ORIGINAL ARTICLE

Intrinsic Properties of the Knee Extensor Muscles After Subacute Stroke

Astrid M. Horstman, MSc, Karin H. Gerrits, PhD, Marijke J. Beltman, PhD, Peter A. Koppe, MD, Thomas W. Janssen, PhD, Arnold de Haan, PhD

ABSTRACT. Horstman AM, Gerrits KH, Beltman MJ, Koppe PA, Janssen, TW, de Haan A. Intrinsic properties of the knee extensor muscles after subacute stroke. Arch Phys Med Rehabil 2010;91:123-8.

Objective: To characterize muscle properties of paretic lower-limb (PL) and nonparetic lower-limb (NL) knee extensors in patients with subacute stroke.

Design: Case-control study.

Setting: Rehabilitation center research laboratory.

Participants: Patients with subacute stroke (n=14) and able-bodied age-matched control subjects (n=12).

Interventions: Not applicable.

Main Outcome Measures: Half relaxation times (HRTs) and maximal rates of torque development (MRTDs) were assessed as indicators of contractile speed using both voluntary and electrically evoked contractions. Moreover, changes in torque were measured during a fatigue protocol (35 electrically evoked intermittent contractions; 1.5s on, 2s off) and recovery.

Results: No differences among groups were found for normalized MRTDs during electrically evoked contractions (P=.117). However, during voluntary contractions both PLs (53% of control, P=.022) and NL (71% of control, P<.001) had significantly lower MRTD compared with control. Both PL (134% of control, P=.001) and NL (123% of control, P=.032) had significantly higher HRTs than control, indicating muscle slowing in patients with subacute stroke. PLs fatigued more and faster than control (P=.011) and both PL and NL recovered slower (P<.001).

Conclusions: The changes in HRTs and fatigue suggest adaptations in muscle properties toward slower, more fatigable muscle shortly after stroke. The inability to make use of contractile speed because of impaired neural activation seems the most limiting factor during the initial phase of torque development in PL. Thus, besides strengthening, muscle endurance and speed should also be addressed during rehabilitation.

Key Words: Electric stimulation; Fatigue; Muscle relaxation; Quadriceps muscle; Rehabilitation.

STROKE LEADS TO SIGNIFICANT muscle weakness in both the lower limb contralateral (PL)[1-3] and ipsilateral (NL) to the lesion.[1,4,5] In a previous study with the same group of patients,[3] we have reported that in patients with subacute stroke, muscle weakness of the NL (torque was 68% of control) could be explained by activation failure (voluntary activation capacity was 75.1% compared with 93.6% in control), whereas in the PL, muscle weakness (torque was 28% of control) could not only be attributed to a reduced activation (57.8% of control) but also to an impaired intrinsic torque capacity (56% of control).

Because the knee extensor muscles are exposed to altered patterns of activity and function after stroke, their contractile properties are assumed to change. A change in muscle fiber composition, characterized by selective type II fiber atrophy and predominance of (slow twitch, oxidative) type I fibers, has been shown in paretic muscles,[6-10] which would lead to concomitant changes in contractile speed of the muscle fibers toward those of slow muscles, accompanied by more fatigue resistance, as found by Toffola et al[11] in patients with chronic stroke. Results are inconsistent in that others[12,13] found enhanced neuromuscular fatigue in patients with chronic stroke, which may partly relate to methodologies used to study fatigue resistance. Moreover, it is unclear whether the fatigue properties of muscles in subacute stroke patients have altered. We anticipate that shortly after stroke, people are more inactive and therefore are likely to develop a lower oxidative capacity. Together with impaired blood flow and capillarization,[14-17] this is expected to lead to a higher fatigability.

Given the altered muscle fiber composition combined with impaired neural drive, the rate of torque development may be even more deteriorated. This ability to develop torque rapidly seems important for balance control and fall prevention.[18,19] Indeed, individuals with stroke seem to perform slower during voluntary contractions of both upper- and lower-limb muscles.[4,20-22] Other studies using electrically evoked contractions[13,23] suggest that the time course of torque development has changed, because of changes in contractile muscle properties, making it intrinsically slower. Nevertheless, as these studies did not compare electrically induced contractions with voluntary contractions, information about the relative contribution of both neural and more local muscular changes is still lacking. More specifically, it is presently unknown to what extent patients with stroke are able to make use of the muscles' maximal torque capacity during fast voluntary contractions of

List of Abbreviations

ANOVA	analysis of variance
HRT	half relaxation time
MRTD	maximal rate of torque development
MVC	maximal voluntary contraction
NL	nonparetic lower limb
PL	paretic lower limb

From the Research Institute MOVE, Faculty of Human Movement Sciences, VU University Amsterdam, The Netherlands (Horstman, Gerrits, Beltman, Janssen, de Haan); Duyvensz-Nagel Research Laboratory, Rehabilitation Centre Amsterdam, Amsterdam, The Netherlands (Gerrits, Koppe, Janssen); Institute for Biomedical Research into Human Movement and Health, Manchester Metropolitan University, Manchester, UK (de Haan).

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Reprint requests to Astrid Horstman, MSc, Faculty of Human Movement Sciences, VU University Amsterdam, Van der Boechorststraat 9, 1081 BT Amsterdam, The Netherlands, e-mail: *a.horstman@fbw.vu.nl*.

