

THE INFLUENCE OF FUNCTIONAL ELECTRICAL STIMULATION ON THE PROPERTIES OF VASTUS LATERALIS FIBRES FOLLOWING TOTAL KNEE ARTHROPLASTY

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ABSTRACT. The influence of functional electrical muscle stimulation (FES) on selected properties of vastus lateralis muscle fibres was studied in patients recovering from total knee arthroplasty for osteoarthritis. Prior to surgery, on the average, muscle biopsies from the vastus lateralis could be characterized as having a predominance of Type I fibres which were significantly larger in cross-sectional area than the Type II fibres in the same sample. Following surgery, muscle biopsies from a group of patients ($n=7$) which received continuous passive motion and no FES, exhibited a marked increase in the proportion of Type II fibres along with a general atrophy of both the Type I and Type II fibres. Patients receiving passive motion and FES ($n=9$) also showed an increase in the relative percentage of Type II fibres. Post-operatively, however, there was no significant reduction in fibre area in the stimulated muscles. These data suggest that FES was effective in attenuating the muscle atrophy associated with total knee arthroplasty but had no influence on those metabolic properties which were related to muscle fibre type classification criteria.

Key words: arthroplasty, continuous passive motion, electrical stimulation, muscle atrophy, osteoarthritis.

Severe osteoarthritis markedly limits ambulatory capacity due to pain, joint instability, and reduced gait efficiency (6, 18, 20, 21). As the condition progresses, the resultant reduction in total muscular work accentuates the severity of the disorder by a weakening of the musculature associated with the affected joint. Total joint arthroplasty has proven to be an effective surgical intervention for severe osteoarthritis (16). However, while many of the joint related factors are eliminated by the surgery, the muscular complications of reduced muscle mass and strength reduction are augmented. It is well recognized that a general negative nitrogen balance develops following a major

orthopaedic surgical intervention (2, 14). In addition, muscle protein synthesis, in particular, is depressed following such surgery (2). As a result, following surgery a patient is faced with the challenge of completing a rehabilitation program with a musculature which has atrophied and weakened to a greater extent than that which existed prior to surgery. Therefore, the burden of recuperation and rehabilitation could be significantly assuaged if muscle mass could be maintained, or the degree of atrophy attenuated, during the post surgical recovery period. To this end, it was of interest to determine if functional electrical muscle stimulation (FES) may be of benefit since it has been reported to be an effective modality for the treatment of muscular atrophy and weakness resultant from a variety of etiologies (for recent reviews see 9, 11). However, other reports have concluded that FES has little, or no, therapeutic effect on skeletal muscles (see 9, 11). Differences in experimental design factors, such as, the stimulus pulse characteristics, length of treatment, and the underlying muscle pathology may account for much of the discrepancy in the literature. Despite the apparent controversy surrounding the effectiveness of FES, it was considered expedient to investigate the efficacy of FES in attenuating the loss of muscle mass of the quadriceps which occurs concomitant with total knee arthroplasty for severe osteoarthritis. In this study, FES was applied under conditions which attempted to control the pulse characteristics, treatment duration, and muscle length during stimulation. Thus, the activity and load patterns on the stimulated muscles of each patient were comparable. Under these conditions, we observed that FES was efficacious in attenuating post surgical muscle atrophy but apparently had no influence on those properties associated with the fibre type characteristics of the muscles.

Table I. Properties of vastus lateralis muscle fibres (mean \pm standard error of the mean) from biopsies obtained at the time of surgery and 7 days post surgery following treatment without (Control) or with FES

	Control		FES	
	Type I	Type II	Type I	Type II
Fibre type (%)				
Surgery	67 \pm 7	33 \pm 7	70 \pm 5	30 \pm 5
Day 7	52 \pm 4*	48 \pm 4*	60 \pm 3*	40 \pm 3*
Area (μm^2)				
Surgery	2 564 \pm 138	1 613 \pm 213	2 932 \pm 378	2 272 \pm 316
Day 7	1 640 \pm 56*	887 \pm 37*	2 697 \pm 161	2 067 \pm 130

* $p < 0.05$ significant difference between surgery and day 7.

PATIENTS AND METHODS

Sixteen patients (aged 61–79 years), requiring unilateral total knee arthroplasty for severe osteoarthritis were studied. Each subject was free of other confounding joint or systemic conditions and satisfied the clinical criteria (pain and disability) for joint replacement. Post surgically, subjects were randomly assigned to different rehabilitation groups which received either continuous passive motion (CPM), $n=7$, 4 females and 3 males; Control Group or CPM plus functional electrical muscle stimulation (FES), $n=9$, 4 females and 5 males; FES Group.

