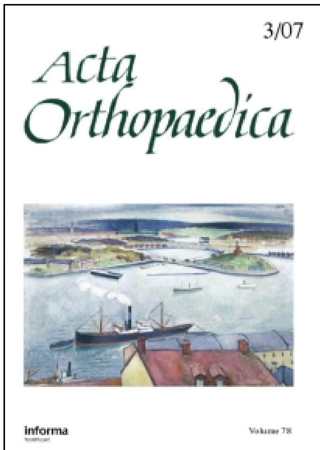

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TENSION AND CREEP PHENOMENA IN PERIPHERAL NERVE

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Tension introduced into peripheral nerves during their surgical repair may reduce the success of this procedure.

Two mechanical factors are important; the tension required to effect a repair, and the rate at which this tension changes after surgery. These two factors have been investigated in the rat sciatic nerve.

The results show an increasing resistance to elongation of the nerves with increasing tension. Under a constant elongation the tension in the nerves reduces by about 30 per cent in the first 10 minutes and by a small amount in the following 20 minutes.

Key words: biomechanics; creep; mechanical properties; microsurgery; nerve repair; peripheral nerve; strength; tension.

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The surgical repair of divided peripheral nerves leaves the nerve in higher tension than in its undisturbed state. This may make the repair liable to pull apart and technically more difficult. It has been suggested that tension in a nerve restricts its blood flow (Lungborg & Rydevik 1973), causes internal haemorrhaging in the nerve (Terzis et al. 1975), and may be implicated in the production of a fibroblastic response (Millesi et al. 1972). These arguments have been used to promote the concept of nerve grafting.

The mechanical properties that govern the tension produced by repair are stiffness (the tension required to increase the length of the nerve) and creep (the relaxation of the tension of the nerve at a constant length). Previous investigations have concentrated on stiffness although this has often been measured at a slow rate which would have allowed creep to influence the results. Non-linear elastic behaviour has been reported in both animal and human material (Millesi et al. 1972, Sunderland & Bradley 1961, a, b, c) in that the tension required to increment the length of the nerve is not proportional to the increase in length. These nerves were shown to offer an increasing resistance to stretch. Some workers have attempted to find the limit of elongation beyond which irreversible changes occur in the mechanical properties (Haftek 1970). In at least one study the elongation produced by a nerve repair has been related to the electrophysiological properties of the nerve after healing (Terzis et al. 1975).

In order to establish the magnitude of tensions developing in nerve repair we have measured the mechanical properties of rat sciatic nerves with reference to three factors:

1. Stiffness
2. Creep behaviour
3. The relative contribution to the mechanical properties of the exposed section of nerve and of the proximal and distal attachments.

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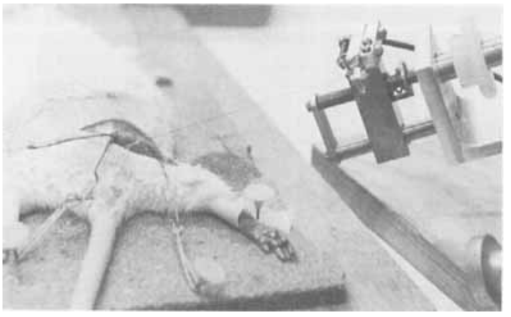

Figure 1. Arrangement of the apparatus for testing the properties of the proximal nerve section.

MATERIALS AND METHODS

Ten domestic white rats of 0.2 kg body weight were investigated. Under intraperitoneal avertin anaesthesia they were taped securely to a wooden block clamped to a bench. About 20 mm of the right sciatic nerve was exposed and freed of mesoneurial attachment from pelvis to knee. The nerve was divided sharply at mid-thigh level, and proximal and distal segments were tested separately.

The end of the divided nerve was attached to a tension/displacement transducer (Figure 1) by a lightly tied suture passed through the nerve 2 mm from the cut surface. The transducer was clamped to the bench in a position which allowed the suture to pull the nerve close to its correct anatomical line. The transducer could then be manipulated to alter the tension in the divided nerve. Electrical signals from the transducer corresponding to tension and elongation were recorded for subsequent analysis. Stainless steel sutures (size 6–0) were used in these experiments because pilot studies had indicated that nylon sutures had mechanical properties comparable with those of the nerve under investigation. Finally a 20 mm length of nerve was exposed, held rigidly at one end and the length was then tested in a similar way to the proximal and distal sections. During all experiments the nerves were irrigated regularly with normal saline.

