MEASUREMENT OF SKELETAL MUSCLES SPASTICITY

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ABSTRACT

Skeletal muscles spasticity is assessed by physical therapists as increased resistance of particular muscle groups to manually induced passive movement. The aim of this investigation was to develop a clinically applicable method for evaluation of spasticity about the knee and to determine the minimum instrumentation necessary for a quick and simple estimation of spasticity. In this study the passive movement was produced by the force of gravity while the resistance was observed from the joint goniogram. Spasticity of the knee extensors was measured on 15 spinal cord injured patients. A mathematical model has been developed describing the experimental position of the extremity together with viscous and elastic properties of the joint and muscle. Records of severe, moderate, and slight spasticity are presented in the paper.

INTRODUCTION

The existing methods for quantitative measurement of spasticity can be divided into neurophysiological and biomechanical procedures. Since the neurophysiological measurements of tonic and phasic stretch reflexes[1] are rather complicated, it can be expected that the biomechanical procedures will sooner find their way into clinical practice. All of them are based on measurement of the resistance of the spastic limb to passive joint movement. Passive movement is induced by means of either electrical motors, hydraulic or pneumatic motors, electrical stimulation, vibration, mechanical inducement of reflexes (tendon tap), or voluntary movements (tracing methods). The parameters measured are in most cases joint forces or torques, joint angles and EMG potentials.

An extensive study of spasticity was performed by Burke et al.[2,3] Passive flexion of the knee was manually induced by the examiner. Tension, goniogram and velocity were recorded together with EMG. Three important properties of spasticity were determined in the measurements: 1) velocity - dependent excitation; 2) length - dependent inhibition; and 3) fatigability on repeated testing. Interesting comparisons of angle-torque curves in Parkinson and control subjects were provided by Nashold.[4] The movement of the forearm was provided by a constant speed motor. The angle of movement was measured by a potentiometer and the amount of resistance to passive motion by a torque meter. Similar instrumentation was used in the experiment performed by Webster.[5] Linear passive motions of the forearm or lower leg were obtained by a special active turntable. Strain gauges attached to the turntable detected the patient's muscular reaction to impressed movement. The author reports disadvantages of the measuring machine: its complexity, unphysiologic testing position and speed limitations. Joint compliance, defined as the ratio of joint rotation to applied torque, has been measured at sinusoidal torques with frequencies between 3 and 12 Hz.[6] The torques were provided by a computer controlled DC torque motor. The EMG of the antagonistic muscles was also measured in the experiment. The sophistication of some of these systems makes them rather unsuitable for routine use in clinically oriented departments.[7]

The difficulty in assessing spasticity is apparent also from the report by Burry[7] that 50% of the patients with spasticity tested claimed a reduction in the spasticity when given an inert substance and told that it was a new form of spasticity treatment. A need for an objective measurement of spasticity is unquestioned.

THE MODEL

Passive movements of the extremity can be induced by gravitational forces. For example, to assess the spasticity of the knee extensors, the lower leg can be dropped from a fully extended horizontal position (Fig. 1). Such experiments were performed by Wartenberg.[8] They consisted of passive swing maneuvers of both upper and lower extremities in order to determine Parkinson Syndrome. The test was only evaluated qualitatively. The leg behaves as a pendulum and its movement can be determined with the help of the model shown in Figure 2. Viscoelastic properties of joint and agonist and antagonist muscle groups are represented by parallel elasticity $K/2$ and viscous damping $B/2$. The moment of inertia J belongs to the leg below the knee, while ϕ is the knee joint angle. T_g is the joint

