Scand J Rehab Med 19: 67–70, 1987

TRANSCUTANEOUS ELECTRICAL STIMULATION OF THE NORMAL RABBIT JOINT

Abraham Weinberger, Michael Dalith, Amos Toren, Paz Volovsky-Toren, Mina Ben-Bassat, Shammai Giler and Jack Pinkhas

From the Department of Medicine "D", the Rheumatology Unit, Institute of Clinical Physiology and Caspar Institute of Pathology and the Institute of Experimental Surgery, Beilinson Medical Center, Petah Tikva and the Tel Aviv University Sackler School of Medicine, Tel Aviv, Israel

ABSTRACT. To determine the effect of transcutaneous electrical stimulation on the rabbit joint, we studied skin and intraarticular temperatures and pressure both before and following the stimulation in nine rabbits. An elevation in skin temperature by a mean of 0.6°C ($p<0.05$) and increase in intraarticular temperature by a mean of 0.8°C ($p<0.01$) was noted following the electrical stimulation. Intraarticular pressure in the stimulated joints has only a trend to increase, but not significantly. In four other rabbits, synovial tissue of the stimulated joint showed blood vessels congestion and interstitial edema. These results suggest that the analgetic effect produced by electrical stimulation on joints may partially involve intraarticular temperature and pressure alterations.

Key words: joint, electrical stimulation, pressure, temperature

Transcutaneous electrical nerve stimulation (TENS), has been recently used as a pain relieving modality. It seems to be more effective in chronic rather than acute pain. TENS has been assumed to block chronic pain which is mainly mediated through C-fibers, while the acute pain, mediated through A-delta fibers, is blocked to a lesser extent (10).

The periosteum, synovia and ligaments are supplied with thin nonmyelinated sensory afferent nerves of the C-fiber type, having a low conduction velocity. Thus, joint pain should theoretically be amenable to TENS treatment.

TENS, which involves delivery of an electrical current through the skin to a peripheral nerve, may provide pain relief in patients with osteoarthritis of the spine (9). Mannheimer et al. (10), have recently claimed that TENS is effective in reducing joint pain in rheumatoid arthritis. All patients with rheumatoid arthritis obtaining pain relief with TENS also reported less stiffness in the treated joint. Other investigators suggest that TENS acts through releasing endogenous morphine-like substances with analgesic properties (1, 15). Other recent evidence suggests that TENS causes dilatation of blood vessels in the synovial tissue (4). These reports, together with the observation that thermal therapy might reduce joint pain (14), brought us to study the possible physiological effect of TENS on experimental animals.

METHODS

Animal preparation. Nine male rabbits (local Israeli strain) weighing 2.5–3.0 kg were anaesthetized by intravenous injection of sodium pentobarbital (25 mg/kg). Both knee joints areas were shaved and cast at a flexion position of 90°. Recording was started 60 min after cast drying.

Temperature measurements. Intraarticular temperature in both knees was monitored and measured through thermocouple needles (Exacon standard measuring probe series TH-103, Type N-2) inserted into the joint space from the medial aspect just beneath the patellar tendon. External skin temperature of the joints was measured through the Exacon standard measuring probe (Series TH-103, Type S-7) placed lateral to the patellar ligament. Rectal temperature was measured through Exacon type RR-C probe. All probes were connected to Exacon Thermometer (Model ML 8700, Type 5W4) Exacon Scientific Instruments, Denmark.

Pressure measurements. Intraarticular pressure was measured with a 19G needle introduced into the joint space through the lateral aspect beneath the patellar tendon while the joint was at 90°, and connected to a pressure transducer (Statham, Hatorey, Puerto-Rico) and to a pressure monitor (Med-Science, St. Louis, Missouri, USA) through a polyethylene extension tube. The needle, extension tube and transducer were filled with normal saline before insertion.

X-ray examinations. The proper intraarticular location of the temperature probes and pressure needles was examined prior to each of the experiments by antero-posterior and lateral aspects radiographs. Basal pressure of about 2 mmHg served as an additional indicator for proper location of the pressure needle in the joint compartment.

Physiological parameters. Heart rate, arterial systolic and diastolic blood pressure of each rabbit were recorded

Table I. *Measurements recording (mean ± SD) in 9 rabbits before and after TENS*
S = stimulated joint, U = unstimulated joint

		Before TENS	Minutes after stimulation			
		0 min	10	20	30	40
Intraarticular temperature (°C)	S	30.8±4.8	31.1±4.5	31.6±4.4*	31.3±4.5*	31.2±4.5**
	U	30.7±4.2	30.7±4.1	30.6±4.3	30.6±4.1	30.6±4.1
Skin temperature (°C)	S	29.9±3.9	30.7±3.0	30.5±3.1	30.6±3.5*	30.5±3.5**
	U	29.9±3.8	30.0±3.2	29.8±3.3	29.7±3.3	29.5±3.3***
Rectal temperature (°C)		36.8±1.9	36.8±1.9	36.7±1.8	36.7±1.8	36.8±1.6
Intraarticular pressure (mmHg)	S	5.6±5.1	8.3±9.0	7.4±8.1	8.2±6.5	8.3±7.8
	U	4.7±4.9	4.2±4.9	5.9±4.6	5.7±4.3	4.8±5.6

