STUDYING GAIT PATTERN WHEN EMULATING MUSCLE CONTRACTURE

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Abstract

In pathological gait it is very important to correctly identify primary gait anomalies originating from damage to the central nervous system and not mistaken them for compensatory changes of gait pattern. For that purpose a mechanical system consisting of specially sewed trousers, special shoes arrangement and elastic ropes attached to the designated locations on the trousers was designed that allows repeatable emulation of muscle contractures of soleus (SOL) and gastrocnemius (GAS) muscles. Six neurologically and orthopaedically intact subjects participated in instrumentally supported kinesiological evaluation. Results show that subjects developed compensatory mechanisms according to the type of artificially imposed muscle contracture

Introduction

Often in clinical studies and praxis we meet cases where damage to the central nervous system manifests in gait anomalies, leading to less efficient gait compared to normal gait. Patient's abilities to properly exert synchronised muscle activation for energy optimal gait are disturbed resulting in greater energy dissipation and efforts required for preservation the body in the upright position. It is a challenging task to establish appropriate diagnosis. Namely it is necessary to identify primary anomalies, which are directly attributable to the damage to the central nervous system or musculoskeletal system and not mistaken them for secondary anomalies, which the individual develops to compensate for unwanted effects arising from primary anomalies. For this purpose instrumented kinesiological assessment and analysis of joint kinematics, kinetics and muscle dynamic EMG signals are indispensable [1].

Very common example of pathological gait represents toe-walking. It is most frequently present in cerebral palsied children and is a result of either prolonged and premature ankle plantarflexors activity, plantarflexor spasticity and/or plantarflexor contractures leading also to bone and soft tissue deformities. Recently two studies investigated the kinematic, kinetic and EMG characteristics of toe-walking ˙[2,3]. Participants in both studies were able-bodied subject who were asked to induce toe-walking by self-restricting their walking. Comparing heal-toe walking and toe-walking Kerrigan et. al. [2] reported of significant reduction in the peak ankle plantarflexor torque and power generation during terminal stance and preswing, whereas in loading response, the moments of the ankle dorsiflexor and knee extensors were absent. Furthermore, during toe-walking Perry et. al. [3] also recorded greater plantarflexion during stance, higher peak and mean plantarflexor moments during loading response and midstance, lower mean plantarflexor moments during terminal stance and lower peak extensor moment in midstance. However it seems that the methodology of inducing toe-walking by asking subjects to self-restrict their walking can not adequately approximate pathological biomechanical conditions where the equinus is induced due to plantarflexor spasticity or contractures. Furthermore, since plantarflexors are constituted by a monoarticular soleus muscle as well as by a biarticular gastrocnemius muscle we can assume that spasticity or contracture of each muscle may have different biomechanical effects on resulting gait pattern in the joints of both lower extremities. Therefore, we need a more refined methodology, which will enable more detailed study into toe-walking gait patterns.

In this paper we present novel mechanical system, which is designed to ensure well-controlled conditions for repeatable emulation of artificially induced toe-walking gait in neurologically intact subjects. The system enables emulation of soleus muscle contracture, gastrocnemius muscle contracture or combination of both muscles contractures. We further present a study on the effects of emulated muscle contractures on gait patterns of six neurologically intact individuals.

Materials and Methods

Contracture emulation system

Fig. 1 shows schematic drawing of the proposed system consisting of specially sewed trousers, special shoes arrangements and elastic ropes attached at the proximal end to the designated locations on the trousers and at the distal end to the fixation frame at the heels of shoe. Trousers are made of durable material able to withstand mechanical loading due to stretching of the elastic ropes. To prevent trousers from moving vertically during walking four leather patches are longitudinally and transversally sewed to the inner side of left and right trouser legs.