Prior to surgery each patient was familiarized with the functions and use of the CPM and FES device (Sutter Biomedical Company Model 9000). The CPM protocol described in detail by Coutts et al. (3) was utilized. Briefly, during the first 48 hours post surgery, CPM provided a 40° arc of flexion from full extension at 1 RPM. Subsequently, 10° of flexion were added each day as tolerated by the patient. Thus, following 7 days of CPM, 90° of flexion was achieved by each subject.

Patients assigned to the FES group received the identical CPM protocol. However, prior to achieving the target angle of flexion (hamstring muscles) or extension (quadriceps muscles), a biphasic square wave with a pulse width of 250 μsec at 30 Hz was applied through surface electrodes placed over the motor points of the respective muscle groups. The amperage was set at the tolerable limit of the individual patient, yet, elicited a visible muscle contraction. The total stimulation "on time" was 10 sec per CPM cycle which corresponded to an average of 1.5 hours of FES per day over the 7 days of treatment.

From each patient, a sample of the vastus lateralis muscle initially was obtained during the arthroplasty surgery and again 7 days post surgery using a Bergstrom biopsy needle (1). The samples were located approximately mid thigh with particular regard at maintaining a consistent depth within the muscle across samples. Thus, the inherent error (4) associated with characterizing the entire muscle with a single biopsy sample was minimized. The estimated 10% error in predicting the fibre type profile of the entire muscle based upon a single biopsy sample (4) must be considered as a confounding inaccuracy in this study. However, data derived from a single biopsy remains reliable and valid recognizing this limitation. The muscle samples were mounted on cork, frozen in isopen-

tane cooled in liquid nitrogen, and stored at -70°C until analyzed. Tissue sections (10 microns) were cut using a cryostat maintained at -20°C . The tissue sections were prepared for the histochemical determination of myofibrillar ATPase under alkaline preincubation conditions, pH=10 according to Nywoye et al. (17). From each biopsy sample 200–300 fibres were classified as Type I (light staining density) or Type II (dark staining density) and their cross-sectional areas measured using a PSICOM 232 (Perceptive Systems, Inc.) computer assisted image analysis system (12). The use of this system eliminates the subjectivity of assigning fibers to either Type I or II based on a visual assessment of the staining intensity. These classifications were made based on the fact that a bimodal distribution of optical densities is found for the alkaline pre-incubation myofibrillar ATPase reaction. Those fibers which were associated with the lower density group were designated as Type I while the remaining higher density fibres were classified as Type II.

A two-way ANOVA and Scheffe test were performed in order to determine the significance of the observed changes in fibre type percentage and fibre area, from surgery to day 7, for both treatment groups. All analyses were performed using the computer based statistical package STATGRAPHICS (STSC, Inc.). Significance was established at $p < 0.05$.

RESULTS

At the time of surgery the vastus lateralis muscle biopsies from each of the patients were characterized by a predominance of Type I fibres (Table I). In addition, on the average, the Type I fibres had greater cross-sectional areas than did the Type II fibres (Table I). There was no discernible sex related differences among the patients for these properties. Relative to reported values from similarly aged subjects with no apparent joint complications, whose tissue was prepared under similar conditions (8, 10), the "normal" vastus lateralis muscle would be characterized as having an essentially mixed (50%) percentage of Type I and II fibres, with the Type II fibres possessing the greater cross-sectional areas. Thus, it appears that the

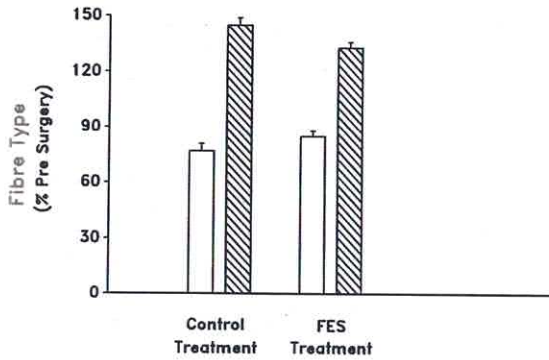


Fig. 1. The percentage of Type I (clear bars) and Type II (cross-hatched bars) fibres in biopsy samples analyzed 7 days following surgery. The mean \pm standard error of the mean for the Control and FES treated groups are expressed relative to (percentage) the values determined in samples obtained at the time of surgery.

osteoarthritic condition markedly alters both of these properties in a muscle associated with an osteoarthritic joint.

