ELECTRONIC BRACE FOR THE MEASUREMENTS AND ELICITING OF MUSCLE CONTRACTIONS IN A DOG'S ANKLE

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Abstract: An experimental electronic brace, which is able to evaluate torque in the ankle joint of a dog elicited by spontaneous or stimulated muscle contraction, has been developed. The brace is also able to impose electrically controlled passive movements on the dog leg. Precise-passive movements, as passive external, electrically-controlled flexion or extension of the ankle of a dog leg, are defined in as speed and angle of rotation/movement. On the other hand, switching in a certain working mode, the brace, equipped with force transducers and a goniometer, could serve for measurements of isometric (*locked mode*) or isotonic contractions (*active mode* and *passive mode*) of a dog leg.

A range of the rotation around the ankle joint is limited between -40 and +55 degrees according to the neutral position. The calculated endurance moment of the brace is 2.41×10^{-4} kg $m^2 s^{-1}$, while the speed of electronically controlled movement of the brace in the *passive* mode is up to 78 degrees/second, respectively. In the *active* mode the brace is able to rotate synchronously with the dog ankle joint with a speed of up to 400 degrees/second. The maximum frequency, on activation of the *tibialis anterior* muscle current, when the amplitude of flexion was 50 degrees, was 7/min. In the *locked* mode the brace is able to measure the amplitude of force of a dog leg isometric contraction elicited by electrical stimulation. The force transducer with a natural frequency of 8 Hz and compliance of 0.4 μm/g represents a very linear dependence of the output voltage upon the load with a transducer sensibility of 0,5 mV/mN at a bridge excitation voltage of 5V. The nominal range of each transducer is 0-70 N.

Elektronska opornica za pasivno gibanje pasje noge in meritev kontrakcije v pasjem kolenskem sklepu

Ključne besede: medicina, fiziologija, merjenja fiziološka, psi, opornice elektronske, rotacija gležnja, krčenje mišic, krčenje mišic spontano,krčenje mišic stimulirano, krčenje mišic izometrično, krčenje mišic izotonično

Povzetek: Izdelali smo elektronsko opornico za pasjo nogo, s katere je moč meriti momente v pasjem gležnju, ki ji izzovejo mišice ob spontanem ali stimuliranem krčenju. Poleg tega je mogoče z opornico izzvati v naprej predvidene pasivne gibe pasje noge z natančno določeno hitrostjo krčenja ali raztegovanja in kotom premika opornice ter s tem na njo pritrjene pasje okončine. Razen tega lahko opornico priredimo za meritve izometrične kontrakcije (locked mode) ali pa izotonične kontrakcije (active mode) ter za prej omenjena programirana gibanja opornice (passive mode).

Kot za katerega se lahko zavrti opornica opornice glede na nevtralno lego, določeno z nevtralno lego pasjega gležnja, je od -40 do 55 stopinj. Izračunani vztrajnostni moment opornice je 2.41×10^{-4} kg $m^2 s^{-1}$. Pri pasivnem, programiranem gibanju opornice je moč nastaviti hitrost rotacije v območju od nekaj stopinj/sek do največ 78 stopinj/sek. V aktivnem načinu pa se opornica lahko zavrti, skupaj z stimulirano pasjo nogo, s hitrostjo tudi do 400 stopinj/sek. Največja frekvenca draženja mišice tibialis anterior, pri kateri je bilo moč izvajati meritve v aktivnem načinu brez popačenja (amplitudi zasuka opornice 50 stopinj) je bila 7/min. Na opornico je bil vgrajen tudi senzor sile, katerega resonančna frekvenca je bila 8Hz, podajnost (compliance) 0.4 μm/g in občutljivos 0.5 mV/mN (napajanje 5V). Občutljivost je bila pri napajanju s 5V v pričakovanem področju merjenih sil (0-70 N), povsem linearna.

Introduction

In physiological studies of muscle contraction and contemporary nerve activity it is suitable to have special equipment for eliciting controlled mechanical contractions of different muscles. The aim of this work was to develop a mechanical system that would be able either to measure or to impose movements of a dog ankle. Therefore, the aim of our work was to develop a special electronic brace for the dog leg. The brace should be able to elicit precisely defined (angle and speed) passive movements of a dog leg. On the other hand, the characteristics of both, isometric and isotonic contractions of a dog ankle muscle, caused by electrical stimulation, should be measured.

