41,42} An electrical stimulation protocol lasting eight weeks is used to transform the muscle into a fatigue-resistant fiber type. During this period the muscle is stimulated using a graded incremental training regimen until continuous stimulation is achieved. The patient controls fecal continence at will by turning an electrical stimulating device on and off to open and close the skeletal muscle neo-sphincter. Widespread applicability of the procedure was limited initially by the need for an external stimulator. Technological advances in the field of electronics have made available electrical stimulation devices that are small, implantable and have long battery lives.

In 1988, Baeten \textit{et al.} reported the implantation of a neuromuscular stimulator in a patient who had been treated previously with a gracilis muscle transposition because of anal atresia. This resulted in a perfectly controllable sphincter function.\textsuperscript{43} In 1989, Williams \textit{et al.} reported a case of construction of a neoanal sphincter following proctectomy.\textsuperscript{44} In 1991, Williams \textit{et al.} then described the use of a neoanal sphincter in 20 patients with fecal incontinence.\textsuperscript{45} Although there were six failures, the results were encouraging because in all patients with functioning neo-sphincters, continence was improved. Complications included severe perineal sepsis in nine patients, including muscle necrosis in four, electrode displacement in four, difficult evacuation in four, fibrosis and stricture in two, and transient neuralgia in two. This high complication rate must be taken in context with the fact that the only other option for these patients was a permanent stoma.

Vascular delay of the gracilis muscle is described as a possible solution to improve blood supply in the distal part of the gracilis muscle.\textsuperscript{46} This concept was applied by Williams \textit{et al.}\textsuperscript{42} and Wexner \textit{et al.}\textsuperscript{46} To prevent ischemia of the distal part of the gracilis muscle vascular delay 4-6 weeks before transposition of the gracilis muscle was used. It was suggested that improvement of the results was attributable to vascular delay prior to muscle transposition. However, Williams \textit{et al.} reported later on elimination of the delay without adverse effects.\textsuperscript{47}

So far no randomized study has been performed to explore whether the final result depends on the type of loop used to wrap the gracilis muscle around the anal canal. Good results have been reported with the gamma loop,\textsuperscript{41} the epsilon loop,\textsuperscript{42} the alpha loop\textsuperscript{48} and the modified epsilon loop.\textsuperscript{49}
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Dynamic Urinary Graciloplasty

Deming was the first to describe the graciloplasty for urinary incontinence in 1926. In a population of children with total incontinence because of epispadia, he detached the gracilis muscle at its insertion under the knee and wrapped it around the urethra. While pressing the knees tightly against each other by activating the adductors, including the gracilis muscle, the patients could actively evoke urinary continence. In 1956 Pickrell et al. reported the same procedure in a series of patients as a success. However, the drawback of this technique was that it is not possible to maintain continence for a long time, because of muscle fatigue. The success of the anal dynamic graciloplasty for treating fecal incontinence led some investigators to explore a similar approach to restoring urinary incontinence. Janknegt et al. and Williams et al. reported use of the same procedure with the addition of an implantable stimulator to electrically stimulate the gracilis muscle flap. Despite the promising potential of this new application of dynamic myoplasty, preliminary outcomes have been disappointing. The main problems seemed to be associated with stricture of the urethra created by the neosphincter as a result of distal muscle ischemia. In an experimental study van Aalst et al. addressed this problem by introducing a new procedure whereby the gracilis muscle is used as a free flap by dividing the main vascular pedicle and the muscle’s origin at the pubic bone and reanastomose its vascular supply. The well-vascularized proximal part of the gracilis flap could now be used to form the neo-sphincter and showed no evidence of stricture of the urethra for a follow-up of 16 weeks.

Dynamic Myoplasty for Stomal Incontinence

A new, and yet to be clinically tested, option for stomal incontinence is the use of dynamic myoplasty. To date, few studies have been done to investigate the feasibility of using dynamic myoplasty to provide stomal continence. The few reported cases done have been discouraging. Cavina et al. electrically stimulated the internal oblique muscle in an attempt to create a continent stoma. However, only one patient was treated using this technique and no follow up has been reported. Merrel et al. reported two different methods of using a free microneurovascular gracilis muscle flap in a dog model for stoma neo-sphincter construction. However, in both cases denervation atrophy of the gracilis flap (fatigue in one and closure of the stomal orifice in the other) was reported to have lead to failure. Konsten et al. used electrically stimulated rectus abdominis muscle flaps in the pig. They described three different designs of using the rectus abdominis muscle for stoma sphincter construction. The first design was the proximal rectus abdominis muscle...
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wrapped around the stoma. The second design was bowel pulled through the middle of the rectus abdominis muscle. Finally a sling was constructed using the distal part of the rectus abdominis muscle. They found that muscle denervation and fatigue lead to failure.
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47 Williams, N.S. The stimulated gracilis neosphincter. Presented at the annual meeting of the American society of colon and rectal surgeons, Montreal, Quebec, Canada, May 7-12, 1995.


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