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WOUND HEALING IN BELOW-KNEE AMPUTATIONS IN RELATION TO SKIN PERFUSION PRESSURE

P. HOLSTEIN, P. SAGER & N. A. LASSEN

Department of Clinical Physiology and Surgical Department M, Bispebjerg Hospital, Copenhagen, Denmark.

In 60 below-knee amputations the healing of the stumps was correlated with the local skin perfusion pressure (SPP) measured preoperatively as the external pressure required to stop isotope washout using $^{131}I^-$ or $^{125}I^-$-antipyrine mixed with histamine. Of the eight cases with an SPP below 20 mmHg, no less than six (75 per cent) failed to heal and required reamputation at the above-knee level. Of the 12 cases with an SPP between 20 and 30 mmHg four cases (33 per cent) failed to heal but of the 40 cases with an SPP above 30 mmHg, there were only four cases (10 per cent) which did not heal. The difference in failure rate is highly significant ($P < 0.01$). Four out of 30 diabetic patients required reamputation as against 10 out of 30 non-diabetics ($0.05 < P < 0.10$). The average SPP was higher in the diabetic group: 57 mmHg (range 18–93 mmHg) compared with 34 mmHg (range 8–68 mmHg) in the non-diabetic group ($P < 0.001$). The postoperative SPP measured on the stumps was on average 8 mmHg higher than the preoperative SPP ($P < 0.001$). The increase took place mainly in stumps with an SPP above 20 mmHg explaining why the preoperative SPP values related so closely to the postoperative clinical course. We conclude that a low SPP can be used to predict ischaemic wound complications, leading to reamputation at a higher level.

Key words: amputation; diabetes; $^{131}I^-$-antipyrine; ischaemia; occlusive arterial disease; skin blood pressure; skin perfusion pressure

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To save the knee is one of the crucial issues in major leg amputation for peripheral occlusive arterial disease. In recent years a number of reports have demonstrated that the local blood pressure as well as the local blood flow correlates with healing of the wound of a below-knee (BK) amputation. (Holstein 1973, Moore 1973, Lassen & Holstein 1974, Barnes et al. 1976, Raines et al. 1976, Kostuik et al. 1976, Hammersgaard & Baadsgaard 1977, Lund & Sager 1977). The present paper presents the pre- and postoperative measurements of the local skin perfusion pressure (SPP) by the isotope washout technique in patients undergoing BK amputations.

PATIENTS AND METHODS

Patients. The study is prospective and comprises all BK amputations for peripheral arterial disease in a 2-year period (1.1.1972–1.1.1974), viz. 67 BK amputations in 65 patients. The distribution according to the age of the patients and the presence of diabetes mellitus is shown in Table 1. Diabetes mellitus, which was present in 34 patients, was of more than 10 years duration in 18 patients and of less than 5 years duration in 7 patients. In 16 cases the patients were being treated with insulin. In most cases the blood sugar was satisfactorily controlled during the course of the hospitalization for amputation. Nine patients had previously had a contralateral major amputation.

Table 1. Age distribution in 67 cases of below-knee amputation

	41–50	51–60	61–70	71–80	81–90	Total
Cases without diabetes mellitus	0	7	8	13	5	33
Cases with diabetes mellitus	3	3	13	11	4	34

Male/female ratio: 41/26 = 1.58. Arithmetic mean age: Without diabetes mellitus (DM) = 70.0 years, with DM = 68.2 years.

Measurements of the SPP

The technique, consisting of measurement of the external pressure required to stop the washout of an intradermal depot of isotopes, has previously been described (Holstein & Lassen 1973, Holstein et al. 1977) and is only briefly summarized.

Approximately 0.1 ml of a sterile solution containing 10–20 μCi $^{131}I^{-}$-antipyrine (or 30–40 μCi $^{125}I^{-}$-antipyrine) and 50 mg histamine diphosphate was injected intradermally and a washout curve was recorded. The external pressure was applied by a blood pressure cuff and measured by a square air-filled plastic cushion (inflatable part, 11 by 11cm) interposed between the labelled skin and the cuff and connected to an ordinary mercury manometer. When the washout rate, which accelerates during the first 2 to 15 minutes, had been constant for about 3 to 5 minutes, the external pressure was raised in steps resulting in a stepwise decrease in washout rate until cessation. At each of the final steps the tracing was observed for about 5 minutes and after washout cessation the external pressure was released to zero in order to secure that the washout was re-established. The washout cessation pressure, viz. the SPP, was determined within an interval of 5 mmHg and was defined as the highest external pressure which allowed a minimal washout to be discerned, plus 3 mmHg.