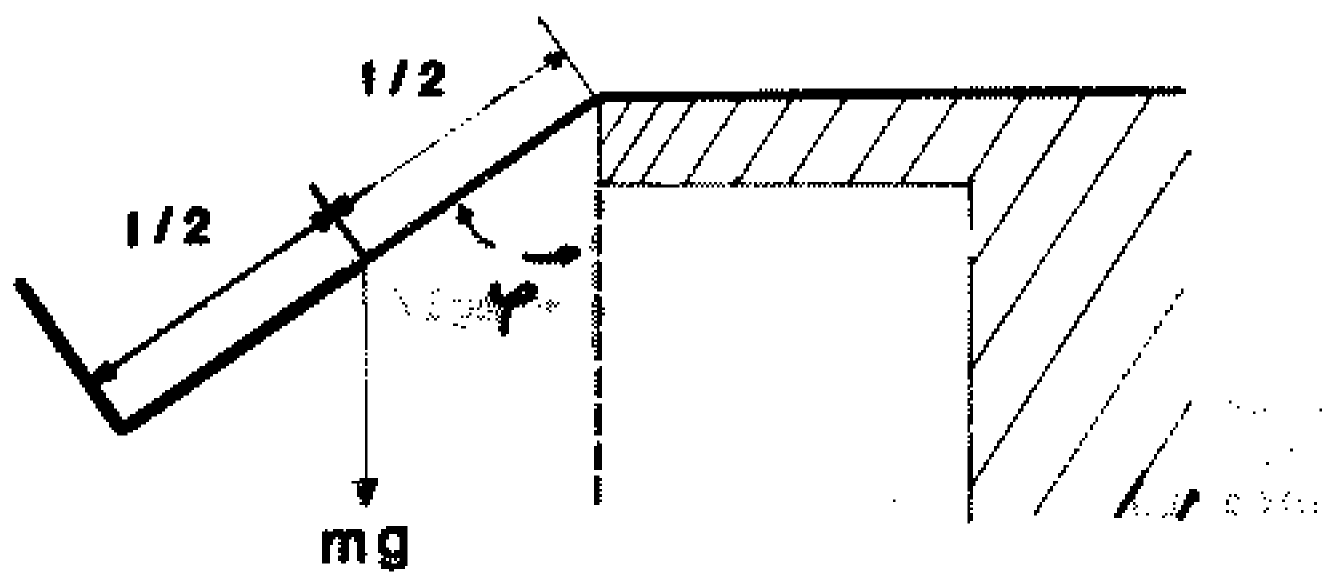
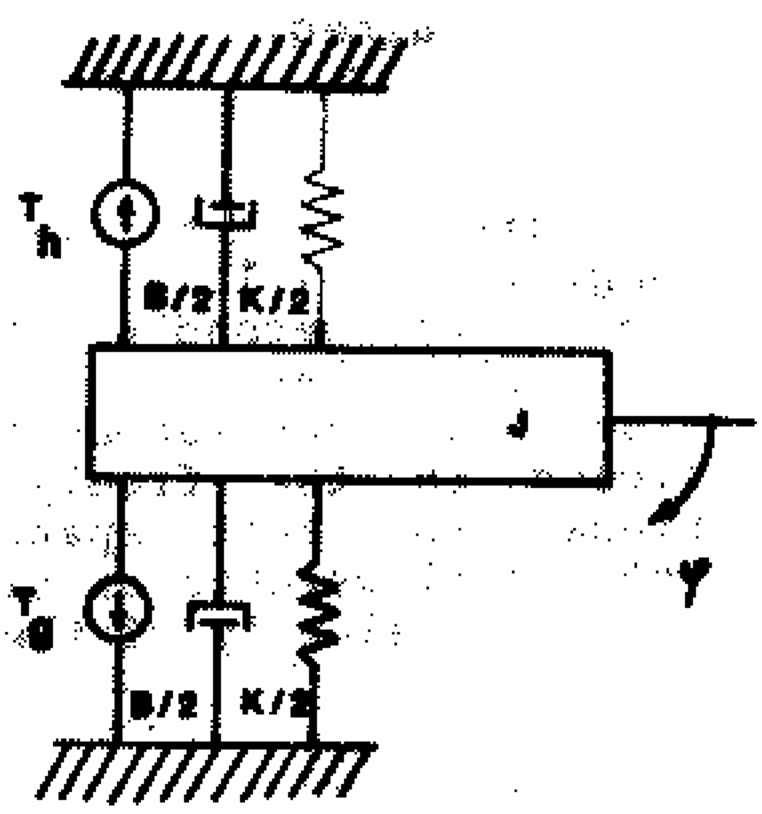


Fig. 1. Schematic of the extremity position during the measurement of knee extensors spasticity.



$$T_h = J\ddot{\varphi} + B\dot{\varphi} + K\varphi + (mgl/2)\sin\varphi$$

Fig. 2. Model of the lower leg.

torque produced by gravity of the limb. The torque of the hypertonia T_h is acting in the opposite direction. The aim of the model is to show the necessary and sufficient biomechanical parameters for the evaluation of spasticity and to study the properties of the experimental situation.

