EVALUATION OF PERIPHERAL MICROCIRCULATION IMPROVEMENT OF FOOT AFTER TARSAL TUNNEL RELEASE IN DIABETIC PATIENTS BY TRANSCUTANEOUS OXIMETRY

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Background: According to recent studies, peripheral nerve decompression in diabetic patients seems to not only improve nerve function, but also to increase microcirculation; thus decreasing the incidence of diabetic foot wounds and amputations. However, while the postoperative improvement of nerve function is demonstrated, the changes in peripheral microcirculation have not been demonstrated yet. The aim of this study is to assess the degree of microcirculation improvement of foot after the tarsal tunnel release in the diabetic patients by using transcutaneous oximetry. *Patients and methods:* Twenty diabetic male patients aged between 43 and 72 years old (mean age 61.2 years old) suffering from diabetic peripheral neuropathy with superimposed nerve compression underwent transcutaneous oximetry (PtcO2) before and after tarsal tunnel release by placing an electrode on the skin at the level of the dorsum of the foot. Eight lower extremities presented diabetic foot wound preoperatively. Thirty-six lower extremities underwent surgical release of the tibialis posterior nerve only, whereas four lower extremities underwent the combined release of common peroneal nerve, anterior tibialis nerve, and posterior tibialis nerve. *Results:* Preoperative values of transcutaneous oximetry were below the critical threshold, that is, lower than 40 mmHg (29.1 ± 5.4 mmHg). PtcO2 values at one month after surgery (45.8 ± 6.4 mmHg) were significantly higher than the preoperative ones ($P = 0.01$). *Conclusions:* The results of postoperative increase in PtcO2 values demonstrate that the release of the tarsal tunnel determines a relevant increase in microcirculation in the feet of diabetic patients. © 2015 Wiley Periodicals, Inc. Microsurgery 36:37–41, 2016.

Diabetic peripheral neuropathy is recognized as the main factor in the etiopathogenesis of diabetic foot ulcers.[1,2] Lack of sensation from neuropathy is responsible for unrecognized repetitive trauma and pressure loading leading to skin injury. Moreover, diabetic metabolic abnormalities make peripheral nerves more susceptible to chronic compression when coursing through their anatomical tunnels.[3,4] Increased pressure has been documented intraoperatively in the medial and lateral plantar tunnels in patients with diabetic neuropathy.[5] Nerve compression causes compression of the vasa nervorum, thus leading to distal nerve ischemia, and decreased axoplasmic flow.[6] This impairs the ability of the nerve to communicate with muscle fibers and skin mechanoreceptors, resulting in loss of function or sensation.

Surgical decompression of peripheral nerves in patients with diabetes is reported to restore sensation and improve function. For the lower extremities, this consists of surgery for femoral nerve, peroneal nerve, or tarsal tunnel release. For the upper extremities, this surgery consists of carpal tunnel release, cubital tunnel release, or decompression of radial nerve.[7]

Surgical nerve decompression at lower-leg fibro-osseous tunnels has been demonstrated to significantly improve sensitivity at the extremities and to reduce the incidence of diabetic foot ulcers in neuropathic high-risk feet.[8]

Surgical decompression of the tarsal tunnel determines an improvement of nerve function as well as an increase in microcirculation.[9] However, while the postoperative improvement of nerve function is demonstrated by improvement in pain levels, recovery of sensation, improved balance, and decreased ulceration and amputation,[10] the changes in vascularization have yet to be evaluated.

The technique of transcutaneous oximetry (PtcO2) allows the estimation of the partial pressure of oxygen on the skin surface by employing noninvasive heated electrodes.[11] Because oxygen is carried to tissues by blood flow in the arteries, TCPO2 is an indirect measure of blood flow. This test is often used to evaluate advanced peripheral arterial disease, a condition in which blood flow to an extremity (usually the leg) is greatly reduced. Results of this test help physicians determine how severely tissues are deprived of blood flow. The test

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Figure 1. Preoperative view of a chronic interdigital ulcer in a patient with previous amputation of the second toe.