Following surgery (7 days), for each of the patients, the fibre type composition of the vastus lateralis biopsy sample was significantly different relative to that observed prior to surgery. That is, the post surgical samples were composed of a significantly higher relative percentage of Type II fibres (Table I, Fig. 1). Furthermore, the specific rehabilitative treatment received during the recovery period, i.e., CPM or CPM and FES, had no influence on this change. In contrast, fibre cross-sectional area was observed to be sensitive to the type of modality employed. A marked degree of fibre atrophy was present in the biopsies from patients receiving only CPM (Table I, Fig. 2). However, with the addition of FES to the CPM based treatment program, fibre atrophy was significantly attenuated and only slightly reduced relative to pre-surgery levels (Table I, Fig. 2).

DISCUSSION

Severe osteoarthritis has been demonstrated to have a significant impact on the properties of the skeletal muscles associated with the affected joint (7, 13, 19). This influence alters not only the morphological properties of fibres but also those biochemical properties which are manifested by the categorization of fibres into "types". In a previous report (13), we developed an etiological hypothesis for the increase (relative to a healthy joint) in the comparative size and proportion of Type I fibres in muscles associated with an osteoarthritic joint. In brief, we suggested that the altered

joint and gait mechanics associated with osteoarthritis impact on the load bearing requirements of the musculature associated with the joint. This in turn induces morphological and metabolic adaptations in those muscles in order to meet these altered functional demands. Presently, it was observed that total knee arthroplasty also can elicit a plastic response from muscle fibres associated with an osteoarthritic joint. Currently, speculation as to the clinical impact of the observed increase in the relative proportion of Type II fibres in the vastus lateralis of osteoarthritic patients following surgery would be inappropriate. However, the fact that this change occurred under both rehabilitation conditions is consistent with our hypothesis (13) that the load bearing history on the osteoarthritic joint determines, at least in part, the properties of the muscles associated with that joint. Despite the fact that FES did generate muscular activity and isometric force in the vastus lateralis during the recovery period, the amount of force elicited may have been significantly less than that experienced during standing and ambulation prior to surgery. On the contrary, the level of muscle activation associated with the FES treatment was sufficient to maintain muscle fibre cross-sectional area. This observation supports a plastic independence, or selective sensitivity, of muscle fibre properties in the face of a functional perturbation. In addition, force related factors may function independently from the overall level of muscle activity with respect to inducing muscle adaptations.

Previously Coutts et al. (3) demonstrated that the addition of CPM to a post-surgical rehabilitative therapy program significantly improved the rate of

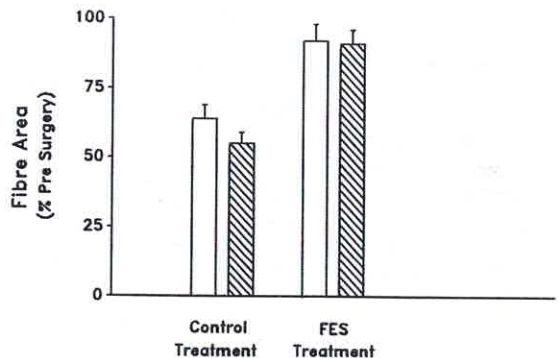


Fig. 2. The mean \pm standard error of the mean cross-sectional area of fibres in biopsy samples analyzed 7 days following surgery. The symbols are the same and the data are expressed as defined in Fig. 1.

achieving various indices of recovery in knee arthroplasty patients. However, our present findings suggest that CPM is ineffectual at attenuating the atrophic response of muscle to surgery. The nearly equivalent loss of cross-sectional area of both Type I and II fibres is consistent with the general reduction in muscle protein synthetic activity observed following surgery (2). The addition of FES to the CPM based rehabilitation program did prove effective in attenuating the loss of muscle mass following surgery. Again, the nearly equivalent maintenance of area in the Type I and II fibres suggests a common mechanism. However, it remains to be tested whether the reduction in protein synthesis activity following surgery is attenuated by FES or whether protein degradation rates also are altered.

In summary, we have observed that FES was beneficial for the maintenance of muscle mass in patients recovering from total knee arthroplasty. Similar positive results have been reported with other orthopaedic conditions such as knee flexion contractures (15) and anterior cruciate reconstruction with cast immobilization (5). However, this modality appeared to be limited in attenuating other changes in muscle that accompanied the surgery. In spite of this limitation, the additional time and effort required by the patient and medical staff to implement a treatment program which includes FES appears justified when muscle atrophy is a major post-surgical complication.

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