Tibial nerve function during tibial lengthening

Measurement of nerve conduction and blood flow in rabbits

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We evaluated in 20 Japanese white rabbits the effects of tibial lengthening on tibial nerve conduction and intraneural blood flow at the end of lengthening. Both tibiae were distracted 1 mm per day. The distraction frequency was in 2 steps (0.5 mm/12 h) on the right side and in 120 steps (0.0083 mm/12 min) on the left. The rabbits were separated into 4 subgroups based on the percentage of lengthening: 0 (control), 10, 20, and 30 percent. In the 2-step group, nerve conduction was delayed at 20 and 30 percent lengthening, compared to the control group, while in the 120-step group, it was delayed only at 30 percent lengthening. Intraneural blood flow in the 2-step group was decreased at 10, 20, and 30 percent lengthenings, while in the 120-step group it was reduced at 30 percent lengthening. Our findings indicate that an increase in the frequency of distraction reduces the impairment of nerve function during bone lengthening.

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Nerve damage is one of the serious complications associated with leg lengthening. Hang and Shih (1977) observed that all 9 of his patients had temporary nerve damage, while De Bastiani et al. (1986) reported no nerve complications in 100 lengthenings. Most nerve complications are transient sensory disturbances. However, one case of permanent nerve disturbance has been reported (Faber et al. 1991). We evaluated the effects of tibial lengthening on the tibial nerve conduction and blood flow in the rabbit.

Animals and methods

20 Japanese white rabbits weighing 3.0–3.5 kg were anesthetized with sodium pentobarbital (30 mg/kg). A longitudinal skin incision was made on the medial aspect of the tibia and the periosteum was incised and retracted. 4 threaded 2.4-mm pins were inserted at right angles to the diaphysis after drilling. A transverse osteotomy was performed using a hand-saw just below the tibiofibular junction between the second and third pins. The pins were then clamped to an unilateral external fixator. Both tibiae were operated on in the same manner.

Lengthening was started from the following day at a rate of 1mm per day. On the right tibia, the frequency of distraction was 2 steps per day (0.5 mm/12 h) by hand, while on the left it was 120 steps per day (0.0083 mm/12 min) by an auto-distractor.

The 20 animals were divided into 4 subgroups of 5 each, based on length gain. The first subgroup had a 10 percent increase in length, the second 20 percent, and the third 30 percent. The fourth subgroup, the control, had no distraction.

When the desired length was achieved, the animal was anesthetized with sodium pentobarbital (30 mg/kg) and given intermittent intravenous doses (10 mg/kg) to maintain anesthesia.

To measure the intraneural blood flow, the tibial nerve was exposed 2 cm proximal to the ankle joint. A platinum electrode was placed in the substance of the nerve and a reference electrode was placed in a subcutaneous pocket in the thigh. Maintaining a respiratory rate between 15 and 20/min and a rectal temperature between 38.5°C and 40°C, the animals were made to inhale hydrogen with oxygen gas for 20 sec. The intraneural blood flow of the tibial nerve was measured using the hydrogen washout technique (Aukland et al. 1964).

Next, an electrophysiological examination was performed. Through a posterior gluteal-to-popliteal incision, the sciatic nerve was exposed and a bipolar stimulating platinum electrode was placed on the nerve at the sciatic notch. Two recording electrodes were placed, one at the tibial nerve junction and one at the tibial nerve 2 cm proximal to the ankle joint. The compound nerve action potential was then recorded using a supramaximal stimulus and the interpeak latency between the two recording points

Table 1. Interpeak latency (msec) related to increase in length

A	2-step	120-step
0 (n 5)	0.93 (0.88–0.98)	
10 (n 5)	1.03 (091–1.13)	0.95 (0.74–1.05)
20 (n 5)	1.26 (0.92–1.53) [a]	1.05 (0.83–1.33)
30 (n 5)	1.34 (1.25–1.50) [a]	1.14 (0.94–1.33) [a]

