Toe Pulse Reappearance Time in Prediction of Aortofemoral Bypass Success

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The noninvasive vascular laboratory has a great potential to influence patient care if it can offer predictive information, which significantly adds to the clinical and angiographic assessment. To evaluate such preoperative data, 80 patients (143 symptomatic limbs) who underwent aortofemoral bypass were re-evaluated one to seven years following surgery. Preoperative vascular laboratory data (segmental pressure profile, quantitative Doppler velocity indices, postocclusive reactive hyperemia and toe pulse reappearance time [TPRT], following a four-minute cuff occlusion), angiography and clinical status were compared with the postoperative symptomatic result. Overall, 27% of the limbs were asymptomatic, 56% of the limbs markedly improved, 7% of the limbs remained unchanged or worse, and 10% of the patients died. Computer analyses of all preoperative data yielded several significant predictive indices, of which the most sensitive was the TPRT. With a TPRT of 0–10 seconds, all patients became either asymptomatic (63%) or markedly improved (37%). With increases in the TPRT, the results worsened, in stepwise fashion. Combinations of pressure and reactive hyperemic indices also permitted successful predictions in patients with multilevel disease. Such preoperative information can play a significant role in identifying the relative risks and benefits of surgery, and may significantly influence the decision for surgery in borderline situations.

THE NONINVASIVE VASCULAR laboratory has been designed to aid in the detection of disease in asymptomatic patients, confirmation of the diagnosis in patients with symptoms, localization of the anatomic segment involved, and intraoperative monitoring during surgery to ascertain the outcome of arterial reconstruction. However, the area in which the noninvasive laboratory has the greatest opportunity to influence patient care lies in its potential as a predictive tool. If it is possible to provide more accurate estimates of the likelihood of the success or failure of a given patient management decision, such as a particular operation, or the long-term relief of symptoms, then the laboratory will prove to be a progressively more valuable resource, which will become essential in the proper clinical management of patients with vascular disease.

Of greatest concern to the peripheral vascular surgeon is his ability to significantly relieve patient symptoms and limb ischemia with arterial reconstruction. Vascular laboratory data obtained prior to such procedures have only recently been correlated with the eventual success of reconstructive arterial operations, and are beginning to provide powerful predictors in the selection of specific surgical procedures in individual cases. This information may represent the most important special contribution of the vascular laboratory to patient management. For this reason, a review of the clinical results in patients undergoing aortofemoral bypass was conducted to evaluate the predictive capability of preoperative noninvasive laboratory measurements.

Methods

At the University of California, San Diego, the vascular laboratory examination for lower extremity arterial disease has routinely included a number of examinations, which include segmental pressures, multiple arterial velocity parameters and several indices of reactive hyperemia. Such preoperative vascular laboratory studies were performed in 80 patients, who subsequently underwent aortofemoral bypass. The lower extremity arterial examination included the following measurements:[5,6]

1) Segmental pressure profile, including pressure measurements at the upper thigh, above the thigh, above the knee, below the knee, above the ankle, and in the toe.
2) Quantitative Doppler ultrasonic velocity analyses

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TABLE 1. *Ankle Pressure Measurements as Predictors in Aortofemoral Bypass*

Ankle Pressure Index	Asymptomatic (Per Cent)	Improved (Per Cent)	Dead (Per Cent)
>0.8	50	44	6
<0.4	24	40	32*
All patients studied	27	56	10*

* $\chi^2 = 8.37$, $p < 0.05$, for group less than 0.4 vs all patients. Others not significant.

at the femoral, posterior tibial and dorsalis pedis artery levels, including calculations of the peak forward velocity, the deceleration rate, and the peak over mean velocity ratio.

3) Postocclusive reactive hyperemia, as measured by the mean Doppler velocity changes in the femoral artery following a four-minute calf occlusion, with a determination of the per cent of increase in mean femoral artery velocity, and the half time for recovery of the curve.
4) Toe pulse reappearance time, as measured by the return of the toe pulsations following a four-minute calf cuff occlusion (TPRT), and by measurement of the time required for the toe pulse to return to half of its preocclusion height (TPRT/2).

