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**ABSTRACT**


**Objectives:** The efficacy of mechanical insufflation–exsufflation, in addition to standard chest physical treatments, was investigated as a first-line intervention for patients with neuromuscular diseases with respiratory tract infections and airway mucous encumbrance.

**Design:** The short-term outcomes of 11 consecutive neuromuscular disease patients with respiratory tract infections and tracheobronchial mucous encumbrance who were administered mechanical insufflation–exsufflation and conventional chest physical treatments in an intensive care unit were compared with the outcomes of 16 historical matched controls who had received chest physical treatments alone. Treatment failure was defined as the need for cricothyroid “minitracheostomy” or endotracheal intubation, despite treatment. The number of subjects administered bronchoscopy-assisted aspiration during the hospital stay was also compared.

**Results:** Treatment failure was significantly lower ($P < 0.05$) in the mechanical insufflation–exsufflation group than in the conventional chest physical treatments group (2/11 vs. 10/16 cases). The use of bronchoscopy-assisted aspiration was similar in the two groups (5/11 vs. 6/16 cases). Mechanical insufflation–exsufflation did not produce serious side effects and was well tolerated by all subjects.

**Conclusions:** Provision of mechanical insufflation–exsufflation in combination with standard chest physical treatments may improve the management of airway mucous encumbrance in neuromyopathic patients; its use should be included in the noninvasive approach to treatment of respiratory tract infections with impaired mucous clearance.

**Key Words:** Mechanical Insufflation–Exsufflation, Neuromuscular Disease, Respiratory Tract Infection, Endotracheal Intubation
In patients with Duchenne muscular dystrophy and other progressive neuromuscular diseases (NMDs), the development of upper respiratory tract infections (URTI) is frequently complicated by pneumonia, atelectasis, and ultimately, acute respiratory failure. These can result in the need for repeated bronchoscopy-assisted aspirations (BAA), hospitalizations, endotracheal intubations (ETIs), and not rarely, in tracheostomy and death.\(^1\)\(^-\)\(^5\)

The onset of acute respiratory failure in patients with advanced NMD is frequently caused by airway encumbrance with mucous. Thus, it is mainly due to weakened respiratory muscles and inability to cough effectively. A noninvasive approach to the management of tracheobronchial secretions based on the combination of expiratory muscle aid and positive-pressure ventilation via a nasal, oronasal interface, or mouthpiece (noninvasive positive-pressure ventilation [NPPV]) has been proposed. This treatment strategy may result in a reduced necessity to resort to nasal suctioning and conventional intubation or tracheostomy.\(^2\)\(^,\)\(^3\)\(^,\)\(^6\)

The standard chest physical treatments (CPT) provided to enhance secretion clearance usually include postural drainage and manual chest percussion. Although standard CPTs are considered the gold standard to which all other bronchial hygiene techniques should be compared,\(^7\) they are often impractical in NMDs because of severe chest wall deformity, and their effectiveness remains controversial.\(^8\)

Among noninvasive expiratory aids, manually assisted coughing techniques, such as anterior chest compression and abdominal thrust, have been shown to be effective in facilitating the elimination of airway secretions in patients with NMDs.\(^2\)\(^,\)\(^8\) Nevertheless, manually assisted coughing is labor intensive and often difficult for nonprofessional caregivers, both during outpatient and in-hospital management, and it depends on precise care provider–patient coordination. Stiffness of the chest wall also has been suggested as a contributing factor to cough ineffectiveness.\(^10\)

The mechanical in-exsufflator (Cough-Assist, J. H. Emerson, Cambridge, MA) is a device that assists patients in clearing bronchial secretions. It consists of a two-stage axial compressor that provides positive pressure to the airway, then rapidly shifts to negative pressure, thereby generating a forced expiration. It is usually applied via a facemask. It commonly produces a decrease in pressure by approximately 80 cm H₂O in 0.2 sec; the insufflation and exsufflation pressure and time are independently adjustable. The device can deliver maximum positive and negative pressures of about 60 cm H₂O. Mechanical insufflation–exsufflation (MI-E) has been reported to effectively mobilize mucous secretions and has been proposed as a complement to manually assisted coughing in the prevention of pulmonary morbidity in NMD patients during URTI.\(^5\)\(^,\)\(^11\) The use of MI-E has been described to be simple and safe enough for application by nonprofessional caregivers (i.e., patient’s home-care attendant, a family member).\(^2\)\(^,\)\(^10\)\(^,\)\(^12\)\(^,\)\(^13\)

Considering this and the dearth of controlled clinical studies, we investigated the efficacy of MI-E in treating URTI in NMD patients by comparing its use to CPT alone.

**METHODS**

We compared the short-term outcomes of 11 NMD patients with URTI who were treated by MI-E in addition to conventional CPTs (group A) with the outcomes of a population of 16 historical control patients who had received CPTs alone (group B). The two groups received similar pharmacologic therapy (antibiotics and steroids as indicated) and NPPV when needed. The patients gave their informed consent to the application of MI-E; those younger than 18 yrs of age reached this decision in accordance with their parents.

**Patients**

Eleven consecutive NMD patients admitted to our intensive care unit between January 2001 and March 2003 with dyspnea due to chest infections were recruited. The diagnoses were based on standard clinical, enzymatic, electromyographic, DNA, and biopsy data.

The diagnosis of URTI was based on the presence of one or more of the following symptoms or signs: coryza, fever, throat irritation or sore throat, hoarseness, and cough. The accumulation of airway mucous was defined as the coexistence of auscultatory rhonchi and oxyhemoglobin desaturation (\(\text{Sa}_\text{O}_2 < 95\%\)).\(^5\)\(^,\)\(^10\) The diagnosis of pneumonia was based on the concomitant presence of infiltrates on chest radiographs.

The control group (group B) consisted of 16 historical controls consecutively admitted to our department between 1996 and 1999; these patients were affected with NMD and had received conventional medical therapy along with CPTs alone. Patients admitted in 2000 could not be considered due to the lack of availability of clinical records. None of the control patients was subsequently enrolled as a study patient.

**Measurements**

The Groups were compared for the variables listed in Tables 1 and 2. The Gilardeau score was used to assess bulbar innervated muscle function.\(^14\) The peak expiratory flow and forced vital capacity,
obtained 10 ± 3.4 mos prehospitalization, were used to assess inspiratory and expiratory muscle weakness. Our laboratory measures peak expiratory flow during a maximal expiratory maneuver from total lung capacity while exhaling into a tight-fitting oronasal mask connected via plastic tubing to an electrospirometer (BAIRES 80, Biomedin, Padova, Italy). Maximum inspiratory and expiratory pressures were not available.

**Treatment**

MI-E was administered as follows.

- Each treatment consisted of about five positive-to-negative pressure cycles, followed by a period of normal breathing or ventilator use for 20–30 secs to avoid hyperventilation; five or more treatments were given in one session. Patients were connected to MI-E by means of a light-weight, elastic oronasal mask.
- The insufflation and exsufflation pressures and timing were independently adjusted according to efficacy and patient tolerance. For a patient using the device for the first time, low pressures were used initially (10–15 cm H₂O) and increased as needed for auscultatory clearing of rhonchi and improvements in oxyhemoglobin saturation. The insufflation and exsufflation phases were cycled manually to better coordinate the device’s cycling with the patient’s inspiratory and coughing efforts. The patients’ subjective report of discomfort or suffocation during insufflation was considered a reason for avoiding further increase in insufflation pressure.
- Treatment sessions were provided as frequently as required to ease dyspnea or oxyhemoglobin desaturation. The daily treatment frequency was recorded in a diary by nurses.
- Treatments were usually administered by a respiratory therapist, except for weekends, when only trained nonprofessional caregivers (i.e., patient’s home-care attendant, a family member, residents) were available to provide MI-E therapy.

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Type of NMD</th>
<th>Reason for Admission</th>
<th>Age, yrs</th>
<th>BMI</th>
<th>Home NPPV, hrs/day</th>
<th>GS</th>
<th>PEF, liters/sec</th>
<th>PaO₂, mmHg</th>
<th>PaCO₂, mmHg</th>
<th>pH</th>
<th>Complications and Clinical Outcome</th>
<th>BAA</th>
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<tr>
<td>Group A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>1A</td>
<td>LGMD</td>
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<td>1</td>
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</table>


*Measured in room air.*
Treatments were usually repeated until one or more of the following were observed: reduction in dyspnea, reduction in respiratory rate, sputum elimination, improved breathing sounds, increased percussion resonance, increased $\text{SaO}_2$ level.

Conventional CPTs consisted of: (1) postural drainage; (2) chest compression or abdominal thrust; and (3) nasotracheal or oral suctioning, when needed. CPTs were usually provided during the daytime immediately before MI-E. Only non-professional caregivers were available to provide CPTs during weekends. For both groups, CPTs were provided about twice a day.

At admission, all of the patients had clinical and physiologic variables consistent with their acute respiratory distress and urgent need for mechanical ventilation. They had at least one of the following: (1) difficulty in breathing, (2) hypercapnia, or (3) acute respiratory acidosis, and they were treated with NPPV delivered by a Puritan-Bennett 7200 ventilator (Nellcor Puritan-Bennett, Carlsbad, CA) using the assist/control mode. Initially, the ventilator was adjusted to obtain a tidal volume of 10 ml/kg and a respiratory rate of 25 breaths/min. The settings were readjusted based on resulting arterial blood gases, with the goal of maintaining $\text{SaO}_2$ at >90% and $\text{PaCO}_2$ at <45 mm Hg. Supplemental oxygen was delivered when necessary to increase $\text{SaO}_2$ to >90%.

Nasal interfaces were used with chin straps to decrease oral leak. NPPV was initially delivered continuously, except for brief rest periods and to use MI-E, to drink water, and to receive liquid nutrition. Continuous mechanical ventilation was administered until dyspnea was relieved and blood gases normalized.

### Study Endpoints and Statistical Analysis

The primary endpoint was treatment failure defined by the administration of cricothyroid “minitracheostomy” or endotracheal intubation due to persistent, severe mucous encumbrance with worsening respiratory distress and worsening (1) dyspnea, (2) tachypnea, and (3) respiratory acidosis. Frequency of BAA during hospitalization was a secondary endpoint. Indications for BAA were persistent sputum retention and oxyhemoglobin desaturation despite manually or mechanically assisted cough. A sample-size estimation with a type I error of 0.05 and a power of 80% determined that a significant clinical difference in treatment failure would be detected with a minimum of 11 subjects per group based on an expected difference in clinical outcome of 0.6 between the study and the control group. Fisher’s exact test was used to compare categorical variables (treatment failure, need for BAA), and Student’s $t$ test was used to compare continuous variables (anthropometric data, degree of dysphagia, pulmonary function and blood gas data at study entry, time spent receiving mechanical ventilation, and duration of hospitalization).

### RESULTS

Table 1 lists anthropometric and other data. Two subjects in group A and 6 in group B were rapidly progressing patients with amyotrophic lateral sclerosis. All had mild to moderate bulbar dysfunction with the exceptions of cases 8A, 8B, and 12B, who had severely diminished glottic function. All of the subjects (except for case 3 in group A) were wheelchair-bound.

The mean number of MI-E sessions per day was 2.7 ± 0.9, including treatments administered by nonprofessional caregivers. The mean insuffla-
tion and exsufflation pressures were 19.1 ± 3 and 33.2 ± 4.6 cm H₂O, respectively. Among patients in group A, treatment failed in cases 2 and 3. Patient 2 experienced stomach distension complicated with repeated episodes of gastroesophageal reflux during the initial sessions of MI-E. This resulted in recurrent bronchospasm and need for endotracheal intubation to protect the airways. This patient, who subsequently underwent a tracheostomy, had been diagnosed with gastroesophageal reflux disease and was receiving proton pump inhibitor therapy. Treatment outcomes are listed in Table 3. There were no side effects, except for patient 7, who developed stomach distension using +20 to −35 cm H₂O but who did not discontinue therapy. Patient 11 developed mild nasal bleeding that ceased without specific treatment. Among the 16 patients in group B, five required endotracheal intubation and five cricothyroid minitracheostomy. The others had uncomplicated courses.

Treatments and outcomes are considered in Table 3. BAA was performed for 5 of 11 patients in group A vs. 6 of 16 in group B (Fisher’s exact P value, 0.47). There was a trend indicating a shorter time spent receiving mechanical ventilation among patients who were administered MI-E (9.4 ± 6.9 vs. 13.5 ± 11.9 days), even though the duration of hospital stay was similar for groups A and B (20.5 ± 20 vs. 19.8 ± 17 days, respectively).

**DISCUSSION**

In the early 1950s devices were introduced to deliver MI-E via facemasks or mouthpieces to facilitate the expulsion of airway mucous. Although there were reports suggesting their effectiveness,17 they never gained widespread popularity due to the increasing application of tracheostomy and invasive suctioning. Noninvasive methods are now being more widely used and are more desirable to patients than is tracheostomy.

Although the use of historical controls and a relatively small number of patients is a limitation, this study, nevertheless, suggests the effectiveness of MI-E in promoting an effective cough. It is important to note that, aside from administration of MI-E to group A, there were no significant changes in personnel or treatment protocols in our department during the study period that might have influenced the outcomes. Of course, we cannot exclude the possibility that unknown or unstratified risk factors (newer and more effective antibiotics, different monitoring technologies, etc.) might have made the groups less comparable.

Our results suggest that the use of MI-E can reduce the need for endotracheal intubation or cricothyroid minitracheostomy and, therefore, nosocomial pneumonia. This avoids airway invasion and preserves airway defense mechanisms, factors that lend to significantly better outcomes in NMD patients.5,18 In addition, because this noninvasive approach reduces the need to resort to nasotracheal suctioning, it can decrease the risk of complications due to invasive suctioning of critically ill patients.19,20

Although MI-E has been demonstrated to be effective for the expulsion of airway secretions, it should be noted that in this study, the frequency of BAA was not significantly different in the two groups. The insufflation and exsufflation pressures and the frequency of MI-E treatments were significantly lower than those reported in previous studies.21,22 Thus, our less aggressive regimen could explain why our outcomes were less favorable. The suboptimal frequency of MI-E, ranging from twice to four times per day, was related to the limited availability of respiratory therapists or properly instructed nonprofessional caregivers in our department. Because most patients were prescribed long-term NPPV, the duration of hospital stays for both groups might have been prolonged by the considerable preparation for discharge home.

MI-E is generally regarded as being potentially dangerous because it can theoretically cause barotrauma or hemodynamic instability. However, no serious cardiopulmonary complications were observed in our patients or in previous studies of >2000 courses of treatment.12 Although aspiration of gastric contents was not found to be associated with MI-E application when the stomach was empty,23 one patient with gastroesophageal reflux dis-

<table>
<thead>
<tr>
<th><strong>TABLE 3</strong> Treatment specifics and outcomes</th>
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<tr>
<td><strong>Group A</strong></td>
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<tr>
<td>Patients who required NPPV, n</td>
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<tr>
<td>Intravenous antibiotic treatment, n</td>
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<tr>
<td>Time spent receiving MV, days</td>
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<tr>
<td>Hospital stay, days</td>
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<tr>
<td>Treatment failure, n</td>
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<tr>
<td>Pts who required BAA, n</td>
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NPPV, noninvasive positive-pressure ventilation; MV, mechanical ventilation; BAA, bronchoscopy-assisted aspiration.
ease developed gastric distension and gastroesophageal reflux. Because the re-entry of digested food and gastric acids into the pharynx can result in aspiration, especially in subjects with airway clearance dysfunction, caution should be observed when using MI-E in patients with a history of gastroesophageal reflux disease, particularly if abdominal distension develops.

Finally, it should be emphasized that in most cases, the administration of MI-E was effective and safely carried out by trained nonprofessional caregivers. We believe that this supports extending the use of MI-E into home management where it can be used in combination with NPPV to reduce the need for hospitalization, thus maintaining a higher quality of life for the NMD patient. In conclusion, the findings of our study provide support for considering the administration of MI-E in combination with conventional CPTs in the management of mucous retention during URTI in patients with NMDs.

REFERENCES

Mechanical Insufflation–Exsufflation Improves Outcomes for Neuromuscular Disease Patients with Respiratory Tract Infections
A Step in the Right Direction

ABSTRACT

Key Words: Mechanical Insufflation-Exsufflation, Neuromuscular Disease, Respiratory Tract Infection, Endotracheal Intubation

The work by Vianello et al., importantly describes the efficacy of mechanical insufflation–exsufflation (MI-E) for avoiding intubation for patients with neuromuscular diseases (NMDs) and upper respiratory tract infections. A painless, noninvasive intervention is used instead of invasive airway management. However, their results were suboptimal because both MI-E and chest physical therapy–only groups underwent bronchoscopy with equal frequency and because as many as 2 of 11 patients treated with MI-E underwent intubation. By contrast, previous reports have demonstrated significant reductions in pneumonia and hospitalizations and virtual elimination of respiratory mortality for cooperative patients with most NMDs. These patients can be managed at home, despite the need for continuous (noninvasive) respiratory support and almost continuous use of MI-E to reverse mucus plug–associated oxyhemoglobin desaturations. The authors recognized that their results might have been better had they used MI-E more aggressively, but a review of the literature reveals that their insufficiently aggressive management approach is the rule rather than the exception.

The reasons for the widespread failure to optimally use mechanically assisted coughing need to be explored. The concept of physical medicine respiratory muscle aids must be understood. Respiratory morbidity can result from inspiratory, expiratory, or bulbar innervated muscle dysfunction. However, the inspiratory and expiratory muscles can be compensated for by applying pressures to the airway (noninvasive ventilation and MI-E) or body (body ventilators and abdominal thrusts) so successfully that >700 ventilator users, many of whom are totally ventilator dependent with little or no measurable vital capacity, have been managed for as long as 55 yrs without resorting to...
tracheotomy. Although physical medicine aids are not effective in compensating for bulbar innervated muscle dysfunction, only advanced bulbar amyotrophic lateral sclerosis and a small percentage of spinal muscle atrophy type patients fail treatment with physical medicine aids and go on to require tracheostomy to prolong survival.

A cough is only as effective as the airway flows generated by the expulsive decompression that occurs on glottic opening during a cough effort. A normal cough expels a volume of air that is four times greater than tidal volume. Therefore, provision of a normal tidal volume for NMD patients whose reduced tidal volumes approach their vital capacities will not optimize their cough flows. An optimal cough volume (for effective lung recoil) can be provided by insufflating the patient’s lungs to a “maximum insufflation capacity.” This can never be accomplished for these patients by limiting insufflation pressures to 25 cm H2O, as used by Vianello et al. Insufflation pressures are commonly limited in this manner because physicians have far more experience in treating lung/airways diseases in which barotrauma is common and pneumothoraces an anathema. Clinical barotrauma is rare by comparison in NMD patients. In >1000 ventilator users, most of whom were depending on MI-E with insufflation pressures of 40–60 cm H2O to spare them from pneumonia and respiratory failure for every one of their upper respiratory tract infections (in some cases over a 52-yr period), no pneumothoraces were ever found.

The effectiveness of MI-E is not directly dependent on the machine pressure settings. Using MI-E via a small pediatric translaryngeal tube at machine pressures of 80 cm H2O does not mean that these pressures are transmitted to the airways. Pressure drop-off across small tubes or blocked airways is severe. The effectiveness of MI-E and the resulting cough flows are dependent, rather, on having full lung insufflation for maximal lung recoil without over expanding the lungs to cause barotrauma. Fortunately, self-directed patients never permit potentially harmful and, indeed, uncomfortable overexpansion. Physicians, however, do not like to rely on patients’ feedback and so they use less effective pressures.

Vianello et al. also noted that pressures were no longer increased when patients complained of “suffocation.” However, proper administration of MI-E should hyperventilate rather than hypoventilate any patient. If insufflation or exsufflation pressures are inadequate or are administered too long, the patient literally cannot breathe. Insufflation to full lung expansion and exsufflation to complete emptying should take place in ≤7 secs. Vianello et al. defined manually assisted coughing as an abdominal thrust. However, for patients whose vital capacities are less than normal, manually assisted coughing is not optimally effective unless preceded by a maximal lung insufflation. Further, MI-E is not optimal unless an abdominal thrust is applied during the exsufflation. This is because the negative pressure applied to the airway has a tendency to collapse airways, as do the positive transpulmonary pressures created during unassisted coughs. Normal abdominal muscle contractions during coughing tend to maintain airway patency. Because the abdominal muscles are too weak to do this for the NMD patient, the abdominal thrust becomes essential to permit effective cough flows. In fact, cough flows are increased significantly more by the maximal insufflation than by the abdominal thrust alone. Thus, lung insufflation is part of manually assisted coughing just as abdominal thrusts are part of mechanically assisted coughing. Abdominal thrusts and MI-E are not only not mutually exclusive, they must be combined for effective prevention of lower respiratory tract infection and respiratory failure.

Vianello et al. used peak expiratory flows as a variable for assessing cough impairment. However, peak expiratory flows do not depend on glottic function. Just as huffing is normally less effective than coughing, one cannot cough without closing the glottis. Similarly, maximum expiratory pressures do not reflect cough effectiveness because such pressures, even when normal, must be transmitted through unobstructed airways to generate optimal cough flows. There is no substitute for measuring peak cough flows when assessing cough effectiveness. Indeed, we find it useful to measure unassisted peak cough flow, peak cough flow from a maximally expanded (air stacked) lung, and “assisted” peak cough flow, coughs from a fully expanded lung with an abdominal thrust timed to glottic opening.