A percent increase in length
[a] $p < 0.05$ compared to the control group

Table 2. Intraneural blood flow (mL/min/100 g) related to increase in length

A	2-step	120-step
0 (n 5)	107 (98–126)	
10 (n 5)	76 (57–90) [a]	99 (74–128)
20 (n 5)	62 (31–94) [a]	85 (31–128)
30 (n 5)	40 (22–84) [a]	57 (35–88) [a]

A percent increase in length
[a] $p < 0.05$ compared to the control group

was measured to obtain tibial nerve data. All examinations were performed three times in a sealed room at 25 °C; the values were then averaged. Throughout all measurements, care was taken not to injure the blood vessels surrounding the tibial nerve.

ANOVA was used to evaluate the influence of length gain and the daily frequency of distraction. The nonparametric Kruskall-Wallis test was used to compare the 4 subgroups in the same step. When significant differences were found, the Mann-Whitney U-test was employed. $P < 0.05$ was considered significant.

Results

Nerve function (Table 1)

As lengthening proceeded, the interpeak latency increased in both the 2-step and 120-step groups. Compared to the controls, the interpeak latency in the 2-step group was delayed at 20 and 30 percent lengthening, while in the 120-step group it was delayed only at a 30 percent increase in length.

Intraneural blood flow (Table 2)

As the percentage of lengthening increased, the values of intraneural blood flow in both 2- and 120-step groups decreased. In the 2-step group, it diminished at 10, 20, and 30 percent lengthening compared to the controls, while in the 120-step group it decreased only at 30 percent.

Discussion

Galardi et al. (1990) found a clear relationship between the amount of elongation and the nerve conduction velocity in patients who had had tibial lengthening performed by the Ilizarov method. Lee et al. (1992) monitored peripheral nerve function with somatosensory evoked potentials (SSEP) in rabbits with tibial lengthening and observed an increase of P1 (the first major positive peak) latency and a reduction of SSEP amplitude with an increasing rate of elongation. Our findings confirm this relation.

There is little information about the effect of the frequency of lengthening on pathological changes in the nerve. Ilizarov (1989) compared the histological differences in soft tissues, including a nerve in the distraction zone, between several different frequencies. However, he did not measure nerve function electrophysiologically. In our study, an increase in the frequency of distraction reduced the degree of nerve conduction disturbance.

Although there have been many studies on intraneural blood flow during acute nerve stretching, we know of no study which evaluates the change of intraneural blood flow during gradual stretching, such as callotasis. We found that intraneural blood flow diminished as lengthening proceeded and an increased frequency of distraction reduced the degree of impairment of the intraneural blood flow.

The pathogenesis of nerve function damage during limb lengthening remains unknown. Some authors believe that it is caused mainly by mechanical damage due to distraction (Galardi et al. 1990, Morishita 1994, Strong et al. 1994, Velazquez et al. 1994). Morishita (1993) reported that the width of some Ranvier nodes of the sciatic nerve in a rabbit increased as the femur was elongated by callotasis. Strong et al. (1994) commented that the nerve injury occurring during his experimental limb lengthening was a combination of Sunderland first and second degree injuries. Others have suggested that disturbance of the axonal flow (Galardi 1990, Davis et al. 1992-3, Strong et al. 1994) or subacute compartment syndrome within the muscle being stretched (Velazquez et al. 1994) might be one of the damaging factors. It is well known that the reduction of intraneural blood flow is one of the damaging factors during acute stretching. During gradual stretching such as callotasis, however, the effect of impaired intraneural blood flow is still obscure. The presence of fibrosis caused by ischemia within the compartment in some clinical limb lengthening cases led Battiston et al. (1992) to believe that the nerve disturbance might be due to a combination of distraction and ischemia. Our findings support the idea that ischemia may be a factor in nerve damage during leg lengthening, in addition to mechanical factors.

