PERCUTANEOUS IMPLANTABLE FUNCTIONAL ELECTRICAL STIMULATION FOR UPRIGHT MOBILITY IN CHILDREN WITH SPINAL CORD INJURY: DESCRIPTION OF SURGICAL TECHNIQUE

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Abstract

Eight children with thoracic-level paraplegia and one adolescent with C7 tetraplegia underwent surgical implantation of a completely implanted 8 channel lower extremity FES system (NeuroControl Corporation, Valley View, Ohio). Intramuscular electrodes were implanted bilaterally using a percutaneous needle insertion technique. Electrodes were implanted to the femoral nerve or vastus lateralis, gluteus maximus, gluteus medius, and posterior fibers of the adductor magnus. The electrode leads were tunneled subcutaneously and connected to the stimulator placed in the right lower quadrant of the abdomen. Stimulated motor responses were characterized at regular intervals to develop stimulation patterns for upright mobility and to track electrode performance. Of 86 electrodes implanted, 72 electrodes (84%) provided consistent functional responses from implant to an average follow-up of 19 months. Fourteen electrodes (16%), 13 of which involved two of the first three subjects, required revision approximately 3 months after implant. Based on our initial experiences, refinements of the implant procedures were implemented.

Introduction/Background

Persons with paraplegia secondary to spinal cord injury (SCI) are commonly prescribed long-leg braces for upright mobility. Problems cited with long-leg braces include difficulty in donning; bulkiness beneath clothing, poor fit in a wheelchair, and difficulty maintaining skin integrity. Our work has shown that functional electrical stimulation (FES) can augment existing function in children with paraplegia who are already highly functional in their wheelchairs by affording them the ability to engage in upright mobility activities. [1,2] In addition, we have learned that persons with paraplegia will more readily accept FES than braces because of its low profile, ease of donning, and potential functional benefits. [1,2]

The purpose of this paper is to describe a percutaneous technique for total implantation of a FES system for upright mobility.

Methods

Subjects

Eight children and adolescents with thoracic-level spastic paraplegia and one adolescent with C7 spastic tetraplegia with intact lower motor neurons (L3 to S3) underwent surgical implantation of a completely implanted lower extremity FES system (NeuroControl Corporation, Valley View, Ohio).

Surgical Procedure

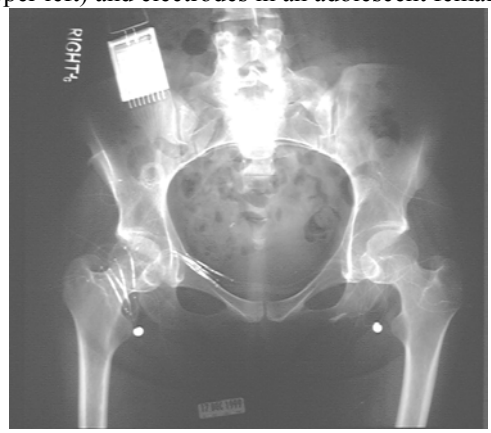
For the surgical procedure, subjects were positioned in supine, and the entire buttocks area and bilateral lower extremities were cleansed and draped. For all subjects, eight muscles were implanted (4 each leg) with intramuscular electrodes for knee extension (vastus lateralis or femoral nerve); hip extension (gluteus maximus and posterior fibers of the adductor magnus); and hip abduction (gluteus medius). Most muscles were implanted with intramuscular electrodes. [3] However, the first 3 subjects received epimysial electrodes for knee extension and hip abduction. To determine electrode placement, a 25-gauge needle was used to probe each muscle near the motor end point. An electrical signal was delivered to the muscle through the probe to identify the exact area of the muscle where the strongest response was obtained. The intramuscular electrode was then implanted into the muscle through a series of cannulas inserted over the needle probe. The muscle response was retested after implantation. If an epimysial electrode was used instead, the electrode was directly sutured to the epimyseum of the muscle after identifying the motor point.

For stimulated knee extension, the first 8 subjects received electrodes implanted near the femoral nerve to activate the entire quadriceps group. To prevent unwanted hip flexion with stimulation to the rectus femoris, a small incision was made and a 1 cm section of the proximal rectus femoris was excised distal to the separation of the main head and reflected heads of its attachment to the pelvis. The most recent subject, subject 9, underwent an alternate method for stimulated knee extension using the vastus lateralis. With this procedure, once the maximum response was obtained, tracking of the

patella was assessed to make sure there was no lateral overpull. As there was adequate strength and no abnormal tracking, an intramuscular electrode was implanted percutaneously. If the tracking or muscle strength were not adequate, then the femoral nerve would have been implanted to utilize the full strength of the quadriceps.

Following implantation of all 8 electrodes, three small incisions were then made: one over the right abdomen halfway between the rib cage and the iliac crest for insertion of the stimulator, and two 2-cm incisions just above the inguinal ligament bilaterally for passing the electrodes to the connector site of the internal stimulator. The internal stimulator was then placed and sutured to the fascia. The electrodes' leads were tunneled subcutaneously and attached to the leads of the internal stimulator (Figure 1). All electrodes were retested through the internal stimulator for sufficient stimulated response, using a radio frequency antenna to deliver the signal to the stimulator. For the subjects who were not skeletally mature as determined by bone age, extra lead wire was incorporated into the system to accommodate growth. Following closure of all incisions, rotational alignment of the tibia and femur were assessed to determine the need for rotational osteotomies to optimally position the lower extremities for standing.