The site of measurement was approximately 10 cm distal to the knee joint on the anterolateral side of the calf just superficial to the anterior tibial muscle. The SPP was also measured below the knee on the contralateral leg. In patients in whom a contralateral above-knee (AK) amputation had previously been performed the control point was chosen to be 15 cm proximal to the end of the stump on the anterolateral side.

About 4 to 8 weeks after surgery the SPP was again measured at the same sites. The patients were examined in the supine position with horizontal legs. Repeated i.v. doses of analgetics (demerole, 35 mg) sufficient to prevent involuntary movements from rest pains were given and, in addition, the legs were supported by sandbags. Conventional auscultatory arm blood pressure was repeatedly measured using a 12 by 26 cm cuff placed around the left arm. Before the examinations the thyroid gland was blocked with 0.5 g potassium iodide given perorally in solution.

Surgery. Forty-nine of the BK amputations were performed using the conventional technique with an anterior and a posterior flap. In 13 cases one long posterior flap was used (Bickel 1943, Romano & Burgess 1971) and in five cases the sagittal technique (Persson & Sundén 1971) was applied. All the SPP measurements were known by the surgeons. The amputation wounds were loosely dressed (Tube gauze®) and suction drainage was employed in most cases. Sutures were removed after 2 to 3 weeks. Immediate fitting systems were not used, but the patients were mobilized as soon as possible on crutches possibly with a splint. Infections were treated by antibiotics after culture.

Primary healing was defined as complete healing of the wound at the end of the fourth postoperative week. Healing by second intention was defined as healing at a later time, possibly after surgical revision, provided that the BK level was maintained. Revision amputation to an above the knee level was considered as a failure.

Statistics. Statistical analysis included rank sum tests, Fisher's exact test and Wilcoxon's test for paired comparisons.

RESULTS

Mortality. Four patients (6.1 per cent) died within the first month after the amputation, but a total of six patients undergoing seven BK amputations died before the final result with regard to healing of the amputation wound could be established. In four of these cases there was ulceration of the stump. In three cases the stump was intact, but the sutures were not yet removed. These seven BK amputations are excluded from the following analysis of wound healing in relation to SPP.

The preoperative SPP. Figure 1 and Table 2 show the correlation between the preoperative SPP and the healing of the wounds. Of the total number of cases with an SPP below 20 mmHg only two out of eight cases healed (25 per cent). The six failures were caused by skin necrosis. With an SPP between 20 and 30 mmHg eight out of twelve cases (67 per cent) healed. The failures were caused by skin necrosis in one case and by skin necrosis in combination with infection in three cases. Above 30 mmHg, 36 out of 40 cases healed (90 per cent). The four failures were due to infection in two cases, infection and necrosis in one case and haematoma and necrosis in one case. The differences in failures in these three groups according to the level of SPP are highly significant ($P < 0.01$).

In the 43 cases amputated using the conventional technique (Table 2) the differences in healing rate for the various SPP intervals parallel the results of the whole series and are highly significant ($P < 0.01$). The results of the amputations applying a long posterior flap and those with the sagittal technique were too small for analysis.

In the 30 non-diabetic cases the differences in healing rates correlated significantly with the level of the SPP ($P < 0.05$, Table 2), but in the 30 diabetic cases no correlation with the SPP was found and there were only four failures in this group compared to 10 failures in the non-diabetic group ($0.05 < P < 0.10$).

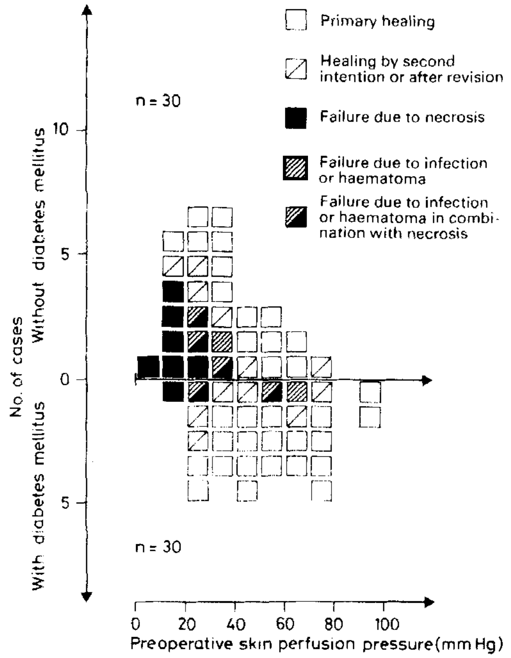

Figure 1. Wound healing in 60 BK amputations in relation to the local skin perfusion pressure. measured preoperatively. (Failure = re-amputation at AK level).