During bone lengthening by callotasis, the tension of surrounding soft tissue increases as elongation proceeds. Ohnishi et al. (1992) compared the resistance to distraction on the fixator in patients who had tibial lengthening at a rate of 1 mm per day, with a frequency of distraction between 2 steps per day by hand, and 1440 steps by an auto-distractor. They found that an acute increase in resistance took place simultaneously with each step of lengthening in the 2-step distraction, while in the 1440-step distraction there was little change. Ilizarov (1989) reported that an increase in the frequency of distraction could promote the formation of new nerve tissue and blood vessels, which could help maintain normal structure. These reports may explain the differences in our study between the 2-step and 120-step groups.

Ilizarov (1989) observed that an increase in the frequency of distraction in callotasis provides better osteogenesis, and Nakamura et al. (1993) reported that this may prevent damage to the articular cartilage in adjacent joints. Our study also showed that it reduces peripheral nerve function damage.

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References

Aukland K, Bower B F, Berliner R W. Measurement of local blood flow with hydrogen gas. Circ Res 1964 ; 14: 164–87.

Battiston B, Buffoli P, Vigasio A, Brunelli G, Antonini L. The effects of lengthening on nerves. Ital J Orthop Traumatol 1992; 18 (1): 79–86.

Davis R J, Bell D E, Crowley N, Redmond M D. Electromyographic changes following limb lengthening. A prospective study. Orthop Trans 1992–3;16: 700.

De Bastiani G, Aldegheri R, Brivio L R, Trivella G. Chondrodiastasis-controlled symmetrical distraction of the epiphyseal plate. J Bone Joint Surg (Br) 1986; 68 (4): 550–6.

Faber F W M, Keeser W, Roermund P M. Complications of leg lengthening: 46 procedures in 28 patients. Acta Orthop Scand 1991; 62 (4): 327–32.

Galardi G, Comi G, Lozza L, Marchettini P, Novarina M. Peripheral nerve damage during limb lengthening. Neurophysiology in five cases of bilateral tibial lengthening. J Bone Joint Surg (Br) 1990; 72 (1): 121–4.

Hang Y S, Shih S S. Tibial lengthening. A preliminary report. Clin Orthop 1977; 125: 94–9.

Ilizarov G A. The tension stress effect on the genesis and growth of tissues: Part II. The influence of the rate and frequency of distraction. Clin Orthop 1989; 239: 263–85.

Lee D Y, Han T R, Choi I M, Lee C K, Chung S S. Changes in somatosensory-evoked potentials in limb lengthening. An experimental study on rabbit tibiae. Clin Orthop 1992; 285: 273–9.

Morishita Y, Ikeda K, Tomita K, Tanaka S. Experimental study of peripheral nerve injury during incremental elongation. J Jpn Orthop Ass 1993; 67 (8): 1289.

Morishita Y, Ikeda K, Tomita K, Tanaka S. Peripheral nerve injury during limb lengthening using the sciatic nerve of the rabbit. J Jpn Soc Ext Fix (JJSEF) 1994; 5: 139–43.

Nakamura E, Mizuta H, Sei A, Takagi K. Knee articular cartilage injury in leg lengthening: Histological studies in rabbits. Acta Orthop Scand 1993; 64 (4): 437–40.

Ohnishi I, Kurokawa T, Horinaka S, Murashima R. Measurements of tensile force during auto-continuous lengthening. Seikeisaigaigeka 1992; 35 (1): 23–8.

Strong W, Hruska J, Czyrny J, Heffner R, Brody A, Wong-Chung J. Nerve palsy during femoral lengthening: MRI, electrical, and histologic findings in the central and peripheral nervous systems—a canine model. J Pediatr Orthop 1994; 14: 347–51.

Velazquez R J, Bell D F, Armstrong P F, Babyn P, Tibshirani R. Complications of use of the Ilizarov technique in the correction of limb deformities in children. J Bone Joint Surg (Am) 1993; 75 (8): 1148–56.