The use of functional electrical stimulation cycles in children and adolescents with spinal cord dysfunction: A pilot study

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Abstract. Background and methods: Children who experience spinal cord injuries (SCI) may develop many complications, including loss of bone mass, osteoporosis, and pathological fractures. Additionally, patients with SCI often rate their quality of life as poor compared to non-injured peers. We examined the effect of functional electrical stimulation (FES) cycle exercise on bone mineral density (BMD) and quality of life (QOL) in six patients ranging in age from 9 to 20 years. BMD was determined using Dual X-ray Absorptiometry scans, and QOL was measured using the Pediatric Quality of Life Inventory (PedsQL™ 4.0).

Results: While patients experienced difficulty in attending sessions consistently, we found a tendency toward improved BMD and QOL associated with the number of months using the FES cycles. In addition, a positive relation was seen between improved BMD and the total number of cycling sessions, as well as between the final rating of QOL and time from injury.

Conclusion: FES cycle exercise has the potential to increase BMD, possibly leading to a decrease in pathologic fractures, as well as to improve QOL, in children and adolescents with SCI. Further investigation is warranted on a larger population of children with SCI in order to establish the full benefits of FES cycle exercise.

Keywords: Pediatric spinal cord injury, FES cycle exercise, bone mineral density, quality of life

1. Introduction

The inability to walk due to spinal cord dysfunction has profound effects on patients, both physiologically and psychologically. Among the physiological complications associated with the loss of walking is a significant reduction in bone mineral density (BMD), resulting in severe osteoporosis. General bone loss from 30% to 50% has been reported in nonambulatory patients, resulting in a high degree of vulnerability to fractures [1]. Psychologically, the loss of ambulation can have a significant negative impact on sense of well-being and sense of control over one’s life [2].

1.1. Effect of spinal cord dysfunction on muscle mass and bone mineral density

Spinal cord dysfunction leading to loss of ambulation results in disuse of the muscles and bones in the lower extremities, resulting in atrophy of the leg muscles [3–5] and osteopenia as a result of a rapid, severe loss of BMD [6–11]. A strong relation has been reported between muscle weight and BMD [12]. According to Frost and Schönau [13], in children there is a relation between bone strength and muscle strength such that muscles that cause the largest loads and the largest bone strains help to control the biological mechanisms that determine whole-bone strength. Thus, the strength of children’s load-bearing bones is highly dependent upon growing muscle strength and how bones respond to it. The implications of this are that both muscle strength
and bone strength are important in the reduction of bone fractures in children with spinal cord dysfunction. Unfortunately, severe muscle atrophy occurs rapidly following traumatic spinal cord injury (SCI) [14], most within 6 months of the occurrence [15]. However, frequent exercise has been found to result in increased muscle strength and endurance in patients with SCI [16,17], as well as in prevention and reversal of muscle atrophy [14,15,18]. Due to disuse of their lower limbs, individuals with SCI also experience a reduction of bone mass in the lower extremities [19]. In adults, a decline in BMD and content in the affected limbs has been found on X-ray as early as 6 weeks post SCI [20]. The rate of loss is thought to be greatest within the first 2 years, resulting in possibly as much as 50% loss of BMD in the proximal tibia [6,7,21]. As a result of this significant loss, individuals with SCI are at increased risk for low-impact fractures [8,22,23], especially of the lower extremities [24]. This fracture incidence has been found to be as high as 34% [25], with most fractures occurring in the presence of minimal or no injury [26]. For example, in a study by Lazo et al. [25], the only significant predictor of the number of fractures was abnormal BMD.

Childhood is a time during which exercise is essential for optimal bone health [27], and bone loss has been found to be most rapid during the first 12 months following a childhood SCI [28]. Studies indicate that children and adolescents who are unable to ambulate have reduced bone mineral content (BMC) in the arms, trunk, and legs compared to an able-bodied control group [29], and have decreased BMD in the hip and possibly the knee compared to children without disability [30,31]. Baseline BMD for children with SCI has been found to be comparable to that of adults with SCI [31], suggesting at least a similar risk for osteoporosis. This implies that the fracture risk for children is at least as high as for similarly affected adults and may become higher as children age due to lack of physical activity during a time that is critical for bone development [30].