These findings should be seen against the impressive difference in distribution of SPP in the two groups. The SPP averaged 33.7 mmHg (range 8–68 mmHg) in the non-diabetic group and 56.7 mmHg (18–93 mmHg) in the diabetic group ($P < 0.001$) and there were only six cases in the diabetic group with an SPP below 30 mmHg.

The level of the most distally palpable pulsations correlated significantly with wound healing and with the SPP (Table 3). All cases with palpable pulsations in the popliteal artery healed. The absence of pulsations in the femoral artery did not, however, rule out healing of a BK amputation.

The postoperative SPP. Postoperative measurements of the SPP on the amputation stumps, including control measurements on the contralateral leg, were made in 54 cases. Figure 2 and Table 4 show the preoperative SPP compared with the postoperative SPP. The SPP on the stumps was on average 8

Table 2. The preoperative skin perfusion pressure (SPP) in relation to wound healing in 60 below-knee amputations

	< 20 mmHg			21–30 mmHg			< 30 mmHg		
	Primary healing	Secondary healing	Failure	Primary healing	Secondary healing	Failure	Primary healing	Secondary healing	Failure
Without diabetes mellitus $n=30$	1 (a)	1	5 (71.4%) (b)	2 (a)	2	3 (42.9%) (b)	11 (a)	3	2 (12.5%) (b)
With diabetes mellitus $n=30$	0	0	1 (100.0%)	2	2	1 (20.0%)	18	4	2 (8.3%)
Total $n=60$	1 (c)	1	6 (75.0%) (d)	4 (c)	4	4 (33.3%) (d)	29 (c)	7	4 (10.0%) (d)
Conventional surgical technique $n=43$	1 (e)	0	5 (83.3%) (f)	2 (e)	3	2 (28.6%) (f)	24 (e)	4	2 (6.7%) (f)

P value (Rank sum test)
Distribution a): 0.0180 d): 0.0028
b): 0.0120 e): 0.0044
c): 0.0050 f): 0.0022

Table 3. Healing of BK amputations and preoperative skin perfusion pressure (SPP) in relation to the level of the most distally palpable pulsations

	Pulsations in the popliteal artery $n=7$	P value	Pulsations in the femoral artery $n=46$	P value	No pulsations in the femoral artery $n=7$
Number of failures	0	>0.1	9	<0.05	5
SPP mean (mmHg)	71.6	<0.01	43.3	<0.01	22.2
range (mmHg)	38–93		13–78		8–48

mmHg higher than the SPP at the identical site as measured preoperatively ($P<0.001$). Corrections of the SPP for changes in systemic blood pressure did not significantly influence this difference. These corrections of SPP were made in proportion to variations in systemic mean blood pressure. On the contralateral leg no significant difference was found between the preoperative and the postoperative measurements.

The figures of the postoperative SPP in relation to wound healing parallel the preoperative figures (Figure 2 and Table 5). In the diabetic cases the average SPP was again significantly higher than in the non-diabetic group: 61.5 mmHg (range 28–108 mmHg) compared with 41.9 mmHg (range 0–83 mmHg) ($P<0.01$).

Rehabilitation. The patients returned to their own homes in 41 out of 56 cases (73 per cent). Of the 66 cases where the patients could

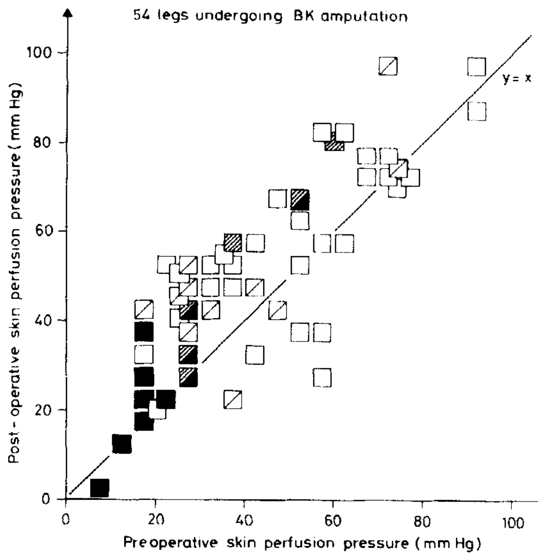

Figure 2. The preoperative skin perfusion pressure correlated with the postoperative skin perfusion pressure in 54 legs undergoing BK amputation. (The symbols are identical to those used in Figure 1).