This study included all patients who had undergone preoperative vascular laboratory testing and aortofemoral bypass, at the Veterans Administration Hospital in La Jolla, in whom a period of follow-up of at least one year or to the time of death was available. All patients were recalled for a follow-up clinical assessment of their status, including an interval history, physical examination, and vascular laboratory examination. The charts were reviewed for the preoperative clinical status of the patient, and both the preoperative angiograms and lower extremity arterial studies were coded for computer manipulation. Data processing was then accomplished using specially developed programs and the Statistical Package for the Social Sciences in a Burroughs 6700 computer at the UCSD Computer Center.

Characterization of the Study Group

All the patients in the study group were males. Only the 143 symptomatic limbs of these 80 patients were considered further. In 67% of the patients, the indication for surgery was claudication alone, while in the remaining 33%, rest pain, ulceration and gangrene were present.

Overall, the hospital mortality rate for aortofemoral bypass in these 80 patients was 1%. Of the patients who survived the operations, when interviewed and examined at least one year later, 27% were asymptomatic, and 56% were significantly improved.

Pressure Measurements

Possible correlations of successful symptomatic relief were examined for each individual segmental pressure index. The only individual pressure measurement with any predictive value, when compared with the overall group response, was the ankle pressure index. If the preoperative ankle pressure index was over 0.8, 50% of patients eventually became asymptomatic (compared with 27% in the total group of 143 limbs), and 94% of the patients obtained significant symptom relief (compared with 83% in the total group). In contrast, if the ankle pressure index was <0.4, only 24% became asymptomatic, and 40% were significantly improved (Table 1). Further, a low ankle pressure index (less than 0.4) identified a number of those patients who were likely to die during the early postoperative years (32%).

Using all available pressure measurements, a classification of single versus multilevel occlusive disease was developed. These data proved to be significant predictors of the outcome of surgery. Patients with monosegment aortoiliac disease had a far greater likelihood of becoming completely asymptomatic (39%) than those with two-level (27%) or three-level (6%) disease. However, the likelihood of significant improvement in symptoms (asymptomatic and improved) was similar in all these groups (Table 2). As might be expected, the prognosis for patients with pure aortoiliac disease was significantly better than for those patients with two significant pressure gradients below the thigh. Thus, the use of all the segmental pressure data permitted clarifying the likelihood of achieving an asymptomatic state to a greater degree than any single pressure measurement

Using the pressure data, an index of leg resistance was derived, by subtracting the ankle pressure index (API) from the thigh pressure index (TPI).[8] The prognosis for patients with a TPI-API of less than 0.2 was significantly ($p < 0.01$) superior to those in whom this

TABLE 2. *Segmental Pressure Measurements as Predictors in Aortofemoral Bypass*

Segmental Pressure Classification	Asymptomatic (Per Cent)	Improved (Per Cent)	Dead (Per Cent)
Pure AI	39	50	4*
AI and 1 gradient	27	55	12
AI and 2 gradients	6	71	18*

* $\chi^2 = 8.24$, $p < 0.02$.

value was greater than 0.2, implying more distal disease in the lower extremity (Table 3).

Velocity Measurements and Derived Indices

The only significant velocity data for the prediction of success was obtained at the ankle level, where both the posterior tibial peak forward and peak/mean velocity data proved to be good discriminators of future success or failure (Table 4). A peak forward velocity of less than 4 cm/second was associated with a high failure rate (35%), while a peak/mean posterior tibial velocity greater than 4 was associated with a higher likelihood of success, than a peak/mean of less than 2 ($\chi^2 = 14.97$). None of the other velocity parameters appeared to have valid predictive importance.