Materials and Methods

The brace

The brace consists of a mechanical joint that could be attached to the ankle of a dog. Such a fixed mechanical joint (ankle) turns around together with the ankle of a dog continuously. The artificial mechanical joint is a construction of one fixed part, artificial ankle and a rotate-able fine bearing, which, fixed on a dog leg, forms common axes with the joint of a dog (Fig. 1). The joint is connected to the actuator by mechanical transmission with a hysteresis angle of ±0.5 degree. The system measures the angle of rotation and the torque induced by the ankle of the dog either due to electrically powered passive rotation of the mechanical joint or electrical stimulation of the dog muscles. The rotate-able artificial ankle has the function of a force transducer at the same time. The brace is constructed in such a way that it could be used for experiments either on the left or on the right leg. It just has to be turned around on the white or black plate (see Fig. 1).

tions divided by angles of rotation and is equal to 2.66:1. The mechanical transmission was selected on the basis of the specified requirements of acceleration and velocity in

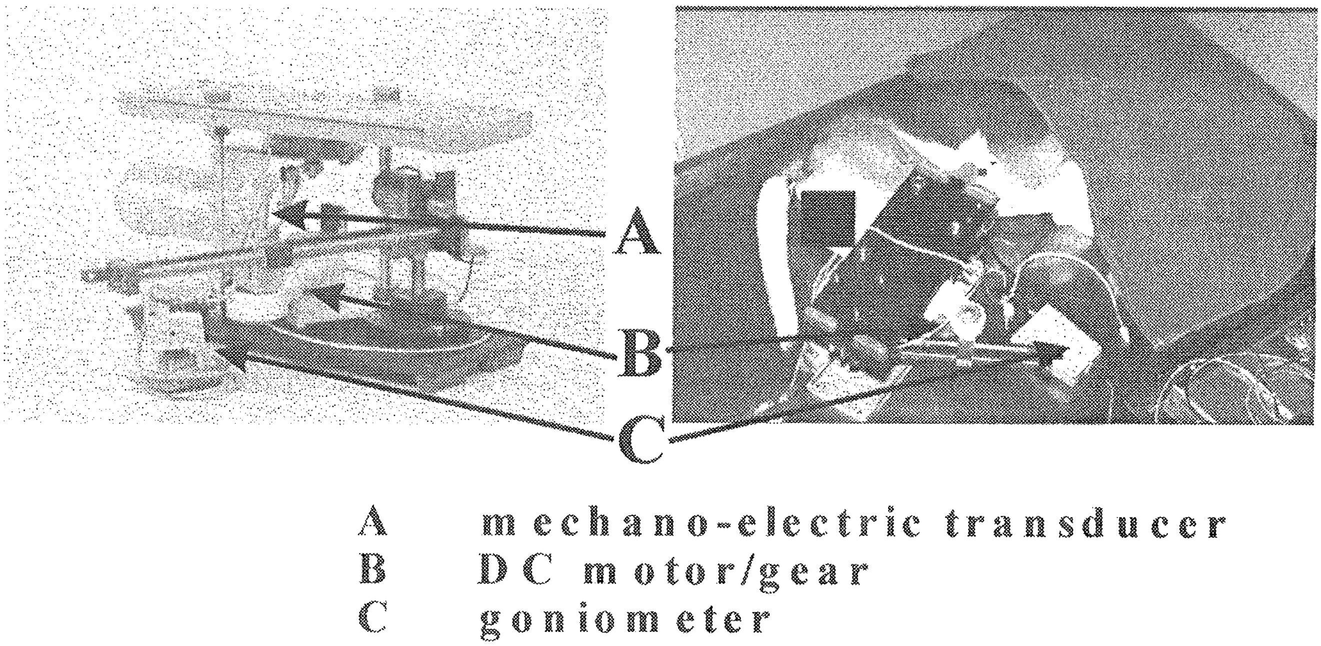

Fig 1. ***The brace.*** *The bear brace is shown on the left of the picture, the positioning of the dog leg into the brace is shown on the right. A) position of force transducer, B) DC motor/gear, C) goniometer.*

Description of the sensors

Mechano-electric transducer

The force transducers were made up of a full Wheatstone bridge composed of four semi-conductor strain gauges /1/ bonded on the artificial ankle (Fig.1.). The voltage signal, produced by a deformation of the semi-conductor strain gauges, is amplified by a precision strain gauge amplifier (Linear Technology, LT 1101).

Sensor of angle rotation – a custom designed goniometer

In order to measure and control an angle in the joint a custom designed goniometer manufactured from a precision potentiometer with a resolution of 0.1 degree (*ITIS d.o.o.*, Ljubljana) is mounted at common axes with the rotate-able artificial ankle (Fig. 1).

Mechanical part of the brace

Passive movements of a dog ankle are elicited electrically by powered motor movements of the artificial ankle brace transmission (Fig. 1).