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Table 1: Subject Characteristics

	Age (y)	Height (m)	Weight (kg)	Sex (men/women)	Stroke Type (haemorrhagic/ischemic	Side of Lesion (left/right)
Stroke patients	56±10	1.74±0.10	74.9±14.3	10M, 4W	5H, 9I	6L, 8R
Control	58±12	1.76±0.06	75.7±11.9	7M, 5W		

NOTE. Values are mean ± SD unless otherwise indicated.
Abbreviations: H, hemorrhagic; I, ischemic; L, left; M, men; R, right; W, women.

the knee extensors and whether this differs between the paretic or nonparetic side. Accordingly, we were interested in whether this muscle slowing was because of the inability to maximally drive the muscles to perform fast contractions and/or that the slowing was because of changed intrinsic muscle properties. Therefore, both voluntary and electrically evoked contractions were used to determine maximal rate of torque development.

For optimizing rehabilitation programs, a better understanding of the degree and nature of impaired muscle function of the knee extensor muscles in patients with subacute stroke is needed. Therefore, the aim of the present study was to compare contractile speed and fatigue characteristics of the knee extensor muscles of subacute stroke patients with those of able-bodied controls. We hypothesized that patients with subacute stroke have slower, more fatigable muscles and are less able to make use of the muscles' maximal torque capacity during fast voluntary contractions, mainly because of impaired neural control.

METHODS

Subjects

Fourteen patients after their first stroke and with lower-extremity hemiparesis entered the study on average 3.5 months after stroke and 2 months after admission to the rehabilitation center (table 1). They were in- or outpatients, and all except one were ambulatory. From this patient group, data on knee extensor and flexor torque (at different knee angles) and voluntary activation have been published elsewhere.[3,24]

The median and quartiles on the Functional Ambulation Categories score were 4 (2.25–4.00), evaluating the measure of independence of walking on a 6-point scale (0–5).[25,26] Twelve able-bodied control subjects volunteered to participate in this study. They were matched ($.470<P<.954$) for age, height, and body mass. Each subject was informed about the procedures. They each filled out a health questionnaire and gave written informed consent. Exclusion criteria were medical complications, severe cognitive and/or communicative problems preventing the ability to follow verbal instructions or limiting the ability to perform the requested tasks, and contraindications for electrical stimulation.

The study was approved by the institutional review board of the VU University Medical Centre, Amsterdam, the Netherlands.

Experimental Setup and Procedures

The measurements described in the present article were part of a protocol spread over 4 measurement days (separated by at least 24 hours). On the first day, electrically evoked contractions and a fatigue protocol (see section to follow: Torque measurements) were performed with both legs, starting with the PL and then the NL. The second day, subjects underwent supramaximal stimulation and superimposed triplets, also starting with the PL, followed by the NL. The third day, torque-angle relationships were recorded from the PL and on the fourth day for the NL. Control subjects performed the measurements with only their right leg.

In a familiarization session, subjects started with a warm-up (consisting of 5 submaximal contractions) with the NL to check whether the instructions were understood. Subsequently, they were trained to perform maximal isometric knee extension contractions. Thereafter, they were familiarized with electrical stimulation. Using a frequency of 150Hz, the current was increased in steps of 10mA until the torque reached 50% of their maximal voluntary contraction torque.

Torque measurements. Measurements were performed on a custom-built (VU University Amsterdam, the Netherlands) Lower EXtremity System.[3] Subjects were placed on the Lower EXtremity System in a supine position and were tilted to the measuring position: seated with their back 10° backward from upright, 80° hip angle, and 60° knee angle (0°=full extension). To avoid changes in hip and knee angle during isometric contractions, subjects were restrained with a hip and trunk belt. Their shank was strapped tightly to a force transducer[a] (range: 0–2kN) with a cuff just above the ankle. Active knee angle was determined with a handheld goniometer[b] using the greater trochanter, the lateral femoral epicondyle, and the lateral malleolus as references.[27] The distance between the epicondyle and a fixed point on the force transducer was used as external moment arm.

Each session started with maximal isometric knee extensions for 3 to 4 seconds to determine MVC torque separated by 2 minutes of rest. MVC torque was taken as the highest value that did not exceed preceding attempts by greater than 10%, allowing a maximum of 4 attempts. Subjects were vigorously encouraged to exceed their previous maximal value, which was displayed on a computer screen to confirm the subject's achievement throughout the test. After explanation of the procedure for electrical stimulation, the skin of the thigh of the subject was shaved (when necessary) and a pair of self-adhesive surface electrodes[c] (13 × 8cm) were placed over the proximal and distal part of the anterior thigh. A computer-controlled constant current stimulator[d] was used with rectangular pulses of 200μs. Current amplitude was increased at 150Hz until 50% of subjects' MVC torque was reached, assuming that then 50% of the knee extensor muscle mass, which could be voluntarily recruited for healthy subjects, was activated. This current was subsequently used in the following procedures: an electrically evoked 80ms contraction at 300Hz to determine the maximal rate of torque development[28] and at 150Hz (700ms) to determine maximal torque at this intensity.

The fatigue protocol lasted 2 minutes and consisted of 35 electrically evoked intermittent contractions (1.5s on, 2s off) at 50Hz. At this 50Hz frequency, torque was approximately 90% of the maximal torque, and high-frequency fatigue was prevented. Recovery measurements occurred at 15, 30, 45, 60, 90 and 180 seconds after the last contraction of the fatigue protocol using the same current amplitude and stimulation frequency to check if and how fast the muscle recovered from fatigue.