Reactive Hyperemia

Both the postocclusive reactive hyperemia (PORH), as measured by the mean femoral artery velocity, and the toe pulse reappearance time were reviewed. Of the two, the PORH was far less discriminating. Large differences in the "per cent increase" of femoral arterial velocity were not associated with statistically significant differences in eventual outcome, and the $T^{1/2}$ data were even less valuable. In contrast, the TPRT/2, or the time for the toe pulse to return to 1/2 its control amplitude, proved to be the single most potent predictor in this study. If the TPRT/2 was less than 10 seconds (the normal range), the likelihood of a patient becoming completely asymptomatic was 63%, and the likelihood of significant symptom relief (asymptomatic or improved) was 100% (Table 5). Every patient in this group was alive and significantly relieved of his symptoms one-year after operation. At the other extreme, a TPRT/2 longer than 90 seconds was associated with an asymptomatic rate of only 10%, and a late mortality rate of 25% from all causes.

Combined Indices

In an effort to separate further the success and failure groups, two or more of the prior indices were combined, requiring the patient to fit several categories in order to be included in the subgroup.

TABLE 3. *Leg Resistance as a Predictor in Aortofemoral Bypass*

TPI*-API†	Asymptomatic (Per Cent)	Improved (Per Cent)	Dead (Per Cent)	Limbs (n)
<0.2	39	52	6	80
>0.2	13	61	17	49

$\chi^2 = 11.7$, $p < 0.01$.
* TPI = thigh pressure index.
† API = ankle pressure index.

TABLE 4. *Posterior Tibial Velocity Measurements as Predictors in Aortofemoral Bypass*

		Asymptomatic (Per Cent)	Improved (Per Cent)	Dead (Per Cent)
Posterior Tibial peak forward velocity (cm/sec)	>8	31	58	7
	<4	11	53	22
$\chi^2 = 8.13$, $p < .02$				
Peak/Mean Velocity	>4	60	20	10*
	<2	13	70	6*

* $\chi^2 = 14.97$, $p < .01$.

When patients with aortoiliac disease and one significant distal pressure gradient (by segmental pressure data) were considered separately, a further analysis was highly selective in predicting the eventual outcome (Table 6). Within this group, an ankle pressure greater than 0.5, and TPRT/2 of 0–20, predicted significant improvement or complete relief of symptoms in every case. On the other hand, an ankle pressure less than 0.5, and TPRT/2 longer than 60 seconds, identified a group with a late mortality rate of 29%, and overall improvement rate of only 57%.

Additional trials of varied combinations of indices, and discriminant analyses of their relative weightings, will be necessary before a final conclusion can be drawn regarding the specific measurements with overriding importance. However, it is already clear that velocity and reactive hyperemia data will improve our ability to predict the precise likelihood of success which may be anticipated following a major reconstruction such as aortofemoral bypass.

Discussion

It is clear that the discovery of valid and statistically significant predictors of the eventual success of major vascular reconstructive procedures for lower extremity ischemia is still in an early stage. Only a few analyses of such data have been published, and the information is based on relatively small series of patients, brief follow-up periods, and only a few standardized measurements.[1–3,7–9] Segmental pressure data have been the most frequently analyzed, but much of this analysis is dependent on the upper thigh pressure measurement, which is subject to significant artifacts. It is well known that an inappropriately narrow cuff will yield a falsely elevated estimate of thigh pressure. However, of even greater significance is the recently demonstrated importance of the distal (toe or ankle) sensing site in measuring thigh pressure in patients with two significant distal pressure gradients below the groin.[4]

TABLE 5. *Toe Pulse Reappearance Time as a Predictor in Aortofemoral Bypass*

TPRT/2 (sec)*	Asymptomatic (Per Cent)	Improved (Per Cent)	Dead (Per Cent)
0–10	63	37	0
0–20	56	42	3
60	13	56	21
90	10	50	25

$\chi^2 = 19.2$, $p < 0.01$
$\chi^2 = 16.5$, $p < 0.01$
$\chi^2 = 16.1$, $p < 0.01$
$\chi^2 = 13.8$, $p < 0.01$

* Time required for the toe pulse to reach 1/2 its control amplitude.