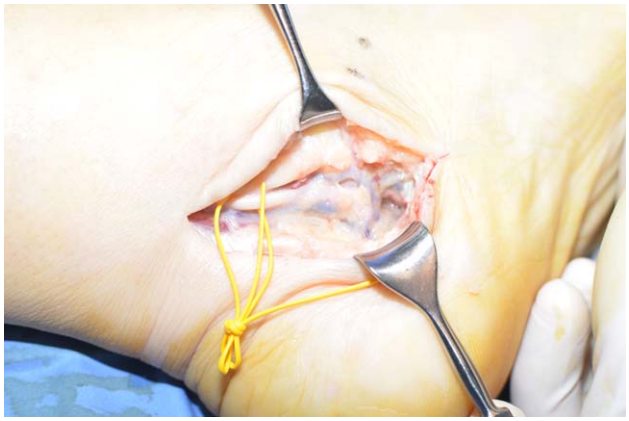

Figure 2. Intraoperative view of the release of the posterior tibialis nerve.

is often especially useful in predicting wound healing or amputation healing.[10]

The aim of this study is to assess the degree of microcirculation improvement of foot after the tarsal tunnel release in the diabetic patients by using transcutaneous oximetry.

PATIENTS AND METHODS

Twenty consecutive patients with forty lower extremities presenting with diabetic peripheral neuropathy and concurrent bilateral tarsal tunnel syndrome were treated in our Department from December 2011 to January 2012. This prospective study included an 18-month follow-up. The overall study period was 3 years.

Patients' age ranged between 43 and 72 years (mean age 61.2 years). All the patients suffered from diabetic neuropathy with superimposed nerve compression as determined by a positive Tinel sign on physical examination[12] and electroneurography. None of our patients present vascular disease related to diabetes.

Eight patients presented diabetic foot wounds at preoperative physical examination (Fig. 1). One of these eight patients had already undergone calcaneal reconstruction with a combined latissimus dorsi and serratus anterior and rib free flap because of a previous trauma.[13]

The postoperative sensory status was evaluated with the Tinel test and the electroneurography. Patients were evaluated by Transcutaneous oximetry (PtcO2) before the surgical procedure and one month postoperatively. Transcutaneous oximetry (TCM4, Radiometer, Denmark) was performed by placing an electrode on the skin at the level of the dorsum of the foot. Tissue hypoxia was defined at value of PtcO2 < 40 mmHg in patients without vascular disease.[11]

With reference to the reliability and stability of the O2 measurement technique, the room temperature controlled and the patients are always measured in the supine position.

Transcutaneous Oximetry

The test was performed in a vascular diagnostic laboratory and caused no discomfort. The area to be tested was first cleaned with alcohol and cleared of any wound dressings. If necessary, the site was also shaved. A gel that conducts electrical impulses was applied, and then the physician placed adhesive sensors containing a platinum electrode that can sense oxygen on the affected limb.

Electrodes in the sensors heated the area underneath the skin to dilate (widen) the capillaries so oxygen could flow freely to the skin, providing an optimal reading. This took about 15 minutes. The readings were converted to an electrical current and the signal was displayed on a monitor and recorded. Once the test was completed, the sensors were removed, the testing sites were cleaned, and any dressings were reapplied.

Surgical Procedure

To perform this operation it is important to have a thorough microsurgical background.[14,15]

All the surgical procedures were performed under epidural anesthesia with the patient in a supine position. A tourniquet was placed around the lower limb to limit intraoperative bleeding.

At the ankle, a curvilinear incision was performed longitudinally between the medial malleolus, anteriorly, and the Achilles tendon, posteriorly, exposing the flexor retinaculum. The tarsal tunnel was opened to identify the tibial nerve by an incision of the flexor retinaculum. The abductor hallucis muscle was distally and plantarly retracted to expose the roof of the medial and lateral plantar tunnels. The ligament that lies over the medial and lateral plantar nerves was released, then the septum between