Vianello et al. and others have reported that manually assisted coughing is labor-intensive and often difficult for nonprofessional caregivers. However, it is next to impossible to manage advanced NMD patients without tracheostomy tubes unless their families and care providers provide virtually all of their care during upper respiratory tract infections. Just as anyone with bronchitis does not wait 6 hrs to cough twice a day, using MI-E 2.7 times a day as reported in the article by Vianello et al. can be grossly inadequate. It is inadequate for hospital staff to take full care of the hospitalized patient and instruct the family just before discharge and to then expect them to prevent another episode. Whereas the family often has the time and
motivation to use MI-E along with abdominal thrusts every 15 mins or so and use oximetry as feedback to maintain normal saturation (without supplemental oxygen) for the home or intensive care patient, one cannot expect the nursing and respiratory therapy staff to do this.

Noninvasive ventilation can be used for continuous ventilatory support acutely or long-term. Because the currently available bilevel pressure-cycled units are limited to pressures of <40 cm H2O, they cannot provide the deep lung volumes needed for effective cough assistance. Although Vianello et al. used a volume-cycled ventilator, they used 10 ml/kg to set the ventilator delivered volumes. Although such a formula is adequate for closed-system assisted ventilation, such as via a tracheostomy tube with an inflated cuff, noninvasive ventilation is an open system. We typically use 1000- to 1500-ml tidal volumes and let the patient’s ventilatory drive modulate air delivery to the lungs.

It is also important to note that although goals of achieving oxyhemoglobin saturation of at least 90% and PaCO2 of 45 mm Hg may be adequate for patients with primarily lung disease, these figures are not acceptable for patients with weak respiratory muscles who should have essentially normal lung tissue. Although we invariably successfully extubate patients with little or no vital capacity to continuous noninvasive positive pressure ventilation when the oxyhemoglobin saturation is >94% in ambient air and CO2 is normal, the extubation failure rate is very high when patients require supplemental oxygen to maintain normal oxyhemoglobin saturation.

In summary, only advanced bulbar amyotrophic lateral sclerosis and some spinal muscular atrophy type 1 patients should ever require tracheostomy tubes to prolong survival. This can only be accomplished if clinicians understand and use both the inspiratory and expiratory muscle aids effectively. The former include the use of simple mouthpiece intermittent positive-pressure ventilation during waking hours and nasal or lip-seal ventilation during sleep. The latter include mechanically assisted coughing with MI-E with abdominal thrusts (albeit gingerly for 1 hr after a meal) to maintain normal oxyhemoglobin saturation. The great majority of patients find MI-E to be most effective at 35–45 cm H2O pressures for insufflations and exsufflations. In experimental models, pressures of +40 to −40 cm H2O have also been shown to provide maximum forced deflation volumes and flows.

Although a less aggressive regimen, the study by Vianello et al. is certainly a step in the right direction. This is especially true for clinicians who, not so long ago, recommended (mini-)tracheostomies to prevent respiratory complications for all NMD patients. Failure to correctly administer physical medicine aids continues to make respiratory failure inevitable for the great majority of people with NMD. Most such patients remain uninformed about noninvasive options when consenting to or refusing bronchoscopy maneuvers, endotracheal intubation, or tracheotomy.

REFERENCES
Evaluation of Iontophoresis and Local Corticosteroid Injection in the Treatment of Carpal Tunnel Syndrome

ABSTRACT

Objective: The aim of this study was to compare the efficacy of local corticosteroid injection with iontophoresis of corticosteroids in the treatment of carpal tunnel syndrome.

Design: This study was a prospective, randomized, unblinded clinical trial with follow-up at 2 and 8 wks. Thirty patients (48 median nerves) with clinical and electrophysiologic evidence of carpal tunnel syndrome were included in the study. Patients were evaluated by use of clinical variables, a functional status scale, a symptom severity scale, and visual analog scale. A total of 48 median nerves were randomly assigned to one of two groups; group 1 received 40 mg of methylprednisolone acetate injected locally in the carpal tunnel, and group 2 received iontophoresis of dexamethasone sodium phosphate. Clinical variables and scales were evaluated at regular intervals: at the beginning and at the end of therapy in the second and eighth week.

Results: Twenty-seven patients (90%) were women and three patients (10%) were men. The mean age of patients was 48.0 ± 8.2 (range, 29–61) yrs. There was a statistically significant improvement in the clinical examination variables, visual analog scale, symptom severity scale, and functional status scale scores of the patients in both of the treatment groups posttreatment at 2 and 8 wks compared with baseline (P < 0.05). However, there was a statistically significant difference between the values of the two group. A significant difference in mean symptom severity scale, functional status scale, and visual analog scale scores was found in second week and eighth week in the injection group compared with iontophoresis.

Conclusion: Our study comparing a standardized treatment protocol for incorporating local corticosteroid injection and iontophoresis of dexamethasone sodium phosphate in carpal tunnel syndrome revealed success of both iontophoresis of dexamethasone sodium phosphate and injection of corticosteroids, but symptom relief was greater at 2 and 8 wks with injection of corticosteroids.

Key Words: Carpal Tunnel Syndrome, Iontophoresis, Symptom Severity Scale, Functional Status Scale, Corticosteroid Injection
Carpal tunnel syndrome (CTS) is the most common entrapment neuropathy of the upper limb in women. The median nerve is compressed between the transverse carpal ligament (flexor retinaculum) superiorly and the flexor tendons (flexor digitorum superficialis, flexor digitorum profundus, flexor pollicis longus) and carpal bones (scaphoid and trapezium) inferiorly. Inflammation of the flexor tenosynovium occurs in CTS. Thickening of the synovium may result in median nerve compression in time. Rheumatoid arthritis, myxoeedema, acromegaly, pregnancy, oral contraceptive pills, fracture, or dislocation of the carpal bones can cause CTS, but most cases are idiopathic.

The clinical diagnosis of CTS is usually easy and sensitive, and it is recommended as the gold standard in medical practice and electrophysiologic studies. In the majority of cases, the diagnosis is made on the basis of history and subjective symptoms. Clinical symptoms consist of paresthesia or hypoesthesia in the thumb, index finger, and long finger and nocturnal paresthesia in the affected digits. Nocturnal pain, weakness, and clumsiness of the hand are typical. Thenar atrophy and sensory abnormality are late findings. In patients having late findings, surgery should be recommended.

Tinel’s sign, Phalen test, and reverse Phalen test are provocative tests to study entrapment of the median nerve. When Phalen sign was positive for CTS, its specificity and sensitivity were 75% and 50%, respectively, whereas Tinel’s sign has a sensitivity of only 23%. The estimated prevalence of clinically and electrophysiologically confirmed CTS in the general population is 2.7%.

Several treatment options, either surgical or conservative (steroid injections, iontophoresis, splinting, nonsteroidal antiinflammatory drugs, physical agents, etc.) relieve pressure on the median nerve (directly or indirectly). Corticosteroid injection is frequently used in the management of CTS. Although it has been shown to be effective, the duration of its effect is short, and long-term effectiveness is controversial.

Iontophoresis (synonyms: cataphoresis, electrophoresis, and ion transfer) is a topical application of an ionized substance through the intact skin by the application of a continuous direct electric current. In physical medicine, iontophoresis is used to deliver medications directly to soft tissues, limiting systemic absorption. Iontophoresis of dexamethasone sodium phosphate (DXM-P) is used in physical medicine and rehabilitation as a treatment modality for patients with various musculoskeletal inflammatory conditions. The aim of this study was to compare the efficacy of local corticosteroid injection with iontophoresis of corticosteroids in CTS.

SUBJECTS AND METHODS

This study was a prospective, randomized, unblinded clinical trial with 2- and 8 wk follow-ups. Forty-five patients referred to the electrophysiological laboratory with a preliminary diagnosis of CTS were taken to the study. A total of 15 patients who did not have electrodiagnostic abnormalities diagnostic of CTS were excluded. A total of 30 patients (48 median nerves) with clinical and electrophysiologic evidence of CTS were included in this study. Research received institutional approval and each patient was told about the study. Clinical symptoms varied in duration from 1 to 120 mos. Patients who previously had received any treatment for CTS or who had a disease leading to secondary CTS and thenar atrophy were excluded.

Clinical examinations were performed in the initial visit and repeated in the second and eighth week after the end of treatment. Tinel’s sign, Phalen test, and reverse Phalen test were carried out in the standard manner. Pain was evaluated by a visual analog scale (VAS).

Motor and sensory nerve conduction studies were performed in median and ulnar nerves by using standard techniques in all patients. All electrodiagnostic tests were performed by the same physician with a Medelec Synergy, version 2.0, electromyography apparatus. Patients with mild and moderate CTS were included in our study.

Patients were evaluated by clinical examination, a symptom severity scale (SSS), a functional status scale (FSS). The outcome measurement tools used were the SSS and the FSS. The clinical SSS is a simple, reproducible, and sensitive scale for evaluating severity of CTS in patients. SSS and FSS consist of 11 and 8 questions, respectively. The answers were rated from 1 to 5 points. The overall score was calculated as the mean.

Clinical variables and scales were evaluated at regular intervals: at the beginning and at the end of therapy in the second and eighth week. Short-term and long-term outcomes were evaluated by a blinded assessor. The patients were randomly assigned to one of two groups; the first group (group 1) received 40 mg of methylprednisolone acetate (1 ml) injected locally in the carpal tunnel and the second group (group 2) received iontophoresis of DXM-P.

The injections were performed by the same physician (F. Gökoglu). The palmaris longus tendon lying on the wrist medially was determined by resistive wrist flexion. If the palmaris longus tendon was present, the injection was made just medial and parallel to the tendon with a 25-gauge needle inserted into the first crease of the wrist at

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an angle of 45 degrees. If the palmaris longus tendon was absent, the injection was carried out just medial to the midline of the ventral aspect of the wrist, in the first crease, at the junction to the hand. If paresthesia was elicited, the needle was withdrawn and redirected more medially.4,9 In patients with bilateral CTS, both hands were injected.

Solution of 0.4% DXM-P was used for iontophoresis. The smoothest galvanic current (Enraf, Netherlands) was used for ion transfer. The “active” electrode that has the same polarity as the ion, was placed longitudinally on top of the median nerve, and the dispersive electrode (of opposite polarity and moistened with water) was placed on the dorsal aspect of the forearm. The generator was turned on, and the amplitude was slowly increased until the patient noted a pricking or tingling sensation. The amplitude (40–45 mA) was maintained through the treatment duration of 20 mins. This treatment was applied every other day for 1 wk.

Statistical Analysis

SPPS 11.5 software (SPSS, Chicago, IL) was used for statistical analysis. Pretreatment and posttreatment measures for VAS, SSS, and FSS were compared by using Wilcoxon’s test. Mann-Whitney U test was used to compare the measures between groups. Correlations were assessed by Pearson’s test.

RESULTS

A total of 48 CTS hands of 30 patients between 29 and 61 yrs old (48.0 ± 8.2) were assessed. Eighteen patients (37%) had bilateral CTS. Twenty-five (83%) patients were housewives, and five (7%) patients had other occupations. Twenty-five of the patients were right-handed.

The baseline clinical characteristics of the patients are shown in Table 1. No side effects were found in either group at the end of the treatment. The distribution of patients according to paraesthesia, numbness, Phalen test, reverse Phalen test, and Tinel sign positivity is shown in Table 2. At the beginning of the study, there was no statistically significant difference between group 1 and group 2 in respect to clinical and electrophysioligic findings (Table 3).

Motor and sensory distal latencies of the median nerve showed no correlation with VAS, SSS, and FSS scores at the beginning (P > 0.05). There was no statistically significant difference between the VAS scores of the groups (P > 0.05) at the first evaluation. After treatment (at 2 and 8 wks), VAS scores of group 1 were statistically lower compared with group 2 (P < 0.0001 and P < 0.001, respectively). There was a significant improvement of SSS and FSS scores in both groups at 2 and 8 wks compared with baseline (P < 0.05). However, significantly better mean SSS and FSS scores were found at the second week (P < 0.01) and eighth week (P < 0.007) for the injection group compared with iontophoresis group (Figure 1).

DISCUSSION

CTS is a common disease according to the American Academy of Neurology, and there is a 10% lifetime risk of developing this pathology.18 Steroid treatment and noninvasive physical therapy may provide temporary benefit for CTS, but surgical decompression is considered the only definitive cure.19 In our study, two conservative treatment methods were compared.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Baseline characteristics of patients</th>
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<tr>
<td></td>
<td>Group 1</td>
</tr>
<tr>
<td></td>
<td>n = 15</td>
</tr>
<tr>
<td>Mean age ± SD, yrs</td>
<td>46.2 ± 8.0</td>
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<tr>
<td>Sex (female/male), n</td>
<td>12/3</td>
</tr>
<tr>
<td>Duration of symptoms ± SD, yrs</td>
<td>42.1 ± 43.3</td>
</tr>
<tr>
<td>Motor distal latency of median nerve, msecs</td>
<td>4.6 ± 0.9</td>
</tr>
<tr>
<td>Sensory distal latency of median nerve, msecs</td>
<td>3.7 ± 0.9</td>
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<tr>
<td>Baseline SSS score</td>
<td>2.7 ± 0.8</td>
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</table>

SSS, symptom severity scale.

<table>
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<th>TABLE 2</th>
<th>Comparison between baseline values and 8-wk values (symptoms and clinical tests)</th>
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<td></td>
<td>Group 1</td>
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<tr>
<td></td>
<td>Baseline, week 8</td>
</tr>
<tr>
<td>Paresthesia, n (%)</td>
<td>19 (95), 3 (15)</td>
</tr>
<tr>
<td>Numbness, n (%)</td>
<td>16 (80), 4 (20)</td>
</tr>
<tr>
<td>Tinel, n (%)</td>
<td>15 (75), 2 (10)</td>
</tr>
<tr>
<td>Phalen, n (%)</td>
<td>17 (85), 3 (15)</td>
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<tr>
<td>Reverse Phalen, n (%)</td>
<td>15 (75), 2 (10)</td>
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<tr>
<th>TABLE 3</th>
<th>The mean of symptom severity scale (SSS), functional status scale (FSS), and visual analog scale (VAS) scores of two groups</th>
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<tbody>
<tr>
<td></td>
<td>Group 1 (n = 15)</td>
</tr>
<tr>
<td>Baseline SSS</td>
<td>2.7 ± 0.8</td>
</tr>
<tr>
<td>Week 2</td>
<td>1.9 ± 0.7</td>
</tr>
<tr>
<td>Week 8</td>
<td>1.6 ± 0.6</td>
</tr>
<tr>
<td>Baseline FSS</td>
<td>2.6 ± 10</td>
</tr>
<tr>
<td>Week 2</td>
<td>1.8 ± 0.9</td>
</tr>
<tr>
<td>Week 8</td>
<td>1.5 ± 0.9</td>
</tr>
<tr>
<td>Baseline VAS</td>
<td>6.2 ± 1.2</td>
</tr>
<tr>
<td>Week 2</td>
<td>4.5 ± 1.1</td>
</tr>
<tr>
<td>Week 8</td>
<td>1.8 ± 1.2</td>
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At the neutral position of the wrist, where carpal tunnel pressure of 3 mm Hg in normal, it is 32 mm Hg in patients with CTS. The pathophysiology of the nerve lesion is ischemic and is due to compression of the vasa nervorum secondary to the increased pressure.

Injection of steroids into the carpal tunnel is believed to reduce perineural inflammation or soft-tissue swelling and may stabilize the neural membrane. In severe cases, steroid injection is insufficient to relieve the pressure on the nerve. Injections may lead to permanent median nerve injury if not performed correctly. For these reasons, injections are most often indicated when the condition is more likely temporary, such as with pregnancy, or if surgery has to be deferred because of a medical condition. The beneficial effects of steroid injections were reported in several studies of idiopathic CTS, which date back many years. Improvement of symptoms may be seen several days after the injection, but symptoms usually resolve in 6 mos.

In a controlled, double-blind study, Girlanda et al. reported that steroid injection was effective for the treatment of CTS. About 50% of the nerves of their patients became worse within 6 mos and 90% within 18 mos. In a small percentage of nerves (8%), the improvement still continued at 24 mos after the injection. In our study, when assessed with VAS, SSS, and FSS scores, the significant improvements were shown in the second and eighth week after therapy for both groups compared with at the beginning.

O'Gradaigh and Merry have compared low and high dose and short- and long-acting corticosteroid injection treatment in CTS at 6 wks and 6 mos. They have shown that there was not a significant difference between long- and short-acting steroids. In our study, group 1 received short-middle–acting corticosteroids and group 2 received long-acting corticosteroids.

Özdogan et al. compared local steroid injection into the carpal tunnel with steroid injection into the deltoid muscle in the short term. The local injection provided symptom relief for significantly more patients than the intramuscular injection. Wong et al. showed that a single injection of 15 mg of methylprednisolone was superior to oral corticosteroids in the treatment of CTS.

Gelberman et al. compared steroid injection in carpal tunnel with splinting for the treatment of CTS. Patients with mild symptoms and physical findings were free of symptoms for >12 mos. Those with severe symptoms of >1 yr of duration had less long-term relief from injection and splinting. In our study, symptom duration of group 2 was more than that of group 1. Duration of symptoms played an important role for determination of treatment response.

In regard to the prognostic value of the baseline neurophysiologic picture, the same severe neurophysiologic impairment was not always associated with a bad prognosis; conversely, patients with mild neurophysiologic impairment sometimes worsened. Similarly, in our study too, no correlation was found between the scores of VAS, SSS, and FSS at baseline and motor and sensory distal latencies of the median nerve.

Iontophoresis is another treatment modality that can decrease symptoms in CTS. As in a study by Anderson et al., we found that the general lack of a strong theoretical representation for the practice of iontophoresis has hampered its wide-spread acceptance among all medical professionals. Although iontophoresis is not widely used currently, it has been successfully applied for the treatment of numerous conditions such as edema, ischemic skin ulcers, muscular pain, Peyronie's disease, hyperhidrosis, arthritis, bursitis, and tendonitis.

It has been claimed that the corticosteroids by iontophoresis can penetrate 7 cm into porcine soft tissue through the skin. The electrical current and corticosteroids provide some analgesic or anti-inflammatory effects. In another study, it was found that DXM-P penetration into tissue of a
After evaluating tissue under the delivery electrode after iontophoresis of DXM-P, several researchers have described a “depot” of drug that is found in the area of the epidermis. This intracutaneous depot represents the highest concentration of the drug detected. Deeper penetration of the drug apparently occurs with passive diffusion but not iontophoretic current. However other factors such as local blood flow will determine the ultimate depth of local penetration. In a study measuring prednisolone levels after iontophoresis, prednisolone was found in the epidermis for up to 4 days after application and was released to the blood for 15 days after application.

The advantages of steroid iontophoresis are (1) being painless, (2) being noninvasive and not causing tissue damage due to needle penetration, (3) providing adequate local and little systemic concentration of the drug, and (4) being sterile. This method avoids the risk of systemic complications of corticosteroids; in addition, it is inexpensive compared with many other forms of treatment for CTS.

Banta applied a standardized treatment protocol for 23 hands with CTS. Four of 23 hands (17%) responded to wrist splinting plus nonsteroidal anti-inflammatory medications. The remaining 19 who failed this medication were treated with iontophoresis. Iontophoresis of DXM-P was successful in 11 hands (58%) at a 6-mo follow-up. In 8 of 23 hands (35%), medical treatment failed. These patients were referred for surgical treatment.

In conclusion, two conservative treatment methods for CTS were compared in our study. There are few studies evaluating the comparison of the way that the corticosteroid is applied. Our study results indicate presence of relief in both clinical and objective measures for each method of application of corticosteroid in a short-term period of 8 wks. There was a significant symptom resolution after 2 wks.

Injection therapy results in significantly better outcomes; however, application of steroid by iontophoresis is a safer method and has no complications or side effects. For this reason, it may be an alternative treatment to the injection. Because follow-up was limited to 8 wks, we cannot comment on recurrence rates or long-term results. Clinical trials to investigate long-term effects of these methods are needed.

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Kinematic Alterations in the Ipsilateral Shoulder of Patients with Hemiplegia Due to Stroke

ABSTRACT


Objective: To evaluate the assumption that shoulder kinematic patterns of the ipsilateral, nonparetic shoulder in hemiplegia are similar to kinematics recorded in a healthy population.

Design: Case control study of a convenience sample of ten patients with hemiplegia due to stroke in the subacute phase compared with a control group of similar age. Three-dimensional positions of the scapula and humerus were measured and expressed in Euler angles as a function of active arm elevation in the frontal and sagittal plane and during passive humeral internal/external rotation at an elevation angle of 90 degrees in the frontal and sagittal plane.

Results: Compared with controls, in the ipsilateral shoulder of patients, we found both a statistically significant diminished scapular protraction during elevation in the sagittal plane (35 ± 5 vs. 51 ± 8 degrees at 110 degrees of humeral elevation) and humeral external rotation during arm elevation in the frontal plane (51 ± 7 vs. 69 ± 14 degrees at 110 degrees of humeral elevation). Maximal passive humeral external rotation was found to be impaired in the frontal (64 ± 13 vs. 98 ± 14 degrees) and sagittal planes (65 ± 11 vs. 94 ± 12 degrees). In addition, there was significantly diminished anterior spinal tilt during humeral internal rotation (−5 ± 10 vs. −20 ± 9 degrees) and diminished posterior spinal tilt during external rotation in the frontal plane (−14 ± 8 vs. −3 ± 6 degrees). Maximal thoracohumeral elevation in patients was significantly impaired (126 ± 12 vs. 138 ± 8 degrees).

