

The distal blood pressure predicts healing of amputations on the feet

The healing of digital and transmetatarsal forefoot amputations was compared with the systolic digital and ankle blood pressure, both measured with a strain-gauge, and with the skin perfusion pressure on the forefoot measured with the isotope washout technique. In 85 out of 134 legs (63 per cent) the amputation healed. The frequency of healing correlated statistically significantly with all three measures of distal blood pressures, the closest correlation being with the systolic digital blood pressure (SDBP). As measured in 110 cases the healing rates were: SDBP < 20 mm Hg: four out of 23; SDBP 20-29 mm Hg: 13 out of 22; SDBP \geq 30 mm Hg: 51 out of 65. Ankle pressures and skin perfusion pressures were less useful. Invasive infection was present in 40 out of 102 diabetic legs and, next to ischaemia, was the major determinant of the healing results.

Key words: amputation level; ankle pressure; diabetic gangrene; digital amputation; digital pressure; skin perfusion pressure; transmetatarsal amputation.

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Healing of a minor amputation on the foot in a dysvascular patient averts major leg amputation. Moreover, minor amputations are often adjuvants in limb salvage arterial reconstructions. For these reasons, predictors of healing are seriously needed. The present investigation was undertaken to compare healing of digital and forefoot amputations with three different distal blood pressure parameters: the systolic digital blood pressure (SDBP), the systolic ankle blood pressure (SABP) and the skin perfusion pressure on the foot (SPPF).

Treatment. The amputations were made to eliminate ischaemic and necrotic tissue and/or to secure drainage of pus. Primary closure of the wound was only occasionally made, i.e. in 15 forefoot and in three digital amputations. Digital amputations were in most cases made as disarticulations in the metatarsophalangeal joints or as transmetatarsal ray resections. In the case of plantar abscess, the foot was radically incised, often cleaved. Repeated surgical procedures were often necessary. Antibiotics were given as soon as the infection was diagnosed. In most cases ampicillin 1 g 4 times per day and cloxacillin 1 g 4 times per day were given as the initial treatment.

Table 1. 134 minor amputations on the feet

	No.	Healing
Transmetatarsal forefoot amputations (primary suture)	13	6
Transmetatarsal forefoot amputations (open amputation)	11	9
Tarsal amputations	2	1
The first toe	32	23
One of the other toes	49	36
Two to four toes	27	10
		(63%)

Patients and methods

Patients. During a 7-year period (1.1. 1972 to 1.1. 1979), 142 minor amputations on the feet were made in 134 patients. Eight patients with eight amputations died before the result as regards healing was accomplished, leaving 134 minor amputations for study (Table 1). The male/female ratio was 2.0. The arithmetic mean age was 65.0 and was about equal for diabetic and non-diabetic cases. Diabetes was present in 102 cases.

The drugs were then adjusted according to repeated cultures and continued until infection had subsided and granulation tissue had covered the osseous structures. Support on the diseased foot was not allowed until this point. Footwear was corrected and external pressure on the lesions was eliminated (Holstein et al. 1976). In diabetic patients, insulin was usually required perioperatively also in the non-insulin-dependent patients.

Measurement of distal blood pressure. The SDBP and the SABP were measured with the strain-gauge technique (Gundersen 1972, Nielsen et al. 1973). The SDBP was measured on the first toe (cuff-width 2.4 cm) or on the second toe (cuff-width 1.6 cm). The SABP was measured with a 12 × 26 cm cuff and a strain-gauge on the first digit or, in the absence of the digit or at SDBP of less than 20 mm Hg, with a strain-gauge round the forefoot. The SPPF was measured with the isotope washout technique (Holstein et al. 1977, Holstein et al. 1983) using ¹³¹I-antipyrine or ^{99m}Tc-pertechnetate as the tracer. The auscultatory arm blood pressure was measured repeatedly using a 12 × 26 cm wide cuff. The measurements were made preoperatively or in the immediate postoperative period with the patient in the supine position and at a room temperature of 25° ± 2°C. The temperature of the toes was at least 25°C before the measurements were started.

