The Usefulness of Transcutaneous Oximetry in Assessing the Success of Percutaneous Transluminal Angioplasty

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Objective: to identify whether monitoring transcutaneous oxygen pressure (TcpO₂) can provide an objective method of assessing the results of PTA.

Materials and Methods: fifty-seven patients (39 Fontaine stage II, 18 stage III or IV) had ABI, TcpO₂ at rest (stages III and IV) or during exercise (stage II) and total work capacity of the leg (stage II) measured before, 24–48 h, 2 and 6 weeks after PTA.

Results: a significant increase of ABI in both groups of patients was detected immediately after successful PTA. TcpO₂ measured on the foot at rest increased in stages III and IV patients immediately after PTA (from 14 (IQR)18 to 25 (IQR)32 mmHg, \(p\) < 0.05) and again after 6 weeks in comparison to follow up two (from 25 (IQR)32 to 35 (IQR)21 mmHg, \(p\) < 0.05). In patients in stage II TcpO₂ decreased in a typical fashion during exercise. Total oxygen drop was most evident before treatment (352 (IQR)458 s mmHg) and decreased significantly immediately after PTA (148 (IQR)175 s mmHg, \(p\) < 0.001).

Conclusions: TcpO₂ measurement is an useful method for investigating the success of PTA. While the macrocirculation improves immediately after successful recanalisation, complete normalisation of the microcirculation may take some weeks, especially stages III and IV disease.

Key Words: Arterial occlusive disease; Ankle/brachial pressure index; Transcutaneous oxygen tension; Oxygen deficiency.

Introduction

Many different methods are used to assess peripheral arterial occlusive disease (PAOD) and the success of recanalisation procedures. Arteriography is usually used to determine the immediate technical success of recanalisation, although it reveals only the morphology of the diseased vessel segment. As an objective measure of success and improvement after recanalisation procedures, noninvasive haemodynamic tests, such as determination of ankle/brachial systolic pressure index (ABI), are commonly used. However, this latter test is also limited, in that ABI gives insight only into the status of large vessels and does not quantitate local tissue perfusion. Furthermore, determination of ABI does not identify arterial occlusions distal to the ankle which may be an important factor in determining the severity of ischaemia of the foot. The ABI cannot be measured accurately in cases with mediocalcinosi which occurs particularly in diabetic patients. Therefore, in some cases, ABI measurements for the identification, quantification and localisation of stenotic or occlusive arterial disease are not sufficient and blood flow impairment cannot be determined by this method alone.

A number of newer techniques have been developed to improve the understanding of the skin microcirculation, which is the pathological target tissue in most patients with advanced PAOD. Transcutaneous oxygen tension (TcpO₂) is an indicator of actual local tissue oxygenation and can provide an insight into the degree of limb ischaemia, and especially into skin oxygen supply. It is also a non-invasive diagnostic tool by which the peripheral circulation can be assessed objectively during exercise. TcpO₂ measurement at rest enables patients with heavy circulation disturbances to be identified, and its measurement during exercise enables patients with claudication to be distinguished from normal subjects. The method appears to be suitable for monitoring changes in oxygen delivery following recanalisation procedures on peripheral arteries, and changes of
However, the validity of TcPO2 measurement in evaluating the effect of recanalisation procedures on peripheral arteries, and its comparison to standard methods, like determination of ABI, for determining therapeutic success, have not been studied definitively.

The aim of our study was to establish the usefulness of TcPO2 measurement for estimating the therapeutic success of percutaneous transluminal angioplasty (PTA) in PAOD patients, to compare its accuracy to ABI measurement for determining the state of macro-circulation, and to follow the restoration of microcirculation after successful recanalisation using the TcPO2 measurement.

**Patients and Methods**

From February through July 2000 we treated 57 patients: 39 claudicants (Fontaine stage II) and 18 had critical limb ischaemia (stage III or IV). The inclusion criteria were: PTA of stenotic or occlusive lesions of lower limbs arteries and accessibility of circulatory disturbances for accurate estimation of their severity using non-invasive and invasive diagnostic procedures. We excluded patients in need of immediate amputation or in whom Doppler pressures could not be determined due to mediasclerosis. Therefore diabetic patients in whom ABI exceeded 0.9, in spite of clinical characteristics of PAOD and angiographically confirmed lesions on peripheral arteries, were excluded.

The mean age of the 41 male and 16 female patients was 65 years (46–89 years). In all patients we registered one or more risk factors of atherosclerosis: diabetes was present in 21 (37%), hypertension in 18 (32%), 26 (46%) were smokers and 16 (28%) had hyperlipidaemia registered.

PTA was performed with a balloon catheter in iliac, femoral or popliteal arteries. In four cases stents were implanted. Forty four stenoses and 13 short segment occlusions (<10 cm) were dilatated. In 21 (54%) Fontaine stage II patients recanalisation was successful, i.e., there were no residual stenoses at the site of balloon dilatation and ABI increased by at least 0.15. In seven (33%) patients the outflow distal to the treated region was poor, i.e., one patent run-off artery. PTA was partially successful in 9 (23%) patients in stage II, i.e. PTA was technically successful but without improvement of ABI. Six (67%) had poor outflow. Finally, PTA was unsuccessful in 9 patients in stage II and outflow was poor in 6 (67%).
therapeutic success of PTA and restoration of microcirculation (Fig. 2).

Results are expressed as median (IQR). The significance of differences between values before and after PTA were evaluated with Wilcoxon matched pairs test, the significance of differences between groups were evaluated with Mann–Whitney U-test. The results were analysed by a computer program Statistica (Stat Soft Inc. 1995, U.S.A.).

