TRANSCUTANEOUS OXYGEN MEASUREMENT IN PERIPHERAL OCCLUSIVE DISEASE

AN INDICATOR OF WOUND HEALING IN LEG AMPUTATION

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In 42 amputations (28 below-knee and 14 above-knee), healing of the stump was found to correlate with the pre-operative transcutaneous oxygen pressure ($tcPo_2$) measured at the planned site of incision. Of 31 patients with a $tcPo_2$ of 30 mmHg or more, 27 healed primarily, three had delayed healing and one failed to heal; of seven patients with values between 20 and 30 mmHg three healed primarily and four had delayed healing; and all four patients with a value below 20 mmHg had stumps which failed to heal and needed re-amputation. It is concluded that a $tcPo_2$ of 20 mmHg or more at the intended site of amputation indicates that the wound will heal.

During the past few years several investigators have evaluated the use of pre-operative transcutaneous oxygen pressure ($tcPo_2$) measurements at the site of incision to predict stump healing after amputation for peripheral vascular disease. These pressure values, however, have been found to vary widely from as low as zero (Burgess *et al.* 1982) to 50 mmHg (White *et al.* 1982). Other studies have shown that pressures of 20 mmHg (Franzeck *et al.* 1982), 35 mmHg (Ratliff *et al.* 1984) and 40 mmHg (Dowd, Linge and Bentley 1983) or more were necessary for the skin of the stump to heal. If the pressure considered necessary for stump healing is set too high, many knees will be sacrificed unnecessarily, and no improvement in prosthetic design can substitute for the loss of a knee. The purpose of the present study was to measure the transcutaneous oxygen pressure at the site of incision before amputation in order to identify the value required for stump healing. For ethical reasons the site of operation was guided by measuring the local skin perfusion pressure (Stöckel *et al.* 1982; Holstein 1982).

PATIENTS AND METHODS

From March 1984 to January 1985 42 amputations of the lower limb were performed on 29 men and 13 women with gangrene and/or severe ischaemic pain. There were 28 below-knee and 14 above-knee amputations. Diabetes

mellitus, which was present in 19 patients, was of more than 10 years' duration in seven, and between 2 and 10 years in 12 patients; six of these 19 patients were insulin-dependent, while the rest were tablet and/or diet-controlled. Selection of the amputation level was guided by pre-operative determination of the local skin perfusion pressure (Stöckel *et al.* 1982).

Transcutaneous oxygen measurement. All 42 amputations were studied prospectively and the transcutaneous oxygen pressures were measured before amputation at the level of the planned incision; each patient was measured in the supine position. The principle and technique of these pressure measurements have been described by Lübbers (1979); we used a commercially available Clark-type oxygen sensor (E 5250) and a TCM-1 oxygen monitor (Radiometer, DK2610 Rodovre). The oxygen sensor was applied to the skin surface and held in place by an adhesive ring and the controlled heating element around the sensor adjusted to 45°C. After checking the zero reading a single-point calibration was made in atmospheric air and corrected for the ambient barometric pressure. All measurements were carried out at a room temperature of 23°C (± 2 °C). Stable readings were always achieved after 20 minutes, at which time the measurements were recorded from the anterolateral side of the calf 10 cm distal to the knee joint in patients selected for below-knee amputation and at the anterolateral side of the thigh 10 cm proximal to the upper margin of the patella in those for above-knee amputation. The value obtained was unknown to the surgeon.

Operation. The below-knee amputations were performed using a long posterior myocutaneous flap in 13 cases, and using equal sagittal flaps in 15 cases. In the thigh, equal anterior and posterior myocutaneous flaps were used in all cases. Postoperatively the wounds were loosely

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covered with a bandage; the sutures were removed an average of 21 days after operation (range 8 to 33 days). Each amputation was then reviewed: primary healing was defined as complete healing of the wound at the end of the sixth postoperative week; secondary healing, possibly including minor operative revision, was said to occur if healing was delayed until after the seventh week. Cases needing re-amputation at a higher level were defined as failures.

