ACTA
ORTHOPAEDICA
et
TRAUMATOLOGICA
TURCICA

Acta Orthop Traumatol Turc 2009;43(5):381-385
doi:10.3944/AOTT.2009.381

Oxygen tensiometry as a predictor of wound healing in total ankle arthroplasty

Total ayak bileği artroplastisinde yara iyileşmesini öngörmede oksijen tensiometresinin rolü

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Objectives: Total ankle arthroplasty (TAA) typically involves an anterior approach to the ankle that has been shown to have a risk for wound healing problems. We explored the possibility of using oxygen tensiometry as a predictor of incision healing problems in patients undergoing TAA.

Methods: The study included 25 patients who underwent TAA with the Scandinavian Total Ankle Replacement (STAR) system at our institution during a three-year period. Transcutaneous oxygen measurements of both ankles were obtained postoperatively to determine whether the results of transcutaneous oxygen tensiometry correlated with wound healing problems. Patients with wound healing problems were compared with those who had an uneventful incision healing.

Results: Seven patients (28%) had wound healing problems after TAA, and five patients (20%) had early wound erythema. Wound healing problems included delayed healing in five patients and dehiscence in two patients. Three patients had transcutaneous oxygen tension of less than 40 mmHg (a threshold for impaired skin oxygenation) on the operative side, of whom one had healing difficulty whereas two did not. When the threshold was extended to 50 mmHg, seven patients (28%) had low readings, two having wound healing problems. There was no significant difference with respect to oxygen measurements between patients with and without wound healing problems (p=0.3).

Conclusion: Oxygen tensiometry is not thought to be useful for predicting patients at risk for postoperative wound healing complications after TAA, suggesting that, if adequate pulses are present before surgery, the trauma of using excessive superficial traction on the skin during surgery is more responsible for wound healing problems than the underlying blood supply.

Key words: Ankle joint/surgery; arthroplasty, replacement; blood gas monitoring, transcutaneous; oxygen; postoperative complications/etiology; wound healing.

Amaç: Total ayak bileği artroplastisi tipik olarak, yara iyileşme sorunları için bir risk oluşturduğu bilinen, ayak bileğine anterior yaklaşımı içerir. Bu çalışmada, total ayak bileği artroplastisi uygulanan hastalarda yara iyileşme sorunlarını öngörmede oksijen tensiometresi kullanımının rolü araştırıldı.

Çalışma planı: Üç yıllık bir süre içinde kurumumuzda STAR (Scandinavian Total Ankle Replacement) ile total ayak bileği artroplastisi uygulanan 25 hastada, transkütanöz oksijen tensiometresi sonuçlarının ameliyat sonrası yara iyileşme sorunlarıyla ilişkili olup olmadığı araştırıldı. Transkütanöz oksijen ölçümleri tüm hastalarda ameliyat sonrasında ve her iki ayak bileğinden yapıldı. Yara iyileşmesinde sorun görülen hastalar ile sorunsuz iyileşen hastalar karşılaştırıldı.

Sonuçlar: Ameliyat sonrasında yedi hastada (%28) yara iyileşme sorunu, beş hastada (%20) ise erken dönemde eritem görüldü. İyileşme sorunu beş hastada geç iyileşme, iki hastada ayrışma şeklindeydi. Üç hastada, ameliyat edilen tarafta transkütanöz oksijen tansiyonu 40 mmHg'nin altında (yetersiz oksijenasyon eşiği) bulundu; bunların birinde yara iyileşme sorunu vardı; diğer ikisinde yoktu. Eşik 50 mmHg olarak alındığında ise, yedi hastada (%28) düşük değerler elde edildi; bunların ikisinde yara iyileşme sorunu görüldü. Oksijen ölçümleri açısından, yara iyileşmesi sorunu olan ve olmayan hastalar arasında anlamlı fark yoktu (p=0.3).

Çıkarımlar: Total ayak bileği artroplastisinden sonra yara iyileşme komplikasyonu riskinin öngörülmesinde transkütanöz oksijen ölçümünün yeri olmadığı sonucuna varıldı. Cerrahi öncesinde hastanın nabızları yeterliyse, ameliyat sonrası yara iyileşmesi sorunlarının sorumlusu, bölgeye kan desteğinden ziyade ciltte uygulanan aşırı yüzeyel traksiyon sonucu oluşan travmadır.

Anahtar sözcükler: Ayak bileği eklemi/cerrahi; artroplasti, replasman; kan gazı monitörizasyonu, transkütan; oksijen; ameliyat sonrası komplikasyon; yara iyileşmesi.