Such measurements are often falsely low by more than 20 mmHg, and clearly distort analyses based on either the thigh pressure, itself, or the thigh–ankle pressure difference. Nevertheless, the thigh and ankle pressure taken alone appear to have some predictive significance, and demonstration of the absence of a significant thigh to ankle pressure gradient is a very reliable predictor of a beneficial result.[8,9] However, none of the series reported to date has compared the results of such pressure analyses to similar predictions developed from the angiograms alone. Clearly, the angiographic demonstration of pure aortoiliac disease is also correlated with a very high success rate, and the noninvasive laboratory is unlikely to improve on this kind of information. More difficult, but more important, is the problem of multilevel disease with an important aortoiliac component. In addressing this subgroup specifically, Sumner and Strandness were unable to identify any valid predictors, using both pressure and exercise tolerance data.[9] Therefore, the combined analysis of segmental pressure, and pulse reappearance time for this group, appears to be an important advance.

Early data involving preoperative vascular laboratory measurements, which were subsequently correlated with the late results of arterial reconstruction, were published by Dean et al. in 1975.[3] An 83%, femoropopliteal bypass success rate was associated with those patients in whom the ankle blood pressure ratio exceeded 0.4. The success rate successively declined with decreasing ankle pressure ratios. If the ankle pressure ratio was less than 0.2, the success rate was only 9%.

Unfortunately, a second review of the importance of the ankle pressure in predicting the outcome of femoropopliteal bypass procedures did not completely confirm the ability of this single measurement to accurately separate the patients with good chances of success from those faced with likely failure. Corson et al. found all but one of the early failures in his study occurred in limbs with a preoperative ankle pressure index less than 0.5.[2] However, late failures occurred in patients throughout the range of ankle pressures, and this measurement was not as well-correlated with eventual success as in the Dean study.

Preoperative vascular laboratory data was correlated with the results of aortofemoral bypass in 42 patients, in an analysis by Bone et al. in 1976.[1] All limbs with a thigh pressure index of 0.85 or less were improved following aortofemoral bypass. In contrast, only 63% of the patients with a thigh pressure index greater than 0.85 were improved. These data documented that the lack of a significant arm to upper thigh pressure gradient was associated with a 37% failure rate of an aortofemoral operation to relieve symptoms. In addition, the importance of the number of segmental pressure gradients distal to the groin was analyzed. All extremities in which no abnormal preoperative pressure gradients could be measured below the groin were symptomatically relieved by aortofemoral bypass. Of those limbs with a single significant (greater than 30 mm Hg) gradient below the upper thigh level, 76% obtained symptom relief. However, if two abnormal preoperative pressure gradients existed below the thigh, the likelihood of success was only 29%. All of these differences were highly statistically significant.

In addition to confirming Bone's preoperative segmental pressure measurements, Garrett also obtained and correlated intraoperative ankle pressure index measurements, in patients undergoing aortofemoral bypass.[7] If the intraoperative ankle pressure index increased more than 0.1 during surgery, the likelihood of clinical relief of symptoms was 100%. Those patients who improved, but continued to have significant

TABLE 6. *Aortoiliac Disease and One Distal Gradient (74 Limbs)*

Ankle Pressure Index	TPRT/2 (sec)	Asymptomatic (Per Cent)	Improved (Per Cent)	Dead (Per Cent)
>0.5	0–20	60	40	0*†
<0.5	>60	43	14	29*
All patients studied		27	56	14†

* $\chi^2 = 6.2$, $p < 0.02$.
† $\chi^2 = 9.9$, $p < 0.01$.

symptoms, had changes in intraoperative ankle blood pressure indexes ranging from 0 to 0.1. All the patients who failed to have any increase in their ankle blood pressure index during surgery had no significant symptomatic improvement from the procedure.

Sumner and Strandness[9] also analyzed their experience with aortofemoral bypass, with particular emphasis on the relative significance of coexisting proximal and distal lesions. While the preoperative ankle pressure index and treadmill walking times correlated well with clinical symptoms of claudication or ischemia, none of the measured indices proved capable of discriminating future successes from failures. Further, 36% of the patients with poor results had preoperative thigh pressures of less than 0.85, in contrast to the universally good results in such patients reported by Bone. Sumner and Strandness suggested that the upper thigh pressure index test fails primarily because upper thigh pressures are subject to significant measurement artifacts.

