A Test Set-up for Evaluation of Effects of Dynamic Strain on Nerve Function

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Abstract

A problem in many car collisions is injuries in the neck region caused by whiplash movements of the head. The knowledge of the underlying mechanisms in this type of injury is, however, limited.

The high strain rate loading on the nerve tissue of the neck in the whiplash motion can be a possible cause of these injuries. In vivo effects of dynamic loading on nerve function are not well documented.

A test set-up has been designed for dynamic in vivo testing of rabbit tibial nerve. A high strain rate elongation is applied to an exposed part of the nerve. The nerve strain is registered by a video image recording system with a strobe illumination. Effects of the elongation on the nerve function are determined by measurements of the maximal conduction velocity and action potential amplitude. A data acquisition software is used for stimulation and recording of action potentials.

The test set-up shows high repeatability in simulated test situation. The motion analysis system provides measurements with high time resolution (300 Hz) and 0,1 % field of view accuracy (0,1 mm).

Introduction

A serious problem closely related to traffic accidents is peripheral nerve stretch injuries generated under dynamic conditions. Brachial plexus injuries in motorcycle accidents are obvious examples. Also, symptoms following whiplash motion, commonly caused by rear end impacts, have a plausible explanation in injuries to the brachial plexa in the cervical region. In Sweden, more than one third of the traffic accidents leading to ≥10% disability (i.e. moderate to severe) can be derived from injuries related to the neck (Nygren, 1984). Many of these injuries lead to diffuse symptoms and the injury mechanisms are to a great extent unknown. The limited knowledge in this field results in uncertain diagnosis and rehabilitation methods.

A number of studies have been performed regarding effects due to different mechanical loading on nerve tissue. Most of these works have studied mechanical properties, or effects of static and quasi static loading, on nerve roots (Sunderland and Bradley, 1961b; Kwan et al, 1988), as well as on peripheral nerves (e.g. Sunderland and Bradley, 1961a,c; Rydevik et al, 1990; Brown et al, 1991; Zoech et al, 1991).

A limited number of studies are reported where dynamic loading has been applied to nerve tissue. Haftek (1970) studied histological effects of dynamic tension on rabbit tibial nerve in vitro. The elongation was applied by dropping loads. The nerves were examined by light and electron microscopy. There was no essential difference in the histological findings after dynamic stretching and quasi static stretching. Studies on unmyelinated squid axon showed graded levels of injury in response to dynamic elongation (Galbraith, 1988, Thibault et al, 1990). Results presented by Saatman and Thibault (1990) demonstrated increasing intracellular calcium concentration after rapid elongation as an injury indicator.

Brown et al (1991) studied *static* nerve tension on rabbit tibial nerve in vivo. The nerves were preserved viable and were for two hours exposed to static strain levels of 8 % and 15 % respectively. The effects of tension on the nerve function were evaluated by measuring compound motor nerve action potentials (CMAP) in a distal muscle. Their results showed a significantly affected nerve function at 15 % strain. There is no similar data available conceming the correlation between *dynamic* nerve tension and nerve function in vivo. It is therefore valuable to further develop the model used by Brown et al (1991) and investigate the effects on nerve function after dynamic loading.

The aim of this study was to develop a test set-up for evaluation of effects of well-defined dynamic elongation on conduction properties of peripheral nerves in vivo.

Material and Methods

Animal Model

New Zealand White rabbits, weighing 2 to 3 kg are used. Anaesthesia is induced by an intravenous injection of diazepam (Valium Novum, 2,0 mg/kg) and an intramuscular injection of Fluanisone 10 mg/ml and fentanyl 0,2 mg/ml (Hypnorm 0,3 ml/kg). Anaesthesia is maintained by additional doses of Hypnorm (0,1 ml/kg) when necessary. The rabbit is lying on one side and the tibial nerve is exposed between the knee and the ankle by a medial incision. All surrounding tissues are gently resected using microsurgical instruments and a stereo microscope. The nerve is continuously irrigated with isotonic saline solution, with a temperature of 37 °C. A heating lamp with a thermostat connected to a temperature probe keeps the local temperature close to the nerve at 37 °C.