Statistical analysis of results included Fisher's test of exact probability and the Mann-Whitney U-test for unpaired data.

RESULTS

Transcutaneous oxygen measurement. Figure 1 shows the correlation between the pre-operative $tcPo_2$ and healing in the 42 amputations. Thirty-one patients (74%) had a pre-operative measurement of 30 mmHg or more; of these, 27 had primary healing while three had secondary healing. One wound from a below-knee amputation failed to heal because of infection: this patient had had a pre-operative $tcPo_2$ of 58 mmHg, which is approximately normal, and an above-knee re-amputation was performed six days after the initial operation. Seven patients had pre-operative values between 20 mmHg and 30 mmHg; of these, three healed primarily and four secondarily. The remaining four patients had pre-operative values below 20 mmHg and all four wounds failed to

below-knee in the non-diabetic group, the difference was non-significant ($P > 0.2$). The overall healing rate was 88%. Four patients died between 6 and 12 weeks after amputation: the wounds in two were completely healed and the sutures had been removed, while the wounds in the others necrosed and re-amputation at a higher level was needed.

DISCUSSION

The results of the present study demonstrate that there is a strong correlation between the transcutaneous oxygen pressure measured at the site of the planned incision and the healing potential of an amputation. A $tcPo_2$ value below 20 mmHg was always associated with necrosis of the stump, but when this measurement exceeded 30 mmHg uncomplicated healing occurred. At borderline values from 20 mmHg to 29 mmHg, 57% of our patients had delayed healing, indicating perfusion rates still compatible with healing.

Like previous observers (Roman and Burgess 1971; Termansen 1977; Holstein 1982; Stöckel *et al.* 1982) we also found a much higher proportion of below-knee amputations in the diabetic group than in the non-diabetic group although the difference was not significant; this probably reflects a higher propensity toward occlusion of the distal tibial and peroneal vessels in diabetics (LoGerfo and Coffman 1984).

As oxygen availability is a limiting factor in wound

Table I. Details of 42 patients, type of operation, pre-operative range and mean $tcPo_2$ value

Amputations	Diabetics	$tcPo_2$ values			Mean	Deaths
		< 20 mmHg	20 30 mmHg	> 30 mmHg		
28 below-knee	15	2	3	23	41.6 $\pm$ 3.7 (2 SEM)	1
14 above-knee	4	2	4	8	31.1 $\pm$ 7.1 (2 SEM)	3

heal because of stump necrosis. The difference in the number of failures in the group with values below 20 mmHg compared to the group with a value above 20 mmHg was statistically significant ($P < 0.002$). The difference in secondary healing in patients with values between 20 mmHg and 29 mmHg compared to those with values of 30 mmHg or more was also statistically significant ($P < 0.05$). There was no difference in the failure rate when the diabetic group was compared to the non-diabetic group ($P > 0.02$). The mean pre-operative transcutaneous oxygen value of the above-knee amputation group showed a significant difference from that of the below-knee group ($P < 0.05$; Table I). The mean value at the amputation level in the diabetic group was 39.2 ± 6.6 mmHg (2 SEM) compared with a mean value of 35.8 ± 6.4 mmHg (2 SEM) in the non-diabetic group but this difference was not significant ($P > 0.05$).

There were twice as many below-knee as above-knee procedures. Although 79% were amputated below-knee in the diabetic group and only 34% were amputated

healing, the question arises whether the determination of transcutaneous oxygen pressure can be used to select the optimum amputation level, that is, the most distal level compatible with healing. To use this method for selecting an amputation site the clinician must know the value required for healing. Ratliff *et al.* (1984) found that pressures above 35 mmHg were associated with successful healing, whereas failures had values below 35 mmHg; nevertheless 10 out of 14 patients with a $tcPo_2$ level between 20 mmHg and 35 mmHg achieved healing after below-knee amputations. White *et al.* (1982) found that values greater than 50 mmHg augured well for wound healing, whereas values of 40 mmHg or less were associated with wound breakdown, and Dowd *et al.* (1983) claimed that a value of 40 mmHg or more was necessary. Only the investigations by Franzeck *et al.* (1982) and Burgess *et al.* (1982) are in agreement with our finding that a value below 20 mmHg at the amputation site was associated with stump necrosis.