Using the model from Figure 2, the moment of spasticity T_h can be expressed with the following differential equation:

$$T_h = J\ddot{\phi} + B\dot{\phi} + K\phi + mgl/2 \sin \phi \quad (1)$$

where m is the mass and l the length of the lower part of the leg. In most practical cases it is interesting to assess the difference in spasticity occurring after different treatments to diminish the hypertonia. As it is not expected that the parameters of the model (J, B, K, m, l) will change, the change in hypertonia T_h can be recorded by measuring joint angle ϕ, velocity $\dot{\phi}$ and acceleration $\ddot{\phi}$. As the parameters are related to each other through the derivation, potentiometer, tachometer, or accelerometer can be used in the measurement.

Solving the linearized equation (1) ($\sin \phi \doteq \phi$) by inserting the numerical values B = 0,5 Nms/rad, K = 0,5Nm/rad, J = 0.5 Nms^2/rad, m = 4 Kg, and l = 0.6 m.[9], the knee joint angle presented in Figure 3 was obtained.

On the other side, the model satisfactorily simulates the rate of change of knee joint angle. The velocity of the swinging leg increases from zero degrees per second to 210 degrees per second. It was found by Burke et[2] al that the velocity threshold of spasticity ranges from 5 degrees/second to 193 degrees/second, well below that developed in the freely swinging leg. The experimental conditions to test spasticity are therefore satisfactory and no additional weights or external springs should be necessary to increase the velocity of the passive movement.

INSTRUMENTATION AND METHODS

In the measurement of knee extensor spasticity, an electrogoniometer was used to assess the joint movement