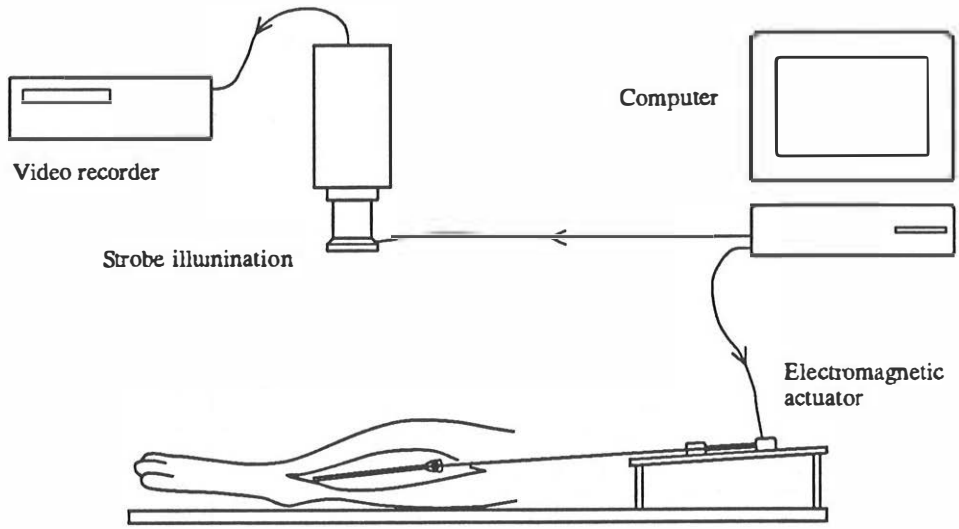

Figure 1 System overview of the tension model. A video camera with a strobe illumination and a computer controlled electromagnetic actuator.

Tension Model

The rabbit leg is fixed to the experimental table with metal screws through the tibia. The ankle is in a plantar flexed position. Circular markers of retro-reflective tape (Ø ≈ 1 mm) are attached to the nerve with cyanoacrylate glue. Markers for calibration are placed on the experimental table. The tension of the nerve is induced by an electromagnetic actuator. The proximal end of the nerve is mounted in a custom designed clamp attached to the actuator. The nerve is cut proximal to the clamp.

The system used for motion analysis is a combination of video film recording and a stroboscope system (Kullgren et al, 1992). This combination results in higher time resolution than standard video filming. A video camera is mounted above the exposed nerve. The camera lens is surrounded by a strobe device consisting of light emitting diodes. A flashing light beam almost parallel with the objective is obtained. During tension the strobe device is illuminating the nerve and the retro-reflective markers. Each field recorded by the video camera covers a time interval of 20 ms. During this time interval, a number of reflections from the markers are registered. The period and the duty cycle of the strobe light are adjusted to the displacement rate to obtain a maximal number of distinguishable reflections. A system overview is shown in figure 1.

Figure 2 shows a plot derived from a number of consecutive fields from a video registration covering the tension of a rabbit tibial nerve. To evaluate the motion, the video fields are transferred to a computer using a frame grabber card. The positions of markers are manually measured in a digital image analysis software (Image, NIH).