Conclusion: Clear kinematic changes in the ipsilateral shoulder in patients with hemiplegia were found, indicating underlying alterations in muscle contraction patterns. The cause remains speculative. These results suggest that the ipsilateral shoulder should not be considered to function normally beforehand.

Key Words: Cerebrovascular Accident, Paresis, Shoulder Joint, Biomechanics
In stroke, functional impairment of the involved upper limb and the occurrence of shoulder pain are well-known problems hampering the rehabilitation process. Remaining functional impairments of the upper limb are reported to vary from 21% to 67%.\(^1,2\) The prevalence of shoulder pain as reported in the literature varies from 16% to 84%.\(^3-9\) Pathogenesis is still unclear. Possible risk factors have been discussed thoroughly in the literature, and only a weak association has been found between shoulder pain and muscle tone,\(^10\) although shoulder pain has also been found to be associated with adhesive capsulitis and disorders of the autonomic nervous system.\(^10\)

Biomechanical analysis is necessary to gain more insight in the underlying mechanisms. A major advantage of such an analysis is that it addresses pathophysiologic mechanisms on an individual basis, thus bypassing the need to assess large groups of patients to find common denominators. Biomechanical analysis preferably starts with kinematic analysis because this is relatively easy to perform and serves as input for further biomechanical modeling using upper limb models such as the Swedish model\(^11,12\) or the Delft Shoulder and Elbow Model.\(^13-15\) Techniques to measure the kinematics of the shoulder, including the scapula with its large motion trajectory underneath the skin, were recently developed. Three-dimensional scapular positions can be measured in a reliable and fast way using a three-dimensional electromagnetic tracking device in combination with the palpation method and a scapula locator.\(^16-21\)

Because of the relatively large interindividual variability,\(^18,20\) it seems an obvious choice to compare kinematics of the paretic shoulder with the ipsilateral, nonparetic shoulder. Studying the literature, however, raised serious doubts concerning the assumption of normal kinematics in the ipsilateral shoulder, necessary for proper comparison. Several studies showed distinct changes in the contralateral hemisphere in unilateral stroke in the form of significant magnetic resonance imaging changes,\(^22\) a change in physiologic responsiveness after posterior temporal infarction,\(^23\) and remote edema.\(^24\) Others showed marked and lasting impairments in strength and coordination of the ipsilateral limb.\(^1,25-28\) Hence, it may be that in the ipsilateral shoulder, scapular position disorders are present. The primary goal of this study was therefore to compare kinematics of the nonaffected ipsilateral shoulder of patients with hemiplegia due to stroke with a control group. Next to the main question of whether kinematics of the nonaffected side could be used as control in the study of shoulder kinematics in the hemiplegic shoulder, results of the study may have clinical consequences because kinematic alterations in the nonaffected shoulder with respect to a healthy population indicate altered muscle contraction patterns, resulting in improper function. Because patients with hemiplegia often have to rely on the ipsilateral side for activities of daily living, this may be important information for the clinician.

**METHODS**

**Subjects**

Ten patients, four men and six women (mean age ± standard deviation, 53.4 ± 10.3 yrs), with hemiplegia after stroke were recruited from the wards of the Rehabilitation Center Amsterdam (Table 1). None of the patients had a history of shoulder complaints; all had experienced their first stroke and were able to perform the measurements in physical, cognitive, and communicative sense. Before starting the measurements, shoulder pain, muscle tone, and arm function were objectified by a Visual Analog Scale, modified Ashworth\(^29\) scale, and Fugl-Meyer\(^30,31\) score, respectively. Information on neglect was obtained from the medical record.

Ten healthy subjects, six men and four women, of similar age (60.8 ± 12.4 yrs) with a negative

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VAS, Visual Analog Scale; M, male; F, female; R, right; L, left; N, no; Y, yes.
history of shoulder complaints formed the control group. For the lack of data on the differences in shoulder kinematics between men and women and because of the sample size, data of men and women were pooled. All control subjects took part in normal daily activities. Before the start of the measurements, the local board of medical ethics approved the study. Measurements were performed after each subject had signed an informed consent statement.

**Instrumentation**

A MotionMonitor electromagnetic tracking device (Innovative Sports Training, Chicago, IL), consisting of a transmitter creating a weak magnetic field in which the position and orientation of several receivers can be measured, was used. A field calibration was performed after which the translational residual measurement error was about 2 mm for each coordinate and the rotational root-mean-square area was <2 degrees for each axis of rotation.32 Measurements were performed according to the protocol formulated by the International Shoulder Group Committee on standardized description of shoulder motion.33 Receivers were attached to the thorax and upper arm by Velcro straps. One receiver was attached to a scapula locator: an adjustable tripod that is to be placed manually over the inferior angle, acromial angle, and scapular spinal triangle, respectively. A fourth receiver was attached on top of a pointer of about 2.5 cm in length, thus forming a spatial digitizer. Reliability, validity, and resolution of the measurement method were discussed previously.18

**Measurements**

Subjects were seated in a plastic chair in front of the transmitter. Before starting the measurements, the scapula locator was adjusted to the scapula to be measured. First, a reference measurement was performed, during which a number of bony landmarks on the thorax, scapula, and humerus were digitized to be able to relate their position to the receivers attached to the bones. The three endpoints of the scapula locator were subsequently digitized after adjustment to relate their position to the attached receiver.

The positions of five bony landmarks (i.e., coracoid process, acromioclavicular joint, scapular acromial angle, spinal triangle, and inferior angle) were used to estimate the localization of the glenohumeral joint rotation center with respect to the receiver attached to the humerus.34 The glenohumeral rotation center provides for the third essential landmark for the reconstruction of a local coordinate system on the humerus.

Both patients and control subjects performed arm elevations in the frontal (forward flexion) and sagittal planes (abduction), respectively. The plane of elevation was dictated and controlled by means of a semicircular pipe with 10-degree marks, placed in the required elevation plane to guide the subject/patient. The subjects were asked to elevate their arm in steps dictated by the marks on the pipe. At each step, the subjects were asked to keep their arm still, allowing for the measurement of the scapular position to take place. Each elevation of the arm was therefore semistatic, subdivided in about 10–15 steps of about 10 degrees of elevation each. As the exact angle of humerus elevation was calculated afterward, the exact width of the elevation interval was not a critical variable. For each elevation angle, the scapula locator was repositioned over the scapula. Position and orientation of the receivers on the thorax, scapula locator, and humerus were subsequently recorded for each motion step. Subjects and patients were instructed to elevate their arm as high as possible, without further specification. Three subsequent elevations for each plane of elevation were performed. In addition to the active arm elevations, measurements were performed during maximal passive internal and external rotation of the upper arm in 90 degrees of elevation in the frontal and sagittal planes, respectively. For these evaluations, the arm of the subject was moved and positioned by the experimenter, with the subject’s elbow in about 90 degrees of flexion. The latter measurements were performed for both the ipsilateral and contralateral shoulder of the patients. Even though both the right and left shoulders of the control subjects were evaluated, for this study, only data from the right shoulder were used because differences in observed variables between left and right shoulders were small and not statistically significant.

**Data Processing**

Using the reference measurements, for each arm elevation angle, the three-dimensional positions of the bony landmarks on the thorax, scapula, and humerus were calculated in the global (transmitter) coordinate system. Local coordinate systems were constructed on the reconstructed bony landmark positions33 (Fig. 1, Table 2). The relative positions of the local coordinate systems were subsequently decomposed and expressed in Euler angles.16,19,33 Order of decomposition was according to the International Shoulder Group proposal33 (Table 2). Rotations of scapula and humerus were expressed in the coordinate system of the thorax. The glenohumeral rotations were obtained by calculating the relative position of the humerus with respect to the coordinate system of the scapula. Five rotations were regarded to be of clinical rele-
vance: the scapular rotation around the (vertical) y-axis of the thorax (i.e., the scapular protraction [external rotation]), the scapular rotation around the (anteroposterior) z- axis of the thorax (i.e., the scapular lateral rotation [upward rotation]), the scapular rotation around the (mediolateral) x- axis of the thorax (i.e., the spinal tilt), the humeral rotation around the y-axis of the humerus (i.e., the axial rotation), and the humeral rotation around the x- axis of the scapula (i.e., the glenohumeral axial rotation).

Maximal thoracohumeral elevation angles were compared using a one-way analysis of variance. To standardize the humeral elevation angles among subjects, data were averaged and smoothed by fitting spline functions through the raw data of the three consecutive trials. The obtained spline functions were subsequently sampled at 30, 50, 70, 90, 110, 120, and 130 degrees of humeral elevation. These smoothed and sampled data were used for further processing. Statistical analyses were only performed at 50, 70, 90, and 110 degrees of humeral elevation because of missing data points. A general linear model multivariate analysis of variance with repeated measures, using humeral elevation as a within-subjects factor, was applied to compare the measures of humeral axial rotation, scapular lateral rotation, scapular protraction, and scapular spinal tilt of shoulders of the control subjects with the ipsilateral shoulders of the patients with stroke.

The data of the internal/external rotation experiments were processed as single observations, and no smoothing and elevation angle correction was applied. A one-way analysis of variance was applied to compare humeral axial rotation, gleno-humeral axial rotation, scapular lateral rotation, and scapular spinal tilt between the shoulders of the control subjects and both the ipsilateral and contralateral shoulders of the patients with stroke. When a significant difference was found, a Scheffé post hoc test was used to determine which groups were different. For all statistical tests, results were considered significant at $P$ values of $<0.05$.

As no previous data existed on the variability of kinematics of stroke patients, we calculated a required sample size based on a normal population. In this study, the interindividual variability of scapular rotations was found to be about 7 degrees. With an alpha of 0.05 and a desired smallest detectable difference of 10 degrees, a sample size of $n = 10$ resulted in a power of 0.8.

RESULTS

General Remarks

An example of the raw data with the fitted spline is presented in Figure 2. Each data point in this graph represents one observation (i.e., one measurement of the relative position of a bone with respect to one axis of the thorax at one humeral elevation angle). This particular example represents the rotation of the scapula around the z-axis of the thorax (i.e., the scapular lateral rotation). Graphic representations of the combined results are presented in Figures 3 and 4. In Figure 3, for each elevation plane, the Euler angles of the three scapular rotations and the humeral axial rotation have been plotted as a function of humeral elevation. Box-plot format, indicating median (horizontal line), 50% of observations (box), and range (whiskers), was used. In Figure 4, the same was performed for the internal/external rotation experiments.

Arm Elevations

Maximal active thoracohumeral elevation angles were significantly ($P < 0.01$) lower in patients (125.7 $\pm$ 11.6 degrees) than in the control subjects (137.7 $\pm$ 8.0 degrees). Comparison of the nonparetic, ipsilateral shoulder of the patients to the shoulders of the control group revealed a significant group-angle interaction for scapular protraction during elevation in the sagittal plane, indicating that the increase in protraction with increasing humeral elevation was higher in control
subjects. Scapular protraction during humeral elevation in the sagittal plane was found to be statistically diminished (38° vs. 51°), and there was significantly less humeral external rotation during elevation in the frontal plane (51° vs. 69°) (Fig. 3).

**Internal/External Rotations**

In the internal/external rotation experiments, a statistically significant lower maximal passive external rotation of the humerus in the sagittal plane was found (65° vs. 94°). Both maximal passive internal and external rotation were significantly impaired during passive axial rotation in the frontal plane (−19° ± 19° vs. −49° ± 20° degrees and 64° ± 13° vs. 98° ± 14° degrees).

Glenohumeral axial rotation was significantly impaired during internal rotation in the sagittal plane (11° ± 13° vs. 38° ± 16° degrees) and during both internal and external rotation in the frontal plane (−26° ± 17° vs. −49° ± 20° degrees and 51° ± 20° vs. 96° ± 20° degrees). Scapular posterior spinal tilt was significantly diminished during external rotation in the sagittal plane (−7° ± 6° vs. −14° ± 9°).
degrees) and frontal plane (−3 ± 6 vs. −14 ± 8 degrees) and enhanced during internal rotation in the frontal plane (−20 ± 9 vs. −5 ± 10 degrees).

In general, the patterns of the ipsilateral shoulder resembled more the paretic shoulder than the shoulder of the controls. Scapular lateral rotation in the ipsilateral shoulder was not statistically different from the control group, although there was a tendency toward lower lateral rotation.

DISCUSSION
General Remarks

In short, we found distinct changes in ipsilateral shoulder kinematics, predominantly in the form of significantly diminished humeral external rotation during arm elevation in the frontal plane and during passive axial rotation in both sagittal and frontal planes and in the form of lags in scapular movement: diminished scapular protraction during elevation in the sagittal plane and diminished posterior spinal tilt during maximal passive external rotation, together with diminished anterior tilt during internal rotation in the frontal plane. Furthermore, there was a tendency toward diminished scapular lateral rotation both during elevation and maximal passive axial rotation in the sagittal plane. There was diminished (−8.7%) maximal thoracicohumeral elevation in patients (125.7 vs. 137.7 degrees).
It should be noted that the Euler angles of the three rotations are not independent of each other, as they represent one three-dimensional movement. This means that interpretations of isolated rotations should be handled with care and that it is important to keep the total movement pattern in mind. The clinical data on, for example, shoulder pain, muscle tone, and arm functionality were only used to get an overview of the characteristics of the population of stroke patients measured, and because of the small size of the population, no further attempt was made to correlate clinical data to the measurements.

Possible Causes of the Observed Changes

Several possible causes for the observed kinematic changes in the ipsilateral shoulder emerge from the literature. First, in the acute phase of stroke, cerebral edema seems to be spreading throughout the brain, up into the contralateral hemisphere.36 This would implicate an impairment of the function of the contralateral hemisphere in stroke as well, which could lead to impairment in strength and coordination in the ipsilateral limb.

Second, several studies have elaborated on the concept of both hemispheres controlling both sides of the body by corticospinal neural pathways that do not cross at the brainstem level. Urban et al.36 found the respiratory musculature to be responding to stimuli applied to both hemispheres, though the response to stimuli applied at the ipsilateral side was weaker. This indicates that when a hemisphere is damaged due to stroke, corticospinal tracts in the ipsilateral side would be affected as well, though to a lesser extent than the contralateral side. Esparza et al.27 found evidence that temporal coordination of the upper limb recruitment is mediated bilaterally by each hemisphere, with the left hemisphere to be more important. Sugarman et al.26 found increased segmentation in the movements of the ipsilateral and the contralateral side of patients with hemiplegia. They assumed a global inability to control motion to be responsible for these findings. The fact that the kinematics of the ipsilateral side more or less resembled kinematics of the paretic side may underline a kind of parallel coordination of both sides of the body.

Third, there is the concept of crowding, meaning that as a result of plasticity of the brain, a number of tasks are taken over by the contralateral side, causing function impairments of the other tasks of the hemisphere as a trade-off.37–40

Fourth, it is not known to what extent the kinematics of the ipsilateral shoulder are affected by changes in muscular tone at the affected side of the body. We expressed both humeral and scapular rotations in the coordinate system of the thorax, reducing the influence of pure thorax rotations. Viewed dynamically, it is theoretically possible that changes in the contralateral side affect dynamics in the ipsilateral side; however, left and right shoulders are a less-coupled system than the hip joints within the pelvic system, where a closed kinematic chain makes rotations in both hip joints influence each other. Hence, it seems less likely that paretic muscles on the other side influence a relatively fixed variable as the scapulothoracic rhythm. To shed more light on the possible relationship between muscle tone on the contralateral side and kinematics on the ipsilateral side, data of a group of patients with clear high tone should be compared with patients with clear low tone. A more indicative study design would be repetitive measurements in the follow-up after stroke to assess kinematics and muscle tone simultaneously. However, if a relationship were found between muscle tone on the contralateral side and kinematics on the ipsilateral side, it would still remain unclear whether this was caused by influences from the contralateral to the ipsilateral side or by direct changes in muscle tone on the ipsilateral side.

Finally, other external causes cannot be ruled out by this study. We chose an age-comparable control group to correct for the possible confounding effect of age, but we did not regard factors such as prolonged inactivity. One way to correct for these influences would have been to measure kinematics in the acute phase of stroke. If kinematic changes were present in the acute phase, then the first two explanations would seem to be the most plausible ones. The finding that the kinematic patterns of the ipsilateral shoulder resembled more the patterns of the paretic shoulder than the control shoulder also supports the concept of impaired cerebral control as the cause of the observed alterations.

The data do not point to capsulitis adhesiva as a factor involved, for this would mean diminished rotations at the glenohumeral joint, causing the rotations of the scapula to be enhanced. The lateral rotation, for example, would show a steeper slope, showing a “scapular lead.”41 Especially, the diminished scapular spinal tilt during maximal passive internal rotation and persistent spinal tilt during maximal passive external rotation of the upper arm is in contradiction with a diminished glenohumeral mobility.

One may speculate about the persistence of the observed changes. Jung et al.28 found the lack of strength in the ipsilateral side after stroke to be lasting. Elaboration of the relationship between time after stroke and the degree of kinematic changes was not a goal of the present study, and the number of patients was too small. We are cur-
rently undertaking a study to measure kinematics during the first months after the onset of stroke. An interesting question will be whether the observed changes are only present during a part of the rehabilitation process, implicating a “critical window.”

**Passive vs. Active Motions**

The main difference between passive and active motions is the additive generation of an external moment in the latter case above muscle activation needed for stabilization and integrity of the shoulder in the former. Passive internal and external rotations were included to test the shoulder to its limits by assessing kinematics during maximal humeral rotations. We thus expected to detect aberrations more easily. Substantial differences were indeed found during the passive test, underlining this premise. We argue that differences in kinematics found during passive motions point to the same as differences found during active motions, namely, the existence of an aberrant muscular contraction pattern.

**Clinical Implications**

The clinical implications of the observed kinematic changes in the present study remain speculative and require further elaboration. It may be that problems in the ipsilateral shoulder in hemiplegia due to stroke cannot be accounted to over-use only, as is commonly done in clinical practice. This is because we found evidence for underlying, potentially harmful, kinematic alterations in the form of inadequate scapular positioning with respect to the humerus, possibly resulting in narrowing of the subacromial space by the major tubercle or overstretch of the scapulohumeral soft tissue. To our knowledge, no information exists on the prevalence of shoulder problems on the ipsilateral side in stroke patients, nor is it clear to what extent problems of the ipsilateral shoulder hamper the rehabilitation process. However, it seems obvious that this is valuable information because stroke patients have to rely heavily on the ipsilateral limb. Shoulder problems can be defined in terms of both functional impairment and occurrence of shoulder pain. Regarding the functional impairment, we found that the patients were still able to use their ipsilateral shoulder, though the maximal thoracic-coumeral elevation angle was less than in the control group. Jung et al.28 found muscle strength to be impaired, which may be a likely explanation of this lower maximal elevation angle. Price et al.,31 studying scapular positions in the hemiplegic shoulder of stroke patients, found a scapular lag (i.e., a diminished scapular lateral rotation that was positively correlated with the impaired function). A tendency for scapular lag was also found in the present study. How a scapular lag should be interpreted is not fully clear. Lack of muscle strength might result in both diminished elevation and scapular lag. There might also be a causal relationship between scapular lag and shoulder function. Scapular lag may reveal a problem in stabilizing the scapula, a prerequisite for proper arm function. Suboptimal positioning of the scapula with respect to the arm would lead to suboptimal length of muscles and, thus, to impaired muscle function and abnormal muscle forces. Lack of coordination is then the main underlying problem. The diminished protraction and spinal tilt can be discussed in the same way. To distinguish between cause and effect, simulations by three-dimensional musculoskeletal models of the shoulder are required.

Shoulder pain may develop as a result of impingement, which is likely to occur as a result of both inadequate positioning of the scapula and diminished axial rotation of the humerus, causing the major tubercle to be rotated away from the coracoacromial arch ineffectively. Both the diminished protraction during elevation in the sagittal plane and the lower axial rotation of the humerus during elevation in the frontal plane will enhance the danger of the major tubercle narrowing the subacromial space.42 This means that the ipsilateral shoulder of stroke patients could be at risk for developing impingement-related shoulder problems. None of the patients we measured experienced pain in the ipsilateral side, but the sample size was too small to draw definite conclusions on this subject, and longer follow-up is needed for further evaluation.

**CONCLUSION**

We found evidence for improper biomechanical function of the ipsilateral shoulder in stroke (i.e., improper stabilization of the scapula and a diminished ability for external rotation of the upper arm). The clinical consequences of the observed kinematic alterations are not clear yet. Meanwhile, both researchers and clinicians should realize that normal function of the ipsilateral shoulder in stroke cannot be taken for granted. For researchers, this is important in kinematic shoulder research concerning the paretic shoulder, in which kinematic and dynamic models may help to understand poststroke shoulder pain and may help to plan treatment modalities in restoring shoulder function. In kinematic studies, the ipsilateral shoulder should not be automatically used as a control. For the clinician, special care may be necessary to keep the ipsilateral shoulder in stroke patients in optimal shape. This is important because proper function of the ipsilateral arm in stroke is crucial for maintaining self-support.
REFERENCES


Patellar Taping Does Not Affect the Onset of Activities of Vastus Medialis Obliquus and Vastus Lateralis Before and After Muscle Fatigue

ABSTRACT


Objective: This study examined the immediate effect of patellar taping with a standard force on the onset of vastus medialis obliquus and vastus lateralis activities before and after muscle fatigue in able-bodied subjects.

