ORIGINAL ARTICLES

Consequences of Repetitive Toenail Cutting by Podiatric Physicians on Force Production, Endurance to Fatigue, and the Electromyogram of the Flexor Digitorum Superficialis Muscles

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Background: We hypothesized that the repetitive use of a toenail clipper by podiatric physicians could induce fatigue of the flexor digitorum superficialis (FDS) muscle, reducing the accuracy of toenail cutting.

Methods: We examined the consequences of cutting a plastic sheet, reproducing the resistance of thick toenails, with a podiatric medical clipper on the maximal handgrip force (Fmax) developed by the FDS muscle and an isometric handgrip sustained at 50% of Fmax, during which endurance to fatigue and changes in the power spectra of the surface FDS muscle electromyogram (root mean square and median frequency) were measured. The same participants randomly performed one or five runs of 30 successive cuttings, each on different days.

Results: After the first and fifth cutting runs, Fmax increased, suggesting a post-tetanic potentiation. During the handgrip sustained at 50% of Fmax, we measured a significant reduction in the tension-time index after the first cutting run. Moreover, after the fifth cutting run, the tension-time index decrease was significantly accentuated, and the decrease in FDS muscle median frequency was enhanced. No median frequency decline was measured during the cutting runs.

Conclusions: These results suggest that the efficacy of occupational podiatric medical tasks progressively declines with the repetition of toenail cutting. We propose solutions to remedy this situation. (J Am Podiatr Med Assoc 104(5): 486-492, 2014)

Many occupational activities require the repeated use of pliers or clippers. This is the case for metalworkers, jewelers, dental hygienists and dental engineers, podiatric physicians, the majority of European chiropodists, and other workers. Obviously, the resistance opposed to cutting or folding the materials greatly varies when the tasks necessitate the cutting of steel, platinum, gold, or rigid thick toenails, but in all cases the repetition of tasks throughout a working day could affect the force developed by the forearm muscles, reducing their action efficacy.

Some studies have already explored the consequences of repeated occupational use of clippers on the efficacy of tasks. Psychophysical studies have evaluated the discomfort of manipulating bent-handle pliers up to certain angles[1] and the effects of repetitive wrist flexion or extension with a power or pinch grip.[2-4] The effects of the design of the pliers on productivity, adding the orientation of the work surface in the sagittal plane and the wrist deviation in two planes as independent variables, have also been examined.[5] We found only one study that analyzed forearm muscle electromyograms (EMGs) to evaluate handling discomfort after design modifications to conventional manual Cleco pliers.[6]

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Apart from the aforementioned occupational studies, changes in the surface EMG spectrum in flexor digitorum superficialis (FDS) muscles during repetitive handgrips[7] or wrist extensions[8] have already been reported. Only when the tasks were executed at high force levels did the authors report EMG signs of fatigue, characterized by a progressive decrease in the median frequency (MF) of the power spectrum. After the repetition of tasks, these studies did not examine changes in the mechanical properties of the forearm muscles and the endurance to sustained fatiguing efforts.

The force failure during a sustained static effort results from a contractile fatigue, called peripheral fatigue. The force decline is sometimes preceded by an MF fall, called central fatigue.[9-11] This indicates reduced recruitment of high-frequency motor units and constitutes an adaptive response that delays the occurrence of force failure, ie, the muscle wisdom phenomenon.[11] It is well-known that the decline in the motoneuron firing rate, measured by the decreased MF, prevails during the holding phase of a static contraction and occurs less often during dynamic efforts, including intermittent handgrips.[12,13] The mechanisms of MF changes preceding the contractile failure are not fully elucidated. Numerous observations suggest that the MF reduction results mostly from activation of the group III-IV muscle afferents,[10,12,13] but other investigators[14-16] attribute part of these EMG changes to a disfacilitation of the motoneuron activity due to the reduced muscle spindle discharge during fatiguing efforts.

The present study was performed in the School of Podiatry, Marseille, and examined the consequences of repeated toenail cutting with a clipper on handgrip force production and endurance to fatigue and EMG signs of fatigue in the FDS muscle. This task involved only one hand, and there was no accompanying body exertion. We verified that the FDS muscle was preferentially recruited during cutting of a plastic sheet with a toenail clipper commonly used by podiatric physicians. We hypothesized that the repeated use of a toenail clipper could reduce the efficacy of occupational podiatric medical tasks.

Methods

Ethical Approval

This research adheres to the principles of the latest revision of the Declaration of Helsinki. The procedures were performed with the adequate understanding and written consent of the participants, and the protocol was approved by the Ethics Committee on Human Experimentation of Comité de Protection des Personnes (CPP) Sud Mediterranee 1.