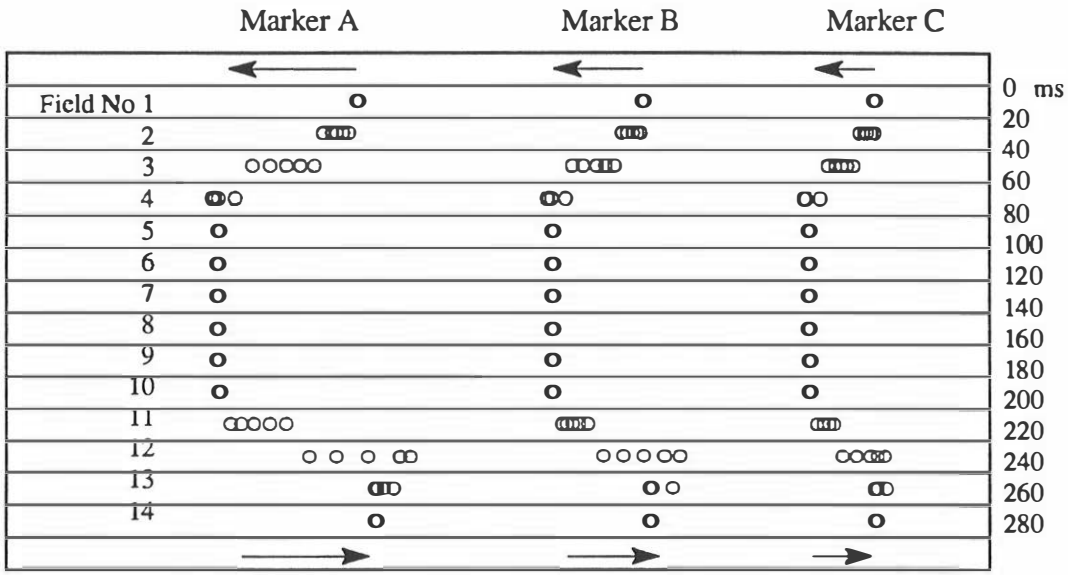

Figure 2 A plot derived from 14 consecutive fields from a video registration of a tibial nerve with three markers. The strobe period is 4 ms (250 Hz) and the duty cycle is 6 %.

The marker co-ordinates are stored in a text file and then analysed. Figure 3 shows longitudinal displacement versus time for the three markers in figure 2. The strain as a function of time is calculated. The resultant strain versus time is shown in figure 4. The frequency and duty cycle of the flashing light as well as the displacement actuator are controlled by a personal computer equipped with a multifunction analogue, digital and timing input/output board and Lab VIEW-software application (National Instruments).

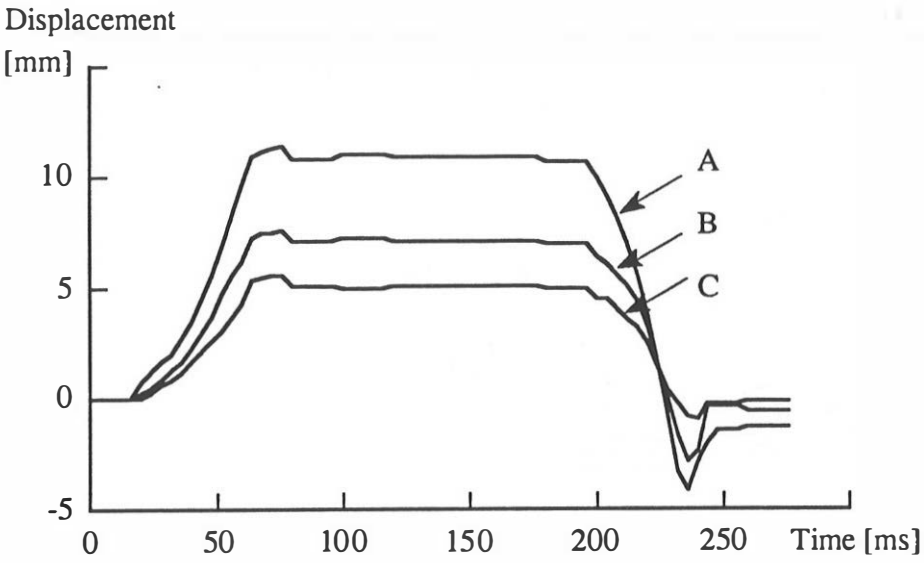

Figure 3 Longitudinal displacement versus time of the three markers shown in figure 2.