Table 1. Preoperative and Postoperative Transcutaneous Oximetry Values

Patient number	Age	Lower limb treated	Presence of preoperative diabetic foot wounds	Decompressed Nerve (s)	Preoperative PtcO2 values (mm Hg)	Postoperative (1 month) PtcO2 values (mm Hg)	Postoperative (18 months) PtcO2 values (mm Hg)
1	43	Right	–	PTN	20	35	35
		Left	–	PTN	32	47	48
2	72	Right	–	PTN	25	40	41
		Left	–	PTN	28	42	41
3	52	Right	Right	PTN	32	50	50
		Left	–	PTN	27	45	45
4	48	Right	–	PTN	28	45	48
		Left	Left	PTN	25	43	45
5	56	Right	–	PTN	26	40	40
		Left	–	PTN	29	47	49
6	64	Right	–	PTN	32	41	43
		Left	–	PTN	30	42	43
7	59	Right	–	PTN	36	45	46
		Left	–	PTN	37	44	43
8	67	Right	–	PTN	39	43	43
		Left	Left	PTN	33	46	47
9	55	Right	Right	CPN + ATN + PTN PTN	16	45	46
		Left	–		22	42	42
10	70	Right	–	PTN	25	39	40
		Left	Left	PTN	28	40	41
11	64	Right	–	PTN	39	61	60
		Left	–	CPN + ATN + PTN	31	49	50
12	58	Right	–	PTN	25	48	49
		Left	–	PTN	26	55	57
13	57	Right	–	PTN	33	64	64
		Left	–	PTN	30	57	60
14	65	Right	–	PTN	25	60	62
		Left	Left	PTN	31	54	55
15	69	Right	–	PTN	27	45	44
		Left	–	PTN	24	49	50
16	65	Right	Right	CPN + ATN + PTN PTN	20	41	41
		Left	–		22	43	43
17	53	Right	–	PTN	26	40	42
		Left	–	PTN	34	42	43
18	68	Right	–	PTN	32	39	40
		Left	Left	PTN	36	50	51
19	71	Right	–	PTN	29	38	39
		Left	–	PTN	35	46	48
20	68	Right	–	PTN	37	45	47
		Left	–	CPN + ATN + PTN	35	48	49

PTN: posterior tibialis nerve; CPN + ATN + PTN: common peroneal nerve, anterior tibialis nerve, and posterior tibialis nerve.

the two plantar tunnels was divided and excised to let vessels and nerves share a new common tunnel (Fig. 2).

Once the nerves were released, subcutaneous tissue and skin were closed with 3–0 Vicryl and 4–0 Nylon Ethilon (Ethicon) interrupted stitches, respectively. A Penrose drain was placed in the wound at the level of the decompression of the posterior tibialis nerve.

Surgical wounds were dressed with nonadherent gauzes and compressive bandage.

Statistical Analysis

Statistical analysis consisted of the comparison between PtcO2 values before surgery and one month after nerve decompression, which was performed by using the Wilcoxon signed-rank test. Statistical significance was set at $P < 0.05$.

RESULTS

All patients underwent a preoperative transcutaneous oximetry evaluation at the dorsum of the foot and all results were below the critical value, that is, lower than 40 mmHg. Preoperative values of transcutaneous oximetry showed a mean value of 29.1 ± 5.4 mmHg.

Thirty-six lower extremities underwent surgical release of the tibialis posterior nerve only, whereas four

Figure 3. Postoperative view of the interdigital space showing the healing of the ulcer.

lower extremities underwent the combined release of common peroneal nerve, anterior tibialis nerve, and posterior tibialis nerve.

Each patient had the identical surgical procedure on bilateral lower extremities in different periods of time. The first operative procedure was performed on the lower extremity with the lowest transcutaneous oximetry values, subsequently followed by the opposing extremity.

At the postoperative transcutaneous oximetry re-evaluation thirty-six out of forty feet (90%) showed an increase in PtcO2 values, also surpassing the critical threshold; while four lower extremities (10%), despite showing a relevant improvement, did not reach the critical threshold.

Postoperative values of transcutaneous oximetry showed a mean value of 45.8 ± 6.4 mmHg. PtcO2 values at one month after surgery were significantly higher than the preoperative ones ($P = 0.01$; Table 1).