In the three tests (proximal, distal and isolated sections of nerve) the following procedure was employed:

1. The nerve was stretched rapidly (within 5 seconds) until the tension was 30 g, and then released back to zero tension. This was repeated and an oscilloscope display of the tension and elongation used to check for repeatable stiffness characteristic.
2. The nerve was stretched to a tension of 30 g and left at this elongation for 30 minutes. The tension was recorded over this time to investigate the tension-relaxation behaviour (creep).
3. The stiffness characteristic was measured again as in the first test. A tension of 30 g was used in the experiments since this corresponds to the tension involved in repairing a severe nerve deficit of several millimetres.

Finally, the stiffness tests were performed on the suture material used in the experiment. This gave the combined stiffness of the suture and tension transducer which could then be subtracted from the measured stiffness of the nerves (Figure 2). Creep tests on the suture and transducer combination showed no measurable tension–relaxation over the time scale of the tests.

Construction of the Tension/Displacement Transducer

The tension transducer consisted of a short length of clock spring with a pair of electrical resistance strain gauges bonded to its surface. Suture was connected to one end of the spring perpendicular to its length and the other end of the clock spring attached to a displacement transducer, an electrical micrometer (Figure 3). Tension in the suture set up bending strain in the clock spring which produced resistance changes in the strain gauges. These resistance changes were detected by a strain gauge amplifier which converted them into a voltage proportional to suture tension.

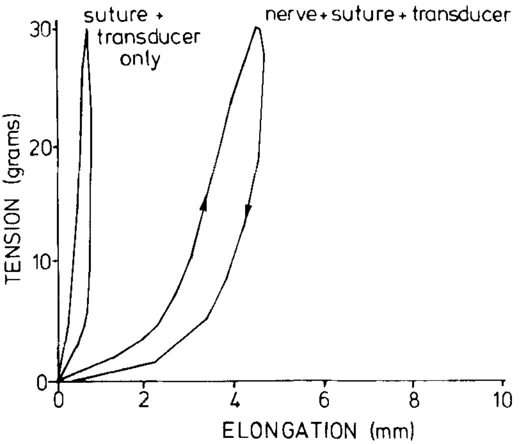

Figure 2. Recordings used to determine the stiffness of a proximal nerve section. Subtracting one curve from the other gives the stiffness of the nerve section alone.

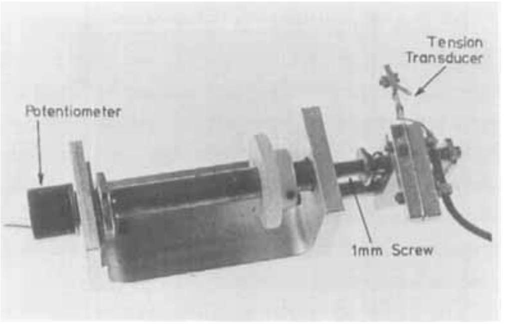

Figure 3. The tension transducer attached to the electrical micrometer.

The electrical micrometer used a 1 mm pitch screw mounted in ball bearings. A block sliding on a guide rod was fixed to a nut on this screw and the tension transducer was mounted on this block. A ten-turn potentiometer coupled to the end of the screw was used to determine the position of the block.

RESULTS

Stiffness measurements

Graphs of tension against elongation for the ten animals are shown in Figure 4. Three factors are apparent:

1. All three portions of the nerve have a non-linear response to stretching, becoming increasingly stiff with increased elongation. The difference in the curves for increasing and decreasing tension are due to hysteresis (energy absorption during stretching). Repeated cycling of stretching and relaxation gave similar results.
2. The proximal nerve segment was stiffer than the distal segment and the isolated section stiffer than both.
3. The shape of the stiffness graph was not significantly altered after tension–relaxation tests at 30 g initial tension. However the results showed increases in nerve length at zero tension following the creep tests (Table 1).