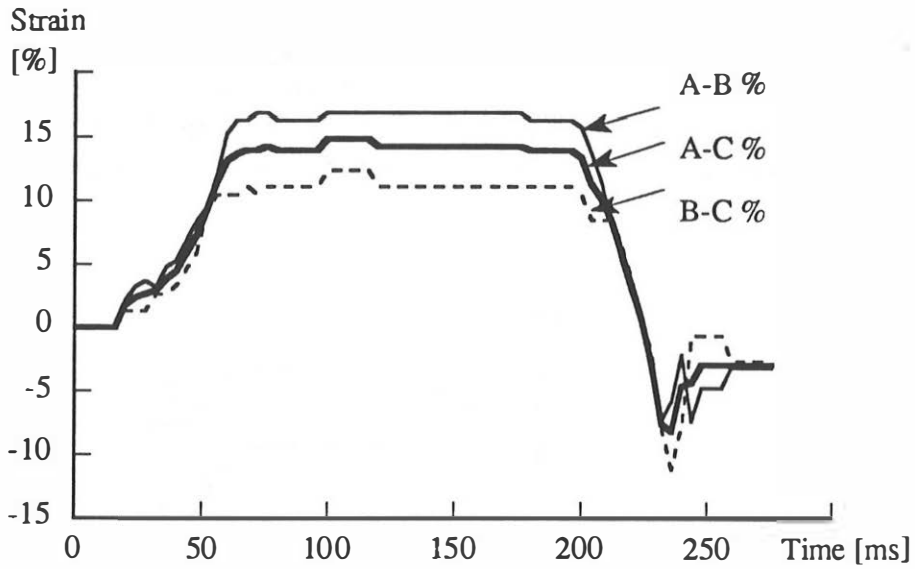

Figure 4 The calculated strain versus time of the three markers shown in figure 2.

Nerve Function

The nerve is stimulated supra maximally (twice the amplitude necessary to obtain maximal CMAP) by a bipolar platinum electrode. A single pulse with a duration of 0,1 ms is used. Motor nerve action potentials are registered with a subdermal platinum needle electrode (Grass E2) placed in one of the foot muscles (abductor hallucis). A reference electrode is placed near the heel bone

(calcaneus). The action potential is recorded by a data acquisition system based on the input/output board mentioned above which also provides the triggering pulse for the stimulation (figure 5). The nerve function is monitored for four hours after the tension. The animal is then euthanised by an overdose of barbiturate, and the nerve is removed for histological analysis.

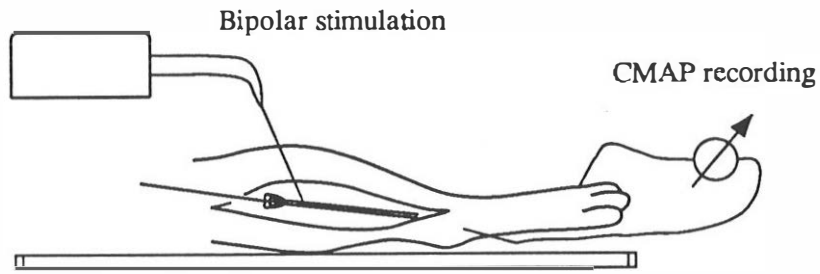

Figure 5 Experimental set-up for studying impulse propagation

Test results

To investigate the repeatability in the actuator system and the accuracy in the video motion analysis system, a series of five tests was performed. A rubber band replaced the nerve. A linear resistance transducer connected to the data acquisition system was mounted on the actuator. The actuator motion showed good repeatability (figure 6).

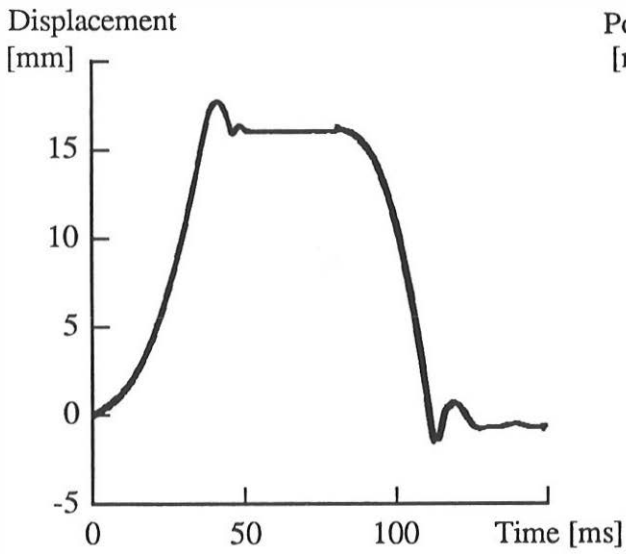

Figure 6 Actuator displacement measured by a linear resistance transducer. Sequence of five tests superimposed.