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Submitted / *Başvuru tarihi:* 02.01.2009 **Accepted / *Kabul tarihi:*** 05.06.2009

Total ankle arthroplasty (TAA) is associated with wound healing difficulties,[1-8] and numerous factors may be responsible for this complication. Difficulty with wound healing occurred in as high as 40% of patients with ankle replacements in the 1970s and 1980s.[9] Newer studies also cite a high rate of wound healing problems, including five of 51 ankles in the study by Anderson et al.[10] and as "the most common complication" in the study by Wood and Deakin.[11] However, there is a decrease in wound complications with surgeon experience, suggesting that more than the intrinsic blood supply is responsible for these wound problems. In a study evaluating 50 consecutive patients undergoing Agility ankle replacements (DePuy Orthopaedics, Warsaw, Indiana, USA), the number of minor wound complications decreased from six in the first 25 ankle replacements to two in the next 25.[7] In the Scandinavian Total Ankle Replacement (STAR; W. Link GmbH & Co., Hamburg, Germany) U.S. study, the first five ankle replacements were compared with a later five at ten different sites.[12] For each site, the first five ankles had a 3.2 times greater chance of having a perioperative wound problem (95% confidence interval, 1.5-6.8; p=0.002) than the second five. The time to wound healing was one week longer in the early group than in the later group (4.5 *vs*. 3.5 weeks, p=0.46). The rate of wound healing problems was 35% in the first five patients, compared to 15% in the later five.[12] Excessive skin retraction, poor soft tissue envelopes, previous surgical scars, skin tension due to joint distraction, tourniquet ischemia, prominent tendon structures, and minimal subcutaneous tissue may all contribute to incision healing difficulties. Wound problems pose a serious risk for deep infection that can result in the need for revision, fusion, or even amputation. In the STAR ankle study by the U.S. Food and Drug Administration, 158 ankles were inserted.[13] In this group, 25 (15.8%) had soft tissue edema, seven (4.4%) developed an infection, and overall 32 (20.3%) had some wound problems. Thus, any action that can be taken to prevent wound complications may be beneficial to patients undergoing total ankle replacement.

The purpose of our study was to determine whether skin oxygenation could be used to predict preoperatively patients at risk for wound complications.

Transcutaneous oxygen tensiometry has been used extensively to determine viable amputation levels, but it has not been investigated in TAA. Inspired by the study of Johnson et al.[14] on the use of skin oxygenation in total knee arthroplasty, we reviewed our population of patients who had total ankle replacement and measured transcutaneous oxygen tensions ($TCPO_2$) to determine whether patients who had experienced wound healing problems also had deficient skin oxygenation.

Patients and methods

We identified patients who had TAA in our practice during a three-year period. On postoperative visits, patients were queried about wound healing problems, and their charts were reviewed. After informed consent was obtained, patients underwent transcutaneous oxygen testing (Novametrix model 840, Novametrix Medical Systems, Connecticut, USA) at five sites: chest (control), medial and lateral aspects of the ankle surgical scar at the midpoint of the wound, and the equivalent areas on the nonoperated ankle. This protocol was approved by the Mayo Foundation Institutional Review Board. The data were reviewed to determine any associations between low $TCPO_2$ and wound healing.

Results

Twenty-five patients (11 males, 14 females) were available for this study. Seven patients (28%) had wound healing difficulties after TAA, and five patients (20%) had early wound erythema. Of the seven patients with wound healing problems, five (20%) had a prolonged course of wound healing, and two (8%) had wound dehiscence. In five patients with prolonged healing, healing occurred at 5, 8, 10, and 16 (2 patients) weeks, respectively. Of the two patients with wound dehiscence, one was treated with split-thickness skin grafting, and in the other the wound was allowed to heal by secondary intention. All the patients with initial wound erythema had resolution by four weeks after their procedure.

Three patients had $TCPO_2$ less than 40 mmHg on the operative side, of whom one had healing difficulty whereas two did not. All low readings were on the medial side of the incision. When the threshold was extended to 50 mmHg, seven patients (28%) had low readings on the operative side: two with wound healing problems, four (16%) without wound healing problems, and one who had wound erythema and slightly delayed healing (4 weeks).