1.2. The use of functional electrical stimulation (FES) cycling with patients with spinal cord injury

Given the high vulnerability to low-impact fractures of the lower extremities of individuals with SCI [24], as well as the relation between this fracture risk and low BMD [32], it is important to attempt to strengthen bone in these areas. A number of studies have examined the use of Functional Electrical Stimulation, or FES, with nonambulatory patients with spinal cord dysfunction. FES uses safe levels of electrical impulses delivered via electrodes applied to target muscle groups to stimulate peripheral nerves [33]. This allows the contraction of muscles in limbs, enabling patients to exercise even though their limbs are paralyzed. Claimed benefits include improvement of contractures and decreases in neurogenic osteoporosis, deep venous thrombosis, and edema, as well as amelioration of spasticity [34–42].

FES-induced cycling has been shown in several studies to have a positive effect on BMD in adult patients with SCI. McDonald and colleagues [43] documented successful and complete reversal of severe osteoporosis in a single adult male following 3 years of FES cycling (1 hour per day, 3 days per week) in conjunction with medication to offset bone resorption. Others have reported improved bone parameters, including increased BMD, in groups of patients following adherence to a 12-month FES cycle exercise program [22,44]. Shorter-term studies of 3 to 6 months have found increases, maintenance, or retarded decreases of BMD [45–49]. Several studies have shown, however, that the positive effects of FES cycling are maintained only with a continued program of regular cycling in a sufficient amount [22,47,49,50].

Given the high bone turnover rate in growing children, FES therapy could have an even greater positive impact on BMD in children than in adults; however, little has been done examining the effects of FES cycling with children who have sustained SCI. In a case series reported by Johnston and colleagues [51], 4 children cycled at home with their parents’ assistance for 1 hour 3 times per week for 6 months. Two children used an FES cycle and 2 cycled passively. Improvements in BMD, muscle volume, and stimulated quadriceps strength; and lower resting heart rate were found for the 2 children who cycled with FES and one of the children who cycled passively. Few changes were found for the second child who cycled passively. In another study of children who exercised at home, BMD at the hip improved for a group who cycled with FES and a group who cycled passively, compared to a group of children who used electrically stimulated exercise (ES). However, femur and tibia BMD improved only for the FES group [52]. Gains in oxygen uptake also were found in children who used the FES cycles compared to a group who engaged in passive cycling [53]. An important conclusion of these studies is that FES cycling can be done at home with good adherence with parental assistance, removing potential barriers to participation and resulting in improved adherence and outcomes [51].
Individuals with SCI have been found to have an increased risk for poor quality of life (QOL) compared to their non-disabled counterparts [54,55]. Not surprisingly, it is through the physical functioning domain that QOL seems to be the most strongly affected [56].

While quality of life issues have generated an increased interest over the past decade, little of this research has focused on children and adolescents. Health-related quality of life (HRQOL) has been examined in some pediatric populations, and findings consistently show lower HRQOL among chronically ill versus healthy populations, with severity of illness negatively related to HRQOL [57–62]. Very few studies have been found regarding children or adolescents with SCI. Holbrook et al. [63] found that major trauma during adolescence was related to decreased QOL compared to national norms, with negative effects lasting at least 24 months after discharge; however, this study specifically excluded SCI.

A large study by Dijkers [2] examining life satisfaction in the SCI population, in which 19% of the participants (412 of 2183) were less than 20 years of age, found that life satisfaction is lower among individuals with SCI than for individuals either without disabilities or with other disabilities. No age effects were found in this analysis, suggesting that the results applied to the younger participants as well as to the adults. Abresch and colleagues [64] conducted one of the few studies that specifically examined QOL in nonambulatory children and adolescents with spinal cord dysfunction. This group was found to report lower HRQOL than ambulatory control children, as well as children with various chronic health conditions or obesity; children with spinal cord dysfunction and concomitant obesity reported somewhat lower emotional functioning than those who were not obese. In their study, non-obese able-bodied control children were found to have an average Psychosocial Health Summary Score of 87.71 (± 8.77) compared to non-obese nonambulatory children with SCI whose average score was 69.48 (± 16.04).