Figure 1: Radiograph of the implanted stimulator (upper left) and electrodes in an adolescent female.



Measures

At yearly intervals, stimulated muscle responses were evaluated by determining the stimulated muscle strength based on the 5 point Manual Muscle Test scale and the pulse duration that first initiated a palpable muscle contraction. Sufficient force production to provide stimulated standing was considered a grade 2 or better muscle strength for the hip extensor and abductor muscles and a grade 4 or 5 muscle strength for the knee extensors.

Results

A total of 86 electrodes were implanted in the 9 subjects, 71 of which were intramuscular (83%) and 15 of which were epimysial (17%). At an average follow-up of 19 months, 72 electrodes (84%) have continued to provide functional responses since implantation. Fourteen electrodes (16%) required repositioning (epimysial) or replacement (intramuscular) primarily due to insufficient force production. Thirteen of the 14 revisions involved the second and third subject. Three of the 15 (20%) epimysial electrodes were repositioned and 11 of the 71 (16%) intramuscular electrodes were replaced. The average time from initial implant to revision was 90 days (+/-50 days).

Of the 14 revised electrodes, 8 involved the hip extensor muscles – either the gluteus maximus (2), posterior fibers of the adductor magnus (2) or transferred biceps femoris (2). In the last case, the insertion of the biceps femoris was transferred to a point above the knee in subject 2 so that when stimulated it would produce pure hip extension. This was done because initially sufficient force could not be elicited from the gluteus maximus muscles. After transfer, however, stimulation of the biceps femoris muscles could not elicit sufficient hip extension force. Subsequently, however, a different approach to gluteus maximus implantation was found to be successful for this subject. Three revisions involved the femoral nerve or vastus lateralis and 3 revisions involved the gluteus medius. One of the gluteus medius revisions was required due to interoperative damage to the electrode lead.

Infection was a problem with subject 2, which was felt to be due to a chronic ischial pressure ulcer that became infected. Despite attempts to treat the infection with several antibiotics, the FES system became infected, requiring eventual removal. The system was completely removed without difficulty.

Discussion/Conclusion

The percutaneous implantation technique of a lower extremity FES system as described here has been successful in providing upright mobility as an adjunct to the wheelchair and has been cosmetically acceptable to these children. [4,5]

In our experience, the use of the intramuscular electrode [3] and the associated percutaneous needle insertion implant technique is a less invasive procedure that requires less time as compared to the approach of exposing the muscle required to implant the epimysial electrode. Importantly, the percentage of intramuscular electrodes that did not require revisions (85%) was low and comparable to that of the epimysial electrodes (80%).

The technique for implantation of electrodes for knee extension via the femoral nerve was the most problematic. The problem with length dependency was isolated to this muscle, requiring revision of 2 electrodes in one subject. The problem manifested as decreased knee extension strength as the hips moved into flexion or into flexion and internal or external rotation. Functionally, because the hips are in flexion at the beginning of the sit-to-stand transition, there was insufficient knee extension force to allow the subject to stand. This problem was seen to a lesser degree with four additional electrodes, however, sufficient knee extension force was retained in hip flexion so that standing could be achieved and maintained.

When implanting the femoral nerve, it is recommended that the extremity be moved into hip flexion and extension as well as rotation after electrode implantation to determine if stimulated knee extension force remains strong at all hip angles. In the latest implant, length dependency of the quadriceps muscle group when implanting the femoral nerve has led us to identification of the vastus lateralis as the first choice for obtaining adequate knee extension.

The electrode revisions required due to insufficient force production were attributed to movement of the electrodes post-operatively. The broken lead at the connector site was discovered while revising a different electrode and was repaired before the electrode malfunctioned.

We found that balancing the degree of internal rotation obtained by the gluteus medius and the external rotation obtained by the gluteus maximum is important for functional standing and walking. Excessive external rotation led to difficulty with the feet contacting the assistive device when the lower extremities were advanced during walking. Excessive internal rotation led to the lower extremities contacting each other during stance and swing, making advancement during swing difficult. Excessive internal rotation also decreased the base of support, which decreased the subject's balance during activities that required reaching. Interoperatively, we now routinely seek to balance internal and external rotation forces contributed by the gluteus medius and gluteus maximus, respectively.

Electrode replacement for the gluteus maximus has been modified over the course of this study. For the first three subjects, electrodes were placed lateral to the sciatic nerve. With subsequent subjects a stronger more stable response has been obtained with implantation medial to the sciatic nerve.

The fact that 13 of the 14 revisions occurred with the second and third subjects of the study suggests a learning curve associated with the placement of electrodes. For the 6 subsequent subjects (average follow up of 17 months), there has been only 1 revision.

For the second subject, the FES system had to be removed due to infection. As the source was thought to be a pressure ulcer, we have continued to stress to our subjects the importance of seeking medical attention if a pressure ulcer of any stage develops. Immediate attention is needed in order to remove the source of pressure or shear.

The surgical procedure has been effective for the subjects in our study, providing them with a means to participate in upright mobility activities with significantly less bracing.

References

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