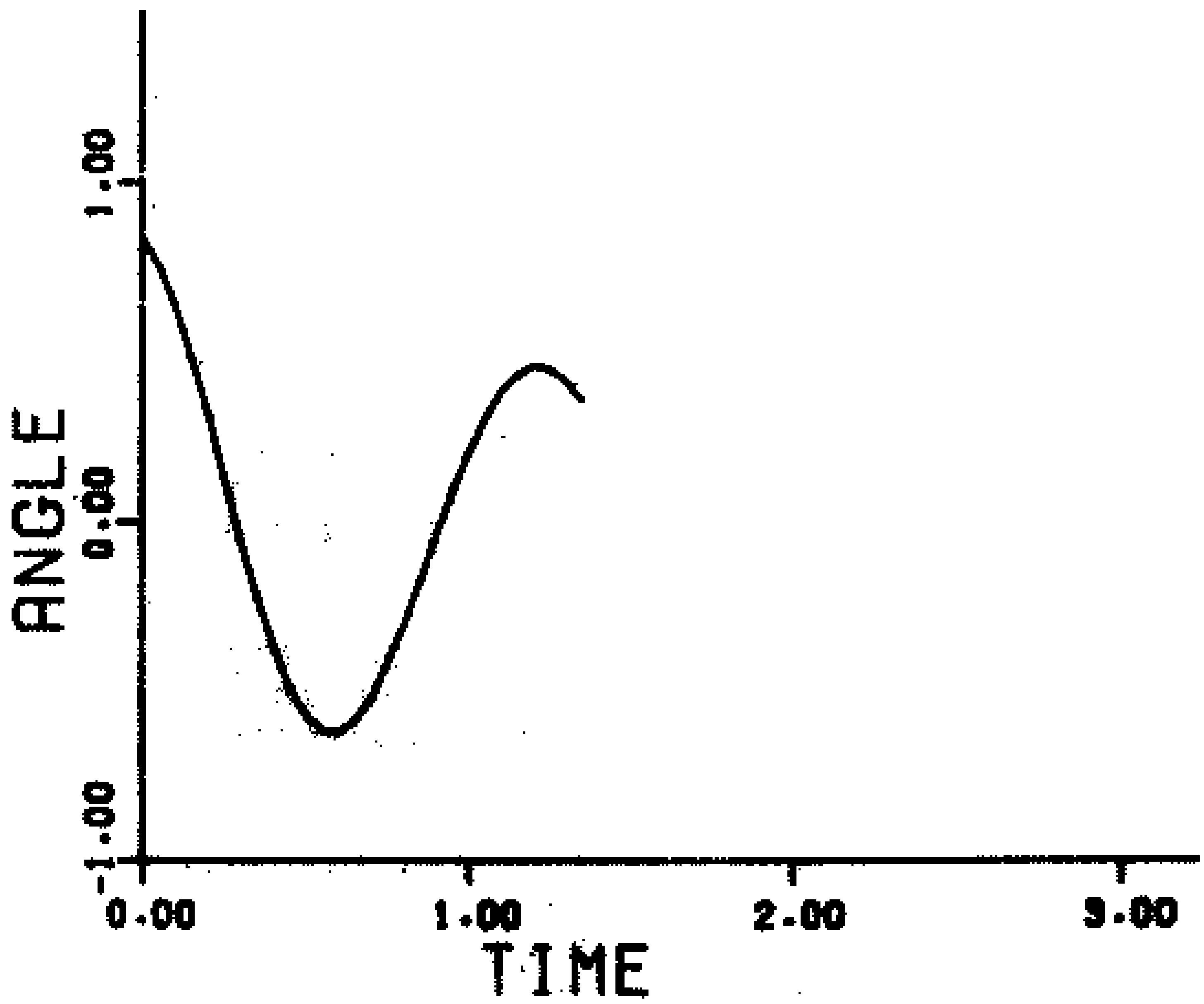


FIG. 3. Knee joint angle (rad) calculated through the model.

kinematics. The start of the measurement was determined by a switch on the patient's ankle held by the examiner. Surface EMG of the quadriceps was measured in order to determine the beginning and the duration of knee extensor activity. Knee joint goniogram, switch output and EMG potential were recorded by use of a visicorder light oscillograph at a chart speed of 100 mm/s.

The patient was placed on his back on a tilt table so that both legs below the knee were bent over the edge of the tilt table. Surface EMG electrodes were placed over the knee extensor muscles, the electrogoniometer on the knee joint, and a switch on the ankle. The patient was asked to be as relaxed as possible. The lower leg (at the place of the switch) was brought to a horizontal position. The limb was then released and allowed to fall freely while recording knee angle and quadriceps EMG on the visicorder.

RESULTS

The proposed method was tested by measuring knee extensor spasticity of 15 spinal cord injured patients. Most of the patients were incomplete paraplegics and quadriplegics. The measurements were performed within a few months following their spinal cord injury. Figure 4 shows how different degrees of spasticity are manifested in the knee goniogram and quadriceps EMG potentials. Figure 4(a) belongs to a healthy subject. The leg swings around the resting position and no EMG is present when the subject is fully relaxed. Figure 4(b) shows a patient with only slight spasticity. There is an irregularity in only the first minimum of the knee goniogram and it is preceded by only a small amount of EMG activity. Figure 4(c) shows the knee goniogram never reaching zero degrees and the EMG occurs at each negative slope of the knee joint angle. Figure 4(d) is an example of severe spasticity. Even less oscillation occurs and high EMG activity is apparent throughout the trace. In one patient with extreme spasticity, the lower leg did not move at all from the fully extended initial position.

It has already been shown by Burke et al that the stretch reflex diminishes progressively as movement is commenced from a more flexed position. It has also been demonstrated by the same authors that the stretch reflex in spasticity increases with velocity of stretch. Both parameters influence our testing when the lower leg is dropped from different initial angles (Fig. 5). A patient's record with minimal spasticity is shown in Figure 5(a). Only at the largest starting angle, representing full extension, was spasticity observed. Figure 5(b) shows the goniogram of a patient with moderate spasticity in which two starting angles demonstrate abnormal records. In a patient with severe spasticity, an abnormal goniogram is observed in all three starting angles (Fig. 5c).

CONCLUSIONS

Four parameters were examined in order to estimate the degree of spasticity from knee angle recordings presented in Figure 4: 1) amplitude of the first minimum; 2) time duration from the start of measurement to the occurence of first minimum; 3) difference in amplitude of the first and the second minimum; and 4) the time duration from the start to the instant when the leg reached the resting position. Only the first parameter appears to be consistent in all measured cases. Simple electronic instrumentation could be built to measure this amplitude and thus provide a quick estimation of spasticity about the knee. The method is especially convenient to evaluate different approaches to reduce spasticity.