Figure 1a shows no trend with regard to medial skin oxygenation in patients with no problems with wound healing or in those with wound healing problems. Statistical evaluation with the Wilcoxon rank sum test found no significant difference (p=0.3) for absolute readings on the medial side of the incision between patients with and without wound healing problems. Evaluation of the lateral side (Fig. 1b), interestingly, showed even a higher trend to higher skin oxygenation in patients with wound healing problems (p=0.08), but this also was not significant.

A regional perfusion index was also obtained. This is the normalized ratio obtained by dividing the oxygen tension at the ankle by the oxygen tension at the chest (the chest value is the maximal skin oxygen tension for an individual). Of the four patients with major wound healing problems, two had regional perfusion indexes less than 0.53 and 0.39. One patient with wound erythema had a ratio of 0.45 on the medial side and 0.36 on the lateral side. No other patients in the study had values less than 0.60 for the operative side, and the average value among patients without problems or erythema was 0.92. The average for patients with wound healing problems was 0.77. This difference was not significant (p=0.76). No clear trends were identified for values on the nonoperative side.

Discussion

In 1987, Taylor and Palmer[15] introduced the angiosome concept. Their anatomical studies defined angiosomes as three-dimensional vascular territories supplied by source arteries and veins to each tissue layer between the skin and the bone. Later, Taylor and Pan[16] found that the skin, bones, and most muscles receive branches from two or more angiosomes, but the muscles of the anterior aspect of the leg were unique in that they were supplied by only one angiosome. Vessels follow the connective tissue framework of the leg from their origin at the source vessels to reach the skin. In the distal aspect of the leg, where there is no muscle, the vessels reach the surface by passing through the connective tissue between the tendons. Skin branches to the anterior surface of the leg from the anterior tibial artery course between the tibia and the tibialis anterior (TA) in 14.5% of cases, between the tibialis anterior and extensor digitorum longus (EDL) in 38.7%, between the tibialis anterior and extensor hallucis longus (EHL) in 22.5%, between the extensor hallucis longus and extensor digitorum longus in 6.4%, and between the extensor digitorum longus and peroneal tendons in 17.7%.[15] The exposure through the anterior ankle, supplied by only one angiosome and with disruption of the perforators to the skin between the tibialis anterior and the extensor muscles in 61.2% [TA to EDL (38.7%) + TA to EHL (22.5%) = 61.2%] of cases may be responsible for the occasional prolonged healing of this skin incision.

Oxygen tensiometry has been studied extensively as a means to determine wound healing potential in patients undergoing amputation.[17-24] A $TCPO_2$ of 40 mmHg has been identified as a threshold in the ability to heal wounds.[17] Thresholds of 30,[21] 20,[18,19,22] and 15[24] mmHg have also been proposed. Johnson et al.[14] performed investigations on the viability of wound edges for healing in a population of patients who had total knee arthroplasty. They found higher $TCPO_2$ on the medial wound side in total knee arthroplasty, corresponding with angiosomic vascular

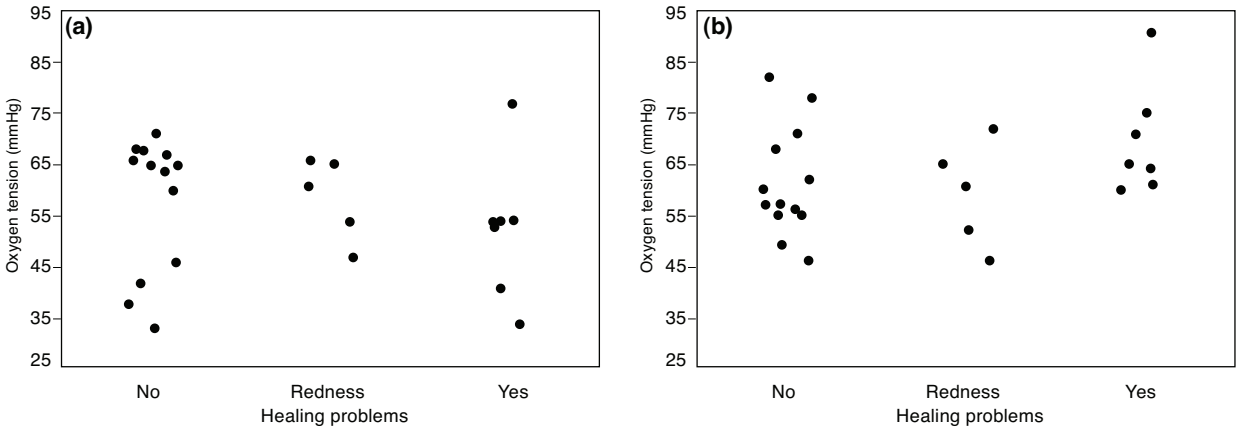

Fig. 1. Transcutaneous oxygen tension ($TCPO_2$) on the **(a)** medial side and **(b)** lateral side of incision in patients who had total ankle arthroplasty.

distribution. Postoperatively, there were substantial decreases in skin $TCPO_2$, the lateral side being more affected than the medial side. Patients with prolonged wound hypoxia experienced wound infection or healing problems. Administration of oxygen helped reverse some of these hypoxic changes.[25] We hoped to extend that work to TAA because incision healing has been identified as a serious complication associated with this procedure.