Participants

Fourteen healthy individuals (seven women and seven men; mean ± SD age, 23 ± 1 years; mean ± SD weight, 63 ± 9 kg) participated in the study. None were involved in an exercise training program. Written informed consent was obtained from all of the participants, and the protocol was approved by our institutional ethics committee.

Protocol

The participants were seated comfortably. As shown in Figure 1, throughout the trial, including the measurements of maximal handgrip force (Fmax), endurance to fatigue during a handgrip sustained at 50% of Fmax, and the cutting runs with the toenail clipper, the dominant forearm was maintained in an intermediate position between prone and supine to hold either the handgrip device (model 5401; Takei Scientific Instruments Co Ltd, Niigata-City, Japan) or a 13-cm toenail clipper

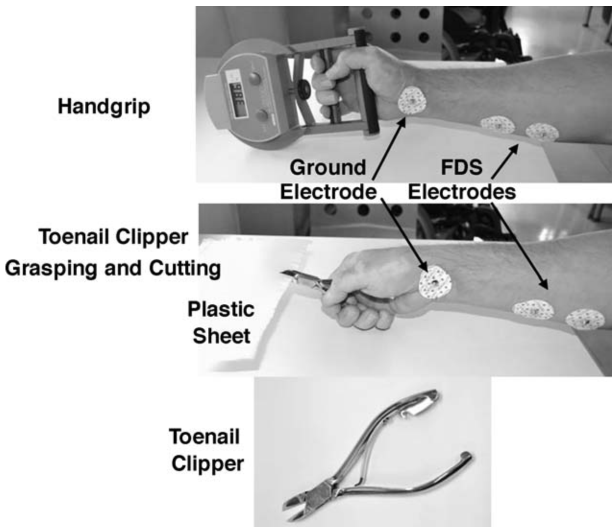

Figure 1. Photographs showing the handling positions chosen by the podiatric physician when executing the static handgrip or cutting with the toenail clipper and giving details on the toenail clipper. The positions of the surface electrodes used to record the electromyographic activity from the flexor digitorum superficialis (FDS) muscle are also indicated.

(Coblentz SA, Stains, France). To mimic the resistance to cutting opposed by thick toenails, we used a 1-mm-thick plastic sheet. In each cutting run, the participant was asked to cut the plastic sheet 30 times with the clipper. Two cutting run protocols were randomly performed in each participant. They executed either one run consisting of 30 cuttings with the toenail clipper or, on another day, five successive cutting runs. One cutting run lasted approximately 2 min, and a 5-min rest period elapsed between two consecutive runs. We encouraged the participant to maintain the same cutting cadence in each run. After the single or five cutting runs had stopped, all of the handgrip measurements were repeated within 5 min.

Static Handgrip Exercise

At the beginning of the experiment, the participants were instructed to perform three maximal handgrips sustained for 3 sec, with a 1-min interval between each. The highest force recording of the three contractions was considered the Fmax. Then, the participants were given visual feedback from the load cell to keep constant until exhaustion for a handgrip sustained at 50% of Fmax. We used a digital chronometer to determine the endurance time when the participant stopped contracting. The tension-time index was the product of the sustained handgrip force by endurance time, corresponding to the total power developed during the sustained contraction.[17]

Electrophysiologic Recordings

As in previous studies,[7,18-20] the surface EMG signal was recorded by a pair of silver–silver chloride electrodes (model 13L20; Dantec Medtronic, Skovlund, Denmark). The electrodes were placed between the motor point and the proximal tendon of the FDS muscle. The interelectrode distance was always 3 cm, and the impedance was kept below 2,000 Ω by careful skin shaving and abrasion with an ether pad. The EMG signal was recorded (MyoSystem 1400A; Noraxon USA Inc, Scottsdale, Arizona) and was amplified with a common mode rejection ratio of 90 dB, an input impedance of 100 mΩ, a gain of 5,000, and a frequency band ranging from 10 to 10,000 Hz. The software program allowed us to calculate the power spectrum, and the EMG signal was digitized with a sampling frequency of 2,000 Hz using the data acquisition card mounted in the computer. The Noraxon software program calculated the root mean square (RMS), an index of global EMG energy, and the MF, defined as the frequency that divided the power spectrum into two regions of equal power. The EMG analyses were continuously performed during the static handgrip sustained at 50% of Fmax and the cutting runs. During the handgrip sustained at 50% of Fmax, RMS and MF were averaged for the first 10 sec of contraction and for a 10-sec period when endurance time was measured. During the pretest 3-sec maximal handgrip, we measured the peak RMS, which was compared with the peak RMS measured during the cutting runs. The peak RMS measured during each cutting task may be considered proportional to the force produced because the RMS and force are proportional during concentric efforts.[21,22] Thus, although we cannot use a load cell to measure the force developed by the toenail clipper when cutting the plastic sheet, the RMS value could serve to evaluate the force developed.