Evaluation. Healing of the minor amputation was retrospectively compared with the segmental blood pressure parameters. A sequence of toe amputations in the same foot made before final healing or major amputation had taken place is considered as one case, i.e. one minor amputation. Since only 12 patients had bilateral toe amputations made at the same time, or during the period studied, each minor amputation is considered as one case. Consequently, the number in tables and figures refers to the number of cases. The nature and extent of the foot lesions often caused one or more segmental blood pressure parameters to be technically impossible to measure. In particular, the SPPF was difficult to record in feet with infection and oedema. In one foot, all three parameters were impossible to measure and in eight feet no measurements were made because of normal pedal pulses. With these limitations healing could be compared with the SDBP in 110 cases, with the SABP in 119 cases and with the SPPF in 43 cases.

Results

Mortality. Within the first month after the amputation, seven patients (5 per cent) died. Six of

these were patients with diabetes mellitus. One patient died later during the healing phase.

Healing and time in hospital. Out of 134 cases of minor amputations, 85 healed (63 per cent). There was no significant difference between the healing rate in diabetic cases (67/102 = 66 per cent) and in non-diabetic cases (18/32 = 56 per cent) (P > 0.1, chi square). The median healing time was 5 months (range 0.75–30) in diabetic cases and 3 months (range 0.75–60) in non-diabetic cases. The median time spent in hospital for those who healed was 2.0 months (range 0–7.0) and for those who had major amputation was 4 months (range 1–12.5), not including time spent in rehabilitation departments.

The systolic digital blood pressure (SDBP). According to previous investigations in this laboratory (Holstein & Lassen 1980) and to the appearance of the histogram (Figure 1), the feet were classified into three groups (Table 2): with SDBP below 20 mm Hg only four out of 23 minor amputations healed. With SDBP of 20–29 mm

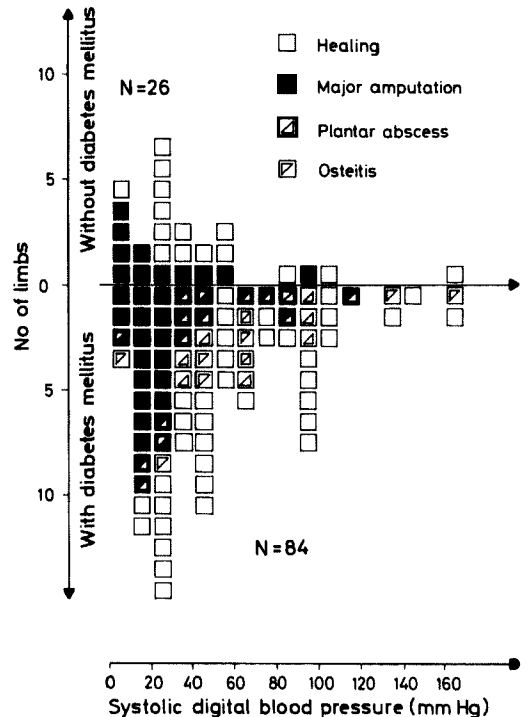


Figure 1. Healing in 110 minor amputations in relation to the systolic digital blood pressure.

Table 2. Healing rates in digital and forefoot amputations with and without diabetes mellitus (DM) in relation to the systolic digital blood pressure (SDBP) as measured in 110 cases

SDBP	<20 mm Hg	20–29 mm Hg	≥30 mm Hg
Without DM	1/7	6/7	8/12
With DM	3/16	7/15	43/53
Digital amputations	2/17	9/17	47/60
Forefoot amputations	2/6	4/5	4/5
Total	4/23(17%)	13/22	51/65(78%)
Confidence limits (95%)	5–39%		67–88%

Hg, 13 out of 22 minor amputations healed – i.e. the “gray zone”. With SDBP of 30 mm Hg or above, 51 out of 65 cases healed. The correlation between the SDBP and the healing rates is statistically highly significant ($P > 0.001$, the rank-sum test). The healing rates in non-diabetic cases and diabetic cases were about equal, and the healing rates in forefoot amputations were about equal to the healing rates in digital amputations (Table 2). As demonstrated on the histogram (Figure 1), the 10 diabetic legs which failed to heal with an SDBP of 30 mm Hg or more suffered invasive infection. One of the four non-diabetic legs which failed to heal with an SDBP of 30 mm Hg or more suffered progressive skin loss because of superficial infection (the patient refused therapy); the other three cases suffered progressive arterial occlu-