Actuator system

The complete actuator system is mounted on an aluminum plate, the base of the brace. It is possible to regulate the motor speed and number of revolutions by the PC controller. The ratio of transmission is defined by motor revolutions divided by angles of rotation and is equal to 2.66:1. The mechanical transmission was selected on the basis of the specified requirements of acceleration and velocity in the passive mode with respect to the friction of transmission. The chosen system comprises a direct current (DC) motor within grounded iron cage to minimize electromagnetic artifacts.

Motor control

An actuator system involving the aforementioned DC motor/gear system (Fig.1) is mechanically connected to the mechanical joint, and joint thus transferring the torque to the dog joint. By position feedback obtained through measuring an angle in the mechanical joint, the motor is regulated in such a way that it rotates at a chosen speed for any angle according to the neutral position of the ankle. The mechanical system is able to operate in three modes: *passive, locked* and *active* mode. In the *passive* mode the brace is able to rotate the ankle by a predefined angle at a different predefined speed. Therefore, in this mode a rotation from the actuator is transferred to the ankle joint, thus imposing a stretch of a dog ankle extensors or flexors. The common friction, expressed as the certain amount of torque in the *passive* mode, is composed of friction of the potentiometer, four fine bearings and the transmission. In the *locked* mode, the position of the motor and artificial ankle is locked at a desired angle in order to measure the isometric torque elicited by electrical stimulation of the muscles or muscle group under investigation. The force transducers, described above, measure the torque of contraction through deformation of the sensors. In order to achieve a dynamic range of measurement in the *active* mode, the system is able to follow the ankle joint rotation with fast cadence elicited by electrical stimulation of a nerve or muscle.

Measurements of passive and dynamic characteristics of the brace

Passive characteristics of the brace

The maximum speed of the ankle movement was determined by goniometric measurement of an angle speed of the spare brace rotation at the highest DC motor performance.

Brace friction

The common friction of the brace was defined by feeding a known DC to the motor and measuring the mechanical energy output. The difference of the input and output energies reveals the friction of the system.

Dynamic characteristic of the brace

The dog muscle contraction was elicited by electrical stimulation of the sciatic nerve using stimuli with frequencies ranging from 0 to 20 min^{-1}. Since contractions of the leg were detected by the brace, we could determine the frequencies where the response of the brace is linear. This means that the ratio of stimulus/contraction detected without artifacts due to the brace friction or endurance is 1.

Endurance moment of the artificial ankle

The endurance moment of the brace was calculated considering the dimensions (14 x 3.3x 1 cm), shape and material (aluminium) of the artificial ankle.

Selective stimulation of fibers in the sciatic nerve of a dog with a 33-electrode stimulating and recording spiral cuff

The cuff was made by bonding two 0.1 mm thick silicone sheets together /2-5/. One sheet stretched and fixed in that position was covered by a layer of adhesive material (NuSil, MED-1511). A second unstretched one was placed on the adhesive and the composite was compressed to a thickness of 0.3 mm. When released, the composite curled into a spiral tube as the stretched sheet contracted to its natural length. 33 electrodes (0.6 x 1.5) mm made of 0.05 mm thick platinum ribbon connected to lead wires were mounted on the third silicone sheet. They were arranged in three parallel spiral groups each containing 11 electrodes at a distance of 0.5 mm. The distance between the spiral groups was 6 mm. Electrodes of the central group were connected to lead wires individually, while the corresponding outer electrodes were shunted to each other and then connected to lead wires. The silicone sheet with electrodes was bonded on the inner side of the cuff. The cuff with an inner diameter of 2.5 mm was trimmed to a length of 20 mm. The lead wires were connected to the connector to be implanted within the lateral subcutaneous tissue for the time between stimulation. Rectangular, bi-phasic, charge balanced, current pulses with a frequency of 20 Hz and amplitude of up to 1 mA were delivered on the central electrode of each GTE within the cuff. As a neutral electrode a hypodermic needle was inserted in the subcutaneous tissue of the thigh, slightly proximal to the cuff.

Selective recording of electro-neurogram (ENG) from the sciatic nerve of a dog

The cuff already described above was used also for the selective recording of the ENG from a dog nerve after passive or active dog leg movements. ENGs are recorded differentially and selectively with the spiral cuff (see above) from two superficial regions of the sciatic nerve innervating mostly the aforementioned muscles /6-7/. Since the motor system has to operate simultaneously with noise-sensitive ENG measurements, the electromagnetic noise of the motor system was reduced by using a RFI filter and ferrite cores on the supply connections. Shielded wires and the motor and proper ground connection were implemented throughout the entire electrical circuit.