Statistical Analyses

Data are presented as mean ± SEM. The normal distribution of the variables was verified with the Kolmogorov-Smirnov test. For temporally repeated data, the changes over time were determined using analysis of variance for repeated measures when the variables were normally distributed or a Friedman test for repeated measures when they were not. Time differences were identified using the Tukey multiple comparison test. Significance was accepted at $P < .05$.

Results

Evaluation of the Force Developed When Cutting with a Toenail Clipper

The peak RMS value measured at the beginning of each cutting run was 21% to 26% of the maximal RMS measured during the pretest 3-sec maximal handgrip (Fig. 2). This measurement gave an approximation of the force developed during the cutting runs.

Post–Cutting Run Changes in 3-sec Maximal Handgrip Force, Endurance to Fatigue, and EMG Changes During the Handgrip Sustained at 50% of Fmax

Figure 3 shows the data obtained in the same participants who randomly executed either one or five cutting runs. After the runs, the Fmax significantly but modestly increased. On the other hand, during the handgrip sustained at 50% of Fmax, there

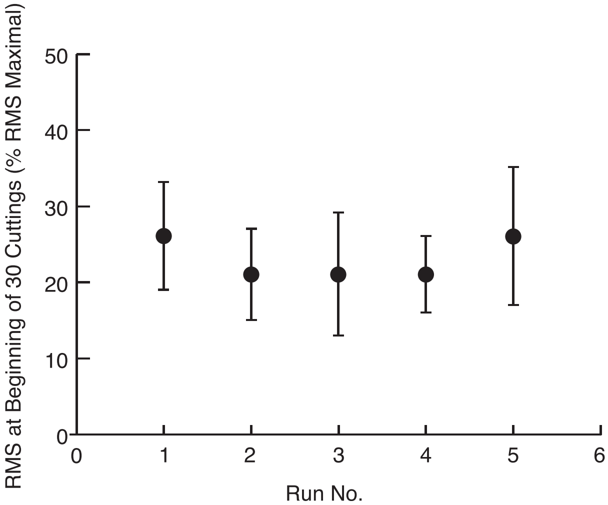

Figure 2. Mean ± SEM peak values of the root mean square (RMS) of the flexor digitorum superficialis muscle measured at the beginning of each run of 30 successive cuttings with the toenail clipper. The RMS values are expressed as a percentage of the peak RMS values measured in the same individuals executing the maximal handgrip before beginning any cutting run.

was shortening of endurance time and the tension-time index, the difference being significantly accentuated in the protocol consisting of five cutting runs. Moreover, Figure 3 also shows that after the five cutting runs, the MF decline was significantly accentuated. The accentuated MF changes were present but not significant after the single cutting run.

EMG Variations During the Cutting Runs

As shown in Figure 4, no leftward shift of the EMG spectrum occurred in the FDS muscle, and we noted a significant but isolated MF increase at the fourth cutting run. The RMS changes were not significant.

Discussion

Data Summary

The present study is the first, to our knowledge, to report data on the consequences of repetitive cutting of toenails with a clipper commonly used by podiatric physicians. After one run of 30 successive manipulations of the toenail clipper, we observed a significant reduction in the tension-time index during the handgrip sustained at 50% of Fmax. The tension-time index decrease was significantly accentuated after the five cutting runs, and the decrease in FDS muscle MF was then significantly enhanced. A modest but significant increase in posttest Fmax was also measured. During the repetitive dynamic cutting tasks, the EMG analyses did not indicate the occurrence of an adaptive muscle wisdom phenomenon, ie, there was no MF decrease to protect the FDS muscle against fatigue.