Interestingly, self ratings of QOL by children with SCI have been found to be better than ratings of their QOL by their parents [65]. Given that children are at a stage of ongoing physical and psychological development, there is a need for research regarding the effects of SCI on their lives and effective interventions separate from that of adults.

Individuals both with and without disability who engage in regular physical activity have been found to be healthier and to live longer than their less active peers [66]. In the general population, in addition to other health benefits, physical activity has been found to contribute to improvement in various psychological dimensions, such as depression, mood, and life satisfaction [67].

The same benefits of being physically active have been found to apply to individuals with SCI. QOL following SCI has been found to be negatively related to perceived loss of physical functioning [68], and individuals with SCI who exercise have been found to show improvements in satisfaction with their physical function, physical appearance, and QOL [69]. Although increased physical activity has been found to be related to improved physical self-efficacy, ease of performing daily activities, perceived health, depressive symptoms, overall subjective well-being, life satisfaction, and QOL in this population [66,67,70], this group is among the most sedentary [66]. Compared to those who are inactive, the reported QOL of physically active individuals with SCI has been found to be better within physical, psychological, social, and context domains [71]. Psychological effects have been found even with passive exercise in adults with SCI paraplegia [72].

In children without disability, low levels of physical activity are related to medical risk factors such as elevated blood pressure and cholesterol levels, and benefits such as reductions in weight and body fat and improvements in aerobic fitness have been found for children who participate in daily exercise [73,74]. Studies also show that adolescents without disability who engage in a high level of exercise have been found to have better relationships with their parents, to be less depressed, and to use drugs less frequently than those with lower exercise levels [75]. Higher levels of psychological well-being, lower anxiety-depression scores, and less social behavioral inhibition also have been found in more active adolescents [76]. Although physical activity has been found to produce both physical and psychological benefits, no studies were found that investigate this issue in a pediatric population with SCI.

Given the available evidence, our hypothesis was that a program of regular FES cycle exercise would have a positive effect on both the physical and psychological...
status of non-ambulatory children and adolescents with SCI. Improvement was expected to be seen in BMD and QOL.

2. Methods

2.1. Study design

This study involved a pre- and post-intervention design with a sample of children and adolescents who were involved in an FES cycle exercise program. Bone mineral density (BMD) was measured with Dual X-ray Absorptiometry (DXA) scans using a GE LUNAR system. Using this system, it is possible to obtain accurate and precise measurements of BMD and bone mineral content (BMC) [77]. These measurements are fast, simple, non-invasive, and low dose (equivalent to several hours of background radiation). DXA has been used in patients with loss of ambulation due to SCI to monitor changes in body composition over time and to evaluate the effectiveness of exercise in preventing or reducing the disease-related complications of SCI [78].

Using the technique outlined by Henderson and colleagues [79], DXA scans were used in the present study to determine BMD at R1 of the right distal femur at baseline, after 3 months of intervention, after 6 months, and for participants who biked for the full duration of the study, at the completion of 9 months of intervention. The distal femur was chosen because, while the distal femur and proximal tibia are the most common sites fractured in patients who are not ambulatory [80], scanning has been found to be more precise at the distal femur [81]. Within the distal femur, R1, which contains mainly cancellous bone [82], was chosen as it has been found to be the most reliably replicable region compared to R2 and R3 [83]. The right distal femur only was analyzed in this study because pre- and post-intervention DXA scans of the left distal femur were not available for all participants.

Quality of life (QOL) was assessed using the Pediatric Quality of Life Inventory (PedsQL™ 4.0; 84). The PedsQL™ 4.0 is a modular instrument for measuring health-related quality of life (HRQOL) in children and adolescents. The PedsQL™ 4.0 is multidimensional, consisting of four modules, three of which were used in this study: Emotional Functioning (5 items), Social Functioning (5 items), and School Functioning (5 items). The Physical Functioning module is not applicable to children and adolescents who are paralyzed, so it was omitted. Scores on these three modules are combined to yield a Psychosocial Health Summary Score. The questionnaire asks how much of a problem each item has been during the past month, using a 5-point response scale. The PedsQL™ 4.0 has adequate internal consistency reliability (alpha = 0.83 for the child Psychosocial Health Summary Score). Validity has been demonstrated using the known-groups method, correlation with indicators of morbidity and illness burden, and factor analysis, and it has been shown to be sensitive to clinical physical change [62].