Results

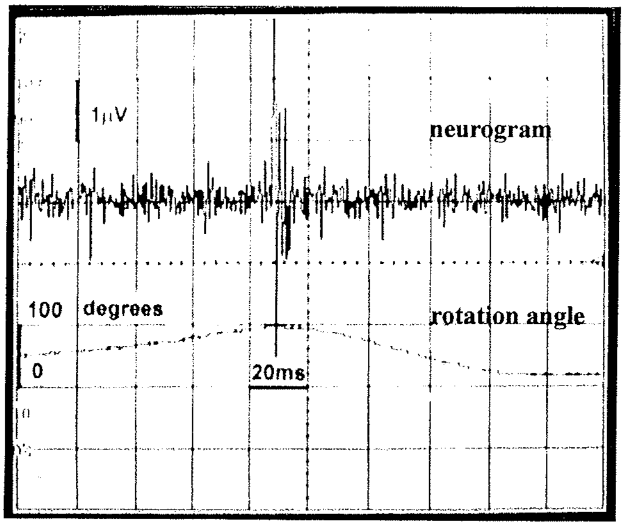

Fig 2. ***Detection of the contraction of the dog ankle in the passive mode of the brace.*** *The upper trace shows a neurogram recorded from the sciatic nerve after rotation of the brace and the dog leg with a DC motor system at 50 degrees.*

In the *passive* mode (Fig. 2) the brace is able to rotate to a maximum extension of 45 degrees and of maximum flexion of 55 degrees, according to the neutral position of the ankle. The DC motor/gear system is able to perform movement of the artificial ankle with a speed of up to 78 degrees/second. However, practically we could not exceed 7 passive movements with maximum amplitude of flexion and extension of a dog ankle per minute during the experiments because of the combination of endurance and friction of the complete system and resistance of the dog ankle.

The friction of the system presents less than 2% of the input electric force. In the *active* mode the brace is able to measure reliably the parameters of a dog ankle contraction elicited by the electrical stimulation of a nerve. In order to follow the ankle joint without resisting the movement, the brace is able to perform an ankle rotation of up to 400 degrees/second synchronously with a dog ankle. The calculated endurance moment of the brace is 2.41×10^{-4} kg $m^2 s^{-1}$. The maximum frequency at which the ratio stimulation/contraction is lower than 1 depends on the amplitude of the brace movement due to the dog's leg contraction. In our experiment, at an amplitude of 50 degree of flexion and sciatic nerve stimulation current of 1.4 mA, the maximal frequency of stimulation was 10/min. Above this, we could not measure the contraction parameters of a dog ankle at the maximum amplitude of flexion and extension without artifact any more.

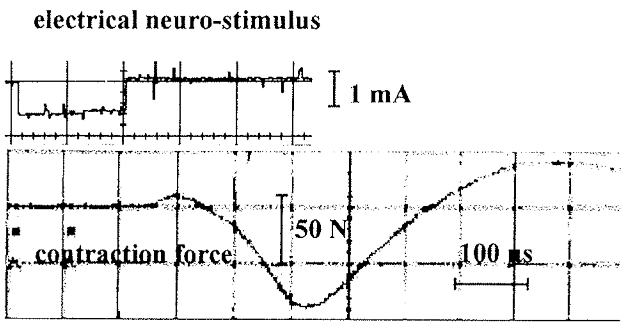

Fig 3. ***Detection of the force of contraction of the dog ankle in the*** locked ***mode of the brace.*** *The upper trace shows the neuro-stimulus applied to the sciatic nerve. The lower trace shows force of the dog leg developed after nerve stimulation.*

In the *locked* mode (Fig. 3) the brace is able to measure the amplitude of force of the dog ankle contraction elicited by electrical stimulation. The transducers with a natural frequency of 8 Hz and compliance of 0.4 μm/g represent a very linear dependence of the output voltage upon the load with the sensibility of transducers being 0.5 mV/mN at a bridge excitation voltage of 5V. The nominal range of each transducer is 0-70 N.

Discussion

According to the aims of the brace construction determined in the introduction, we can conclude that all of the aforementioned requirements were met. The brace is a suitable tool for the study of contractions of different muscles or muscle groups of a dog leg as a result of selective stimulation of a peripheral nerve. On the other hand, nerve activity from a peripheral nerve, describing the torque and angle of rotation in the ankle joint as a consequence of flexion or extension elicited by the brace or by passive movements of the leg, could be recorded. The limitation of the transducer is that it has a relatively high endurance that could not be easily diminished. It enables recordings of muscle contraction parameters at higher frequencies of nerve stimulation. On the other hand, the brace, due to its low friction, permits the recording of isotonic forces of contraction. When using the *locked* brace mode, measurements of isometric muscle are also possible. The brace is a suitable and low price research tool. Its construction could be easily adapted to the experiments on animal legs of different sizes and force of contraction.

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