Design: This study tested 29 mature able-bodied subjects. The surface electromyographic onset time of their vastus medialis obliquus and vastus lateralis was measured after a posteroanterior perturbation at the knee in a single-legged standing position. The measurements were taken under three conditions in random order of true patellar taping, sham patellar taping, and no patellar taping. Afterward, subjects performed a knee-extension exercise until their quadriceps fatigued, and the above tests were repeated to test the effect of fatigue on the outcome.

Results: There was no statistically significant difference with patellar taping on the electromyographic onset time of the vastus medialis obliquus and vastus lateralis compared with the placebo-taping and no-taping conditions ($P = 0.455$). There was no statistically significant difference in onset of vastus medialis obliquus and vastus lateralis muscles before and after muscle fatigue ($P = 0.304$).

Conclusions: The present study suggests that patellar taping does not enhance the temporal activation of vastus medialis obliquus in both fatigue and nonfatigue conditions on able-bodied subjects.

Key Words: Knee, Taping, Muscle Activity, Patellofemoral Joint
Patellar taping, first reported by McConnell, is a popular choice of treatment for patients with patellofemoral pain syndrome (PFPS). It has been reported that patellar taping in PFPS could reduce anterior knee pain, improve the patellofemoral joint alignment, regulate the mediolateral pulling force on patella, and facilitate vastus medialis obliquus (VMO) activity, thus stabilizing the patella. Despite the fact that there have been many studies about the effect of patellar taping on pain, neuromuscular performance, and patellar alignment in patients with PFPS, controversy still exists regarding its efficacy. McConnell reported that patellar taping facilitated VMO activation and controlled abnormal patellar alignment. Hilyard reported that taping should be used temporarily to correct the abnormal patellar movements, whereas other authors only found the taping procedure to reduce pain but not facilitate the VMO activity. Therefore, whether patellar taping has a facilitative effect in VMO activation is still uncertain. To understand the effects of patellar taping on muscle activation, there is a need to study the effect of taping on able-bodied subjects. If patellar taping could facilitate VMO activities in normal subjects, it would suggest a mechanism for its effects in those with PFPS.

Fatigue is a natural sequel of prolonged exercise, and it is defined as “a response that is less than the expected or anticipated contractile response for a given stimulation.” Previous studies have shown that there were different muscle activation patterns in fatigue or nonfatigue conditions. Muscle fatigue that results from exercises serves as a potential mechanical inhibition on muscle activation and maintains intracellular homeostasis. It is not known if patellar taping can enhance the activation of the quadriceps muscle group in a fatigued condition and if the effects on VMO activation by taping would also happen with muscle fatigue. If patellar taping is found to facilitate VMO in a fatigued state, it will have a vital implication for people who are active in sports activities because they can apply patellar taping before exercises so as to prevent abnormal patellar movements during quadriceps muscle fatigue.

Therefore, the aims of this study were to examine (1) the immediate effects of patellar taping with a standard force on the onset of VMO and vastus lateralis (VL) activities during sudden perturbation and (2) the effect of patellar taping before and after quadriceps muscle fatigue in able-bodied subjects.

METHODS

A total of 29 able-bodied subjects (15 men, 14 women) with a mean age of 21.5 yrs (range, 15–30 yrs) and mean body weight of 57.5 kg were recruited for this study. All except one of the subjects were right leg dominant. All subjects were active but not participating in any lower limb exercise training program that might affect their muscle recruitment pattern. They had no history of knee surgery or knee pain requiring medical treatment in the previous 6 mos, and they had to refrain from strenuous exercise 2 days before the tests so as to prevent muscle fatigue. The study was reviewed and approved by the human subjects ethics review subcommittee of the Hong Kong Polytechnic University, and all subjects gave their written consent before testing.

Testing Procedures

Two active surface electrodes (B&L Engineering, Santa Fe Springs, CA) were used to record the electromyographic (EMG) times of VMO and VL of the dominant leg, which was defined as the leg the subject used to kick a ball. The skin over the midpoint of the VMO (4 cm superior and 3 cm medial to the superomedial border of patella) and VL (10 cm superior and 7 cm lateral to the superior border of patella) was shaved, lightly abraded with fine sandpaper, and cleansed with 75% alcohol to reduce skin resistance. Electrodes were applied over the midpoint of both muscles along their fiber directions, and an accelerometer (Kistler 8772A10, Kistler Instrument, Amherst, NY) was applied over the tibial tuberosity to register the knee movement. Electrodes were not removed after application until completion of all the tests so as to increase the reliability of EMG recordings.

During the tests, subjects were asked to perform single-legged standing with their dominant leg. To avoid VMO and VL activities being affected by the hip position, subjects were to stand with their knee straight and hip in neutral rotation. A table was placed in front so that the subjects could put their hands lightly on the table for balance. To simulate a sudden unplanned action such as during sports activities, a 4-kg medicine ball was used to provide perturbation to the knee joint. The ball was suspended with a sling from the ceiling so that it could be adjusted to be at the level of the subject’s knee joint. The examiner pulled the ball back until the sling made an angle of 60 degrees to the vertical behind the subject and, on release of the ball, it would exhibit a pendulum swing and hit on the back of the subject’s knee to produce a flexion perturbation. During the process, the subject’s ears were shielded so that he or she could not hear the moment of ball release (Fig. 1). The tests were conducted in six conditions, with the orders of the first three and last three randomized, and surface
EMG times of VMO and VL were recorded as follows:

1. Knee perturbation without patellar taping before muscle fatigue.
2. Knee perturbation with placebo patellar taping before muscle fatigue.
3. Knee perturbation with 3 kg of medial patellar taping force before muscle fatigue.
5. Knee perturbation with placebo patellar taping after muscle fatigue.
6. Knee perturbation with 3 kg of medial patellar taping force after muscle fatigue.

In the first three tests, a rest of 2 mins was given between each test to prevent muscle fatigue. The electrodes with a built-in gain of 330 and bandpass filter of 10–312 Hz were connected to an input box. The common-mode rejection ratio of the amplifier was 95 dB. The amplified signals were full-wave rectified and input into a data acquisition unit (DataQ Instruments, Akron, OH), which sampled at 500 Hz. The digitized signals were output to a personal computer with WinDaq Pro software (DataQ Instruments) for recording.

The signals from the accelerometer were synchronized with the EMG recordings. The instant of perturbation was demarcated by the accelerometer output, and the onset of muscle activity was defined as the time when the EMG signal exceeded the mean resting signal by more than 3 SD for at least 25 msecs.\(^{18}\)

The reliability of the above perturbation model and EMG onset identification was established with five other able-bodied subjects. These subjects were tested in condition 1 three times and the onset time of VMO and VL were recorded and compared with intraclass correlation coefficient (3,1) to establish reliability. The result of the intraclass correlation coefficient was 0.7, which indicated a moderate to high reliability\(^{19}\) of this measuring technique.

**Patellar Taping and Muscle Fatigue Exercise Protocol**

Patellar taping followed the procedures described by Ng and Cheng.\(^8\) In brief, 5-cm-wide adhesive tape (Strappal, Smith and Nephew, Charlotte, NC) was applied firmly over the lateral border of patella, and the other end of the tape was connected to a strain gauge transducer (Ronso Electronic, Hong Kong) with a digital-force display unit. In conditions 2 and 5, the examiner applied the tape from the lateral to the medial aspect of the knee without any tension. In conditions 3 and 6, the examiner pulled on the strain gauge transducer until a force of 3.0 kg was displayed and, at the
same time, secured the tape to the medial aspect of the knee to provide medial glide to the patella.8

After finishing with the first three testing conditions, the subjects performed a knee extension exercise on an isokinetic machine (Cybex NORM, Cybex Lumex, Ronkonkoma, NY) until their extension peak torque dropped to <50% of the original value for ten consecutive extensions, which was regarded as fatigue of the knee extensor muscles. When muscle fatigue developed, the above tests were repeated. To control for the interrater variability, only one examiner performed the taping procedure for all the subjects, and the sequence for the three tests before and after muscle fatigue was randomized.

Data Analyses

The examiner who analyzed the data was blinded to the testing conditions of the subjects so that any subjective bias was eliminated. Because this study aimed to examine the relative activation times of VMO and VL after perturbation, the absolute onset time of each muscle was recorded and the difference between the two times (VMO onset minus VL onset) was calculated and compared across the testing conditions with two-way repeated measures analysis of variance, with taping condition and fatigue being the two independent variables. The $\alpha$ value was set at 0.05 for the analysis of variance.

RESULTS

The mean values and standard deviations of the six testing conditions are presented in Table 1. The analysis of variance result revealed no interaction between the two independent variables. Analysis of the two main factors revealed no statistically significant effect of patellar taping ($P = 0.455$) or muscle fatigue ($P = 0.304$).

DISCUSSION

McConnnell1 was among the first to report the efficacy of patellar taping for treating anterior knee pain. Since that report, there have been a number of studies on the effects of patellar taping on patellofemoral joint alignment, pain relief, and VMO activation.4–9 The unique feature of the present study is that it examined the effect of patellar taping in able-bodied subjects in terms of VMO and VL temporal activation before and after fatigue with a sudden perturbation model so as to determine the physiologic actions of patellar taping under a reflex condition. The present results suggest that patellar taping may not alter the onset time of selected quadriceps muscle activities.

The inclusion of a placebo taping condition was to determine if the effect of patellar taping would be due to proprioceptive stimulation on the skin rather than the mechanical taping force. However, the present findings suggest that patellar taping, whether applied as a placebo measure or with real medial gliding force, has no significant effects on the VMO and VL activation time in able-bodied subjects.

A previous study by Gilleard et al.20 on the temporal relationship of VMO and VL activation in subjects with PFPS had demonstrated a change in VMO and VL activation time during functional tasks, such as ascending and descending stairs. They reported that the EMG onset time of VMO was facilitated with patellar taping in both ascending and descending stairs whereas that of VL was delayed after taping. However, these results are not shown in the present study, and the difference between the two studies may be due to the selection of subjects and model of testing. Subjects in the study of Gilleard et al.20 were patients with anterior knee pain syndrome, and their levels of pain might be altered after the taping procedure. In a recent study,8 subjects with anterior knee pain were reported to have a reduction of about 50% in their pain perception after patellar taping, which is clinically meaningful and significant. Similar results were also reported by Crossley et al.,21 with most patients having a significant reduction of pain, ranging from 13% to 78%, with patellar taping. The pain modulation effect with patellar taping could affect the physiologic responses of the quadriceps muscles such as the timing of activations. Because the subjects in the present study did not have knee pain, the pain modulation effect of patellar taping may not have a role for these subjects, and therefore, the EMG onset time of VMO and VL was not changed. Second, the present study tested the subject with a perturbation model that was different from the testing method of Gilleard et al.,20 which involved going up and down stairs. The perturbation model tests the reflex muscle recruit-

### Table 1

<table>
<thead>
<tr>
<th>Condition</th>
<th>No Tape, msecs</th>
<th>Placebo Tape, msecs</th>
<th>Real Tape, msecs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before fatigue</td>
<td>0.357 (2.13)</td>
<td>−0.144 (1.65)</td>
<td>0.133 (1.76)</td>
</tr>
<tr>
<td>After fatigue</td>
<td>0.977 (2.33)</td>
<td>0.713 (2.27)</td>
<td>0.948 (3.38)</td>
</tr>
</tbody>
</table>

February 2005

Patellar Taping and Muscle Fatigue

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ment, whereas stair climbing does not involve reflex muscle activities.

The present study focused on the EMG onset time of VMO and VL, and there was no recording of the magnitude of these muscles activities. It is possible that despite no change in the temporal activation pattern of the VMO and VL, their absolute activities in terms of levels of contraction might have been altered with the taping procedure. This would have an implication on the normal tracking of patella or the magnitude of retropatellar pressure, the predisposing factors of PFPS.

The present results reveal that VMO had later EMG onset time than VL in most testing conditions (Table 1). This may be explained by the fact that the role of VMO is for controlling the patella position rather than for generating knee extension moment.22 The perturbation model in this study was a sudden knee flexion movement that would primarily require the actions of knee extensors to counteract the flexion moment. This may explain why VMO had later EMG onset time than VL.

The exercise protocol used in the present study was not targeted for any particular muscle of the knee. Even though the primary function of VMO is for controlling the sideways movements of patella rather than contributing to the development of knee extension moment,22 it was decided that a knee extension exercise program should be used in the present study because this exercise simulates the normal functioning of this muscle group.

The fact that the subjects had dropped by 50% or more in their knee extension peak torque for ten consecutive isokinetic knee extension trials after the exercise implied that the exercise program was effective in fatiguing the quadriceps muscles. Tests 4–6 were conducted immediately after the exercise, and the whole procedure took <30 mins to complete. Based on a previous report, fatigue in VMO and VL would have <7% recovery in the first hour after exercise.14 Therefore, the present results can be considered as a true reflection of the muscles during their acute postexercise fatigued state.

Because this exercise model represents the simple flexion and extension movement of the knee, these results may be applicable for a variety of functional movements of this joint on the sagittal plane. The finding of no significant effect of muscle fatigue on the VMO and VL activation timing suggests that these muscles would adapt to the prolonged taping. Whether this exercise model is representative of clinical conditions is unknown.

Unlike the tests with stair climbing or walking, the present model of testing with knee perturbation may be regarded as being not functional. However, this model tests the reflex recruitment of VMO and VL, which is highly relevant to sports activities, and it has not been reported in previous studies. Unlike walking or stair climbing, the reflex action is not actively guarded by pre-event motor planning; thus, it could reveal the spontaneous reaction of VMO and VL during a sudden movement with and without taping. This finding could further our understanding of the basic physiologic mechanism of patellar taping, and thus, help explain its action in subjects with PFPS.

There are some limitations of this study that should be considered when interpreting the findings. Only the immediate effect of patellar taping was tested, as the tape was applied to each subject for approximately 2 mins. This does not simulate the clinical application in which the tapes would be applied for a much longer period of time. Whether the muscles would adapt to the prolonged taping differently is not known, and this needs to be examined with further studies. The perturbation model originally designed to test the reflex muscle activities might not have prevented preexisting muscle activities due to the subjects’ expectation of the perturbation before the release of the medicine ball. Furthermore, this perturbation model is not functional; therefore, the findings of this study may not be applicable to functional activities such as normal walking or stair climbing. The subjects in this study were screened so that they did not have any associated knee problems. Therefore, the findings are not generalizable to people with predisposing factors of anterior knee pain or to those who have early signs of PFPS. Finally, with the small subject number and the large variance of the data, the test did not have a high statistical power; thus, the possibility of a type II error cannot be excluded.

CONCLUSION

Patellar taping does not alter the relative activation time of VMO and VL in able-bodied subjects before and after muscle fatigue conditions.

ACKNOWLEDGMENTS

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Knee Extensor Isometric Unsteadiness Does Not Predict Functional Limitation in Older Adults

**ABSTRACT**

**Objective:** To determine how knee extensor steadiness is related to age and difficulty performing everyday tasks.

**Design:** In this cross-sectional study performed at a research laboratory, 50 older adults (age range, 56–95 yrs) performed steadiness testing at 50% of maximum strength and were timed and rated on four tasks of daily living: chair rise, stair ascent and descent, and walk. The independent variables of age, steadiness, and strength-to-weight ratio were entered into regression models with the ratings and time to complete the four everyday tasks as dependent variables.

**Results:** The strength-to-weight ratio was the only significant predictor in the multiple regression models, explaining 29%, 33%, 14%, and 14% of the variance in gait speed and time to complete a chair rise, stair ascent, and stair descent, respectively. Similar results were seen with task ratings. Age was not correlated with steadiness ($r = 0.25$, $P = 0.07$).

**Conclusion:** This study suggests that knee extensor isometric steadiness performance does not carry over to tasks of everyday living, and older subjects, regardless of age, have similar steadiness values. Because the strength-to-weight ratio predicted the most variance in functional performance, it is recommended that muscle strength be improved to increase function in older adults.

**Key Words:** Steadiness, Elderly, Aging, Function, Muscle Strength
Successful performance of everyday tasks in the elderly demands correct information transfer from the visual, somatosensory, and neuromuscular systems.\textsuperscript{1–3} Unfortunately, these collaborating physiologic systems deteriorate with aging and result in functional limitations, thus increasing the risk of developing a physical disability.\textsuperscript{4} The efficient transfer of information through these systems can be estimated using laboratory-based measures.\textsuperscript{5} For example, the variation in force fluctuations while controlling sustained submaximal forces about a target level has become a common laboratory-based measurement for the estimation of visuomotor accuracy.\textsuperscript{6–8}

The variation in force fluctuations during a sustained submaximal knee extensor contraction, or generally known as steadiness, is greater in older than younger adults.\textsuperscript{9,10} The physiologic mechanism of the age-related reduction in steadiness (increase in the variation of force fluctuations) is not fully understood. However, because the control of force fluctuations and performance of everyday tasks rely on the accuracy of the visuomotor system, one could surmise that knee extensor steadiness may be related to everyday task performance. This hypothesis is supported by the growing literature suggesting the increased variability in movement and the loss of motor control associated with aging is partially responsible for the slowness of movement and gait speed in aged individuals.\textsuperscript{11,12}

For example, with regard to gait speed, increased stride length variability contributes to the slowness of gait speed.\textsuperscript{13,14} In addition, stepping down requires a complex mixture of motor planning and intended trajectories\textsuperscript{15} that may overwhelm the deteriorated visuomotor system of the elderly, thus increasing the likelihood of falling down the stairs.\textsuperscript{2}

The measurement of knee extensor force fluctuations in the elderly provides for an estimation of visuomotor performance that may be related to functional limitation. From a clinical and research perspective, it would be advantageous to have a single estimation of visuomotor performance and thus an easily identifiable risk factor for functional limitation. Furthermore, because knee extensor unsteadiness in the elderly can be improved with training,\textsuperscript{9} it could become a modifiable risk factor. However, for this to happen, more research is needed to discover a possible link between the control of knee extensor force fluctuations and functional limitation.

Two pieces of information would help to establish a link between steadiness and functional limitation. First, is submaximal control of the knee extensors associated with functional limitation? Second, is there an age-related reduction in steadiness among older adults as evident with the loss in muscle strength and functional ability? To answer the first question, older individuals with and without functional limitations need to be tested to determine the association with knee extensor steadiness. Regarding the second question, previous studies documenting the age-related reduction in knee extensor steadiness have typically compared older (\textgtrsim 70 yrs of age) with younger adults (\textless 25 yrs of age), with an age difference of approximately 40–50 yrs.\textsuperscript{6,10} Knee extensor steadiness should also be documented in older adults between 50 and 90 yrs of age, which would help to understand how steadiness is altered in later life.

The primary purpose of this study was to determine how knee extensor steadiness during an isometric task is related to performing four everyday tasks that included chair rising, walking at a fast pace, and stair ascending and descending. Because knee extensor steadiness seems to be dependent on the efficient transfer of information from the sensory to the muscular system, we hypothesized that stair ascending/descending and gait speed would be associated with knee extensor steadiness. Because chair rising is dependent on muscular strength or power as opposed to accurate movement as with stair climbing or walking,\textsuperscript{16} we expected that there would be no relationship with chair rise ability. A secondary purpose of this study was to cross-sectionally analyze knee extensor steadiness in later life.

**METHODS**

**Subjects**

To recruit subjects, advertisements were posted and presentations made at local senior centers. On interest in the study, subjects were interviewed by phone and asked about their age and ability to perform some common tasks of everyday living. These questions were used to help recruit a wide age range of subjects and subjects with varying success in everyday task performance. A total of 16 men and 34 women with and without difficulty performing tasks of everyday living volunteered for the study. Before visitation to the laboratory, each subject was asked several health questions to assess the possible risks associated with resistance exercises.\textsuperscript{17} If a possible health risk was identified through the survey, the subjects’ physician was contacted for clearance into the study. Subjects reported no neurologic diseases or medications that were known to influence the dependent variables of interest. Detailed information about subject demographics can be found in Tables 1 and 2. All subjects provided written informed consent before participation in the experiment. The Institu-
tional Review Board at Syracuse University approved the experimental protocol.

Experimental Design

Before testing, subjects were measured for body height and weight and answered a survey on current health conditions, impairments, and activities of daily living and instrumental activities of daily living. Subjects then underwent a unilateral leg-extension strength test with the right leg followed by a steadiness task. During the 15-sec steadiness task, subjects received visual feedback for a target force at 50% of maximal voluntary isometric contraction (MVIC) via a computer monitor.

After the strength and steadiness tasks, subjects were asked to perform four tasks of daily living as fast as comfortably possible: ascending and descending a flight of stairs, rising from a standard-height chair, and walking at a fast pace. Male subjects were both taller and heavier than female subjects. *P = 0.00.

Survey

Subjects were asked to answer a section from the from the Longitudinal Study of Aging survey that deals with activities of daily living and instrumental activities of daily living performance. All questions about activities of daily living performance began, “Because of a health or physical problem do you have ANY difficulty. . .,” and ended with information about the specific task. If the subject answered “yes” to the question, a follow-up question asked, “By yourself and without special equipment, how much difficulty do you have. . .” performing the said task? Subjects were asked to choose “Some, A lot, or Unable to do” for the follow-up question.