Table 4. The preoperative skin perfusion pressure compared with the postoperative skin perfusion pressure

	Preoperative values mean mmHg	Preoperative values range mmHg	P value	Postoperative values mean mmHg	Postoperative values range mmHg
Amputated leg $n=54$	43.9	8–93	<0.001	51.7	0–108
			<0.001	52.4 x)	0–93 x)
Contralateral leg $n=54$	63.4	28–98	>0.10	62.4	28–103
			>0.10	62.6 x)	23–95 x)

x) values corrected for changes in systemic blood pressure.

Table 5. The postoperative skin perfusion pressure (SPP) in relation to wound healing in 56 below-knee amputations

	<20 mmHg			21–30 mmHg			>30 mmHg		
	Primary healing	Secondary healing	Failure	Primary healing	Secondary healing	Failure	Primary healing	Secondary healing	Failure
Without diabetes mellitus $n=27$	0	0	3(100.0%)	1	1	2(50.0%)	11	5	4(20.0%)
With diabetes mellitus $n=27$	0	0	0	1	0	2(66.7%)	17	5	2(8.3%)
Total $n=54$	0	0	3(100.0%) (a)	2	1	4(57.1%) (a)	28	10	6(13.6%) (a)
Conventional surgical technique $n=41$	0	0	2(100.0%) (b)	2	1	3(50.0%) (b)	23	6	4(12.1%) (b)

P value (Rank sum test)
Distribution a): 0.0136
b): 0.0292

Table 6. Number of weeks spent in hospital in relation to the healing of the BK amputation and to rehabilitation

No. of BK amputations	Healing of the BK amputation	Weeks in hospital preoperatively mean	range	postoperatively mean	range
34	Primary healing	2.7	(0.5–12)	15.4	(1–39)
12	Secondary healing	2.7	(0.5–7)	24.2	(7–53)
14	Revision to AK level	6.3	(0.5–20)	22.2	(4–51)
7	Death before healing	1.5	(0–3)	4.2	(0–17)
No. of BK amputations	**Rehabilitation**	**preoperatively mean**	**range**	**postoperatively mean**	**range**
26	Ambulant with BK prosthesis*)	2.4	(0.5–8)	18.8	(4–53)
7	Ambulant with AK prosthesis	5.8	(2–11)	22.8	(9–53)
15	Failed attempt at walking	3.8	(0.5–12)	23.5	(10–51)
19	No attempt at walking	3.4	(0–20)	8.0	(0–29)

*) 14 of these were the PTB type.

walk independently prior to amputation, rehabilitation as regards walking with a prosthesis was achieved in only 33 cases (50 per cent). The ability to walk was not regained in the remaining 33 cases due to death in 10 cases, disability from arthritis or blindness in 5 cases, poor mental and physical condition in 11 cases and to bilateral major amputation in 7 cases.

The period of hospitalization (Table 6) increased by about 8 weeks, on average, in cases of wound complications. Rehabilitation or attempts at rehabilitation approximately doubled the period of hospitalization.

One of the two stumps which healed in spite of a preoperative SPP of below 20 mmHg broke down later because of mechanical stress from the prosthesis. In the other case the stump was never fitted with a prosthesis because the patient died. Thus none of the eight BK amputations with a preoperative SPP below 20 mmHg were successful from a point of view of walking rehabilitation. For SPP above 20 mmHg the ability of the stump to tolerate a prosthesis did not correlate with the SPP.

Out of the 14 BK failures, i.e. reamputations at the above-knee level, the AK stump healed in 13 cases. In one case the patient died with infection of the stump.

DISCUSSION

In the past 5 years a number of reports on objective methods of determining the amputation level have been published. These studies concern a variety of methods including determination of the local blood pressure and the local blood flow (see survey in Table 7). It appears that preoperative blood pressure values of above 20 to 40 mmHg and flow values of above 0.6–2.6 ml/min/100 g tissue are indicative of a high success rate. At lower blood pressures or blood flow values the prognosis is doubtful.