Table 3. Healing rates in digital and forefoot amputations with and without diabetes mellitus (DM) in relation to the systolic ankle pressure (SABP) as measured in 119 cases

SABP	<50 mm Hg	50–99 mm Hg	≥100 mm Hg
Without DM	0/2	8/17	7/10
With DM	0/3	18/32	40/55
Digital amputations	0/5	18/36	41/57
Transmetatarsal forefoot amputations	0/0	8/13	6/8
Total	0/5(0%)	26/49	47/65(72%)
Confidence limits (95%)	0–52%		60–83%

sion, as evidenced by decreasing segmental blood pressure and/or progressive necrosis.

In 20 out of the 110 cases where digital measurements were made, the second toe was used instead of the first toe. The healing rates for second toe measurements (as included in Figure 1 and Table 2) were: with SDBP below 20 mm Hg: one out of three; with SDBP of 20 to 29 mm Hg: two out of three; with SDBP of 30 mm Hg or above: 11 out of 14. Thus, second toe measurements seem to be useful in cases where the first toe is not available. There were 15 cases (not included in Figure 1 and Table 3), where no digital pressures could be measured; in 10 of these cases the digits had been amputated, and seven of these 10 feet healed. In the other five cases there were necroses of the digits and only one of these five feet healed.

The systolic ankle blood pressure (SABP). With SABP below 50 mm Hg none of the five feet healed (Figure 2 and Table 3); with SABP of 50–99 mm Hg, 26 out of 49 feet healed, i.e. the gray zone; with SABP of 100 mm Hg or above, 47 out of 65 feet healed ($P < 0.01$, the rank-sum test). The healing rates in diabetics versus non-diabetics and the healing rates in forefoot am-

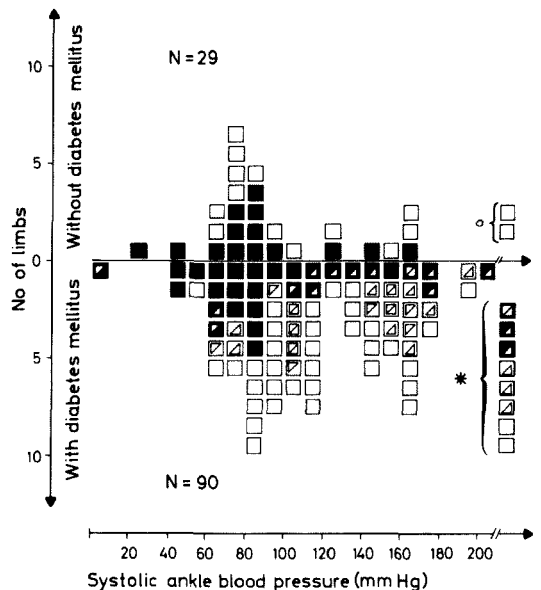


Figure 2. Healing in 119 minor amputations on the feet in relation to the systolic ankle blood pressure. Asterix: eight diabetic legs with non-compressible arteries. Open circle: two non-diabetic legs with pressures of 221 and 250 mm Hg (hypertensive patients).

putations versus digital amputations were about equal. Thirteen out of the 15 diabetic legs which failed to heal in spite of an SABP of 100 mm Hg or more suffered invasive infection. One of the three non-diabetic legs which failed to heal in this pressure interval suffered progressive skin loss because of superficial infection (the patient who refused therapy).

SABP values may be falsely high, in particular in diabetic legs, because of rigid arterial walls. In eight diabetic cases the arteries could not be occluded by cuff pressures of 250 mm Hg, even though the arm blood pressures were well below 200 mm Hg. Three of these legs suffered invasive infection and failed to heal.