* $p<0.01$, ** $p<0.05$ by Wilcoxon matched paired signed-ranks test and by Student's paired *t*-test when compared to time zero. *** Significant ($p<0.05$) by Wilcoxon matched paired signed-ranks test and by Student's paired *t*-test when compared to time 10'.

through an ear arterial cannula (Cathlon 20-G, Critkon Inc., Tampa, Fl., USA) connected to a pressure transducer and a polygraph (Grass Instrument Co., Mass., USA). Respiratory rate was recorded through a pressure cuff placed around the rabbit's chest and connected to a pressure transducer and a polygraph. Partial pressure of the arterial blood gases ($PaCO_2$, PaO_2) and pH were measured.

Transcutaneous electrical nerve stimulation. TENS to the joint area was applied from a Neurogar® stimulator (Agar Electronics, Ginosar, Israel) at a stimulation frequency of 80–100 Hz, pulse duration of 0.4–0.6 msec and intensity of 15–25 mAmps through conductive silicon rubber electrodes placed on the lateral (active) and medial (passive) aspects of one joint. Pulse modulation was used in order to avoid habituation to the continuous stimulation.

Experimental protocol. Post-preparation period of 60 min was given prior to the beginning of the nine rabbits studied. Each experiment included two groups of measurements, before the electrical stimulation and after, in which one joint was stimulated while its parallel hind joint served as a control. The whole length of each experiment was 75 min, which was divided as follows: three readings of each joint were taken at 10 min intervals before the stimulation. Then TENS was continuously applied to one (right) joint for 5 min. Post stimulus measurements were four times recorded at 10 min intervals (for 40 min).

Synovium histology

In order to study the effect of TENS on the synovial tissue, electrical stimulation was applied to 4 rabbits additional to the ones included in the above experiment. The rabbits were sacrificed by an overdose of intravenous sodium pentobarbital 10 min following 5 min of TENS to the right hind joint. Synovial specimens of both knee joints (stimulated and nonstimulated) were obtained from the area overlying the infrapatellar pad, placed in 10% formalin, stained with hematoxylin-eosin, encoded and read "blindly" by one of us (M. B.-B.).

Statistical analysis. Two-way analysis of variance: Randomized blocks (2), Wilcoxon matched paired signed-ranks test (13) and Student's paired *t*-test were used.

RESULTS

Control values. The mean (± SD) of initial temperatures were as follows: rectal 36.8±1.9°C; skin over the joint 29.9±3.9°C; intraarticular 30.8±4.8°C. No significant changes in the rectal temperature were noted during TENS. The initial mean intraarticular pressure in the resting knees at 90° was 4.7–5.6 mmHg. This is in agreement with the findings of other investigators who have reported positive atmospheric pressure in flexed joints (7, 11). Respiratory rate, $PaCO_2$, PaO_2, heart rate and arterial blood pressure were (mean ± SD) 74.4±2.9 rate/min, 20.9±1.3 mmHg, 94.3±5.5 mmHg, 285.4±9.8 rate/min respectively and remained stable before and following TENS.

Temperature and pressure changes. A significant and persistent increase of intraarticular and skin temperatures was observed following TENS (Table I), changes which did not occur in the unstimulated joints (Fig. 1). An increase in intraarticular pressure of the stimulated leg (although not statistically significant) was also recorded (Table I).

Synovial histology. Synovial specimens from the 4 stimulated joints showed mild congestion of blood vessels with interstitial edema in three and a normal appearance in one, while the control specimens appeared normal.

DISCUSSION

TENS was effective when the electrodes were placed above the sore region, on the trigger point, or above the appropriate nerve (3, 5, 12, 16). The exact mode of action of TENS has not yet been clearly defined.

Some assume that its action is related to a possible electrical stimulation of sympathetic fibers, and others suggest a placebo effect.

We showed that in the animals treated with TENS, arterial vasodilatation of the synovial vessels occurred following the stimulation applied directly to the joint surface. These findings were accompanied by an intraarticular temperature rise. Therefore, one of the mechanisms to which the TENS effect as an analgesic modality might be attributed is the electromechanical production of heat, which causes vasodilatation and hyperemia. Alternatively, the TENS effect occurs by the stimulation of the nerves which causes vasodilatation, bringing an increase in the blood flow rate which in turn produces a higher temperature.

The tendency of intraarticular pressure increase observed in our study might be attributed to a rise in synovial fluid volume due to extravasation, a phenomenon we noted previously (17).