Transcutaneous oxygen tensiometry has been used to evaluate skin perfusion in relation to other procedures of the foot and ankle. Poynton and O'Rourke[26] examined blood flow in the skin surrounding the Achilles tendon. They noted that increasing ankle plantar flexion from 20° to 40° resulted in a decrease in $TCPO_2$ up to 49%. They concluded that ankle position might have an impact on wound healing after procedures involving the Achilles tendon. Although not directly applicable to TAA, that study highlighted the important role of $TCPO_2$ in wound healing as well as positional changes.

Measurement methods and conditions also can affect the reliability of $TCPO_2$ readings. Moosa et al.[27] found that simply placing the limb in a dependent position increased $TCPO_2$ readings. Therefore, in our patients, measurements were consistently obtained with the patient in the supine position to avoid an artificially high reading. This approach is especially relevant for incision healing after total ankle replacement because our patients are instructed to keep the operated limb elevated ("toes above your nose") as much as possible in the early postoperative period. This prevents swelling and serves as a mechanical aid for preventing deep vein thrombosis.[28] Moosa et al.[27] also found, as did Johnson et al.[14] and others,[18,24] that inspired oxygen administration increased $TCPO_2$. Thus, oxygen therapy may have a positive effect on wound healing. Rooke and Osmundson[29] validated that single measurement of $TCPO_2$ can be reliable. Even with somewhat variable probe placement, repeat measurements in their study varied by less than 25%. This result is especially relevant to our study because many patients undergoing total ankle replacement had to travel long distances to have their surgical procedures at our tertiary facility, and repeat visits for additional measurements would have been prohibitive.

Despite the promising hypothesis that low $TCPO_2$ could be a factor in wound healing, we were unable to demonstrate its predictive effect on wound healing. Our study is limited in that we assessed patients postoperatively. However, we believed that the postoperative readings would make changes in $TCPO_2$ even more acutely detectable. Furthermore, all the patients had clinically apparent acceptable blood supply to undergo operation. All had palpable anterior and posterior tibial pulses. Thus, these patients had already been preselected as having enough blood supply for wound healing and their $TCPO_2$ might have been suspected to lie within a narrow range of normal. Additionally, the number of patients was low because of the limited number of ankle operations that the senior surgeon (JKD) was allowed to do as part of the U.S. Food and Drug Administration STAR ankle study.

Many factors can affect wound healing, and $TCPO_2$ is only one of these factors. Multiple authors have discussed modifications in intraoperative management as a means to avoid complications,[3,5,7] including postoperative incision healing. These include minimizing the duration and force of retraction, retracting with deep retractors only, minimal handling of the skin edge, early tourniquet release, holding the ankle in 90° dorsiflexion postoperatively with a splint or cast to decrease wound tension and anterior tibialis tenting of the skin, and postoperative administration of oxygen. Although any or all of these techniques may be advocated, the authors are unaware of any specific study validating these methods. However, given the fact that wound problems go down with increasing number of total ankles done by a single surgeon, it is the authors' belief that it is technique-related. Currently, the senior author (JKD) attempts to limit skin retraction by placing a deep retractor (Gelpi or similar device) on the capsular layer immediately after opening the wound to lessen the need for superficial retractors.

Although use of $TCPO_2$ for determining amputation level has been validated in patients with vasculopathy and its use has been explored in total knee arthroplasty and other settings, we did not find that $TCPO_2$ would be able to predict healing in patients who had TAA. Other wound healing factors may well overshadow the importance of $TCPO_2$, making it difficult to detect its effect on healing of the surgical incision. Thus, if the blood supply is adequate clinically, transcutaneous oxygen tensiometry screening is not believed to be sufficient to warrant its use as a method of predicting wound healing

problems in patients undergoing ankle replacement surgery through the standard anterior incision. Instead, judicious use of retractors placed deep to the level of skin is recommended.

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