With reference to the four patients that underwent the combined release of common peroneal nerve, anterior tibialis nerve and posterior tibialis nerve no difference in blood flow was observed compared to the posterior tibialis nerve only.

With reference to the postoperative management, three lower suffered from a dehiscence of the surgical wound, which was conservatively treated, extremities

As regards the neurological symptoms, thirty-eight lower extremities (95%) showed a marked improvement, while two lower extremities (5%), despite surpassing the critical PtcO2 value, did not show any improvement in pain sensation.

Patients were followed up for 18 months. The mean value of transcutaneous oximetry at the end of follow up was 46.75 ± 6.67 mmHg. All the eight preoperative foot wounds healed completely (Fig. 3). No recurrence of diabetic foot wounds or indication for amputation were found in these patients. None of the patients underwent lower limb amputations. Postoperative results of Tinel test and electroneurography performed at 3 and at 6 months after surgery were negative for all patients.

DISCUSSION

Peripheral nerve decompression in diabetic neuropathy plays a pivotal role in terms of regain of the plantar sensation, balance and deambulation improvement, and pain resolution.[16] Several studies confirmed that patients with diabetic neuropathy who also have a superimposed chronic nerve compression, demonstrated by a positive Tinel's sign, can anticipate clinical improvement following neurolysis of the entrapped nerves.[17]

Peripheral nerve compression syndromes involve several nerves, not only in the lower extremities but also on the arms (carpal tunnel syndrome, cubital tunnel syndrome, and radial nerve entrapment syndrome), on the trunk (i.e., brachial plexus compression), and head (chronic migraine headaches). There are several techniques for surgical decompression of peripheral nerves, such as the tarsal tunnel release with the excision of the flexor retinaculum, the carpal tunnel release either with the traditional approach, ultrasound-guided,[18] with minimal access,[19] or with nervous grafts.[20]

Beside the improvements in neurological symptoms, Ducic et al. observed that peripheral nerve decompression in lower extremities decreases the incidence of diabetic foot wounds and amputations.[21] This observation leads us to think that an increased pressure within anatomical tunnel could impair not only the nervous function but also the microcirculation.

In this regard, Blount et al. demonstrated that an epineurectomy of the tibial nerve also provides a localized sympathectomy to the posterior tibial artery, which results in enhanced blood flow from vessel dilatation. However, in the same article, the authors highlighted the need to correlate the presence of sympathetic fibers in the specimens with blood flow measurements both before and after the surgical nerve decompression.[9]

The technique of transcutaneous oximetry allows the estimation of the partial pressure of oxygen on the skin surface by employing noninvasive heated electrodes. This noninvasive procedure is also useful in predicting wound response to hyperbaric oxygen treatment as well as limb salvage after revascularization procedures.[21,22] The choice of a one month time frame for measurement was determined because any blood flow change related to the surgery itself should be completed.[11]

In diabetic patients, the impaired metabolic state predispose peripheral nerves to distal chronic compression syndromes within known anatomical tunnels. As such,

surgical decompression surgery contributes to limb salvage in diabetics by alleviating symptomatic peripheral neuropathy.

Recent studies have highlighted the double role of peripheral nerve surgery in improving nerve function and increasing microcirculation. Our study focused on the evaluation of the increase in microcirculation by performing transcutaneous oximetry before and after tarsal tunnel release on twenty consecutive diabetic patients.

The release of the flexor retinaculum improves neurological symptoms because the nerve is decompressed and causes an increase in microcirculation because of the decompression of the vessels that are compressed in the anatomical tunnel by the swollen nerve (diabetes-related edema).[6]

According to our findings, surgical decompression of the tarsal tunnel determines a considerable increase in postoperative PtcO2 values, which also overpassed the limit defined for tissue hypoxia in the majority of cases.

CONCLUSIONS

The results of postoperative increase in PtcO2 values demonstrate that the release of the tarsal tunnel determines a relevant increase in microcirculation in the feet of diabetic patients.

CONFLICT OF INTEREST

The authors have no conflicts of interest or financial ties to disclose.

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