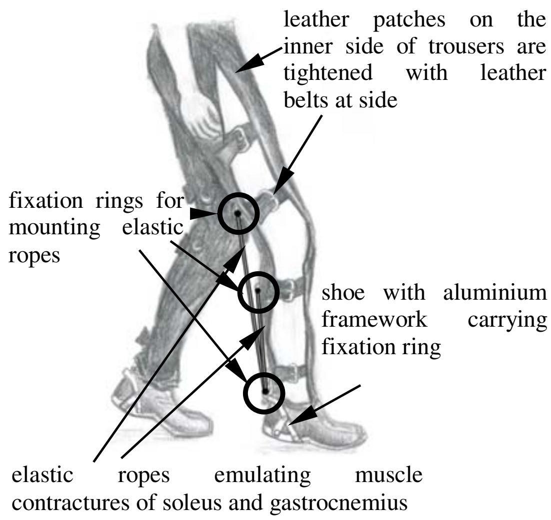

Fig 1: schematics of a subject during walking with emulation of SOL and GAS muscle contracture. The system consists of specially designed trousers and shoes and elastic ropes, representing emulated muscle contractures.

Additionally, fastening four leather belts on each leather patch keeps the whole arrangement firmly embraced to the thigh and shank of the lower extremity. Trouser legs on outer sides up to the pelvis level remain unstitched, providing enough space for fastening the belts and at the same time leaving hip, knee and ankle joint uncovered and freely movable. Iron fixating rings are mounted directly on trousers and leather patches at the approximate positions where particular muscles are attached to the bone. Iron nuts, tightening fixating rings on both sides of leather patches, were covered with soft leather tissue ensuring soft skin contact and firm attaching points for elastic ropes. Located beneath and posterior and above and posterior to the knee joint axis first and second fixating rings correspond to proximal ends of SOL and GAS muscles respectively. Distal ends of both muscles are attached to the heel arrangement of the shoe proximal to the ankle joint axis on the third and final fixating ring. Two aluminium bars are bent in the shape of shoe and mounted on shoes with iron screws and nuts trough shoes heels. Carrying the third fixating ring the first bar is on both sides of the shoe supported by the second bar, together forming triangles and thus preventing the frame from moving. Muscle contracture is emulated with one or more elastic ropes connected in parallel. When choosing appropriate length and stiffness of elastic ropes we had to prevent elastic rope to exceed it's elastic limits, which would induce unwanted perturbation in walking. Decision which elastic rope is appropriate to satisfy this condition and at the same time induce well-controlled changes in gait pattern was reached according to the trial and error tests.

Participants

Six subjects of similar age, height and mass (mean age ± standard deviation, 22.5 ± 1.87 y; mean height, 175.0 ± 4.2 cm; mean mass, 64.2 ± 4.2 kg) participated in this study. Subjects were free from any muscoloskeletal or neurological impairments that would affect their gait.

Experimental conditions

Providing good possibilities to emulate several constraining conditions the study was limited to emulation of muscle contractures of soleus and gastrocnemius individually (in text referred as SOL or GAS muscle contracture) or in combination (in text referred as SOL-GAS muscle contracture) each time using two elastic ropes emulating muscle contractures. Recordings when subjects were equipped with proposed system but with no elastic ropes attached (referred as normal gait) were taken for comparison. We used VICON motion analysis system consisting of six 50 Hz cameras with infrared strobes for capturing three-dimensional motion of lower extremity and pelvis and two AMTI force platforms for recording ground reaction forces. By means of VICON Clinical Manager we calculated ankle, knee and hip joint angles, moments and powers for the movement in the sagittal plane. Participants were instructed to walk at average walking speed of approximately 1 m/s. Using a time watch trials were excluded from further analysis if the time taking the subject to overcome the distance of seven meters differed for more than one half of a second from the expected time of seven seconds. In each experimental condition i.e. type of emulated muscle contracture at least four clear steps with the left leg (equipped with elastic ropes in the second experimental condition) were recorded and averaged in each sample of gait cycle.