The skin perfusion pressure on the forefoot (SPPF). None of the four feet with an SPPF below 20 mm Hg healed (Figure 3 and Table 4). In the gray zone with an SPPF of 20–39 mm Hg, seven out of 18 feet healed and with an SPPF of 40 mm Hg or above 12 out of 21 feet healed ($P < 0.05$). Five out of the six diabetic legs lost at more than 40 mm Hg suffered invasive infection. One of the non-diabetic legs lost at this pressure interval suffered skin loss.

Diabetes mellitus. Out of the 109 diabetic feet, there were 102 with infection. In 40 feet, the

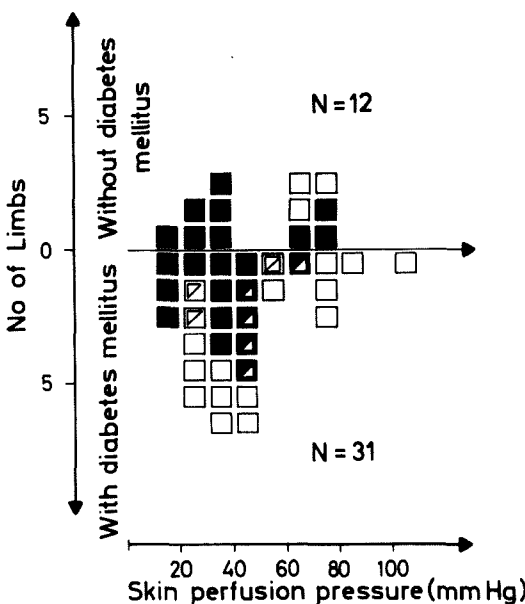


Figure 3. Healing in 43 minor amputations on the feet in relation to the skin perfusion pressure.

Table 4. Healing rates in digital and forefoot amputations with and without diabetes mellitus (DM) in relation to the skin perfusion pressure on the feet (SPPF) as measured in 43 cases

SPPF	<20 mm Hg	20–39 mm Hg	≥40 mm Hg
Without DM	0/1	0/5	3/6
With DM	0/3	7/13	9/15
Digital amputations	0/3	2/9	5/12
Forefoot amputations	0/1	5/9	7/9
Total	0/4(0%)	7/18	12/21(57%)
Confidence limits (95%)	0–60%		34–78%

infection was invasive in the form of osteitis and/or plantar abscess (Figures 1, 2 and 3). In 52 cases there was mixed infection, viz. significant growth of two bacterial strains or more. The 10 most commonly cultured strains are listed in Table 5. In non-ischæmic legs, i.e. with an SABP of 100 mm Hg or with palpable pulsations, invasive infection was less frequent in the insulin-dependent group: 11 out of 31 (35 per cent) as compared to the non-insulin dependent group: 21 out of 30 (70 per cent) ($P < 0.01$, Fischer's exact test). The healing rate was also better in the insulin-dependent group, 27 out of 31 (87 per cent) as compared to the non-insulin-dependent group, 19 out of 30 (63 per cent) but the difference was not statistically significant ($P > 0.1$). The immediate postoperative blood-sugar regulation was better in those who healed than in those who came to major amputation. There was no correlation between the duration

Table 5. The 10 most commonly cultured microorganisms from the feet with infection

	No. of cases
Staphylococcus aureus	77
Streptococcus faecalis	19
Proteus vulgaris, morganii	19
Peptostreptococcus	17
Escherichia coli	14
Coryne species	14
Streptococcus pyogenes	12
Klebsiella	11
Staphylococcus albus	9
Pseudomonas aeruginosa	9

of diabetes mellitus and the rate of healing. Out of 67 diabetic feet in which minor amputations healed, 17 cases (25 per cent) suffered severe neuropathic problems as evidenced by recurrent ulcers for more than 3 years postoperatively, either at pressure points or in the amputation scar.

Vascular surgery. Ten out of 17 minor amputations following vascular surgery healed and these cases had SDBP values of 20 mm Hg or more. Among the seven cases that failed to heal, the SDBP were above 20 mm Hg in three cases; invasive infection (one case) and reocclusion of the arterial reconstruction (two cases) were the causes of major amputation in these cases.