In order to determine the overall effect of FES on QOL, as well as any effects at different points during the intervention, the PedsQL™ 4.0 was to be completed by participants whenever a bone scan was performed.

2.2. Participants

Participants with para- or tetraplegia secondary to spinal cord dysfunction (traumatic spinal cord injury and transverse myelitis) who had no sensation in the lumbar and sacral region were eligible for the study. Exclusion criteria included: diseases known to affect bone metabolism; a history of hip or knee dislocation or subluxation; pressure sores in the areas of treatment; metallic hardware in the femur; a history of peripheral nerve injury, lower motor neuron disease, or chronic corticosteroid use; or use of medications that can affect bone mineral density. Individuals with pacemaker devices or unhealed fractures also were excluded.

Each potential participant underwent a medical and laboratory evaluation after signing the informed consent and within the month prior to beginning the exercise program. Radiographs of the lower extremities were performed in order to rule out fractures. Participants had preservation of at least 100 degrees of hip and knee flexion. A Physical Therapy screening was conducted, and a trial of electrical stimulation was completed in order to determine the appropriateness of and tolerance to functional electrical stimulation. A DXA scan was performed in order to establish baseline BMD.

The Institutional Review Board of UMDNJ-Robert Wood Johnson Medical School (New Brunswick, NJ) approved this study.

2.3. Intervention

Participants exercised using FES cycling with the RT 300 FES cycle (Restorative Therapies, Baltimore, MD). With the RT 300, patients cycle from their wheelchairs. Surface electrodes are placed on the right and left
quadriceps, hamstring, and gluteal muscles according to a standardized protocol. The electrodes are connected by a cable to the RT 300, which controls the electrical stimulation patterns being sent and, with motor support, produces a smooth, quiet cycling motion. The RT 300 is designed for children as young as 4 years and features special pedals that are highly configurable for different child sizes and orthopedic issues. Stimulation rpm [45–50], pulse duration (250 µs), and frequency (33.3 Hz) were fixed. Amplitude ranged from 70–120 mA, and average stimulation ranged from 16.50–29.7 µC. See Fig. 1 for a photo of a child using the RT 300 FES cycle.

At-risk participants were monitored for autonomic dysreflexia during training. Blood pressure and heart rate were monitored during the initial evaluation and the first session of cycling. Once it was established that there were no adverse physiological responses, ongoing blood pressure and heart rate monitoring were not continued for subsequent sessions.

Participants were scheduled to attend three cycling sessions per week on non-consecutive days for up to 30 minutes (plus a 2 minute warm up and 30 second cool down) per session over a 9-month period. Families were required to provide their own transportation to Children’s Specialized Hospital (CSH). During the study, the participants continued to participate in their standard, primary rehabilitation program.

2.4. Data analysis

Descriptive analyses are presented for baseline data and change scores in BMD and QOL. Statistical analyses of the effect of FES on BMD and QOL, given the total number of FES biking sessions, the number of months biked, the average number of biking sessions per month, and the time from injury at the initial evaluation, were performed using nonparametric two-tailed Spearman’s Rank Correlation Tests. All means, standard deviations, and correlations presented are for n = 6 subjects, except where noted.

3. Results

Six patients between the ages of 9.67 years and 20.42 years (mean = 16.57, s.d. = 4.42; 3 males) met criteria and participated in the study. Time from injury ranged from 0.67 years (8 months) to 9.25 years (111 months) (mean = 3.92, s.d. = 3.11), with one child (9.25 years) having been injured at 3.67 years, following scoliosis surgery. While the study was designed for three sessions of cycling per week on non-consecutive days for up to 30 minutes per session over a 9-month period, actual participation ranged from 15 to 69 total biking sessions (mean = 39.00, s.d. = 19.57) over a 2- to 9-month period (mean = 7.17, s.d. = 2.79; mean biking sessions per month = 5.74, s.d. = 2.02). No at-risk participant experienced a dysreflexive episode in response to electrical stimulation during this study. Table 1 presents patient demographics and baseline characteristics. Due perhaps in part to the small sample size, the correlations, while positive, did not reach statistical significance at p = 0.05.