Mechanisms of Fmax Increase After the Cutting Runs

The increase in handgrip Fmax after the protocols of one or five cutting runs strongly suggests the existence of a post-tetanic potentiation. The animal study by Hirst et al[23] has shown that the post-tetanic potentiation, evoked in spinal α-motoneurons of the cat by repetitive stimulation of group Ia nerve fibers from muscle spindles, is accompanied by an increase in the probability of occurrence of high-frequency motor units. The post-tetanic potentiation represents a response of the transmitter release system.[24]

EMG Changes During the Cutting Runs

It was not surprising that no MF decrease was measured during repetitive cutting with the toenail clipper. Indeed, the changes in the EMG power spectra in the forearm muscles during dynamic handgrip[7] or wrist motion[8] and in the limb muscles during cycling[18,25-28] and swimming[19] show great interindividual variability. Moreover, Dai and coworkers[8] clearly showed that the EMG signs of muscle fatigue during repetitive wrist motions against different loads markedly depend on the magnitude of the load. In the present study, the force developed during use of the toenail clipper could be only approximated from the magnitude of RMS changes concomitantly measured in the FDS muscle. This approximation showed that the RMS increase represented approximately 20% to 25% of its maximal value measured during the pretest maximal handgrip, indicating a force level much lower than that determined by Dai et al[8] and too modest to elicit the muscle wisdom phenomenon. As noted previously herein, the prevailing recruitment of high-frequency motor units during the cutting runs could favor the reduced endurance to fatigue of the FDS muscle after the runs.

Post–Cutting Run Handgrip Function Alterations and EMG Changes

We measured significant reductions in endurance to fatigue after the single and five cutting runs, and the