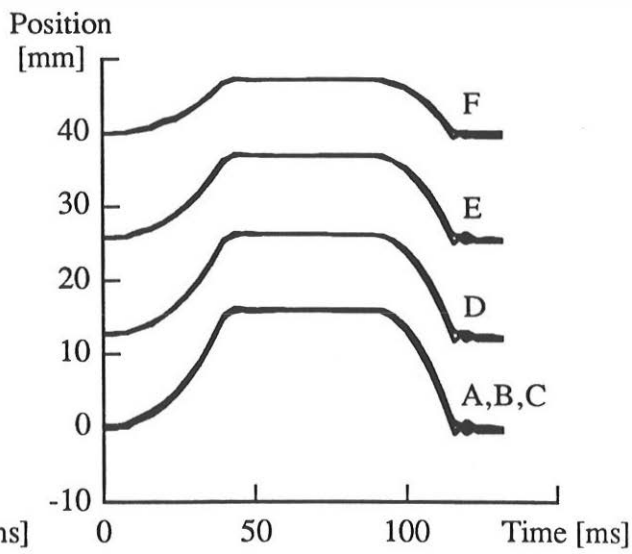

Figure 7 Linear displacement of the actuator and markers on a rubber band measured by the video analysis system. Sequence of five tests superimposed.

The test series was also analysed with the video system. The strobe period was 4 ms (250 Hz) and the duty cycle was 6%. In total, 35 images (7 images per test) were measured. Analyse of the measurements of the calibration markers, 210 observations in all, indicated an accuracy of 0,8 pixel (0,1 % of field of view). With the field of view chosen, the real world measuring accuracy was approximately 0,1 mm.

Figure 7 shows longitudinal position versus time of three markers on the actuator (A, B and C) and three markers on the rubber band (D, E and F). In areas where the motion is small (≈ 1 target size), the accuracy is lower due to overlap of the marker reflections. The overlap problem is illustrated in figure 2, field 2. This problem does not exist for still targets.

Discussion

Injuries in the neck region, following relative motion between the head and the torso at a moderate trauma level cause a wide range of symptoms. The terminology used in the literature is not absolutely consistent. The term "whiplash injury" was first used according to injuries after the extension-flexion motion obtained in a rear-end collision. Later the meaning has been extended to injuries in more types of impacts, e.g. not only in rear end but also in side and frontal car collisions. The kinematics of the head and the neck in these cases are however different.

In Sweden, there is a fast rising number of whiplash injured people reported with long term disabilities. The symptoms may include neck pain and stiffness, headache, pain in shoulders and arms, visual symptoms, and numbness. The underlying mechanisms of these injuries are however unknown and the possibilities for finding physical sign and for treatment are limited.

The nerve tissue in the neck region outside the spinal canal constitutes a complex net of peripheral nerves, the brachial plexus. These nerves are most likely exposed to a tension trauma in a whiplash motion. The wide range of symptoms in different locations in the shoulder part of the torso and the upper extremities may indicate that injuries occur at different levels in the nerve plexus.

The rabbit tibial nerve is considered as a suitable animal model for this type of experiment. Lundborg (1970) showed that mobilisation of the nerve over a 150 mm section is possible without loss of the nerve function. Brown et al (1991) showed no significant decrease in CMAP during three hours clamp application after nerve cut in sham experiments. There is a big advantage in the use of an in vivo model since ischaemia probably plays an important role in the pathophysiology of stretch injuries (Lundborg, 1970; Lundborg and Rydevik, 1973).

The video motion analysis system is based on the use of a standard equipment and results in a fast and convenient analysis. The measuring accuracy in the images is 0,1 % of the field of view. With the field of view chosen in this test set-up the real world measuring accuracy is approximately 0,1 mm. The present method provides non contact measuring possibilities of the resultant strain on the nerve with high time resolution.

In the literature there is a disagreement regarding which structural component of the peripheral nerve that is responsible for its tensile strength (Sunderland and Bradley, 1961a; Haftek, 1970). Inside the nerve there will probably be a non-uniform strain distribution. The applied tension in the present study should be seen as a trauma to the whole nerve bundle. The resultant surface strain is the measured trauma parameter.