3.1. Bone mineral density and FES cycling

Mean BMD in the right distal femur for our 6 participants at the initial evaluation was 0.591 g/cm² (range = 0.310–0.763; s.d. = 0.184). Mean BMD at the participants’ final DXA scan was 0.581 g/cm² (range = 0.314–0.759; s.d. = 0.190). However, the individual change in BMD among the 6 participants ranged from...
Table 1

Patient demographics and baseline characteristics

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age*</th>
<th>Gender</th>
<th>Etiology</th>
<th>Class.</th>
<th>Time from injury**</th>
<th>Fracture history</th>
<th>Osteoporosis initial X-ray</th>
<th>Baseline BMD</th>
<th>Baseline QOL</th>
<th>Mo. biked</th>
</tr>
</thead>
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<td>1</td>
<td>19.92</td>
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<td>MVA</td>
<td>C5</td>
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<td>Mild</td>
<td>0.707</td>
<td>63.333</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>9.67</td>
<td>Female</td>
<td>MVA</td>
<td>AIS C</td>
<td>5.42</td>
<td>3</td>
<td>Severe</td>
<td>0.310</td>
<td>63.333</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>12.92</td>
<td>Female</td>
<td>Scoliosis</td>
<td>Thorac</td>
<td>9.25</td>
<td>3</td>
<td>Severe</td>
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<td>78.333</td>
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</tr>
<tr>
<td>4</td>
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<td>AIS A</td>
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<td>61.667</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>20.42</td>
<td>Female</td>
<td>MVA</td>
<td>AIS A</td>
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<td>None</td>
<td>0.763</td>
<td>N/a</td>
<td>6</td>
</tr>
</tbody>
</table>

*Age in years and fraction of year at initial evaluation. **Time from injury in years and fraction of year at initial evaluation.

Fig. 2. Change in bone mineral density per patient by total biking sessions. *N = 6. The numbers within the figure correspond with the patient numbers in Table 1.

$-0.029 \text{ g/cm}^2$ to $+0.251 \text{ g/cm}^2$ (mean = 0.062, s.d. = 0.110).

A positive, though nonsignificant, relation was found between the change in BMD and the total number of FES cycling sessions from their first to last DXA scan ($r_s = 0.77$), suggesting that BMD increased with the number of biking sessions (see Fig. 2). A positive relation also was found between the change in BMD and the number of months using the FES cycle from their first to last DXA scan ($r_s = 0.77$), suggesting that BMD also increased with the number of months biked (see Fig. 3). A weaker but still positive relation was found between the change in BMD and the average number of biking sessions per month ($r_s = 0.60$), as well as between the change in BMD and the time from injury at the initial evaluation ($r_s = 0.49$).

3.2. Quality of life and FES cycling

Four of the six participants completed the PedsQL on at least 2 occasions. At minimum, each completed the PedsQL at their initial evaluation before beginning the cycling program and at or following their last cycling session. The number of PedsQL questionnaires that were completed ranged from 2 to 4 over a 4 to 12 month period from initial to final PedsQL. All means, stan-
Fig. 3. Change in bone mineral density per patient by number of months biked. *N = 6. The numbers within the figure correspond with the patient numbers in Table 1.

Fig. 4. Initial and final quality of life per patient by number of months biked. *N = 4. The numbers within the figure correspond with the patient numbers in Table 1.

Fig. 5. Initial and final quality of life per patient by time from injury. *N = 4. The numbers within the figure correspond with the patient numbers in Table 1.

The mean Psychosocial Health Summary Score for our participants at their initial evaluation was 66.67 (s.d. = 7.82, range = 61.67–78.33), with three of the four participants reporting initial QOL below the Abresch et al. SCI sample of 69.48 [64]. Following participation in the exercise program, the mean of our sample exceeded that of Abresch et al. with improved QOL reported by three of the four participants, whose post-intervention scores met or exceeded the Abresch et al. sample (mean = 73.75, s.d. = 11.41, range = 60.00–86.67). The mean change from the initial to the final PedsQL was 7.08 (s.d. = 8.21), although change scores ranged from −3.33 to 16.67 (See Figs 4 and 5).

The correlations between the change in QOL and both the total biking sessions and number of months biked, while nonsignificant, suggest a positive trend ($r_s = 0.60$ and $r_s = 0.74$, respectively). Figure 4 presents the relation between the initial and final QOL...
scores and the number of months biked. As can be seen in Fig. 4, the two participants who biked over the full 9 months of the program showed the greatest improvement in QOL.