Such modality of TENS may be of therapeutic value in noninflammatory arthritis as recently shown by Lewis et al. (8) who applied it in osteoarthritis of the knee. They found that the duration of pain relief during active therapy with TENS was significantly longer than that during placebo. It has been suggested that TENS should be used with caution in inflammatory arthritis since increase in intraarticular temperature and vasodilatation might cause more damage to the joint by increasing the rate of collagen breakdown with specific collagenases (6). On the other hand, heat may increase synovial tissue permeability to anti-inflammatory medications and thus increase the drug efficacy. One has to bear in mind the marked difference in size between rabbit and human knees. This implies that further studies in humans are required before drawing final conclusions about the physiological effects of TENS on normal joints.

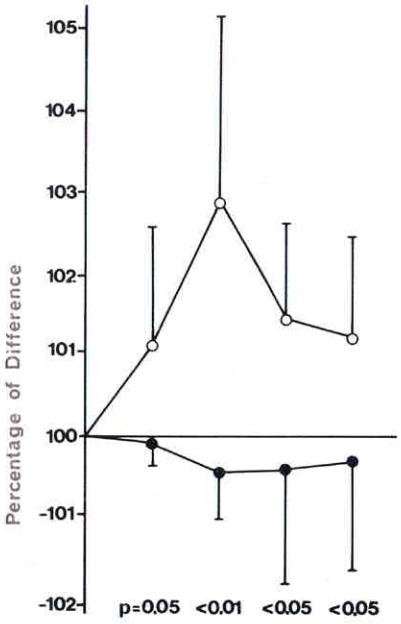

Fig. 1. Intraarticular temperature changes of stimulated (○–○) and unstimulated (●–●) joints. The Wilcoxon matched paired signed ranks test was used in which the percentage of difference in temperature of each point recording (10′, 20′, 30′, 40′) of the stimulated joints was compared to the unstimulated ones.

ACKNOWLEDGEMENT

We wish to thank Mrs R. Don for statistical assistance.

REFERENCES

1. Adams, J. E.: Naloxone reversal of analgesia produced by brain stimulation in the human. Pain *2:* 161, 1976.
2. Armitage, P.: Statistical Methods in Medical Research, pp. 217–225. John Wiley & Sons, New York, 1971.
3. Bates, J. A. V. & Nathan, P. W.: Transcutaneous electrical nerve stimulation for chronic pain. Anaesthesia *35:* 817, 1980.
4. Dooley, D. M. & Kasprak, M.: Modification of blood flow to the extremities by electrical stimulation of the nervous system. Southern Med J *69:* 1309, 1976.
5. Evron, S., Schenker, J. G., Olshwang, D., Granat, M. & Magora, F.: Post-operative analgesia by percutaneous electrical stimulation in gynecology and obstetrics. Eur J Obstet Gynecol Reprod Biol *12:* 305, 1981.
6. Harris, E. D. & McCroskery, P. A.: The influence of temperature and fibril stability on degradation of cartilage collagen by rheumatoid synovial collagenase. N Engl J Med *290:* 1, 1984.
7. Levick, J. R.: An investigation into the validity of subatmospheric synovial fluid pressure recordings and their dependence on joint angle. J Physiol *289:* 55, 1979.
8. Lewis, D., Lewis, B. & Sturrock, R.: Transcutaneous electrical nerve stimulation in osteoartherosis: a therapeutic alternative? Ann Rheum Dis *43:* 47, 1984.
9. Loeser, J. D., Bloch, R. G. & Christman, A.: Relief of pain by transcutaneous stimulation. J Neurosurg *42:* 308, 1975.
10. Mannheimer, C., Lund, S. & Carlson, C. A.: The effect of transcutaneous electrical nerve stimulation (TENS) on joint pain in patients with rheumatoid arthritis. Scand J Rheumatol *7:* 13, 1978.
11. O'Drisoll, S. W., Kumar, A. & Salter, R.: The effect of the volume of effusion, joint position and continuous passive motion on intraarticular pressure in the rabbit knee. J Rheumatol *10:* 360, 1983.

12. Shealy, C. N. & Maurer, M.: Transcutaneous nerve stimulation for the control of pain. Surg Neurol *2:* 45, 1974.
13. Siegal, S.: Nonparametric Statistics for the Behavioural Sciences, pp. 68–77. McGraw-Hill, Toronto, 1956.
14. Swezey, R. L.: Rehabilitation aspects in arthritis. *In* Arthritis and Allied Conditions (ed. D. J. McCarty), 9th ed., pp. 534–538. Lea & Febiger, Philadelphia, 1979.
15. Ternius, L. A. & Wahlstrom, A.: Morphine-like ligand for opiate receptors in human CSF. Life Sci *16:* 1759, 1975.
16. Vanderark, G. D. & McGrath, K. A.: Transcutaneous electrical stimulation in treatment of post-operative pain. Am J Surg *130:* 338, 1975.
17. Weinberger, A. & Schumacher, H. R.: Tissue response to mechanical trauma and the effect of cold, heat and ultrasound on traumatized canine joint. *In* Progress in Rheumatology (ed. I. Machtey), pp. 47–49. John Wright & Sons, Bristol, 1982.

Address for offprints:

Prof. A. Weinberger, M.D.
Head, Rheumatology Unit
Department of Medicine "D"
Beilinson Medical Center
Petah Tikva 49100
Israel