Documentation of physical activity was brought forth by reports suggesting that knee ex-
tensor steadiness may be altered after exercise training, but it was added after testing 12 subjects. Therefore, only 38 out of 50 subjects were asked about their current physical activity level, which was primarily used to ensure that subjects were of a similar activity level. Physical activity was coded into three categories: no regular exercise, mild regular exercise, or routine exercises. Subjects ranked as “mild exercisers” occasionally swam, walked, or biked but were not enrolled in an exercise program. Subjects who were categorized as “routine exercisers” participated in an organized exercise program that met several times per week.

Measurement of Force

A knee extension dynamometer (MedX, Ocala, FL) was used for measurement of torque during both MVIC and steadiness tests. The subjects were seated with the hip position at a right angle and the knee at 60 degrees of full extension. The seat was positioned so that the lateral epicondyle of the knee matched the axis of rotation of the lever arm. Pelvic and calf restraints were placed over appropriate regions and tightened to minimize synergistic muscle action.

The force transducer (HBM Type U1T-XX125, Marlborough, MA) used during testing was positioned at the axis of rotation and measured force through the lever arm (length, 30.48 cm). The analog signal from the force transducer was digitized at 1000 Hz with a 12-bit data-acquisition card (PCI-1200, National Instruments, Austin, TX) and displayed on a 43.2-cm video display. The resolution of our system was adjusted for each subject by using the calibration factor of the force transducer and the 50% MVIC force level to determine the output voltage of the isometric steadiness test. The input gain was then altered to maximize the resolution of the system. The input gain of 2, 5, 10, and 20 resulted in a resolution of 0.114 Newton-meters (Nm)/bit, 0.066 Nm/bit, 0.035 Nm/bit, and 0.024 Nm/bit, respectively. Maximizing the resolution limited the error in the steadiness measure associated with the differences in absolute strength between individuals. Forces used during the steadiness test ranged from 24.2 Nm to 105.6 Nm. All force data were collected and analyzed using Labview 5.01 (National Instruments).

All subjects were familiarized with the equipment and practice trials were given before testing. During the test, the lever arm was locked and subjects were instructed to push against the pad (located at the shin) as hard and as fast possible for 2–3 secs. Verbal encouragement was given throughout the test. Isometric torque was concurrently displayed to provide visual feedback. Subjects repeated strength trials until two consecutive trials were within 5% of each other. The peak trial was recorded in Newton-meters and used for data analysis. To equally compare subjects, we calculated a strength-to-weight ratio (STR/WT = Nm/kg) by dividing unilateral leg extensor muscle strength (Newton-meters) by body weight (kilograms).

Quantification of Isometric Steadiness

After assessment of MVIC, isometric steadiness was evaluated on the right leg at 50% of MVIC (Fig. 1). The 50% MVIC load was chosen to represent possible loads experienced during functional tasks and for comparison with previous studies. Subjects were asked to exert the force to a target level, which was indicated by a horizontal red line on a computer screen, and maintain that level as steady as possible for 15 secs (Fig. 2). The y-axis (i.e., vertical gain) was adjusted to allow similar visual representations between subjects with differing contraction loads. A minimum of two practice trials and up to five practice trials was given to each subject. These practice trials were followed by three trials that were recorded for data analysis. There was no statistical difference between the recorded trial 2 and 3; thus, the learning effect was minimized by trial 3. The visual display was placed 1 m directly in front of the subject. Steadiness was calculated as the standard deviation about the average force (coefficient of variation = [SD/average]*100) over the middle 8-sec epoch of each 15-sec trial. The trial with the lowest coefficient of variation was recorded and used for data analysis. A representative sample of force fluctuations during the knee extensor isometric steadiness test at 50% of MVIC is shown in Figure 2.

Assessment of Everyday Task Ability

Subjects were asked to perform four everyday tasks, which included ascending and descending 11 steps (height, 19 cm; depth, 28 cm), rising from a chair (seat pan height, 45 cm), and walking as fast as comfortably possible across a lighted hallway. Before task performance, each subject was given a scripted set of directions. Subjects were categorically rated and timed on both the stair ascent and descent and chair rise tasks, but only timed on the walk test. Each task is described in detail below.

Stair Ascent and Descent

Subjects performing the stair ascent and descent task were categorized based on their use of the handrail and balance. The verbal directions to the subject were, “On the word ‘go,’ please ascend/descend these flight of steps, one leg after another, as fast as comfortably possible. If you absolutely need the handrail, please use it, but if you don’t need it, then don’t use it.” When a subject needed
to use the handrail for balance or weight support, they were categorized as having difficulty performing the task. If a subject was able to climb all steps one leg after another without using the handrail, they were categorized as having no difficulty performing the task. Reliability of this rating scale has been previously established (r = 1.0 and 0.93 for intertrial; r = 0.74 and 0.78 for interinvestigator for stair ascent and descent tasks, respectively).20

Chair Rise

Directions for the chair rise were, “On the word ‘go,’ please rise from the chair with your hands across your chest, as fast as you can. If you absolutely need your hands to rise from the chair, please do so; otherwise, do not.” During the chair rise task, subjects who needed to scoot toward the front of the chair, lift their feet, and rock to the front to produce momentum or place their hands on the armrests or on their legs to push themselves up to standing position were categorized as having difficulty performing the task. Subjects who did not exhibit these strategies were categorized as having no difficulty performing the task. Reliability of this rating scale has been previously established for the chair rise task (r = 0.95 for intertrial; r = 0.93 for interinvestigator).20 Timing of the chair rise and stair ascent/descent began when the subject initiated the task and ended when the subject completed the task.

Fast Walk

Subjects were asked to walk 7.62 meters at their fastest pace.21 Directions to the subject were, “On the word ‘go,’ please walk across this hall as fast as comfortably possible; pretend you are late for a meeting or the bus and you need to walk as fast as possible, but you cannot run.” Because there are many factors that cause an older adult to walk slowly (i.e., stride length and stride frequency), no categorized scale was used for the walking task. The time to complete the task was calculated into gait speed and used for data analysis.

Data Analysis

A one-way analysis of variance was used to test mean differences in age and anthropometric data between each sex and difficulty group. To control for alpha inflation, a modified Bonferroni procedure was employed.22 χ² analyses were used to determine differences in activity levels between groups at each task. Chair rise, stair ascent, and stair descent were analyzed separately using two types of statistics: multiple and logistic regression. Multiple regression was used to evaluate time to complete the task. Logistic regression was used for the dichotomous dependent variables, coded as 1 = difficulty and 0 = no difficulty. Because walking speed was not categorized, it was only analyzed using multiple regression. The independent variables for these models included steadiness (coefficient of variation), STR/WT, and age. The inclusion of age in these models was used to control for the previously reported relationship of age to both steadiness6 and STR/WT.23 Both beta and standardized beta coefficients were obtained, along with squared semipartial correlations, which were used to determine the amount of unique variance attributed to each independent variable. Standardized beta coefficients for logistic regression were calculated according to equations devised by Menard.24

To cross-sectionally study steadiness alter-
ations with age, a simple linear regression model was developed. To test the possibility of a nonlinear association between age and steadiness, a quadratic regression model was employed. All statistical tests were performed using STATA 7.0 software (College Station, TX). A $P$ value of $\leq 0.05$ was used to reject the null hypothesis.

RESULTS

Subjects having no difficulty rising from a chair and no difficulty ascending and descending a flight of stairs were younger than subjects with difficulty performing the tasks (Table 3). Subjects with no difficulty ascending or descending the stairs were also taller than subjects having difficulty performing the task (Table 3). This finding was a result of male subjects having less difficulty performing the tasks of everyday living and being taller and heavier than female subjects. For example, only three male subjects had difficulty with the chair rise, whereas 16 female subjects had difficulty performing the task. The activity level of subjects in each group was similar, regardless of task (Pearson $\chi^2$, $P > 0.05$).

Multiple Regression Model

The full model $R^2$ value was significant ($P < 0.001$) for each task (Table 4). The beta coefficient of STR/WT was the only significant independent variable for each task. The squared semipartial correlation for STR/WT was higher than any other independent variable and explained most of the variance in task completion time, regardless of task. Age and steadiness did not have significant beta coefficients and explained very little of the full model variance.

Logistic Regression Model

The full model $R^2$ value was significant ($P < 0.001$) for each task (Table 5). The beta coefficient for STR/WT was the only significant coefficient in each task. This means that a 1 SD loss in STR/WT results in 0.63 SD increase in difficulty performing chair rising, whereas a standard deviation increase in force fluctuations only results in a 0.12 SD increase in difficulty performing a chair rise. Overall, both age and steadiness were not related to difficulty performing any task.

Surprisingly, the $R^2$ values for both multiple and logistic regression models were similar. Therefore, using either categorized rankings or time to complete the task yielded consistent results. Even some standardized beta coefficients in multiple and logistic models were similar (i.e., STR/WT in the chair rise model), thus strengthening the relationship between the categorized measurements of difficulty and time to complete the task. Discrepancies between the two models did occur with age, approaching significance in stair ascent and descent when measuring time to complete the task.

Steadiness and Age

There was no relationship between steadiness and age using the linear ($r = 0.25$, $P = 0.07$) or nonlinear regression model ($r = 0.26$, $P = 0.18$). The predicted fit between the two models is displayed on Figure 3.

DISCUSSION

The purpose of this study was to determine if steadiness along with other traditionally accepted correlates of functional ability are related to rising from a chair, ascending/descending a flight of stairs, and gait speed. We hypothesized that steadiness, a form of motor control, would be related to stair ascending/descending ability and gait speed but not to chair rise ability. In fact, the beta coefficient for steadiness was highest (beta $= 0.241$, $P = 0.09$) in the stair ascent task when using the categorical ranking. However, the standardized beta coefficient for gait speed was low. Therefore, our hypothesis was rejected for stair ascent/decent and gait speed and accepted with chair rise.

### TABLE 3 Descriptive data for subjects grouped by difficulty level

<table>
<thead>
<tr>
<th>Group</th>
<th>$n$</th>
<th>Age, yrs Mean (95% CI)</th>
<th>Height, cm Mean (95% CI)</th>
<th>Weight, kg Mean (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chair rise</td>
<td>ND</td>
<td>73.8 (71.2–76.4)$^a$</td>
<td>164.7 (161.2–168.3)</td>
<td>76.1 (70.2–82.1)</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>80.0 (75.6–84.5)</td>
<td>163.3 (159.1–167.6)</td>
<td>73.3 (67.6–86.9)</td>
</tr>
<tr>
<td>Stair ascent</td>
<td>ND</td>
<td>73.2 (70.7–75.7)$^a$</td>
<td>166.0 (162.6–169.5)$^a$</td>
<td>78.0 (72.1–83.9)</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>82.0 (77.9–86.2)</td>
<td>160.7 (156.8–164.7)</td>
<td>73.8 (63.7–83.8)</td>
</tr>
<tr>
<td>Stair descent</td>
<td>ND</td>
<td>73.1 (70.5–75.6)$^a$</td>
<td>166.7 (163.1–170.2)$^a$</td>
<td>77.6 (71.5–83.9)</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>80.5 (76.4–84.6)</td>
<td>160.8 (157.0–164.7)</td>
<td>75.1 (66.2–83.9)</td>
</tr>
</tbody>
</table>

ND, no difficulty; D, difficulty.
Subjects having difficulty on the three tasks were younger than subjects having no difficulty. Subjects having difficulty on the stair ascent and descent task were shorter than subjects without difficulty.

$^a P < 0.05$. 

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This study supports the compendium of literature that shows muscle strength is a strong correlate of everyday task performance. It also supports the idea that age may not be an important factor for determining task performance when compared with muscle strength. These findings have prompted many clinical and research professionals to use resistance training to improve everyday task performance. Depending on the functional ability of the group studied, resistance training in older adults has shown positive improvements in function.

**Steadiness and Function**

It was hypothesized that knee extensor isometric steadiness, a measure of visuomotor performance, may be an indicator of functional limitation. The link between the laboratory test of isometric steadiness and functional ability seems possible because both require the efficient transfer of information from the visual, somatosensory, and neuromuscular systems. For example, gait generates a multitude of somatosensory cues from the visual system and feedback about limb displacement from muscle spindles and joint receptors. Decrement in the somatosensory system attribute to the variation in steadiness and gait speed, and thus, a relationship between the two may exist. Furthermore, the variability in step length is partially responsible for the slowness of gait in older adults, possibly resulting from an error in the transfer of information from the somatosensory and neuromuscular systems. However, because

---

### TABLE 4: Multiple regression model for time to complete each task of everyday living

<table>
<thead>
<tr>
<th>Parameter</th>
<th>β</th>
<th>Beta</th>
<th>P</th>
<th>sr²</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chair rise</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.33</td>
</tr>
<tr>
<td>STR/WT</td>
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<td>0.00</td>
<td>0.33</td>
<td></td>
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<tr>
<td>Age</td>
<td>−0.03</td>
<td>−0.23</td>
<td>0.09</td>
<td>0.04</td>
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</tr>
<tr>
<td>Steadiness</td>
<td>0.39</td>
<td>0.071</td>
<td>0.57</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>Stair ascent</td>
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<td></td>
<td></td>
<td></td>
<td>0.34</td>
</tr>
<tr>
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<td>−4.54</td>
<td>−0.416</td>
<td>0.00</td>
<td>0.14</td>
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<tr>
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<td>0.14</td>
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<td>0.06</td>
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</tr>
<tr>
<td>Steadiness</td>
<td>0.14</td>
<td>0.057</td>
<td>0.65</td>
<td>0.003</td>
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</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>0.49</td>
</tr>
<tr>
<td>STR/WT</td>
<td>−5.54</td>
<td>−0.41</td>
<td>0.00</td>
<td>0.14</td>
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<tr>
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<tr>
<td>Steadiness</td>
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<td>−0.04</td>
<td>0.74</td>
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<tr>
<td>Gait speed</td>
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<tr>
<td>STR/WT</td>
<td>0.49</td>
<td>0.587</td>
<td>0.00</td>
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<tr>
<td>Age</td>
<td>−0.006</td>
<td>−0.151</td>
<td>0.22</td>
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<tr>
<td>Steadiness</td>
<td>−0.014</td>
<td>−0.075</td>
<td>0.50</td>
<td>0.005</td>
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</tr>
</tbody>
</table>

Beta, standardized beta coefficient; sr², squared semipartial correlation (the amount of R² that is uniquely attributed to the independent variable); STR/WT, ratio of leg extension peak isometric torque to body weight.

R² for each model is significant (P < 0.001). STR/WT is the only significant predictor of each task. Age and steadiness are not related to time to complete the any task.

### TABLE 5: Logistic regression for categorized ratings of each task of everyday living

<table>
<thead>
<tr>
<th>Parameter</th>
<th>β</th>
<th>Beta</th>
<th>P</th>
<th>R²</th>
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<tr>
<td>Chair rise</td>
<td></td>
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<td></td>
<td>0.36</td>
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<td>STR/WT</td>
<td>−4.24</td>
<td>−0.629</td>
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<td>Steadiness</td>
<td>0.183</td>
<td>0.122</td>
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<tr>
<td>Stair ascent</td>
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<td></td>
<td></td>
<td>0.50</td>
</tr>
<tr>
<td>STR/WT</td>
<td>−4.61</td>
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<tr>
<td>Age</td>
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<tr>
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<tr>
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<td></td>
<td>0.49</td>
</tr>
<tr>
<td>STR/WT</td>
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<td>−0.672</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>Age</td>
<td>0.042</td>
<td>0.104</td>
<td>0.47</td>
<td>0.47</td>
</tr>
<tr>
<td>Steadiness</td>
<td>0.302</td>
<td>0.164</td>
<td>0.24</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Beta, standardized beta coefficient (i.e., a 1 SD decrease in STR/WT is associated with a 0.55 SD increase in difficulty on the stair ascent); STR/WT, ratio of leg extension peak isometric torque to body weight.

R² for each model is significant (P < 0.001). STR/WT is the only significant predictor of difficulty performing each task.

**STR/WT**

This study supports the compendium of literature that shows muscle strength is a strong correlate of everyday task performance. It also supports the idea that age may not be an important factor for determining task performance when compared with muscle strength. These findings have prompted many clinical and research professionals to use resistance training to improve everyday task performance. Depending on the functional ability of the group studied, resistance training in older adults has shown positive improvements in function.
these subjects represented a specific part of the population that would be expected to show steadiness difficulties (low-functioning older adults), the results show that knee extensor isometric steadiness is not an indicator of functional limitation.

Fifty-percent MVIC during the steadiness test was used to mimic the intensity of everyday tasks in older adults.\textsuperscript{19,33} Higher intensities were not used to prevent muscle fatigue, which would influence the steadiness measurement.\textsuperscript{34} Knee extensor isometric steadiness has not been used to explain variance associated with the time to complete or difficulty performing everyday tasks, which was done in an attempt to understand how unsteadiness of the knee extensors contributes to everyday task performance. This rationale was developed based on the different strategies older adults use when performing gait,\textsuperscript{35} chair rise,\textsuperscript{36} and stair climbing\textsuperscript{37} when compared with younger adults. Taken together, these altered strategies when compared with younger adults reflect the loss of stability and muscle strength. However, these strategies do not seem to be related to the ability to control muscle force during an isometric contraction.

Our findings may be influenced by a predominance of men in the no-difficulty group. For example, only three men had difficulty performing the chair rise task, one man had difficulty with the stair ascent, and two men had difficulty with the stair descent task. However, a post hoc analysis showed that there was no difference in steadiness between sexes ($P = 0.74$). Therefore, sex should not influence the steadiness measurement, and our results are not biased by this difference in groups.

Another aspect of our results that needs to be explained is the discrepancy in self-report and observed performance of function. For example, 11 subjects reported they had difficulty performing bed/chair transfers, whereas 17 subjects were observed as having some type of difficulty performing the task. These discrepancies are commonly reported when comparing observed and self-report data, and our findings are consistent with others who reported that subjects tend to overestimate their everyday task ability. Therefore, this finding should not detract from the overall results of the study.

Recently, interventions have been developed to counteract the loss of steadiness associated with aging.\textsuperscript{10,38} According to our results, the purpose of this training should not be to improve steadiness to counteract the loss of function associated with aging. Steadiness training, however, may serve as a method for understanding neuromuscular system adaptation and thus may serve as a basic science research tool.\textsuperscript{39}

In light of these findings, one may surmise that isometric steadiness is not related to everyday function because the movements are distinctly different, with everyday tasks being dynamic in nature. For example, in the elbow flexors, older adults have greater force fluctuations during eccentric and concentric movements when compared with isometric contractions.\textsuperscript{40} Because tasks of everyday living are dynamic movements, future research should examine how isotonic steadiness is related to task performance. In addition, the intensity level of the steadiness test used in this study may not reflect altered motor strategies and thus mask differences in subjects with and without difficulty performing everyday tasks. It should also be noted that these findings are limited to the time domain (i.e., coefficient of variation of force); future research may find the frequency structure of force oscillations to be related to functional limitation. Finally, our measure of difficulty was based on a categorized ranking; a more sensitive measure of functional limitation using kinematic motion analysis may be better suited to determine the relationship with isometric steadiness.

**Steadiness and Age**

Because the average age of the young subjects in previous studies that examined knee extensor steadiness was approximately 20 yrs of age, a secondary purpose of this study was to highlight a potential relationship between age and steadiness in later life. If a relationship did exist, one could surmise that this change in neuromuscular control may attribute to functional limitation, similar to how muscular strength is linearly related to functional ability. Our results suggest there is no relationship between age and steadiness when exam-
impaired in a group of older adults ranging in age from 56 to 95 yrs. Therefore, knee extensor isometric steadiness is not reduced in later life and thus does not play a similar role as muscular strength in predicting functional limitation. These results, however, are limited to 50 subjects; a larger and wider age range sample may provide further insight into the relationship between knee extensor isometric steadiness and age.

This new information about the relationship between knee extensor isometric steadiness and age does offer more insight into age-related changes in motor control. For example, previous studies between old and young adults suggest that older adults are less steady than younger adults in the first dorsal interosseous, elbow flexor, and the knee extensor muscles at low intensities that range from 2% to 10% of MVIC. However, several studies have reported no differences between young and old adults in knee extensor steadiness at intensities of >20% MVIC. Our methods and results are most consistent with Tracy et al., who showed no difference between young and old adults at 50% MVIC. Our decision to use a higher intensity for the steadiness test stemmed from previous work showing older adults require, on average, 80% of maximal muscle strength to successfully accomplished chair rise and stair ascent/descent tasks. However, isometric steadiness at higher intensities may not be influenced by aging because they cause an increase in discharge rate of the motor neuron pool, which reduces force fluctuations. Therefore, it is recommended that future research be performed at lower intensities at which differences between ages seem to exist.

CONCLUSION

This study suggests that knee extensor isometric steadiness is not an independent predictor of performance on chair rise, stair ascent/descent, and gait speed tests. Clinicians and researchers are advised to use knee extensor isometric steadiness testing at 50% MVIC as a basic research tool for studying the neuromuscular system. The use of isometric steadiness testing as an applied measurement to help explain decrements in everyday function needs further exploration. Regarding the relationship between knee extensor isometric steadiness and age, it seems that higher intensities should be avoided when attempting to study age differences in motor control via isometric steadiness testing.

As shown previously, STR/WT contributes to difficulty performing everyday tasks more than chronological age. Taken together, because STR/WT is strongly related to task performance, clinicians and researchers should focus their efforts on improving muscle strength in older adults.