Figure 5 presents the relation between the initial and final QOL scores and the months post injury at the initial evaluation. As seen in this figure, improvement in QOL was shown by the three participants who had been injured the longest. While not statistically significant, both the correlation between the initial QOL and the months post injury \( r_s = 0.60 \) and the correlation between the final QOL score and the months post injury \( r_s = 0.80 \) suggest a positive trend.

4. Discussion

While patients experienced difficulty in attending sessions consistently, we found a tendency toward improved BMD and QOL associated with the number of months using the FES cycles. In addition, a positive relation was seen between improved BMD and the total number of cycling sessions, as well as between the final rating of QOL and time from injury.

In several studies, FES cycling has been found to either increase BMD or significantly retard its loss in adults with SCI [22,43–49]. Little work has been done with children with SCI, however, the information that is available suggests that FES cycle exercise can have a positive effect on BMD in this population as well [51, 52].

The current study contributes to this literature in suggesting that a program of regular exercise using an FES cycle ergometer may result in improved bone mineral density in children and adolescents who have experienced SCI. Our study was hampered by a small sample size and poor compliance with the cycling regimen. Perhaps in part as a result of the small sample size, our results did not reach statistical significance; however, the positive correlations do suggest a potential for improvement in BMD for the participants who cycled most often and for the greatest number of months. We also noted possible limitations in obtaining BMD measurements using the DXA scan. Because we were measuring a region of interest (distal femur) and not the traditional hips and spine, there was a greater potential for error during the scanning process. While efforts were made to ensure consistent and accurate measurement of BMD, error may have been introduced if the defined region of interest was not exactly analyzed at each visit. Nevertheless, DXA scanning remains an important tool in the diagnosis and management of osteoporosis, and its regular use in children and adolescents with potential bone loss should be encouraged before pathological fractures occur.

In addition to physical sequelae, SCI has a negative effect on quality of life and psychological well-being [54,55,68]. Available information indicates that life satisfaction and QOL among children with SCI is lower than among either children without disabilities or children with other disabilities or chronic conditions [2, 64].

Three of the four participants in this study who completed questionnaires reported their initial QOL below the mean of the Abresch et al. SCI sample [64]. The exception was the child who has been injured the longest and at the earliest age, and who reported initial QOL above the Abresch et al. mean. Following their participation in the FES cycling program, three of the four participants showed improved QOL and rated their QOL at or above the Abresch et al. sample. These three participants had been injured the longest (between 48 and 111 months), and their QOL ratings were higher than that of the participant who was injured most recently (19 months ago). This is consistent with the results of studies that have found that time since injury is related to well-being, life satisfaction, and QOL in individuals with SCI [85–87]. In a study by Tonack and colleagues [87], increased time since onset of SCI was positively related to community participation, and psychological complications, current health rating, and community participation were the only variables found to significantly predict life satisfaction. Thus, it is possible that as time goes on children and adolescents become more adjusted to their condition and begin to integrate more fully into the community, contributing to improved satisfaction with their lives and increased QOL. It also is possible that participating in our FES cycling program gave them the opportunity to participate in an exercise activity that they previously thought was restricted to individuals without their impairment, contributing to a more enriched QOL.

The improved quality of life seen for these participants also could be the result of the opportunity to engage in an activity that they thought would have a positive effect on their health and well-being and that made them feel more like their uninjured peers. It also is possible that the attention they received from staff when they were here using the FES cycle contributed to their psychological well-being and enhanced their QOL. We also do not know if other factors in their lives changed during the time between their initial and final QOL eval-
...tions that might have affected their perceived quality of life. Whatever the reason, enhanced quality of life and a feeling of self-efficacy are essential for children and adolescents who have become paralyzed following SCI.