Data analysis

Resulting gait pattern recordings for six participants were included in the further statistical analysis. Comparing particular type of artificially induced pathological gait to subject's normal gait differences in joint moments were examined. Focusing on the differences in ankle and knee peak and average moment values in midstance (10-30% of GC) and terminal stance (30-55% of GC) we performed one-tailed t-test pair-wise comparison between particular experimental conditions. The level of statistical significance was set to $p < 0.05$.

Results

Figure 2 shows representative recordings of a gait pattern measured in one of the subjects. Each graph shows trajectories measured under all four selected experimental conditions. There is a considerable difference between the resulting kinematic and kinetic patterns. Artificial constraint imposed by elastic ropes emulating SOL and SOLGAS muscle contracture forces ankle in excessive plantarflexion throughout gait cycle whereas in case of GAS muscle contracture the difference is not so explicit. Likewise the knee was flexed throughout stance phase and the range of motion in hip decreased, which resulted in shortened step as opposed to normal walking. Noticeable differences are present also in joint moment patterns Characteristic two-teeth profile occurs in the ankle when SOLGAS muscle contracture present opposed to not so extensive ankle plantarflexor moment increase in other two cases. Furthermore opposite effect on knee extensor moment could be noticed when comparing SOL and GAS muscle contracture. Whereas in SOL muscle contracture reduction of knee extensor moment in midstance was recorded in GAS muscle contracture knee extensor moment markedly increased in terminal stance. In most constrained situation of SOL-GAS contracture characteristic behaviour of both cases is summarised, namely midstance is characterised with knee extensor moment reduction whereas terminal stance with knee extensor moment increase. The power trajectories show characteristic power absorption pattern in the ankle in the early stance phase accompanied by decrease of power absorption at the knee. During push-off there is increased power absorption in the knee joint. Power generation in the hip joint in the early stance phase is somewhat increased.

Statistical analysis including results of all six subjects results supported these findings (figure 3). Regardless of type of muscle contracture greater peak and mean ankle plantarflexor moment was recorded in midstance compared to normal gait at the same time indicating statistical significant difference between SOL and GAS muscle contracture and SOLGAS muscle contracture whereas in terminal stance differences are less evident. In knee joint the differences are less evident in midstance and more explicit in terminal stance when compared to normal walking, as results show considerable greater peak and average knee extensor moment.

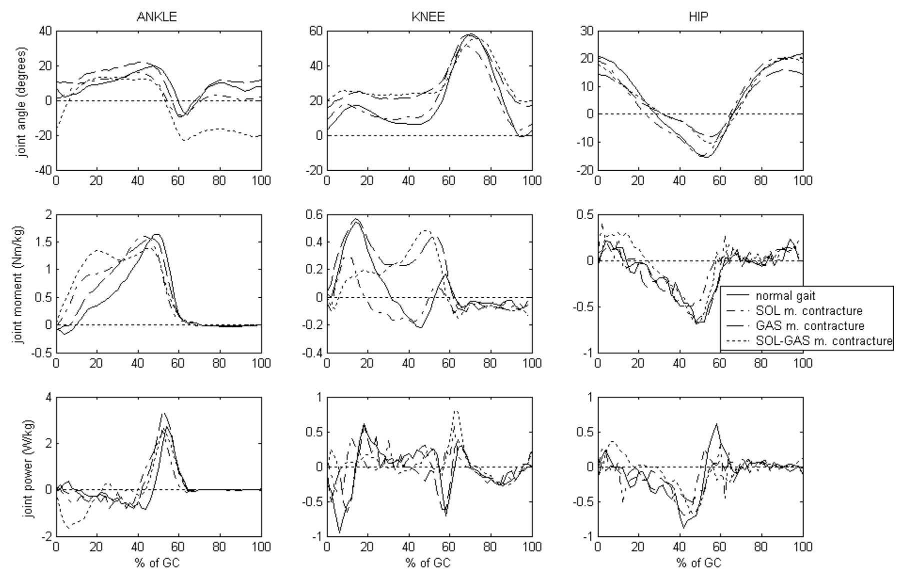

Fig 2. representative gait patterns of subject's left leg when normally walking and when emulating SOL and GAS muscle contractures separately and in combination on the left leg