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Sports-Related Knee Injuries in Female Athletes

What Gives?

ABSTRACT


Knee injuries occur commonly in sports, limiting field and practice time and performance level. Although injury etiology relates primarily to sports specific activity, female athletes are at higher risk of knee injury than their male counterparts in jumping and cutting sports. Particular pain syndromes such as anterior knee pain and injuries such as noncontact anterior cruciate ligament (ACL) injuries occur at a higher rate in female than male athletes at a similar level of competition. Anterior cruciate ligament injuries can be season or career ending, at times requiring costly surgery and rehabilitation. Beyond real-time pain and functional limitations, previous injury is implicated in knee osteoarthritis occurring later in life. Although anatomical parameters differ between and within the sexes, it is not likely this is the single reason for knee injury rate disparities. Clinicians and researchers have also studied the role of sex hormones and dynamic neuromuscular imbalances in female compared with male athletes in hopes of finding the causes for the increased rate of ACL injury. Understanding gender differences in knee injuries will lead to more effective prevention strategies for women athletes who currently suffer thousands of ACL tears annually. To meet the goal in sports medicine of safely returning an athlete to her sport, our evaluation, assessment, treatments and prevention strategies must reflect not only our knowledge of the structure and innervations of the knee but neuromuscular control in multiple planes and with multiple forces while at play.

Key Words: Anterior Cruciate Ligament, Athletic Injuries, Female, Biomechanics

INTRODUCTION

Girls and women are more active than ever in competitive athletics. Although the first Olympic event open to women was swimming in 1912, it would take six decades for passage of the education amendments of 1972, Title IX, and another 16 years for the 1988 Civil Rights Restoration Act, which reinforced compliance with Title IX. Title IX was enacted to level the playing field for women in athletics by mandating increased institutional support for women’s programs. More recently, the United States women’s world cup soccer champion team and the WNBA have provided venues for positive public support of women in athletics. Older women who may not have had access to competition at a younger
age are getting the public health message about the health benefits of physical activity and taking advantage of available opportunities in sports.

As participation in sports continues to grow, the sports medicine clinician will treat female athletes presenting with knee pain and injury. Although female athletes experience similar injuries to men in comparable sports, there are some types of knee injuries that occur more frequently in women. It is paramount that physicians and other health care clinicians and researchers in the field of sports medicine determine the causative factors in this inequity as we continue to study maximization of sports functioning for our athletes. Gender differences in knee injury epidemiology, anatomy, neuromuscular control, and training and conditioning must be addressed in our didactic teaching about sports-related knee injuries so that healthcare providers can perform the best evaluation, physical assessment, and treatment planning. With increasing knowledge of causative factors in knee injuries, more effective and appropriate prevention strategies can be implemented for at risk individuals.

**Knee: Form Follows Function, But Let’s Not Forget Neurophysiology and Physics**

Much of our undergraduate and medical school training revolves around understanding the articulations that make up the knee joint, the muscles and their attachments, and the neural structures innervating the knee’s sensory and motor activities. Beyond learning the intricacies of the tibiofemoral joints and the patellofemoral joint, one cannot discuss the function of the knee without considering the proximal articulations (hip, pelvis, and spine) and distal articulations (ankle and foot) as knee function will depend upon and be dictated by the proximal and distal position of the lower limb and trunk. Similarly, one cannot ignore the proprioceptive function of receptors in multiple structures, including the anterior cruciate ligament (ACL) or quadriceps, and the alterations in proprioceptive function related to pain, edema or loss of continuity.

More fundamental is the acknowledgment that forces of gravity, momentum, and ground reaction in multiple planes of motion dictate sports-related knee function. In no arena is this more pertinent than when one considers noncontact ACL injuries. Multiplanar control at the knee may be directly impacted by foot position, ligamentous laxity, muscle fatigue after repetitive eccentric contractions or knee joint positioning that inhibits rather than recruits the optimal muscle cocontraction patterns; therefore, all these areas are being studied in conjunction with the increase in noncontact ACL injuries in girls and women compared with boys and men.

This article will review the relevant literature in the area of knee injuries in women. After a brief review of anatomy, clinical and basic science research in the area of ACL injury will be reviewed along its various directions. Studies on hormonal effects on human ligament biomechanics evolved from animal studies. Studies of proprioception and balance in female athletes have developed from work on proprioception and balance in ACL-injured or ACL-deficient athletes. Studies of interventions to reduce injury risk are based on human biomechanical studies noting the differences in how males and females jump and land. Ongoing work includes interventional studies of neuromuscular training programs with elegant designs that one can use to direct prevention programs in the future in hopes of eliminating or at least reducing the higher injury rates in girls and women.

**Knee Anatomy**

The knee joint, the largest joint in the body, is comprised of three articulations: the patellofemoral and the medial and lateral tibiofemoral joints. Knee movements are simplified primarily to flexion and extension however the knee is able to move in 6 df, including three translational and three rotational. The medial and lateral menisci lie within the medial and lateral compartments, respectively. The meniscus act as shock absorbers and stabilize the knee by deepening the shallow tibial articular surfaces. Meniscal injuries commonly occur in the context of knee flexion, rotation and compression. Age-related mensical degeneration can cause fragility of the meniscus predisposing to tears with minimal trauma.

The medial (tibial) and lateral (fibular) collateral ligaments act to prevent valgus and varus movements of the knee as well as medial and lateral rotation. (Fig. 1) The medial collateral ligament (MCL) extends from the medial epicondyle of the femur to the medial condyle of the tibia, attaching to the medial meniscus. MCL injuries can occur in conjunction with acute medial meniscal tears. The lateral collateral ligament (LCL) extends from the lateral epicondyle of the femur to the fibular head. Posteriorly, the knee is protected by the oblique popliteal ligament, an extension of the semimembranosus muscle, and the arcuate popliteal ligament, which extends from the lateral condyle of the femur to the posterior aspect of the fibular head.

The cruciate ligaments, including the ACL and posterior cruciate ligament (PCL), prevent anterior and posterior translation of the knee joint. (Fig. 1) The ACL extends from the anterior intercondylar region of the tibia to the medial aspect of the
lateral condyle of the femur. It prevents anterior displacement of the tibia, primarily in a flexed position, and hyperextension of the knee. The PCL extends from the posterior intercondylar region of the tibia to the lateral aspect of the medial condyle of the femur. It protects against hyperflexion of the knee joint and posterior translation of the tibia. The cruciate ligaments travel through the femoral notch.

The patella is part of the extensor mechanism of the knee, along with the quadriceps femoris muscle, quadriceps tendon and patellar tendon. The patella adds considerably to the stabilizing force of the extensor mechanism with patellofemoral joint reactive forces resulting when the patella is compressed against the femur. Patellofemoral pain syndrome most typically presents because of chronic overload. Increased femoral internal rotation can lead to abnormalities in tracking of the patella and is often caused by femoral anteversion, tight lateral thigh musculature, and weak gluteus medius.

Multiple muscles act across the knee with long lever arms from the femur above and tibia below. These muscles are capable of generating and transferring considerable force to the knee. Ground reaction forces are transferred proximally via the weight-bearing knee to the hip and trunk; many sports require the unweighted lower limb to generate forces across the knee, as in kicking. Muscles about the knee regulate forces in the lower extremity and decelerate the body over the lower limb during running, landing, cutting, and stopping. Primary muscles of knee control include the quadriceps anteriorly, the hamstrings (especially the semimembranosus), and gastrocnemius posteriorly, the gluteus medius and tensor fascia lata/iliotibial band laterally and the adductors medially. In sporting activities, the repetitive, eccentric nature of musculature activity about the knee may lead to fatigue related injuries.

Epidemiology of Knee Injuries

The risk factors for lower extremity injuries have been divided into both extrinsic (from factors outside the body) and intrinsic (from factors within the body). Extrinsic risk factors include level of competition, skill level, shoes and orthotic equipment, and playing surface. Intrinsic risk factors include age, sex, phase of the menstrual cycle, ligamentous laxity, previous injury, aerobic fitness, body size and limb girth, limb dominance, flexibility, muscle strength and imbalance, reaction time and postural stability, anatomic alignment and foot morphology. Although the focus of this paper is on gender differences, risk factors will be discussed in regards to sex hormones/menstrual cycle, anatomic considerations, and neuromuscular imbalances. See Table 1 for an overview of these topics and references. It may be that the salient risk factors for sports-related knee injury differs between men and women.

Gender as a Risk Factor

In regards to gender difference, many studies have shown that female athletes sustain more knee injuries than male athletes, specifically ACL sprains. Anterior knee pain is more common in women athletes than men. In one study of male and female professional basketball players evaluated by their athletic trainers, females suffered 60% more injuries than males, with knee and
TABLE 1 Risk factor for knee injury in female athletes

<table>
<thead>
<tr>
<th>Risk Factor for Knee Injury</th>
<th>Reference</th>
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<td>NCAA injury rates differ, female &gt; male</td>
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<td>Chandy et al.15</td>
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<td>Professional basketball injury rates differ, female &gt; male</td>
<td>Powell et al.14</td>
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<td>Sex Hormones</td>
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<td>Injury rate differs by menstrual cycle phase</td>
<td>Myklebust et al.23</td>
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<tr>
<td>No variation in ligament laxity in different phases</td>
<td>Wojtys et al.24</td>
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<td>Oral contraceptive use offered no injury protection</td>
<td>Slauterbeck et al.25</td>
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<td>Anatomic Considerations</td>
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<td>Q angle higher in injured female athletes</td>
<td>Shambaugh et al.31</td>
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<td>Static postural faults correlated with higher injury rate</td>
<td>Loudon et al.33</td>
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<td>Griffin et al.20</td>
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<td>Shelbourne et al.41</td>
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<td>Notch size not associated with increased injury risk</td>
<td>Schickendantz et al.42</td>
</tr>
<tr>
<td>Notch shape associated with increased injury risk</td>
<td>Teitz et al.43</td>
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<td>Neuromuscular Imbalances</td>
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<td>Proprioception deficits in ACL-deficient or ACL-injured</td>
<td>Ireland44</td>
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<tr>
<td>Single leg stance deficits females &gt; males</td>
<td>Barrack et al.45</td>
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<td>Jumping and landing strategies differ female vs. male</td>
<td>Wojtys et al.46</td>
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<td>Jumping landing did not differ female vs. male</td>
<td>Barrett et al.47</td>
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<tr>
<td>Females with greater valgus dominant knee</td>
<td>Corrigan et al.48</td>
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<td>Females with highly dominant dominant leg</td>
<td>Hewett et al.51,52</td>
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<td>Preseason strength and conditioning deficits associated with injury</td>
<td>Schultz et al.53</td>
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<td>Preseason conditioning program associated with reduced injury</td>
<td>Rozzi et al.54</td>
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<td>Quadriceps-dominant pattern in female athletes</td>
<td>Fagenbaum et al.54</td>
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<td>Quadriceps-dominant pattern in elite athletes</td>
<td>Ford et al.57</td>
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<td>Eccentric muscle fatigue in female athletes</td>
<td>Hewett et al.59</td>
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<tr>
<td>Stiffness/elasticity differences females vs. males</td>
<td>Knapik et al.60</td>
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</table>

thigh injuries most common.17 In a study of female secondary school basketball players, injuries to the knee accounted for 91% of season ending injuries and 94% of injuries requiring surgery.15 It is estimated that 1 in 3,000 individuals in the United States sustains an ACL injury, accounting for 100,000 injuries annually, with women at higher risk in particular sports.20 Researchers have calculated that in 2002 there were approximately 7,000 ACL ruptures in high school female basketball players alone, using an injury rate of 1 per 65 participants, and 452,728 female high school basketball players in the United States.18,21 The relationship between gender and increased rate of ACL tears has been well documented; however, the relationship between gender and other lower extremity injury is less clear.22

**Sex Hormones and Menstrual Cycle Considerations**

Fluctuation in sex hormones during the menstrual cycle has been studied as a risk factor for ACL tears in female athletes with varying results, implicating both the follicular and ovulatory phase as times of highest risk.23–25 There are methodological issues that may explain the variability in findings, with many studies relying on athlete self-report of menstrual cycle phase at the time of the injury. A recent study that measured hormone metabolites in urine, to determine both menstrual phase at the time of injury and cycle length, showed poor correlation of urine metabolite based determination of menstrual phase with self-report of menstrual phase.24

The menstrual cycle is generally divided into
three phases—follicular, ovulatory, and luteal—with some researchers further dividing luteal into early and late luteal phase. However, there are differences in the number of days defined in each phase between studies. This variable time interval for defining cycle length can directly impact the study findings, adding to the confusion. In addition, some athletes take oral contraceptive pills, which may introduce another bias if exogenous hormones act differently than endogenous hormones. In a review of college varsity athletes sustaining noncontact ACL injuries, oral contraceptive use did not protect against injury. This topic needs further elucidation.

Finally, the mechanism of action of the sex hormones to increase the rate of ACL tears remains to be elucidated. Estrogen and progesterone receptors have been found on the rabbit ACL. This finding implies that sex hormones may influence the structure and function of the human ACL, perhaps compromising load bearing and proprioceptive feedback, however this has not been proven in human studies. A recent study of knee laxity throughout the menstrual cycle, using waking temperature and self-report of menstruation to define menstrual cycle phase and the KT-2000 arthrometer (Medmetric Corp, San Diego, Calif) to measure knee laxity, demonstrated that knee laxity did not vary with menstrual phase, either before or after acute bouts of exercise. Further study of the role of human reproductive hormones and ACL injury is warranted.

**Anatomic Considerations in Knee Injury**

Various studies have considered anatomic determinants of the knee and their role in the higher knee injury rates in women, but none have directly correlated anatomy with causing the increased incidence of noncontact ACL tears in women. The Q-angle (quadriceps angle) is defined as the angle between the line connecting the anterior superior iliac spine and the midpoint of the patella, and the line connecting the tibial tubercle and the same reference point of the patella. Recreational basketball players who suffered knee injuries were found to have a higher Q-angle than uninjured players. A review of the literature on Q-angles measurements concluded that this measure is of limited value overall in individuals presenting with anterior knee pain. The miserable malingering syndrome, including pronation of the feet, increased femoral anteversion, and increased genu valgus, was thought to be contributory to anterior knee pain in women, but no studies have documented this finding. Static postural faults, studied with stepwise logistic regression, showed that the factors demonstrating statistically significant differences between the ACL-injured female athletes and age-matched controls included excessive navicular drop, knee recurvatum and excessive sub-talar joint pronation. Although studies have shown that women are more likely to have joint laxity, this has not been directly correlated to the higher knee injury rate seen in women.

Numerous studies have been done to determine the relationship between the size and shape of the femoral notch and ACL injury rate. The notch width index, the width of the anterior outlet of the notch divided by the total notch width at the level of the popliteal groove, is the measurement used frequently in studies of ACL injuries. It has been compared side to side and in injured vs. non-injured athletes, with conflicting findings regarding its association with ACL injury rate. The shape of the intercondylar notch has been studied, with A-shaped notches associated with increased injury rates and perhaps related to a smaller ACL. Published findings from a symposium on ACL tears in female athletes concluded that notch dimensions and ACL injury seem to be associated with injury, but that this association was not proven to be causal. The expert panel did not see a role for prophylactic notchplasty to widen the femoral notch in a patient’s uninjured knee.

**The Role of Dynamic Neuromuscular Imbalances and Knee Injury**

Dynamic control of the knee is an area of research related to ACL tears in women that continues to grow. Proprioception and reaction time, postural stability, limb dominance, muscle stiffness and firing patterns, and landing biomechanics are all being studied in hopes of elucidating risk factors for knee injury in women, specifically noncontact ACL tears. This line of research stems from previous work looking at ACL-deficient or ACL-injured subjects and their neuromuscular patterns to infer what factors may be related to ACL injuries.

The ACL has been studied in injured athletes both with and without ACL reconstruction. Numerous studies of proprioceptive capacity in ACL-deficient athletes demonstrate deficits in the involved limb compared with uninjured. In the postreconstruction group that continues to have an unstable knee despite findings of mechanical stability on ligamentous measurements, the remaining instability is presumed to be related to proprioceptive deficits. There are multiple measures to assess proprioception and neuromuscular control at the knee employed in the literature, including (1) Testing joint position sense by setting the subject’s limb at a predetermined angle, then asking the subject to reproduce this angle; (2) Testing threshold to perception of passive movement; (3) Testing muscular activation and latency of reflex contraction after force application; and (4) Testing standing balance with stabilometry. Female athletes are being tested compared with males to look for differences in proprioception...
and neuromuscular control at the knee that might increase their risk of injury.

One possibility for the higher incidence of knee injury in women compared with men may be a disparity in knee proprioceptive and neuromuscular control in female athletes.51 Single leg stance stability was better in female control subjects than in males; however, in subjects with ACL deficiency, males had significantly more single leg stability than females, both pre- and postoperatively, and the deficit in single leg stance perpetuated longer postoperatively in females.52

Studies have shown that women run, land, and jump differently than men when playing sports.53,54 The usual mechanism for noncontact ACL tears involves a deceleration before change of direction or landing with the knee between full extension and 20 degrees of flexion.55,56 Therefore, the differences in landing and other movement strategies between male and female athletes have the potential to explain at least some of the disparity in noncontact ACL injury rates. Male and female high school basketball players were studied with three dimensional motion analyses while landing a drop vertical jump and preparing to immediately perform a maximum vertical jump.57 Female athletes landed with greater maximal valgus angle and with significant differences between their dominant and nondominant knees, compared with males.

Neuromuscular Patterns: Ligament, Leg and Quadriceps Dominance

Subjects with high valgus moments at the knee have been referred to as ligament dominant.58 The inability of the leg musculature to control motion results in high strains across the ACL as it acts to limit valgus force. Women have also been found to have a highly dominant leg, with significant side-to-side strength and flexibility deficits noted.59 This mismatch may lead to a higher incidence of ACL injury to the dominant knee, as it preferentially works to limit the forces of gravity, or a higher risk of injury to the nondominant knee, as it is significantly weaker and less able to manage such forces. This leg dominance as a possible factor in ACL injury in women has been studied in conjunction with side-to-side differences, not only in valgus loading, but with preseason strength, flexibility, and coordination deficits correlating with injury rate.60

Quadriceps dominance is another pattern of neuromuscular control that may be associated with ACL injury. In a laboratory study, anterior tibial translation applied to the limbs of female and male athletes was met by different strategies, with females initially firing their quadriceps, and males and untrained females initially firing their hamstrings to counter the load.36 This has been described as a quadriceps-dominant pattern in female athletes. Quadriceps contraction without cocontraction of the hamstrings can lead to greater loading of the ACL.61 Hamstring cocontraction acts synergistically with the ACL, decreasing anterior and rotatory displacement of the tibia from 15° to 80° of knee flexion.62 In a laboratory study using EMG during isokinetic testing, elite athletes with hypertrophied quadriceps had less cocontraction of their hamstrings than recreational athletes or non-athletes.63 Hamstring activation during leg extension was proposed as a stabilizer of the knee, and serves as the basis for ACL prevention programs that teach motor control with greater knee flexion to activate the hamstrings. A controlled laboratory study of eight female and six male college varsity basketball players failed to show a significant difference in knee muscle activation patterns, with females landing with greater knee flexion and demonstrating time to peak force measures similar to their male counterparts, and contrary to previous studies.64 It is not clear whether this particular group of female athletes had been previously trained to land with greater knee flexion in their preseason training program. The hamstring/quadriceps ratio has been used historically for assessment of muscle balance using concentric values (Hcon/Qcon) for both muscle groups. However, to describe physiologic function about the knee joint, the hamstring/quadriceps ratio should be calculated using Hecc/Qcon for knee extension, and Hcon/Qecc for knee flexion.65 This change to a more functional H/Q ratio has implications for ACL research studies and for prevention and rehabilitation programs.

Muscle Strength And Knee Stiffness

Women have less quadriceps and hamstring strength than men, even after normalizing for body weight.66,67 Conditioning exercises have imparted some protection against injury.68,69 In a study of 20 healthy athletic women, fatigue from eccentric quadriceps femoris exercise, but not eccentric hamstring exercise, produced delayed onset of vastus medialis, rectus femoris and vastus lateralis firing during crossover cutting training.70 The gastrocnemius muscle fired earlier with quadriceps fatigue, presumably to aid in dynamic knee stabilization. The authors argue that gastrocnemius training in knee rehabilitation and training programs for female athletes is necessary. Several authors have also studied knee stiffness, or muscle contractility across the knee joint that acts to dissipate forces across ligaments, and have found gender differences, although others have not.51,71 Stiffness is regulated in part by mechanoreceptors in the knee ligaments and capsule that influence muscle spindle afferents from agonist and antagonist muscles.72,73 Training may impact these responses. Other intrinsic factors that play a role in
muscle stiffness, such as musculotendinous elasticity, may not be amenable to training.74

**Prevention Strategies**

The identification of neuromuscular imbalances in women forms the basis for ACL injury prevention training interventions. Recommendations include training to counter dominant-leg dominance, ligament dominance, and quadriceps dominance in women. Many researchers feel that specific training programs may lessen the risk of noncontact ACL tears in females. For instance, recommendations for hamstring training were made by researchers who noted quadriceps-dominant muscle activation patterns on EMG testing, or in response to anterior tibial translation.36,63 Strength training is also recommended, given the gender differences in hamstring and quadriceps strength.