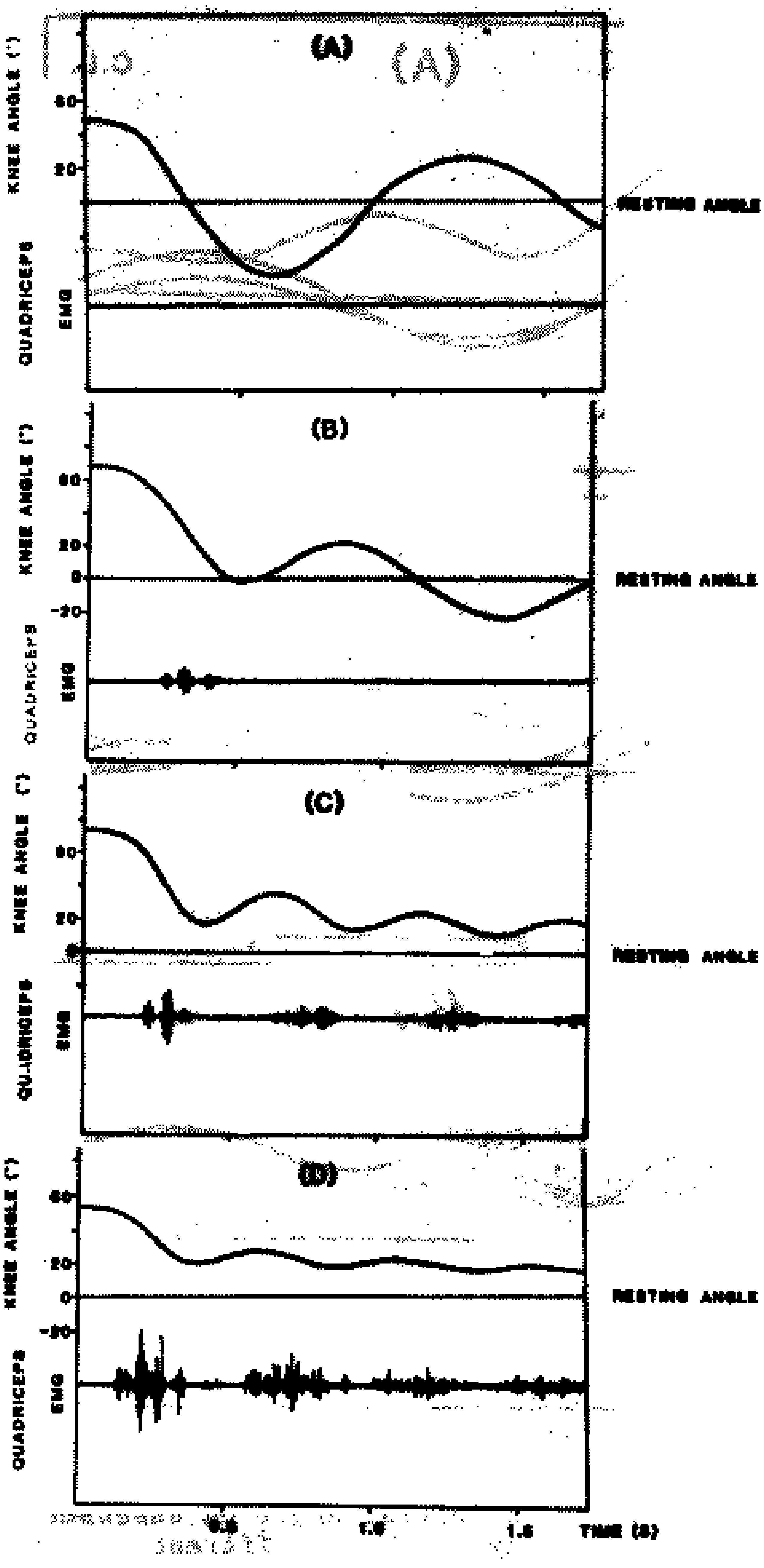


Fig. 4. Examples of different degrees of spasticity: (a) absent, (b) slight, (c) moderate, (d) severe.