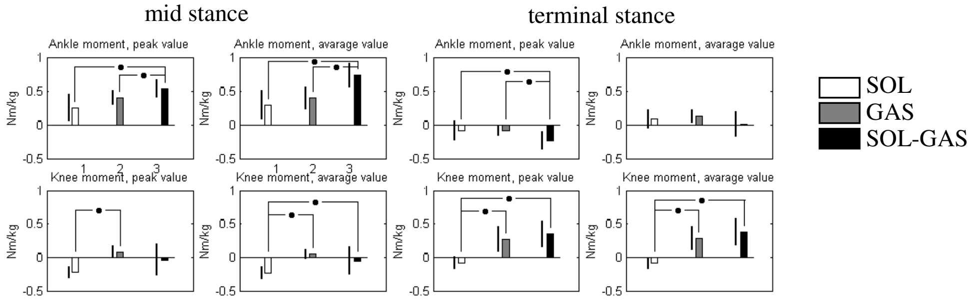

Fig. 3: For left leg comparing ankle and knee peak and average moment deviations from normal gait between different experimental conditions

Discussion

We have developed a mechanical system, which enables well-controlled imitation of SOL and GAS muscle contractures in neurologically and orthopaedically intact subject. The created biomechanical conditions are good approximation for spastic or contracted muscle. By varying the stiffness of the elastic ropes and also by utilizing various combinations of plantarflexor muscles contractures we are in position to investigate the role of each pathological combination in controlled conditions. Since the primary cause of altered gait pattern is known we can identify secondary, compensatory changes.

The main goal of this paper was to study the resulting gait patterns of emulated toe-walking, and compare our results with those of Kerrigan and Perry [2,3]. There are substantial similarities between the results for the ankle joint. The ankle is in pronounced plantarflexion, the ankle moment has characteristic double tooth shape and the power absorption in the ankle at the initial contact is evident. For the knee joint the results presented in fig. 2 and 3 are in agreement with [2,3] for the SOL condition and in for the GAS and SOL-GAS restraining conditions where knee joint is in marked flexion throughout stance and the knee extensor moment is substantially higher throughout the stance phase. The behaviour in the hip joint is similar to the one reported in Kerrigan. The differences observed in the knee joint indicate that there exist several toe-walking kinematic and kinetic patterns that must depend on degree of each plantarflexor muscle pathological state. Furthermore results in figure 3 support these findings and additionally emphasize that the differences in ankle and knee moment values show significant differences between particular restraining conditions.

The single disadvantage of the developed system is that the subjects needs to be of similar height and weight due to the size of trousers and shoes. Also a subject with substantially greater power generation capacity could overwhelm the strength of elastic ropes, therefore a direct comparison

between the subjects would not be possible. For these reasons subjects of similar height, weight and physical condition needs to be chosen to participate in the experiments, making the results between subjects directly comparable.

The developed system in its present form can be used only for emulation of SOL and GAS contractures, however, it can easily be expanded to allow emulation of contractures of other muscles of lower extremity. by mounting mechanical rings at the appropriate anatomical sites on the leather patches of the trousers. A variety of combinations can be studied and compared to gait patterns recorded with a single muscle contracture emulation.

References

[1] HANSON C. J., and JONES L. J.: Gait abnormalities and inhibitive casts in cerebral palsy. J. Am. Podiatr. Med. Assoc., 79, 1989, 53-59

[2] KERRIGAN D. C., OILEY P. O., ROGAN S., and BURKE D. T.: Compensatory advantages of toe walking. Arch. Phys. Med. Rehabil., 81, 2000, 38-44

[3] PERRY, J., BURNFIELD, J. M., GRONGLEY, J. K. and MULROY, S. J.: Toe walking: muscular demands at the ankle and knee. Arch. Phys. Med. Rehabil., 84, 2003, 7-16

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