Discussion

In the past 10 years a number of reports on objective methods of predicting the healing of ulcers and amputations on the feet has been published. The ankle pressure is the most widely used parameter. Some authors have found the ankle pressure to be valuable (Carter 1973, Raines et al. 1976, Verta et al. 1976, Baker & Barnes 1977, Wagner & Buggs 1978, Holstein & Lassen 1980, Nicholas et al. 1982), while other authors have found it less useful (Gibbons et al. 1979, Mehta et al. 1980, Bone & Pomajzl 1981). A gray zone of healing is poorly defined and failures are not infrequent at high pressures, either because of infection or because ankle pressures are estimated too high at medial sclerosis. These limitations are confirmed in the present investigation. However, the ankle pressure is still a valuable parameter because low values (< 50 mm Hg) indicate that the limb is seriously threatened and because it can be measured in nearly all cases.

Healing of foot lesions in relation to digital pressures was studied by Carter (1973) and by Holstein & Lassen (1980). In Carter's series digital pressures in non-diabetics of above 30 mm Hg indicated a good healing prognosis. This was also found in Holstein & Lassen's series (1980), which moreover demonstrated a 71 per cent risk of major amputation at digital pressures below 20 mm Hg and that there was no difference in critical healing pressures between diabetics and

non-diabetics. Paaske & Tønnesen (1980) found that digital pressures below 10 mm Hg were associated with an 82 per cent risk of amputation, and Barnes (in discussing the paper by Gibbons et al. 1979) stated that minor amputations of the feet healed in non-diabetics at digital pressures above 10 mm Hg and that diabetics failed to heal when the digital pressure was below 25 mm Hg. The above data on digital healing pressures are consistent, but critical healing values of SDBP of as high as 45 mm Hg have also been reported in series of diabetics (Carter 1973, Bone & Pomajzl 1981). The present paper confirms our previous findings (Holstein & Lassen 1980), i.e. that digital pressures below 20 mm Hg as well as digital pressures above 30 mm Hg are very predictable, and that the number of borderline cases is small. For this reason, we consider the digital pressure to be the best predictor of healing.

The most important limitation in the use of digital pressures is that the toes are not always available for measurements. Total digital necrosis or the lack of toes cannot by definition be considered as representing zero-pressure with a bad prognosis of the limb. This situation requires further evaluation. The digital pressures should only be included in digital pressure statistics when measured on vital digits. The presence of ulcerations on the toes, however, does not preclude digital pressure measurements, and the figures in this series suggest that measurements on the second toe are as valuable as measurements on the first toe.

The skin perfusion pressure is valuable in determining the level of major amputation (Holstein et al. 1979a, b, Kolind-Sørensen & Marqversen 1979, Støckel et al. 1981, Holstein 1982, Thyregod et al. 1983) and has been used since 1972 (Holstein 1973). Measurements of the skin perfusion pressure on the feet are technically difficult in the case of oedema and infection. The data of the skin perfusion pressures point to low values, i.e. below 20 mm Hg, as very predictive of healing failures, but it is difficult to identify the pressure level that indicates adequate perfusion because of the frequent infections. However, values of 40–50 mm Hg seem to be adequate if infection can be controlled. This is in agreement with our previous study of perfusion pressures on the heel as measured with

the photoelectric technique (Holstein & Lassen 1980) and it is about 10–20 mm Hg more than that required for healing of a below-knee amputation. However, it must be emphasized that the elimination of tissue in major amputations is great, leading to better circulation of the remaining stump (Lassen & Holstein 1974, Holstein et al. 1979b, Holloway & Burgess 1978). For this reason and because of frequent infections on the feet, it is not surprising that healing on the foot requires a higher preoperative perfusion pressure.

Failure of healing of minor amputations on the feet implies serious consequences. More precise figures concerning the digital, the forefoot, the tarsal and the Syme's level and the influence of primary closure of the wound can be obtained. The available data, however, are helpful in estimating healing prognosis and in highlighting infection, which may cause loss of diabetic legs even with normal arterial supply. In preventing such disasters the elimination of the infected foot by ankle disarticulation, as popularized by Wagner's group (1977), probably ought to be used on a wider scale.

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