More recently, prospective studies of exercise interventions have been completed. An exercise intervention study demonstrated that a progressive five-phase balance board training program decreased the incidence of ACL injury by 7-fold in high level male soccer players.69 In a study of elite female handball players, an ACL injury prevention program with 3 different sets of exercises performed three times a week during a training period of 5–7 wk, and then once a week during the season, resulted in improved dynamic, but not static, balance.75 Eleven female athletes trained with a three-phase jump training program and demonstrated increased knee flexion with landing, reduced knee adductor and abductor moments at the knee, increased strength of the hamstrings muscles, and limited peak landing force by 22%.59 This type of plyometric training resulted in reduced rates of injury in trained vs. untrained female athletes studied prospectively through high school volleyball, soccer, and basketball seasons.68

In recognition of the running, jumping, and landing differences between genders, recommendations have been made that athletes avoid high-risk positions such as landing on one limb or with knee extension.76 The focus for coaching interventions is to teach performance in a safety position: flexed hips and knees, avoiding adduction and internal rotation of the femur and external tibial rotation.77 (Fig. 2) There have been no studies documenting the success of this type of coaching intervention.

Identifying individuals at risk may be another means of reducing ACL injury rate. In preparticipation screening of just over 2700 high school athletes, musculoskeletal problems were the leading cause of restriction from sports activity, and the second leading cause for recommended follow-up.78 It may be that preparticipation screening could be used to identify dynamic neuromuscular imbalances that place girls and women at risk of knee injury. Further study in this area is needed. It may be necessary for female athletes to show proficiency in strength, flexibility, and advanced motor skills required for cutting and jumping sports to participate.79

**Current Recommendations and Future Directions**

The literature reviewed in this article demonstrates that girls and women are at greater risk of knee injuries, especially in cutting and jumping sports.
sports, than boys and men in similar sports. A number of variables that affect ACL injury rate are being considered, none of which likely works in isolation. To solve this serious problem of noncontact ACL injuries, basic science and clinical researchers are working together with clinicians and team personnel in hopes of bringing the latest information to female athletes in the field. This will allow for in vivo testing of exercise interventions and additional prospective studies of hormones, anatomical variables, and dynamic neuromuscular imbalances to eliminate this mismatch in injury rate.

In the interim, the current studies should be used to direct us in an evidence-based approach to care and prevention. Female athletes should be screened for neuromuscular imbalances in the preparticipation physical examination. Ideally, jumping and landing techniques should be observed, with specific recommendations made when dangerous behaviors are observed, such as landing on an extended knee. Training programs should include plyometric activities that train the lower limb in multiple planes of movement, incorporating acceleration and deceleration. The goal of training is for each female athlete to develop a repertoire of movement patterns to deal effectively with the forces of gravity and momentum, allowing for quick, coordinated cocontraction of muscles about the lower limb, pelvis, and trunk to avoid overload of the ACL and patellofemoral joint.

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Pigmented Villonodular Synovitis
An Uncommon Presentation of Anterior Hip Pain

ABSTRACT

Pigmented villonodular synovitis (PVNS) is a rare, benign, idiopathic proliferative disorder of the synovium that results in villous or nodular formation in joints, tendon sheaths, and bursae. The disease can be localized or diffuse. Its estimated prevalence is 1.8 cases per million in the United States. Large joints, such as the knee and hip, are commonly affected. Patients with this condition typically present with symptoms of mild discomfort and associated stiffness of the involved joint; however, the spectrum of presentations is broad. We present a case of an otherwise healthy 40-yr-old man who presented for evaluation of stiffness and pain in the anterior hip. His initial presentation, work-up, and course will be discussed, along with a brief review of the literature.

Key Words: Pigmented Villonodular Synovitis, Hip Pain, Case Report

Hip pain resulting from articular pigmented villonodular synovitis (PVNS) is an uncommon benign neoplastic process of the synovial membrane presumed to be of histiocytic origin.1 It commonly affects large joints such as the knee and hip, but it may apparently affect any synovium. Review of the literature demonstrates cases involving the temporomandibular joint, zygapophyseal joints, calcaneonavicular joint, midtarsal joints, and interphalangeal joints to name a few.2–4

Jaffe et al.5 proposed the name pigmented villonodular synovitis in 1941 and described two forms: small, peduncular lesions (localized nodular synovitis), and lesions with diffuse involvement of the synovium (PVNS). PVNS affecting the knee usually preserves the joint space; however, PVNS of the hip usually presents with diffuse articular involvement, juxta-articular bony lytic lesions, and extensive joint destruction, presumably because of the limited intraarticular space and strong capsular containment.6–9

Men and women are affected most commonly between the third and fifth decades of life. Late diagnosis is frequent because most patients present with slow progressive symptoms, the hip is difficult to palpate, and radiographs may be normal in the early stages.10–12 Treatment consists of synovectomy alone or combined with arthroplasty when significant joint arthrosis and symptoms are associated with the disease.13 Refractory cases may have somewhat improved outcomes with postsynovectomy adjuvant treatment such as external beam radiation therapy or intraarticular injection of yttrium-90.
CASE REPORT

The patient was a 39-yr-old male software programming executive who presented to an outpatient musculoskeletal clinic for evaluation of vague hip discomfort of approximately 8 mos of duration. The patient reported vague “abnormal sensations” in the hip girdle region for a number of years, but he had noticed a significant progression of his symptoms during the preceding 8 mos. He had difficulty describing the quality of his discomfort, but he stated that his symptoms were intermittent, usually in the right buttock or the groin, and occasionally radiating from the right groin into the anterior thigh to the knee (but never below). He attributed his symptoms to being more sedentary over the preceding year, spending a lot of time working at his computer. He reported that walking routinely made his symptoms worse and that stretching seemed to help. He had no specific treatment to this point other than taking 200 mg of ibuprofen twice a day, as needed, with some relief. He otherwise was a healthy man with no other medical history. He previously was a competitive gymnast and also enjoyed skate boarding, but he denied any trauma from his activities or otherwise. His review of symptoms was negative except as noted in the history of the present illness. He specifically denied any numbness or tingling, bowel or bladder disturbance, back pain, nocturnal symptoms, night sweats, or unexplained weight loss. His family history was remarkable for thalassemia (although he was never tested) and metastatic bladder cancer in his father.

Directed physical examination of the right hip demonstrated significant loss of range of motion. With the hip flexed to 90 degrees, there was 5 degrees of internal rotation and 30 degrees of external rotation. On the contralateral side, there was 20 degrees of internal rotation and 45 degrees of external rotation. Internal rotation on the right caused mild right buttock-area symptoms but no groin pain. Muscle testing was normal bilaterally, with the exception of mild weakness noted in the right hip abductors. There was no groin pain with resisted hip adduction. There was no leg length discrepancy or pelvic obliquity. Lumbar and sacroiliac examination was entirely within normal limits. The remainder of the neurologic exam was normal as well.

Anteroposterior pelvis and right lateral hip plain films were performed in the office that demonstrated severe degenerative changes. Also noted are multiple lucencies about the intertrochanteric region, femoral head, and femoral neck consistent with pigmented villonodular synovitis or potential metastases.

FIGURE 1  Anteroposterior view of the pelvis.

FIGURE 2  Frog view of the right hip demonstrates severe degenerative changes, including joint-space narrowing, subchondral sclerosis, and cysts about the right hip. Also noted are multiple lucencies about the intertrochanteric region, femoral head, and femoral neck consistent with pigmented villonodular synovitis or potential metastases.
cluding serum protein electrophoresis, complete blood count, C-reactive protein, prostate specific antigen, and a basic chemistry panel, was also completed and all tests were within normal limits except for mild anemia and microcytosis, consistent with his family history of thalassemia. Magnetic resonance imaging of the right hip demonstrated innumerable low T1- and low T2-signal lesions about the right hip joint (Fig. 3). These findings were consistent with and confirmed the diagnosis of PVNS. The patient was referred to orthopedic surgery for further discussion of potential definitive treatment options (i.e., synovectomy vs. total hip arthroplasty) and for the concern of pathologic fractures secondary to the large lesions noted in the femoral neck. A second surgeon, concerned with possible avascular necrosis given the patient’s family history of thalassemia, proposed a surgical bone and synovial biopsy to make the definitive diagnosis and likely confirm PVNS. The patient decided against any surgical intervention or biopsy at this point and opted for the most conservative treatment.

**DISCUSSION**

The precise cause of PVNS is still uncertain. Jaffe et al.\(^5\) first proposed the name, described the main histopathologic features, and originally proposed an inflammatory pathogenesis. This theory has not been uniformly supported. Others believe it is a neoplastic process such as a giant cell sarcoma arising near or inside the synovial space or tendon sheath. This theory is supported by the monoclonality and chromosomal abnormalities identified in these lesions.\(^1\) Other possible causes include trauma, disturbances of metabolism, and hemorrhage.

Histologically, the lesion of PVNS demonstrates dense infiltrates of polygonal or spindle cells with abundant cytoplasm and vesicular nuclei; some of the cells contain hemosiderin. Multinucleated giant cells are sometimes present, either scarcely or in large numbers. Aggregation of foamy cells can also be seen. Abundant production of collagen, fibrosis, and hyalinization may be evident in patients with long-standing disease.\(^1\) Recent studies have identified both proliferating synovial cells and inflammatory cells within the PVNS lesions.\(^1\) It seems that there are different ratios of these cells observed in localized vs. diffuse disease. The pathogenetic interaction between neoplastic and inflammatory cells in PVNS in not yet fully understood.

The clinical presentation of PVNS is often insidious. Patients seek medical consultation months or years after the onset of symptoms due to the often mild and slowly progressive nature of the disease process. At the time of presentation, patients often complain of monoarticular pain that has been present for a few months. The pain can be intermittent with pain-free intervals or may just wax and wane in timing. During a flare, the pain may be quite severe, which may represent active hemorrhage into the joint. During these periods, the patient may report positional relief of pain (typical of a joint effusion, hemarthrosis, or synovial process).

The differential diagnosis can be quite broad. Common things such as osteoarthritis need to be excluded. Osteoarthritis typically presents in older adults and affects multiple joints. Radiographically, polyarticular involvement is more suggestive of osteoarthritis and helps to exclude the diagnosis of PVNS. Tuberculosis arthritis can also have a subtle presentation. Radiographs in this disease process demonstrate hallmark findings of juxta-articular osteoporosis and loss of articular cartilage that distinguish tuberculosis arthritis from PVNS. Other differential diagnoses include synovial sarcoma, hemophilia, synovial hemangioma, and rheumatoid arthritis. Synovial sarcoma is typically extraarticular and presents with calcifications in one third of patients.\(^1\) Hemophilia and synovial hemangioma may be associated with intraarticular bleeding and hemosiderin deposition, the former being excluded with laboratory testing. Rheuma-
toid synovitis and synovial hemangioma are difficult to differentiate from PVNS. Rheumatoid synovitis classically demonstrates thinner synovial proliferation with less hemosiderin deposition.\textsuperscript{20} It should be noted that histologic evidence of PVNS has been documented in the tissue of patients with rheumatoid arthritis.\textsuperscript{21} PVNS should be in the differential in any young patient who presents with arthritis, with or without a mass, involving a single major joint.

Blood tests are usually not helpful in making the diagnosis of PVNS, but they may be helpful in excluding other diagnoses. Physical exam may demonstrate decreased range of motion and possible effusion. Joint aspiration classically demonstrates a blood-tinged or brown-pigmented fluid. Microscopic analysis of joint fluid demonstrates large numbers of multinucleated foreign-body giant cells, with a large amount of coarsely granular, yellow-brown hemosiderin pigment.\textsuperscript{22}

Radiographically, the classic appearance of PVNS on plain-film radiographs is soft-tissue swelling or a mass about the joint, usually with joint space preservation; however, the joint space will be destroyed as the disease progresses. Erosions and subchondral cysts are common, particularly when PVNS occurs in the hip, ankle, or elbow.\textsuperscript{23} Periarticular osteoporosis is not usually seen. Intraarticular calcifications and osteophytes are rare. The effusion may seem dense on plain films or computed tomographic scan due to the high iron content. Magnetic resonance imaging will demonstrate the effusion, and the hemosiderin-laden soft-tissue masses will be seen as areas of low signal intensity on T1- and T2-weighted sequences. This is more pronounced on the gradient-echo than on spin-echo images. The size of the lesion may seem larger than the real lesion—so called blooming phenomenon—due to the magnetic susceptibility effect caused by the hemosiderin.\textsuperscript{24,25} The differential diagnosis based on magnetic resonance imaging includes hemophilia arthropathy, soft-tissue sarcoma, fibromatosis, synovial chondromatosis, septic arthritis, and inflammatory arthropathies.

No strict guidelines exist for the treatment of PVNS; however, many authors agree that young patients without compromise of the articular cartilage should be treated with extensive synovectomy. Synovectomy may be performed open or arthroscopically. The arthroscopic approach is better tolerated and results in more rapid recovery for most patients; however, open synovectomy has much lower recurrence rates, particularly in diffuse cases.\textsuperscript{17} Total-joint arthroplasty may be combined with synovectomy when the joint cartilage is severely compromised.\textsuperscript{7,10,13}

Other treatments such as radiation therapy and radioisotope synovectomy have been attempted with good result.\textsuperscript{9,24–29} Radiation therapy is usually used in malignant tumors as definitive or adjuvant treatment. In PVNS, it has been suggested when total synovectomy is not possible due to extensive disease or when recurrence and repeat surgery would lead to impaired function. Reported complications from radiation treatment have included joint stiffness, femoral fracture, and impotence. Potential adverse effects of radiation therapy also include poor wound or graft healing and late radiation-induced sarcomas in young individuals. Because PVNS is a benign disorder, radiation therapy should be considered with caution.

Intraarticular injection of yttrium-90 has been described in the literature, and in small studies, it has been shown to be beneficial in treating the disease process and preventing recurrence, particularly when administered early in the course.\textsuperscript{29,30} Potential adverse effects include radionecrosis of the extraarticular soft tissues, febrile reaction, local painful reaction, and leakage of the radioactive material from the joint space to the entire body via the lymph nodes. With systemic leakage, there are also the possible risks of infertility and malignant changes with chromosomal damage to mitotic cells, although none of these have been reported.

Conservative treatments include physical therapy to preserve range of motion, use of assistive device for ambulation, and judicious use of analgesics and nonsteroidal antiinflammatory medications. To date, there have been no formal studies examining the efficacy of any of these recommendations; however, they are accepted as the standard of care.

**SUMMARY**

PVNS is a rare but important cause of hip pathology that should be considered in the differential diagnosis of hip stiffness and pain in otherwise young and healthy individuals. Early diagnosis is key to providing a cure and decreasing the chance of recurrence. Magnetic resonance imaging is the optimal imaging study in which hemosiderin-laden tissues will be seen as areas of low signal intensity on T1- and T2-weighted sequences, which are highly suggestive of the diagnosis. Synovial biopsy remains the gold standard for diagnosis.

There is no consensus on the optimum treatment; however, most authors seem to agree that debulking is key and that intraarticular radioisotope injection with yttrium-90 is relatively safe and may improve recurrence rates. Open debulking procedures seem to have lower recurrence rates but require prolonged rehabilitation periods relative to the arthroscopic procedure. Because our patient had such an advanced case (i.e., severe joint...
destruction), his symptoms will warrant the need for invasive treatment, which will eventually be total hip arthroplasty. Physiatrists have the unique opportunity to aid in making an early diagnosis and providing a comprehensive rehabilitation program aimed at maintaining range of motion and function throughout the perioperative period.

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Asterixis Related to Gabapentin as a Cause of Falls

ABSTRACT

Negative myoclonus, commonly known as asterixis, is often observed in patients with toxic-metabolic encephalopathies or focal brain lesions. It is a movement disorder characterized by postural lapses resulting from brief cessation of tonic muscular contraction. Negative myoclonus has a characteristic appearance on needle electromyography. Lapses in continuous postural muscle activity can lead to falls. This increased risk of falls makes it particularly important to recognize and treat negative myoclonus, especially in patients with multiple medical problems, deconditioning, and gait disturbances. To our knowledge, there have been no published reports implicating negative myoclonus as a cause of falls in adults. We present a case of asterixis as a cause of falls and near falls in a patient with metastatic breast cancer and normal mental status who was receiving gabapentin.

Key Words: Falls, Asterixis, Negative Myoclonus, Gabapentin

Falls and near falls occur in about one third of the elderly, and they can lead to major deilities in a large proportion of patients.1 Falling is associated with injury, immobility, weakness, and isolation. One of the most disabling consequences of falling is the fear of another fall. Falls may occur as the result of a number of disorders, including muscle weakness (stroke, spinal cord injury, and myopathy), syncopal episodes (orthostatic hypotension, aortic stenosis, and cardiac arrhythmias), Parkinsonism, ataxia (vitamin deficiency, cervical spondylosis, cerebellar dysfunction, and spinal cord dysfunction), apraxia (normal pressure hydrocephalus), gait disturbances (Trendelenburg gait from L5 radiculopathy), vertigo, and movement disorders (myoclonus and tremor).1,2

Myoclonus can be classified as either positive or negative myoclonus. Positive myoclonus, also known as myoclonus, is a type of movement disorder characterized by involuntary bursts of muscle activity. These bursts of muscle activity cause brief, jerky, shock-like movements. Negative myoclonus is also a motor phenomenon that is characterized clinically by involuntary movements. These movements are superficially similar to those seen with positive myoclonus. Pathophysiologically, however, negative myoclonus differs from positive myoclonus in that the defect is a brief and sudden interruption, as opposed to increase, in muscular activity. Negative myoclonus is synonymous with the

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term “asterixis,” a word that was coined by Adams and Foley to describe transient postural lapses resulting from brief cessation of postural tonic electromyographic (EMG) activity. Asterixis is often used to describe the negative myoclonus seen in patients with toxic-metabolic encephalopathies or focal brain lesions.

The combination of positive and negative myoclonus has been known to cause a severe disturbance of balance and gait in patients with myoclonic encephalopathies. Negative myoclonus, in particular, interferes with balance and gait by disrupting control of postural adjustments. This loss of postural control can allow or provoke adverse changes in the position of the body’s center of mass. As a result, patients frequently report feeling unsteady and having a fear of falling. Postural lapses during stance generally occur when a substantial number of muscles are involved or when antigravity muscles are affected.

It stands to reason that the periodic loss of postural control induced by negative myoclonus could lead to falls. Despite the fact that both negative myoclonus and falls are reasonably common, our review of the literature did not reveal previous reports of falls attributable to negative myoclonus in adults. We present a case of negative myoclonus as contributing to falls in a patient with breast cancer who was receiving gabapentin.

CASE REPORT

A 74-yr-old woman with a medical history of diabetes, hypertension, and stage IV breast cancer with metastasis to bone and liver was admitted to the Memorial Sloan-Kettering Cancer Center for frequent falls and near falls. Her falls had occurred as an outpatient and did not result in injury. When she was seen by the physical therapist as an inpatient, she subjectively reported a fear of falling. Her bilateral lower limbs would buckle transiently and recover spontaneously during transfers and ambulation. She was provided with a rolling walker and safety education from the physical therapist. A rehabilitation medicine consult was requested for further evaluation.

The patient had been diagnosed with breast cancer in 1981 and underwent a right-sided modified radical mastectomy followed by chemotherapy with cyclophosphamide, methotrexate, and 5-fluorouracil (CMF). A recurrence of her cancer with bony metastases to the thoracic spine was discovered in 1998. She was treated with tamoxifen, Arimidex, and pamidronate and with radiation therapy to the thoracic spine at the T7 through T9 levels. Radiation was followed by cyclophosphamide, methotrexate, and 5-fluorouracil chemotherapy. Her disease continued to progress, and by early 2002, she had developed new metastasis to the liver and bone, including the base of the skull and spine. She was treated with doxorubicin, oral dexamethasone, and pamidronate. In mid-2002, she developed T8 epidural spinal cord compression and underwent a posterolateral decompression and fixation without residual neurologic sequelae. Subsequent imaging of her brain and spinal cord did not reveal any additional areas of spinal cord compression, brain metastasis, or leptomeningeal disease. No abnormalities of hepatic or renal function, anoxia, or drug intoxication had been reported in her medical history.

Her medications included gabapentin (300 mg orally twice a day) for neuropathic pain presumed to be secondary to chemotherapy-induced neuropathy, glyburide, metoprolol XL, hydrochlorothiazide/losartan, 100-μg fentanyl patch every 3 days, omeprazole, docusate sodium, bisacodyl, epoetin alfa, and sucralfate. Her gabapentin dose had been stable for several months.

On physical examination, her vital signs, including temperature, respiration rate, blood pressure, and pulse were normal. The cardiac, lung, and abdominal examination revealed no abnormalities. Neurologic examination revealed an alert and oriented elderly woman. Her gait was slightly broad based and unsteady, with occasional bilateral knee buckling. The patient demonstrated mild bilateral dysmetria on finger-to-nose-finger and heel-to-shin examination. Negative myoclonus was noted in the bilateral upper limbs by noting a characteristic “flap” while the patient actively extended both hands at the wrists. Negative myoclonus was also noted in the bilateral lower limbs by having the patient actively extend the leg at the knee while the examiner supported the knee. No positive myoclonus was observed and there were no abnormal movements in the face or trunk. Cranial nerves and tone were normal. Sensory examination, including light touch, pinprick, and position sense were normal. Muscle strength was grade 4/5 and symmetric in all muscle groups tested in the bilateral upper and lower limbs. Deep tendon reflexes were absent throughout.