The benefits of using an objective test pre-opera-

tively in order to predict the best level of amputation would result not only in a greater healing rate but, of equal importance, in more below-knee amputations being performed than if clinical judgement alone were used (Christensen 1976). The $tcPo_2$ in patients with severe ischaemia increases at more proximal levels: this may explain why the critical value has been found to be higher in groups of patients with a relatively high proportion of above-knee amputations. If the value thought

(Holstein, Sager and Lassen 1979; Holstein, Dovey and Lassen 1979; Holstein 1982) or by the photo-electric technique (Stöckel *et al.* 1982) have proved to be the most reliable method of predicting the success or failure of stump healing. Holstein (1982) showed that when local perfusion pressure was below 20 mmHg the stumps failed to heal but when above this level healing was successful. At borderline perfusion pressures (between 20 and 30 mmHg) the failure rate was 50%. As 20% of can-

Fig. 1

Healing and wound complications in 28 below-knee (BK) and 14 above-knee (AK) amputations in relation to the pre-operative local transcutaneous oxygen pressure.

to be required for stump healing is too high, then too many knees will be sacrificed. If in our present study we had used 40 mmHg as the critical value, then 11 below-knee amputations which healed would have been above-knee amputations and only two below-knee amputations would have been spared from failure (Fig. 1). Knotte and Bohmert (1977) also used $tcPo_2$ measurements to evaluate the viability of ischaemic skin areas; they found that values above 20 mmHg represented adequate perfusion, while with less than 10 mmHg healing was compromised. Recently the investigation by Wyss *et al.* (1984) showed that values less than or equal to 20 mmHg were associated with failure of stump healing in most non-diabetic patients. All the evidence suggests that the previous values of 35 mmHg, 40 mmHg and 50 mmHg found to be required for healing of the stump are too high.

Comparison of values. Measurements of local skin perfusion pressure, either by the isotope wash-out method

didates for amputation have values which fall into this pressure zone (Holstein 1982), better parameters of low perfusion pressures are needed. The study by Wyss *et al.* (1981) provided considerable insight into the relationship between transcutaneous oxygen pressure and local perfusion pressure: in their investigation $tcPo_2$ value reached zero when the perfusion pressure decreased below 20 mmHg. Furthermore, the $tcPo_2$ was found to be very sensitive at perfusion pressures between 20 and 40 mmHg, that is, small increments in perfusion pressure resulted in large increments of transcutaneous oxygen pressure. Thus, since it is between 20 and 30 mmHg in perfusion pressure that healing of the stump is least predictable (Holstein 1982; Stöckel *et al.* 1982), $tcPo_2$ measurements may well be more accurate in predicting the outcome of an amputation and thereby facilitate the more precise selection of an amputation site.

Because transcutaneous oxygen pressure reflects

and integrates other important factors in oxygen delivery—such as haemoglobin concentration and haemoglobin oxygen saturation (Lübbers 1979)—and takes into account the oxygen diffusion impairment seen in diabetics due to a thickened capillary base membrane (LoGerfo and Coffman 1984), it may be more accurate than measurement of local skin perfusion pressure. Finally, the $tcPo_2$ technique is simple, non-invasive and can be repeated along the limb, unlike the measurement of local skin perfusion pressure which requires special expertise, access to a nuclear medicine or clinical physiology department and sometimes causes discomfort. However, in order to use the $tcPo_2$ method for selecting an amputation level, results of its use must be shown to be superior, or at least as good as those obtained by measurement of local skin perfusion pressure (Holstein 1982; Stöckel *et al.* 1982). A prospective trial comparing the measurement of $tcPo_2$ with that of skin perfusion in a consecutive series of patients requiring amputation is needed to obtain this information.

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