The study was approved by the Slovenian ethical committee and all subjects gave informed consent to participate.

Results

Figure 3 shows the changes after PTA in ABI in the successfully treated patients in stages II and stages III/IV.

TcpO2 on the foot increased in patients in stages III/IV immediately after PTA and again after six weeks in comparison to follow-up two. TcpO2 measured 10 cm below the knee increased in these patients only immediately after the procedure (Fig. 4).

In claudicants the work load capacity of the diseased leg improved shortly after PTA from 144 (IQR: 50) to 245 (IQR: 201) ($p < 0.001$) and again after two weeks to 356 (IQR: 268) ($p < 0.05$). In successfully recanalised patients in stage II the procedure had no influence on TcpO2 at rest. However, the total oxygen drop (oxygen deficiency – Fig. 2) decreased significantly immediately after successful PTA. The improvement of total oxygen drop was more pronounced in patients with good outflow distal to the treated region compared to patients with poor outflow (Table 1). The total oxygen deficiency also decreased significantly after PTA in patients with partial success of PTA, whereas oxygen deficiency apparently increased in unsuccessful PTA cases (Table 1).

After the end of exercise the time of restoration of TcpO2 to the starting value ($T_2$ on Fig. 2) decreased...
immediately from 240 (IQR: 206) to 180 (IQR: 172) s ($p < 0.01$) and decreased even more when measured two weeks after the successful procedures: 120 (IQR: 127) s ($p < 0.01$). The time period from the start of exercise to the start of oxygen decrease ($T_3$ on Fig. 2) increased immediately after successful PTA from 20 (IQR: 42) to 60 (IQR: 52) s ($p < 0.001$). The type of dilated lesion (stenoses or occlusion of artery) had no influence on changes of TcpO$_2$.

### Discussion

The measurement of TcpO$_2$ gives direct insight into local tissue perfusion and oxygenation which is the most important indicator of tissue ischaemia. Several studies have shown that TcpO$_2$ at rest is a reliable indicator of the degree of severe limb ischaemia. However, several intrinsic (individual differences in vascularity, thickness of the skin, oedema, inflammation) and extrinsic (postural changes, temperature of the electrode) factors must be taken into consideration when interpreting the results. TcpO$_2$ measurements at rest have not proved useful in quantifying mild ischaemia, because of overlapping values between controls and claudicants. However, measurement of TcpO$_2$ during exercise clearly distinguishes those two groups, because there is a steal of blood flow from the skin to the exercising muscles in PAOD patients.

ABI improved immediately after successful recanalisation in all stages of PAOD. This improvement was neither related to the type or extent of disease nor to the presence of diabetes.

However, some patients in stage II in our study showed no significant increase in ABI (neither immediately nor 6 weeks after the procedure), although PTA was considered angiographically and clinically to have been successful. These patients also showed an increase in oxygenation and in performed work capacity of the diseased leg. It could mean that improvement of microcirculation was more important than flow changes of the macrocirculation. These data suggest that determination of ABI is not always an adequate method for assessing the results of arterial recanalisation procedures.

In our patients with severe ischaemia a significant increase of TcpO$_2$ at rest occurred immediately after successful PTA, especially distally on the foot. This was followed by additional improvement six weeks after recanalisation, presumably because of a more gradual improvement in the microcirculation. Similar results have been shown for patients with critical leg ischaemia who underwent arterial surgery or PTA. Some authors suggest this is caused by reperfusion injury, but we did not observe this injury.

In our claudicants there was a significant, exercise induced drop in TcpO$_2$ on the foot. The most diagnostic and useful parameters are the total oxygen drop (total oxygen deficiency), and the partial oxygen drop that indicates the oxygen deficiency after the end of exercise. Analysis of the pattern of TcpO$_2$ trace changes in a claudicant’s leg during exercise revealed that the decrease in oxygen tension started shortly after the beginning of exercise, and that it returned with a time delay to the normal value after the end of exercise. This finding suggests that, although the total limb blood flow returns to its resting value quite quickly, the flow distribution and oxygen extraction remain abnormal for a much longer period.

We observed normalisation or improvement of the TcpO$_2$ profile after successful recanalisation – total and partial oxygen drop decreased, the time of restoration of TcpO$_2$ to the starting value shortened and the time period from the start of exercise to the start of oxygen drop lengthened. This is most probably due to an improvement of blood inflow with a consequent sufficient inflow of blood to the exercising muscle, preventing a steal of blood from skin to muscles. The improvement was greater in patients with better
outflow distal to the treated region. This is in agreement with the study in which patients were followed after vascular surgery.\textsuperscript{4,15,16} The presence of the diabetes had no influence on immediate therapeutic success.

In a group of patients with partial therapeutic success – technical success (treated arterial segment recanalised) with clinical improvement but without ABI increase – there was a significant drop in the total oxygen deficiency after PTA. This result shows that TcpO\textsubscript{2} measurements during exercise have diagnostic value in patients with intermittent claudication and might be useful where ABI is nondiagnostic.

Thus, in claudicant patients, changes of TcpO\textsubscript{2} during exercise (the total oxygen drop, the partial oxygen drop, the time of restoration of TcpO\textsubscript{2} after exercise and the time period from the start of exercise to start of oxygen decrease) were reliable and reproducible indicators of success of PTA. These changes in oxygen profile were closely related to changes of ABI.

In patients with unsuccessful PTA, an increase of total oxygen drop was observed immediately after PTA. The reason could be additional damage to major arteries or collaterals during the procedure.

References

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