Laboratory values, including sodium, potassium, calcium, glucose, creatinine, prothrombin time, activated partial thromboplastin, and urinalysis, were normal. A limited needle EMG examination of the extensor carpi radialis (Fig. 1) and right vastus lateralis (Fig. 2) was performed and demonstrated intermittent pauses of 40–100 msecs on submaximal sustained contraction.

The clinical diagnosis of gait disorder secondary to negative myoclonus and mild ataxia was made. Gabapentin was discontinued because no
other of the patient’s medications had a known association with negative myoclonus. The EMG was not repeated after discontinuation of the gabapentin. The patient was prescribed bilateral soft knee supports for ambulation. Physical therapy continued for lower limb strengthening, gait training, balance training, and safety education for fall prevention. The soft knee supports minimized the buckling of the patient’s knees as she ambulated with the rolling walker. Before discharge to a subacute rehabilitation facility, the patient’s gait had improved somewhat, and she was able to ambulate safely with supervision and a rolling walker. There were no reported instances of falls during the hospital course. She was lost to follow-up once discharged to the subacute rehabilitation facility, and later died of her metastatic breast cancer.

DISCUSSION

Myoclonus (or positive myoclonus) is a term used to describe involuntary movements that are “brief and shock like.” As in clonus, myoclonus is a monophasic phenomenon caused by the involuntary contraction of a muscle, muscle group, or body segment. These contractions are caused by a transient increase in muscle activity. Myoclonic contractions are usually irregular in rhythm and amplitude and involve a muscle group or body segment (segmental myoclonus). These brief bursts of muscle activity (with or without tonic muscular contraction) lead to the abnormal movements that are seen clinically.

Myoclonus can be demonstrated on needle EMG as a burst of electrical muscle activity from either the resting state or from tonic contraction. The pathophysiology of myoclonus is not well understood and may be a manifestation of a wide variety of pathologic conditions affecting the brain, spinal cord, or even the peripheral nerves. Many types of drugs and toxins have been reported to induce myoclonus, including bismuth salts, valproic acid, lithium, antipsychotic agents, and monoamine oxidase inhibitors. Myoclonus can be seen in epilepsy or in other neurologic conditions.

In contrast to positive myoclonus, the brief, jerky, involuntary movements of negative myoclonus are due to an interruption of muscular activity that causes a sudden postural pause. It usually involves tonically recruited muscles, and the interruption of antigravitational muscle activity results in downward displacement of the joint. Negative myoclonus can be demonstrated in the hands by asking the patient to gently squeeze the examiner’s fingers; this results in brief and subtle lapses of tonic muscle activity. Like positive myoclonus, negative myoclonus can be classified as cortical or subcortical, in terms of its origin, and as rhythmic or irregular. It becomes more prominent after sustained activity and is exacerbated by fatigue.

Negative myoclonus interferes with balance and gait by disrupting the control of postural adjustments and thereby provoking abnormal changes in the position of the center of mass. Patients frequently report feeling unsteady, having a fear of falling during walking, and the sensation that knees will “give way.” Postural lapses may occur during stance only when significant numbers of muscles involved in antigravity posture are affected simultaneously.

FIGURE 1 Needle electromyographic (EMG) recording from the right extensor carpi radialis (ExtCarRad).

FIGURE 2 Needle electromyographic (EMG) recording from the right vastus lateralis (VastusLat).
Negative myoclonus can be observed in a variety of clinical conditions ranging from the physiologic form, seen occasionally with the onset of sleep or after prolonged exercise, to the pathologic form observed in patients with toxic-metabolic encephalopathies or with focal brain lesions (asterixis). There is also a paroxysmal form of negative myoclonus known as epileptic negative myoclonus that is seen in epileptic patients. A case report on two children with idiopathic partial epilepsy of childhood has been described. These reports demonstrate epileptic negative myoclonus manifesting as intermittent falls and fecal incontinence.

Asterixis is most easily demonstrated by asking patients to actively extend their wrist with their arms in the extended position. If asterixis is present, the examiner will observe brief and repetitive loss of wrist extension so that the hand seems to flap (liver flap). Asterixis was first described in patients with hepatic encephalopathy, but it is now known to represent a nonspecific neurologic finding associated with multiple forms of toxic and metabolic encephalopathies (hepatic, uremic) and occurs in patients with focal lesions of the central nervous system, including subcortical and brainstem structural lesions. A number of drugs have been shown to be associated with asterixis, and they include gabapentin, carbamazepine, valproic acid, phenytoin, lithium, clozapine, L-dopa, ifosfamide, and ceftazidime. A case demonstrating asterixis as a clinical sign of phenytoin toxicity has been described. Asterixis has also been shown to be a primary manifestation of ifosfamide encephalopathy in a patient who had been treated for plasmacytoma. Neurotoxic substances are also associated with asterixis, in particular, ammonia and manganese.

Electrodiagnostically, negative myoclonus is characterized by an interruption of EMG activity for 50–200 msecs. The duration of the silent period can last up to 400 msecs. The longer the duration of postural lapses, the more pronounced and potentially disabling is the movement disorder. Asterixis can be focal or multifocal (involvement of several adjacent muscles simultaneously), but it is usually multifocal in distribution and is very rarely generalized. It often has an arrhythmical presentation and is present only during a tonic, postural muscle contraction. Accordingly, it is never present when a person is at rest.

Involvement of serotonergic, GABA-ergic, benzodiazepine, cholinergic, and dopamine systems could play a role in myoclonic disorders. A number of drugs have been used in the treatment of myoclonus, including 5-hydroxytryptophan, carbidopa, L-dopa, clonazepam, sodium valproate, primidone, apomorphine, ethosuximide, and piracetam. There is no study analyzing the effect of antimyoclonic drugs on negative myoclonus. The value of physical therapy has not been evaluated, but it could be potentially beneficial. Our patient responded to physical therapy, safety training, use of an assistive device, and soft knee supports, all of which probably contributed to functional improvement in addition to discontinuation of gabapentin.

Treatment of negative myoclonus should involve identification and correction of metabolic abnormalities and withdrawal of potentially causative or contributing agents, as was done in our patient. Prevention and treatment of hepatic encephalopathy in cirrhotic patients with ammonia-lowering strategies, including lowering dietary protein intake, use of lactulose, neomycin, sodium benzoate, and L-ornithine-aspartate, is recommended. Central nervous system–acting drugs such as benzodiazepine receptor antagonists (flumazenil) and dopamine agonists (L-dopa and bromocriptine) have been used, but with limited success. If an offending causative agent has been identified, such as phenytoin or ifosfamide, it should be discontinued or titrated to a lower dosage.

CONCLUSION

In the present case, multiple medical conditions likely contributed to her history of falls. Although the patient had some degree of what was presumed to be neuropathic pain from chemotherapy, her physical examination did not demonstrate any sensory deficits and the chemotherapeutic agents she had been exposed to are not particularly neurotoxic. She did have symmetrical weakness, likely due to deconditioning, that would be expected to contribute to her falls; however, it was only mild and was out of proportion to the marked knee buckling exhibited on ambulation. It is most likely that the patient’s negative myoclonus was a major contributor to her knee buckling and frequent falls.

The cause of this patient’s negative myoclonus is also elusive. Her laboratory values did not support a metabolic cause, and save for gabapentin, none of her medications were thought likely to be contributing. The patient did improve when the gabapentin was discontinued, but her physical therapy had been continued and soft knee supports had been added. The relative contributions from each of these modalities cannot be determined.

To the best of our knowledge negative myoclonus has not been described in the literature as a potential cause of falls in adult patients. Because the major clinical manifestation is interruption of tonic postural muscle activity, negative myoclonus may significantly interfere with balance and pos-
tural control during standing and ambulation. It also could result in the subjective sensations of unsteadiness and knee buckling and the fear of falling. The presence of negative myoclonus may be particularly worrisome in patients who are debilitated, deconditioned, or have other disturbances of gait that increase their fall risk. Physicians taking care of such patients need to be particularly vigilant in recognizing negative myoclonus on physical exam. Moreover, negative myoclonus should be considered in the differential diagnosis of patients with multiple falls or near falls that do not have an obvious cause. If necessary, a needle EMG can help confirm the diagnosis of negative myoclonus. Once identified, appropriate treatment of metabolic abnormalities should be instituted, and any offending agents known or suspected to cause negative myoclonus should be discontinued or have their dosages decreased.

REFERENCES
Intraspinal Dural Distraction Inciting Spinal Radiculopathy: Cranial to Caudal and Caudal to Cranial

ABSTRACT


LaBan previously described the precipitous onset of lumbar radiculopathy in 12 patients who were receiving therapeutic, intermittent cervical traction for a primary complaint of cervical radiculopathy. Cranial-to-caudal traction of the intraspinal pia with cervical spine distraction was cited as the dynamic link believed to have provoked the lumbar radiculopathy. This present communication adds an additional case and describes an equal but opposite occurrence, a case of caudal-to-cranial dural distraction that provoked cervical radicular pain. In this instance, the complaint of elbow pain associated with a cervical radiculopathy could be attributed to caudal-to-cranial intraspinal pia traction acting on its intraforaminal thecal extension surrounding the C8 spinal root, previously sensitized by a herniated disc.

Key Words: Cervical Radiculopathy, Lumbar Radiculopathy, Neuromusculoskeletal Rehabilitation, Spinal Traction

In 1992, LaBan et al.1 described the precipitous onset of a lumbar radiculopathy in 12 patients who were receiving therapeutic intermittent cervical traction for a primary complaint of cervical radiculopathy. Cranial-to-caudal traction of the intraspinal pia with cervical spinal distraction was cited as the dynamic link provoking the symptoms of lumbar radiculopathy.

Recently, a 69-yr-old patient presented with complaints of “left elbow pain” initially aggravated by same-side great toe and foot/ankle dorsiflexion and then subsequently exacerbated by an ipsilateral straight leg–raising maneuver. A cervical myelogram with a postmyelogram computed tomographic scan subsequently demonstrated a large posterolateral disc herniation at C7-T1 on the symptomatic side. In this instance, the complaint of elbow pain associated with a cervical radiculopathy could be attributed to caudal-to-cranial intraspinal pia traction via its intraforaminal thecal extension enveloping the C8 spinal root previously sensitized by the prolapsed disc. In this instance, the cervical radicular pain was precipitated by distal distraction of the lumbar roots intimately surrounded by their meningeal extensions. Conversely, a 33-yr-old female nurse complaining of right-sided neck and shoulder pain as a residuum of an auto accident was also placed on cervical traction for a primary complaint of cervical radiculopathy.
intermittent cervical traction with a primary diagnosis of cervical radiculopathy. With the initial distracting weight of 15 pounds, she immediately experienced acute lumbar, buttock, and right leg pain. Magnetic resonance imaging demonstrated the presence of degenerative disease and a posttraumatic annular tear of the L5 disc. As in the initial 1992 report of 12 similar patients, cervical traction with the spine in a position of flexion was perceived to have distracted an already taut, prefixed pia, precipitating the acute symptoms of lumbar radiculopathy. As was observed in these two cases, pia traction, either cranial to caudal or caudal to cranial, has a potential of inciting spinal radicular pain, particularly when the symptomatic spinal root has been presensitized by either trauma or inflammation.

CASE REPORTS

Case 1

A 69-yr-old woman was admitted to the hospital with a primary complaint of severe left elbow pain. She had a history of multiple lumbar surgeries and a cervical spinal fusion. On clinical examination, she demonstrated limited cervical spine range of motion, with a periarthrosis of both shoulders. There was marked weakness in the left C7-C8 myotome distribution as evidenced by decreased strength in the triceps, pronator teres, and the hand intrinsic musculature. The patient was also noted to have decreased two-point discrimination over the left C8 dermatome distribution. Proprioception was also impaired bilaterally over the great toes, with a symmetrical reduction of the deep tendon reflexes at the knees and ankles. There was no evidence of long tract signs. Left-sided straight-leg raising was limited by increasing left elbow pain, subsequently exacerbated by ankle dorsiflexion and great toe—extension maneuvers. Roentgenographic examination demonstrated extensive degenerative changes of the cervical spine with a stable fusion and at lumbar levels only postoperative changes. A postmyelogram CAT scan revealed a C8-T1 (Fig. 1). Initially managed with intravenous narcotics, the patient was subsequently discharged on oral analgesics. In consultation, spinal orthopedic surgery recommended continuing conservative, nonsurgical therapy.

Case 2

A 33-yr-old female nurse was evaluated as an outpatient after a motor vehicle accident with a primary complaint of neck, right shoulder, and arm pain and of low-grade lumbar discomfort. The clinical examination demonstrated a positive Spurling’s head compression test to the right with concomitant weakness in the same side C6 myotome distribution, as evidenced by decreased strength in the supraspinatus, deltoid, biceps, and pronator teres muscles. Palpable discomfort was noted over the right sacroiliac joint and, to a lesser degree, over the sciatic notch. The deep tendon reflexes were symmetrically equal, strength was normal, and straight leg—raising was unrestricted. Bladder and bowel function was reported as normal, and there was no evidence of long tract signs.

Roentgenographic examination of the cervical spine was within normal limits. The patient was administered intermittent cervical traction at an initial distraction weight of 15 pounds after hydrocolator packing. She immediately developed right buttock and posterior thigh radiation in the sciatic nerve distribution to the right calf. Straight leg—raising was now markedly limited to 30 degrees, and there was a significant reduction in right ankle jerk. Ipsilateral weakness was also noted in the extensor hallucis longus muscle. Magnetic resonance imaging examination revealed low-grade, multiple-level degenerative changes in the lumbar spine, with a posttraumatic tear of the anulus of the L5 disc (Fig. 2). Electrodiagnostic examination, including electromyography and spinal-evoked potentials, were both normal. After a second of three planned lumbar epidural steroid injections, the patient’s heretofore severe and intractable sciatic pain complaint improved significantly.
DISCUSSION

In the previous report, 12 patients receiving intermittent cervical traction for symptoms of cervical radiculopathy were described as developing acute lumbar radiculopathy. In each case, an initial reduction in the cervical distraction weight and a modification of the patient’s posture position during treatment (i.e., increased hip and knee flexion) immediately eased the sciatic radiculopathy. In each case, within 3 wks of discontinuing cervical traction therapy, significant improvement in the sciatica was reported.

Historically, it has been held that as the osseous spinal column flexes and extends, the contained spinal cord and its nerve roots are displaced in both a caudal and cranial direction. However, Breig, in his 1960 classic monograph Biomechanics of the Central Nervous System, demonstrated otherwise. Instead, he noted that the spinal cord adapts to distraction by an initial elastic and subsequently plastic deformation. Axial movement of the cord responding to the changing length of the encompassing spinal canal does not, in fact, occur. With neck flexion, the cord elongates with a simultaneous decrease in its diameter. In extension, it compresses axially, with transverse folds developing on the cord surface and its cross-sectional area increasing.

When dissected from its enveloping pia, the spinal cord in response to traction behaves as a nonresistant semifluid cohesive mass. However, when the enveloping pia is intact, an axial tensile force abruptly develops throughout the entire length of the pia, markedly limiting additional responses to distraction, especially in a position of spinal flexion.

In a similar manner, the nerve roots themselves are relatively fixed within their respective neural foramina. They resist the “in and out” moment generated by axial spinal canal or limb movement. Instead, they, like the cord, demonstrate an initial elastic and then plastic deformation as they adapt to movements of the spinal cord or the adjacent limb. In spinal extension, the nerve roots also shorten developing transverse folds on their surface and assume a serpentine course as they increase their cross-sectional diameter. Conversely, in spinal extension, the enclosed nerves and root sleeves straighten and elongate.

The cord and its spinal roots can be significantly affected by pathomechanical forces acting locally and having a remote affect. These tensile forces potentially affect both the cord itself and its spinal nerves, particularly those at either end of the cord (i.e., those having the most oblique course within the cranial posterior fossa or the cauda equina).

Although spinal ventroflexion may initially act to the detriment of an immediately adjacent nerve root prefixed by root-sleeve fibrosis or a prolapsed disc, an enhanced traction effect may also be transmitted via an overly taut pia throughout the entire length of the cord, inciting radicular symptoms at distal levels. Disc protrusions or a local loss of flexibility of the osseous spine and inherent senescent changes related to stiffening of the cord itself can multiply these potentially pathologic tensile forces. These forces may be transitory, provoking only episodic low-grade edema of the spinal root or, over time, incite a more permanent, progressive fibrosis of the spinal nerves and its root sleeves. Breig has demonstrated that contrary to Forestier’s previous description, the nerve root does not slide within the dural sleeve. Therefore, friction does not develop between the root and its dural sleeve because both structures are contiguous and are simultaneously deformed within the osseous foramina by axial movements of the cord. Instead, periradicular fibrosis arises from repeated trauma between the dura and the surrounding osseous walls of the neural canal within the periradicular space. This process of root-sleeve fibrosis in part
can be directly related to increasing angulation of the nerve roots accommodating to adjacent spinal structural changes (i.e., shortening of the osseous spine induced by degenerative disc disease). This process may culminate with scared nerve roots directly adherent to the dura and the surrounding bony ostia. With chronic inflammation and progressive cicatrization of the nerve root, the normal elasticity and plasticity of the root is lost due to progressive interstitial gliosis. In spinal flexion, the nerve root and its dura no longer “unfold,” potentially inciting local radicular symptoms. Increasing axial tension may also be relayed throughout the length of the cord by increased stiffening of the pia. The spinal roots immobilized in the neuroforamina by both the proximal dural fibrous bands (i.e., the ligaments of Hofmann) and distally by the epineural sheaths are vulnerable in this position to direct compromise by a prolapsed disc. The clinical response of the spinal nerve root to a disc protrusion primarily affecting its vascular supply is often variable, mitigated by the presence or absence of the proximal restraining dural ligaments, the mass of the disc and the force and area of compression, and the inherent elasticity and plasticity of the neural tissue, among other factors. As these two clinical cases demonstrate, there may be a direct rather than a casual relationship among the symptoms of sciatica or brachiocephalgia, especially in a spinal position of flexion. In this regard, the common denominator seems to be increasing axial tension via the pia lying in intimate juxtaposition to a previously sensitized spinal root.

As Breig\(^3\) has so elegantly demonstrated, as the spinal cord itself is able to conduct neural impulses from one place to another, its enveloping meninges has the capacity to convey mechanical axial traction forces remotely in response to pia stretching. Patients developing radicular complaints remotely during therapeutic mechanical traction (i.e., cranial-to-caudal or caudal-to-cranial traction) should have therapy immediately discontinued.

REFERENCES
Heterotopic Ossification in Traumatic Brain Injury

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A 19-yr-old man with traumatic brain injury from a motor vehicle accident was admitted to a rehabilitation unit after 2 mos of acute care hospitalization. His initial Glasgow Coma Scale score was 6. The patient had a prolonged period of coma and had undergone ventriculoperitoneal shunting for increased intracranial pressure. At admission, the patient was confused and inappropriate (Rancho Los Amigos level V). He had a left spastic hemiplegia, left hip and knee flexion deformities, and a left ankle plantar-flexion contracture. Range of motion in the left hip, knee, and ankle joints was limited and painful. A hard, nontender mass was palpable in the right quadriceps muscle. Heterotopic ossification (HO) was clinically suspected. Plain radiographs revealed minimal soft tissue calcification near the right mid-femur but did not show ectopic bone or other bony abnormality around the left hip. Serum alkaline phosphatase level was elevated at 143 units/liter (normal, 37–107 units/liter). A triple-phase bone scan showed a diffuse but irregular increase in radiopharmaceutical uptake inferior to the left hip joint and medial to the right mid-femur on the delayed images (Fig. 1). These findings were consistent with active HO. Reha-

![Figure 1: Delayed total body images of the triple-phase bone scan show diffusely increased radiopharmaceutical uptake lateral and inferior to the left hip joint and medial to the right mid-femur (arrows).]
bilitation included aggressive range-of-motion exercises to the left hip, knee, and ankle joints and serial casting to increase knee extension. Oral antispasticity medication was administered to reduce spastic hypertonia. Indomethacin was used to treat/prevent HO and to reduce pain.

HO is the formation of new bone in soft tissue. The prevalence of clinically significant HO in the traumatic brain injury population is estimated to be 10–20%. Major risk factors for HO development include immobility, limb spasticity, and prolonged coma. HO does not develop intra-articularly, and in traumatic brain injury, it tends to occur in decreasing frequency around the hips, elbows, shoulders, knees, and at times, in the thigh. HO may present with range-of-motion limitation, pain, swelling, erythema, or other features of inflammation. Bony ankylosis, nerve and vascular compression, or lymphedema may also occur. These findings are non-specific, and diagnostic testing (plain radiographs, triple-phase bone scan, serum alkaline phosphatase) is usually required for confirmation.

Early diagnosis of HO in the traumatic brain injury population is essential so as to limit additional disability and pain. Nonsteroidal antiinflammatory drugs, etidronate sodium, range-of-motion exercises, and spasticity management may be used to prevent HO development or progression. Treatment of established, severe, functionally limiting HO includes surgical resection and forceful manipulation.

Radionuclide triple-phase bone scan is particularly sensitive for detection of early HO. Positive phase I (dynamic blood flow) and phase II (blood pool) scans may precede a positive phase III (delayed) scan by 2–4 wks. A positive phase III scan can precede radiographic findings of ossification by 1–4 wks. This test can also provide a measure of bone maturity. Serial scans can be used to gauge progression of the process and also to guide the timing of possible surgical resection, which is usually done when the HO is mature.