The motion analysis system used requires markers attached to the moving object. The chosen method to do this by using cyanoacrylate glue may have some influence on the nerve function. This influence has to be investigated with sham experiments. To minimise the effects of the substance, the attachment should be done carefully with a minimum amount of glue.

The present method measures the effects of stretch regarding nerve function on motor fibres. These fibres are large and fast conducting. However, judging from the wide range of symptoms related to whiplash injuries, it is more likely the afferent fibres that are primarily involved. Consequently, the nerve function test should be further refined and measurements of the sensory nerve function should be made.

Studies of parameter changes such as variations of the magnitude of the strain, strain rate, and the pulse duration are to be performed. Determination of injury criterion and levels for deterioration of nerve function may help us to prevent nerve injuries related to relative motion between the head and the torso. An injury criterion may also be needed when setting safety standards and designing safety systems. The presented model seems to be a useful tool to increase the knowledge regarding effects on nerve function following dynamic loading.

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References

Brown, R. A., Pedowitz, R. A., Rydevik, B. L., Woo S. Y., Hargens, A. R., Massie, J., Kwan, M. K., Garfin, S. R.: Effects of acute, graded strain upon efferent conduction properties in the rabbit tibial nerve. Submitted, 1991

Galbraith, J. A.: The effects of mechanical loading on the electrophysiology of the squid giant axon. Dissertation, University of Pennsylvania, 1988

Haftek, J.: Stretch injury of peripheral nerve: Acute effects of stretching on rabbit nerve. J Bone Joint Surg 52B, 354-365, 1970

Kullgren, A., Lie, A., Tingvall, C.: A photogrammetric system for registration of fast three-dimensional movements in laboratory crash tests. IRCOBI, Verona, 1992

Kwan, M. K., Rydevik, B. L., Brown, R. Triggs, K., Myers, R. R., Woo, S. L-Y., Garfin, S. R. : Selected biomechanical assessment of lumbosacral spinal nerve roots. The Lumbar Spine. Miami Florida, April 13-17, 1988

Lundborg, G.: Ischemic nerve injury. Experimental studies on intraneural microvascular pathophysiology and nerve function in a limb, subjected to temporary circulatory arrest. Scand J Plast Reconstr Surg (Supl 16), 1970

Lundborg, G., Rydevik, B.: Effects of stretching the tibial nerve of the rabbit: a preliminary study of the intraneurial circulation and the barrier function of the perineurium. J Bone Joint Surg 55B, 390-401, 1973

Nygren, Åke.: Injuries to car occupants - some aspects of the interior safety of cars. A study of a five-year material from an insurance company. Dissertation, Dept Oto-Rhino-Laryngology, KS., Traffic Safety Group Folksam, Dept Traffic Safety, CTH. Acta Oto-Laryngologica, Supplement 395, 1984

Rydevik, B. L., Kwan, M. K., Myers, R. R., Brown, R. A., Triggs, K. J., Woo, S. Y., Garfin, S. R.: An in vitro mechanical and histological study of acute stretching on rabbit tibial nerve. J Orth Res, 8,694-701, 1990

Saatman, K. E., Thibault, L. E.: Myelinated nerve fiber response to dynamic uniaxial stretch. Proceedings IRCOBI, Berlin, 115-125, 1991

Sunderland, S., Bradley, K. C.: Stress-strain phenomena in human peripheral nerve trunks. Brain, 84, 102-119, 1961a

Sunderland, S., Bradley, K. C.: Stress-strain phenomena in human spinal nerve roots. Brain, 84, 120-124, 1961b

Sunderland, S., Bradley, K. C.: Stress-strain phenomena in denervated peripheral nerve trunks. Brain, 84, 125-127, 1961c

Thibault, L. E., Genarelli, T. A., Margulies, S. S., Marcus, J., Eppinger, R.: The strain dependent patophysiological consequences of inertial loading on central nervous system tissue. Proceedings IRCOBI, Lyon, 191-202, 1990

Zoech, G., Reihsner, R., Beer, R., Millesi, H.: Stress and strain in peripheral nerves. Neuro-Orthopedics, 10, 73-82,1991