The most significant predictive value in the study by Sumner and Strandness was the identification of patients with low thigh-to-ankle pressure gradients who have localized aortoiliac disease. In those patients with monosegmental aortoiliac disease and a low "index of run-off resistance" (thigh pressure–ankle pressure/brachial pressure), virtually all limbs improved after operation. However, none of the hemodynamic indices, measured by this group, proved to be reliable in predicting the results of aortofemoral bypass in patients with multilevel disease.

Finally, a similar review, including both segmental pressure indices and segmental plethysmography, was reported by O'Donnell et al.[8] In this study, thigh pressure was not a good predictor of eventual success. However, three other valuable indices were identified. Both the calf pressure and pulse volume recorder (PVR) amplitudes proved to be important measurements, permitting good separation of eventual successes in those patients considered to have purely aortoiliac stenoses by angiography. However, both failed to discriminate the outcome in patients with combined aortoiliac and distal disease.

O'Donnell also evaluated a measurement of runoff resistance, the FP Ω [thigh pulse volume amplitude (PVA) – ankle PVR ÷ 15 mm], which proved to be a most valuable measurement; when greater than 0.2, a 100% failure rate followed, while the failure rate dropped to 31% with an FP Ω less than 0.2. Finally, the average FP Ω in those patients with an eventual success was 0.36, in contrast to a of 0.76 mean in the failures ($p < 0.001$).

Quantitative velocity and reactive hyperemia analyses, which have only been obtained in a few laboratories, do appear to add another important index, particularly in the prediction of a group of patients in whom aortofemoral bypass is likely to fail. Most valuable, however, was the index of overall limb flow impairment measured by the toe pulse reappearance time after a 4 minute cuff occlusion at the midcalf level. As a simple single index, the TPRT/2 offers the greatest promise of evaluating the potential benefit of aortofemoral bypass in all preoperative patients, regardless of the angiographic and segmental pressure classification of the complexity of their disease.

The potential of using combinations of measurements, including pressure, velocity, and reactive hyperemia data, remains to be fully explored. Discriminant analysis and the application of derived weighting factors may permit even more selective characterization of preoperative patients. However, even with the present limited information, the predictive power of these preoperative factors is very impressive. A spectrum of the likelihood of becoming asymptomatic from 0 to 63% may be determined, and the likelihood of overall symptomatic improvement can be demonstrated to vary from 32 to 100%. With such information already available, additional investigations will certainly be stimulated, data criteria standardized, and more potent predictors derived in the years to come.

References

1. Bone GE, Hayes AC, Slaymaker EE, Barnes RW. Value of segmental limb blood pressures in predicting results of aortofemoral bypass. Am J Surg 1976; 132:733.
2. Corson JD, Johnson WE, Logerfo FW, et al. Doppler ankle systolic blood pressure: prognostic value in vein bypass grafts of the lower extremity. Arch Surg 1978; 113:932.
3. Dean RH, Yao JST, Stanton PE, Bergan JJ. Prognostic indicators in femoropopliteal reconstruction. Arch Surg 1975; 110:1287–1293.
4. Franzeck U, Bernstein EF, Fronek A. The effect of sensing site on segmental limb pressure measurements. Submitted for publication.
5. Fronek A, Johansen K, Dilley RB, Bernstein EF. Non-invasive physiological tests in the diagnosis and characterization of peripheral arterial occlusive disease. Am J Surg 1973; 126:205.
6. Fronek A, Coel M, Bernstein EF. The pulse-reappearance time: An index of over-all blood flow impairment in the ischemic extremity. Surgery 1977; 81:376.
7. Garrett WV, Slaymaker EE, Heintz SE, Barnes RW. Intraoperative prediction of symptomatic result of aortofemoral bypass from changes in ankle pressure index. Surgery 1977; 82:504.
8. O'Donnell TF, Lahey SJ, Kelly JJ, et al. A prospective study of Doppler pressures and segmental plethysmography before and following aortofemoral bypass. Surgery 1979; 86:120.
9. Sumner DS, Strandness DE. Aortoiliac reconstruction in patients with combined iliac and superficial femoral arterial occlusion. Surgery 1978; 84:348.