In none of the larger series reported did a precise value indicating wound failure appear. Our series points to the preoperative SPP as a very sensitive means of predicting the results; when the SPP is below 20 mmHg the results are poor and when it is above 30

Table 7. Index of healing of major amputation according to assessment of local blood pressure and local blood flow

	Investigator	Method	Amputation	Poor arterial supply: Criterion	Poor arterial supply: Healed	Poor arterial supply: Failed	Good arterial supply: Criterion	Good arterial supply: Healed	Good arterial supply: Failed
Local blood pressure	Holstein 1973; Lassen & Holstein 1974	Skin perfusion pressure (isotope washout) Preliminary investigations	BK and AK	<20 mmHg:	0	5	>40 mmHg	31	3
	Barnes et al. 1976	Systolic pressure by Doppler technique	BK	Undetectable: signal	1	5	>20 mmHg	43	4
	Raines et al. 1976	Systolic pressure by Doppler technique	BK	Undetectable: signal	0	3	> ? not indicated	24	0
	Lund & Sager 1977	Skin perfusion pressure (isotope washout)	BK	<40 mmHg:	10	6	>40 mmHg	21	4
	Hammersgaard & Baadsgaard 1977	Skin perfusion pressure (isotope washout)	BK	<20 mmHg:	4	2	>30 mmHg	49	1
	Holstein, Dohn and Jansen (in preparation)	Skin perfusion pressure (isotope washout)	BK	<20 mmHg:	1	8	>30 mmHg	61	2
Local blood flow	Moore 1973	^{133}Xe washout (injection)	BK	<0.6 ml/min/ 100 g tissue	0	3	>0.6 ml/min/ 100 g tissue	29	1
	Moore 1974	^{133}Xe washout (injection)	BK	<2.6 ml/min/ 100 g tissue	0	3	>2.6 ml/min/ 100 g tissue	30	0
	Kostuik et al. 1976	^{133}Xe washout (epicutaneous)	BK TK* AK	< 1.5 ml/min/ 100 g tissue	8	2	> 1.5 Ml/min/ 100 g tissue	22	0

*TK = Through knee

mmHg the results are good. At borderline pressures from 20 to 30 mmHg a number of clinical factors, however, are liable to influence the result. The general condition of the patient, the condition of the skin at the selected level, the surgical technique and the postoperative treatment are all involved. Moreover, the SPP is not constant along the line of a planned amputation. The SPP varies with the systemic blood pressure and with the condition of the main arterial pathway. In addition the elimination of a greater part of the leg, i.e. of the low pressure tissues may cause the stump pressure to rise. In another paper (Holstein & Lassen) the postoperative increase in average stump pressure observed in the present series will be discussed. The average postoperative increase in stump pressure was only 8 mmHg and a significant effect of amputation occurred mainly in legs with an SPP above 20 mmHg (Figure 2). This also explains why the preoperative figures relate so closely to the postoperative course.

Diabetic patients are often better candidates for BK amputations than non-diabetic patients (Cranley et al. 1969, Condon & Jordan 1970, Persson & Sundén 1971, Romano & Burgess 1971, Termansen 1977). This is also the case in our series and can be explained by the finding of a significantly higher SPP in the diabetic group.

It is not surprising that the arterial supply at the BK level is on average better in the diabetic patients. Typically a BK amputation in vascular insufficiency is required because of tissue lesions localized peripherally, i.e. on the foot and the diabetic foot is especially vulnerable. This is so because the frequent major artery lesions of the thigh and pelvis are often combined with small artery lesions on the foot (Pedersen & Olsen 1962, Ferrier 1967, Faris 1975) implying peripheral ischaemia. Moreover skin lesions from minor trauma such as pressure ulcers are liable to occur due to peripheral neuropathy and finally infection always threatens the diabetic foot. Thus the diabetic patient is liable to lose his foot (leg) in spite of a good arterial supply at the BK level—and at an age a few years younger. (Table 1) than the non-diabetic patient.

There were only six diabetic cases with a preoperative SPP below 30 mmHg at the BK level in this series. More data are required to evaluate the prognosis of BK amputations at low pressures in diabetes. Such data will be published (Holstein, Dohn and Jansen) demonstrating that no substantial difference exists between the healing of amputation wounds in diabetics and non-diabetics in the various SPP intervals.

Three out of four failures in the diabetic BK amputations were caused by or complicated by infection. However, it should be emphasized that infection was a common complication too in the non-diabetic group—especially at low pressures.

The high costs of amputation with regard to occupancy of hospital beds have previously been reported (Hansson 1964). Wound complications and rehabilitation take time and since BK amputees are more frequently rehabilitated to walking than the AK amputees, the average time spent in hospital is longer for the BK amputees (Warren & Kihn 1968, Weaver & Marshall 1973, Holstein et al. 1979).

The use of objective methods to determine the amputation level will reduce the number of reamputations caused by a poor blood supply. Moreover it is important to have reliable objective figures of the blood supply in case of wound complications caused by haematoma and/or infection. If ischaemia can be excluded the stump may often be saved by early surgical revision and proper antibiotics.

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Correspondence to: P. Holstein, Surgery Department M, Bispebjerg Hospital, 2400 Copenhagen NV, Denmark.