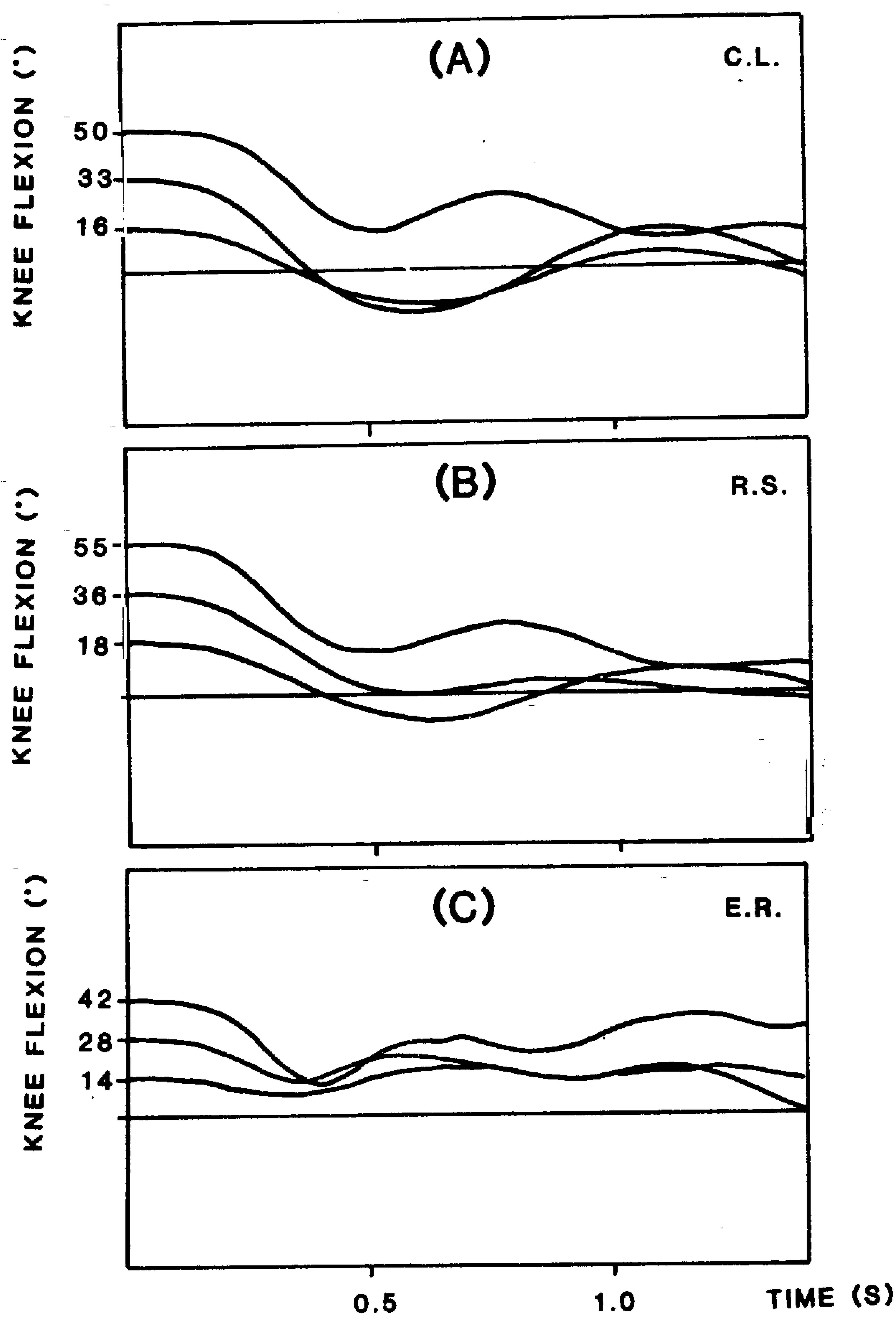


Fig. 5. Influence of initial angle on assessment of spasticity in three different patients.

The same method and instrumentation was also successfully used for measurement of knee flexor spasticity. Patients were seated on a high chair, their lower leg flexed maximally and then dropped. Similar testing of spasticity can also be applied about the hip, shoulder and elbow. Some additional weights or external springs probably would be necessary to increase the velocity of passive movement about the ankle and wrist.

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