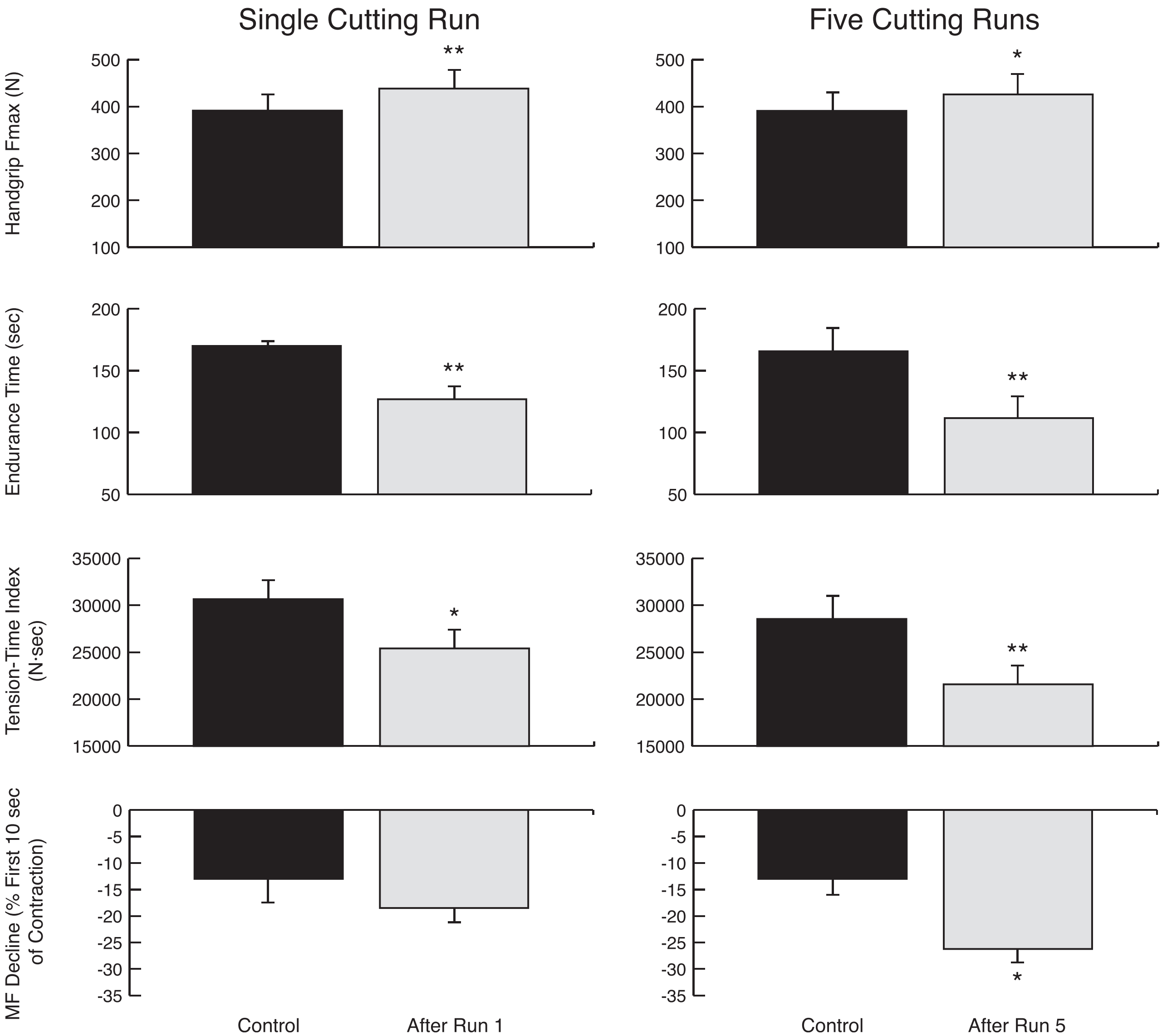

Figure 3. Mean ± SEM pretest (control) and posttest values of the maximal handgrip force (Fmax), endurance time, tension-time index, and relative changes in median frequency (MF) of the flexor digitorum superficialis muscle power spectrum measured during a handgrip sustained at 50% of Fmax until exhaustion. The test consisted of either one or five runs of 30 successive cuttings with a toenail clipper. *$P < .01$, **$P < .001$ versus control.

MF decline in the FDS muscle EMG was accentuated. These effects persisted for several minutes after the cutting runs had stopped, and we supposed that they resulted from the release of metabolites from the working muscles during the cutting runs. The leftward shift of the EMG power spectrum during fatiguing sustained contraction is attributed to activation of the group III-IV muscle afferents.[10,12,13] Electrophysiologic animal studies have clearly shown that the activation of these muscle afferents persists for several minutes after fatiguing muscle contraction[29] and also that lactic acid, inflammatory mediators, and reactive oxygen species are responsible for this activation.[30,31]

Conclusions

We observed that repetitive toenail cutting with a clipper used by podiatric physicians, mimicking routine daily occupational podiatric medical tasks, significantly reduced the performance of the forearm muscles and, thus, the accuracy and efficacy of

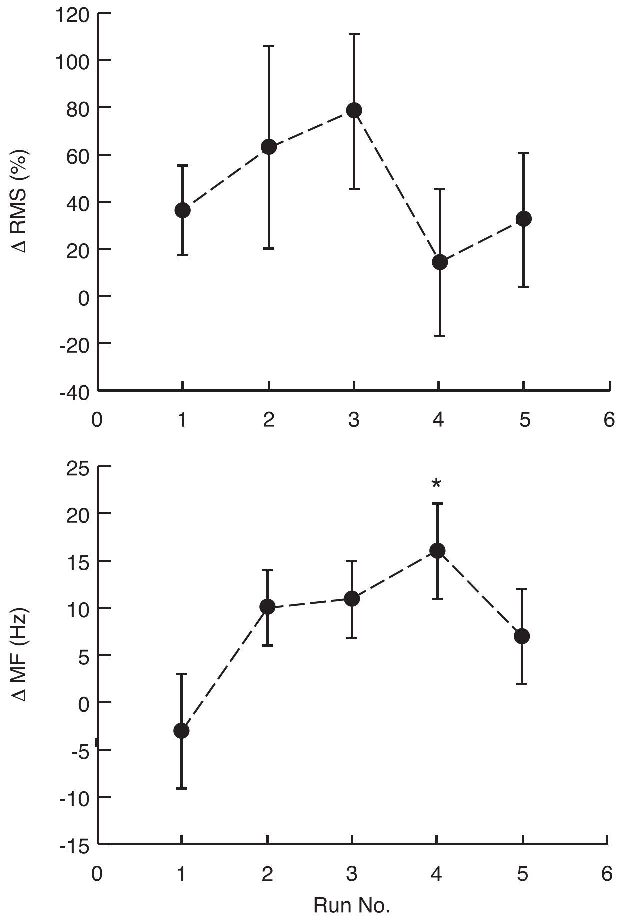

Figure 4. Mean ± SEM changes in root mean square (RMS) and median frequency (MF) of the flexor digitorum superficialis muscle electromyogram occurring from the first to the 30th cutting in each successive run. *$P < .01$.

the toenail cutting tasks. A significant reduction in endurance to fatigue already occurred after a single cutting run, which consisted of grasping the toenail clipper 30 times and corresponded to the routine task performed in both feet of the same patient. The typical day of a podiatric physician is composed of approximately a dozen care events, ie, a dozen toenail cutting runs. The simplest solution could be to elapse more time between patients or to perform other actions to treat other areas of the foot. The definitive solution to remedy this situation could be to urge the manufacturers to overhaul the mechanism of the toenail clipper to reduce the force produced by the practitioner.

It would be interesting to reproduce the same protocol combining the force measurements and EMG analyses in other occupational activities involving repetitive cutting of materials opposing higher resistance to cutting.

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Conflict of Interest: None reported.

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