Long term adherence to an exercise program is an important factor in continued improvement in BMD and QOL in people with SCI [22,47,49,50]. Adherence is an issue in any exercise program, even among individuals without impairment. The typical drop-out rate within the first 6 months of initiating a self-monitored exercise program in the general population is approximately 50% [88]. Virtually the same rate of adherence has been found for people with SCI who are participating in a structured exercise program, with the largest drop occurring between 3 and 6 months of the beginning of the program [89,90]. Hicks and colleagues [89] found that while adherence was high among the 52% who completed their 9-month exercise program, with attendance at 82.5% of the available sessions, at 3-month follow-up, the adherence rate outside the research setting had dropped to 42.7% [91]. Accompanying this decrease in exercise adherence was a significant decrease in perceived QOL and a trend toward increased pain and stress. While individuals with SCI have been found to express an interest in being physically active, both motivational and socio-environmental factors have been identified as barriers to exercise, including lack of accessible facilities, affordable equipment, and personal assistance, in addition to fear of injury [92]. Other possible reasons for this decrease in adherence include the perception of pain [91], fitting the sessions into a busy schedule [44], and convenience, attractiveness, and availability of equipment [93].

Regular physical activity has been found to contribute to health, longevity, and psychological functioning, regardless of the presence of a disability [66,67]. While the QOL of people with SCI who are physically active is better in multiple areas than those who are inactive [71], as a whole they tend to be among the least active group [66]. FES cycling has tremendous potential for children and adolescents who are living with paralysis as a result of SCI to be physically active, availing them of the physical and psychological benefits of regular exercise that their peers without SCI enjoy.

The ability to exercise like their peers without SCI could result in improved cardiovascular health, stronger bones leading to fewer stress fractures, and improved quality of life. However, research has shown that 4 to 8 hours of FES cycling per week is necessary in order to meet the recommended caloric expenditure that is believed to be associated with persistent health benefits in adults with SCI [94], and the positive effects of FES cycling on BMD are maintained only if the cycling regimen is adhered to consistently and in a sufficient amount [22,47,49,50]. The implication is that, in order to maintain good bone health, children who have experienced paralysis following SCI will need to commit to a lifelong regular exercise program.

The original goal of our study was to recruit 24 children; 12 who would use the FES cycles on a regular basis during the first 9 months, and 12 who would serve as control subjects by using the cycles during the subsequent 9 months. It was not possible to recruit this number of children, and of the 10 who agreed to participate, only the 6 reported above succeeded in attending at least 15 biking sessions over a 9-month period. While not specifically queried, the main issue preventing attendance seemed to have been the fact that in order to use the equipment the children were required to set aside a significant amount of time and find their own transportation to CSH. In contrast, Johnston and colleagues were able to place exercise equipment in the homes of children with SCI. As a result, they were able to recruit a much larger group of children who exercised regularly at home with parental supervision [51–53,95]. This suggests that the most effective and cost efficient means by which to enable children with SCI to partake in a regular exercise program is to place the FES cycles in their homes so they are readily available. This can be accomplished only with an appropriate level of funding, either at the research level or through patients’ health insurance plans.

One final caveat to our results is the fact that 3 of the 6 participants were over 18 years of age. The American Academy of Pediatrics defines pediatrics as up to 21 years of age, and as a pediatric facility, we care for children from birth to 21. In addition, several researchers who have conducted studies in the past involving bone composition in children with SCI have included adolescents to age 20 or 21 [29,31,43]. However, we acknowledge the fact that the skeletal maturity of these older adolescents might be more similar to that of adults than children. Because they are in an early stage of development, it is possible that young children who have been injured before they have reached peak bone mass or muscle maturity will respond more quickly and/or more effectively to a regular regimen of FES cycling, provided they begin such a regimen as soon as possible following their injury. If this is the case, it is possible that our results have been weakened by the...
inclusion of these older adolescents. Alternatively, it is possible that, given their skeletal immaturity, young children require a more intense exercise regimen in order to achieve the same results as older adolescents. In that case, our results will have been strengthened by the inclusion of these older participants and will not be representative of the effectiveness of our program for young children. This can only be determined by conducting studies that involve exclusively younger children.

Further research needs to be done on larger groups in order to establish the full benefits of FES cycling exercise for children who have experienced spinal cord injuries. Longitudinal studies are critical in order to follow children who are engaging in regular FES cycling in order to track both the occurrence of stress fractures and quality of life, and compare them to pre-exercise rates. However, accessibility of equipment will remain a major issue that must be addressed.

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Conflict of interest

The authors report no conflict of interest.

References


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