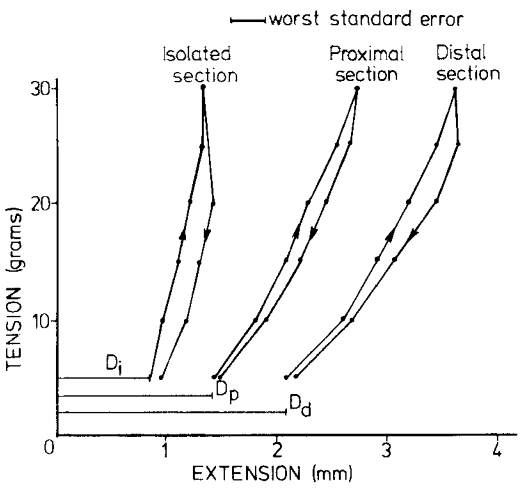

Figure 4. Stiffnesses of the three nerve sections tested. The curves show mean results from the ten animals and the D values give an estimate of the extension produced by 5 g tension.

Table 1. Length increases after creep test for the three nerve sections

	Mean length increase after creep test: mm (s.e. in brackets)
proximal section	0.6 (0.2)
distal section	0.9 (0.4)
isolated section	0.4 (0.2)

Attempts to find the ultimate strength (rupture tension) of the nerves were frustrated by the suture cutting out of the nerve. In one successful experiment a rupture tension of 200 g was measured.

Tension–relaxation (creep) measurements

These experiments were intended to simulate the mechanical circumstances of the

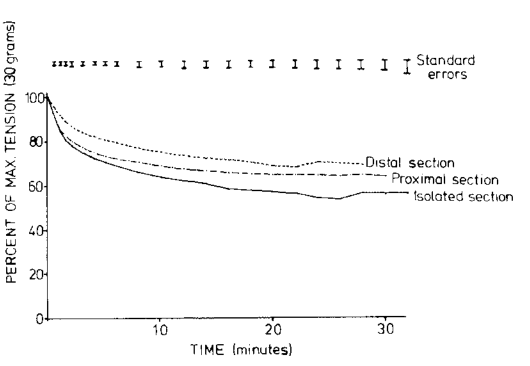

Figure 5. Creep properties of the three nerve sections tested (mean results from ten animals).

nerve after repair under tension. Graphs showing the decay of tension over time are shown in Figure 5. This tension was initially 30 g and fell to about 20 g after 10 minutes. There was a further small reduction in the following 20 minutes. Comparison of the creep results from the three sections tested showed significant differences. The isolated sections displayed the most creep and the distal sections the least.

DISCUSSION

Our results agree with those who found increasing stiffness of peripheral nerves with elongation and that a nerve creeps to reduce applied tension. In our experimental conditions most tension–relaxation occurs in the first 10 minutes following the application of a tension. The total reduction in tension is of the order of 30 per cent. Although from our results it appears that at 30 minutes the rate of creep is close to zero and falling, it is possible that creep continues at a low rate beyond the limit of our measurement leading to a much greater reduction in tension. It is possible that such long term creep does occur as an adaptive response enabling nerves to grow in response to tension. However, experimental work on dogs (Highet & Saunders 1943) failed to demonstrate any such long term increase in nerve length.

The question of what tension is required to damage a nerve is a source of controversy. Liu et al. (1948) claimed that the perineurium was destroyed by an elongation of 6 per cent, while Hoen & Brackett (1956) found little evidence of damage with a permanent elongation of 100 per cent. These widely disparate figures probably relate to whether the nerve was measured against its retracted length, its original length, or the length at which a measurable tension was taken up. Many investigations have shown that little tension is required to stretch the nerve in the first phase of elongation. We believe that measuring tension rather than elongation is a more accurate and reproducible method.

It was found that a sustained tension of 30 g produces an elongation of 10–20 per cent in the nerve and an increase in length at zero tension of 2–5 per cent. This deformation had no significant effect on the stiffness characteristic. It is possible that creep under tension is the result of a process such as fluid expulsion which can reverse over a period of time after tension is removed.

The isolated nerve section was stiffer than the proximal end which in turn was stiffer than the distal end. The same order was maintained for creep results, the isolated section creeping most and the distal section least. Since similar lengths of nerve were involved in each case these results are consistent with the nerve having crept to a similar increase in length rather than reduction in tension. Comparison of the stiffness results for the isolated section and proximal and distal ends indicates that about half of the elongation of the proximal and distal ends comes from the exposed length of the nerve, the remainder being in the unexposed nerve and its attachments.

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