

## Non-invasive Vascular Tests Reliably Exclude Occult Arterial Trauma in Injured Extremities

KAJ JOHANSEN, M.D., PH.D., KIM LYNCH, M.D., MARLA PAUN, R.V.T., AND MICHAEL COPASS, M.D.

**We evaluated the ability of noninvasive vascular tests to exclude clinically significant occult arterial damage in injured extremities. In a preliminary study, a Doppler arterial pressure index (API) (the systolic AP in the injured extremity divided by the AP in an uninvolved arm) of  $< 0.90$  was found to have sensitivity and specificity of 95% and 97%, respectively, for major arterial injury. The negative predictive value for an API  $> 0.90$  was 99%. Because these values suggested that noninvasive vascular tests might effectively be substituted for "exclusion" arteriography in patients at risk for silent extremity arterial injuries, we then conducted a trial in which arteriography was performed in extremity trauma victims only when the API was  $< 0.90$ . Among 100 traumatized limbs (84 penetrating, 16 blunt) in 96 consecutive patients, 16 of 17 limbs (94%) with an API  $< 0.90$  had positive arteriographic findings, and seven underwent arterial reconstruction. Among 83 limbs with an API  $> 0.90$ , followup (including duplex scanning in 64 limbs) revealed five minor arterial lesions (four pseudoaneurysms, one arteriovenous fistula) but no major injuries. Arteriograms for extremity trauma fell from 14% to 5.2% of all angiographic studies performed ( $p < 0.001$ , Chi-square). These studies suggest that noninvasive vascular tests can reliably exclude major occult arterial damage in injured extremities. Screening for such injuries with Doppler arterial pressure measurements, reserving arteriography for limbs in which the API is  $< 0.90$ , is safe, accurate, and cost effective.**

Contrast arteriography is an accurate but invasive, expensive, and time-consuming means to rule out occult arterial injuries in traumatized extremities. Recent studies (1, 2, 5-8, 11, 15, 17, 21, 23) have demonstrated that, when used for screening asymptomatic trauma patients, arteriography is infrequently positive and even less commonly alters overall management. We recently suggested that Doppler pressure measurements, normalized to an arterial pressure index (API), are highly sensitive and specific for such occult extremity arterial injuries (10). On the basis of these data we proposed that API might be a useful tool for screening patients with injured extremities, and designed a diagnostic algorithm to be used with such patients (Fig. 1). We prospectively evaluated this proposal in a consecutive series of trauma patients, and herein report the results of this trial.

### PATIENTS AND METHODS

Following completion of our arteriography-controlled evaluation of the reliability of API in discriminating between dam-

aged limbs with and without major arterial injuries (10), we evaluated 100 subsequent extremity injuries in 96 consecutive victims of trauma at Harborview Medical Center (HMC) in Seattle. Patients with blunt or penetrating trauma [between the axilla and the wrist flexion crease (upper extremity), and the inguinal ligament and malleoli (lower extremity)] were included. All patients with obvious "hard" signs of arterial injury (arterial bleeding, rapidly enlarging hematoma, arteriovenous fistula, a distal pulseless extremity) underwent immediate management and were excluded from this analysis. All remaining patients underwent Doppler arterial pressure measurement (Medasonics, Mountain View, CA) in the injured extremity distal to the wound, and in an uninvolved arm. A standard arm blood pressure cuff was used, placed just above the ankle for lower extremity injuries or just proximal to the wrist for arm injuries. The API was calculated as previously described (10).

Patients with an API less than 0.90 underwent immediate contrast arteriography. Patients with an API greater than 0.90 underwent management of other injuries, serial Doppler API determinations, and (in 64 cases) duplex sonography (ATL Mark IV, Advanced Technology Laboratories, Bothell, WA) from 1 hour to 3 days after admission to the HMC Emergency Department. Duplex studies were performed between 8:00 A.M. and 6:00 P.M. on weekdays only. Patients with positive duplex sonographic findings or those with new clinical signs of arterial damage underwent immediate contrast arteriography from 3 days to 9 months after initial injury. All patients were urged upon discharge to return to the Vascular Clinic at least once, where they would be re-examined, including API determinations and duplex sonography.

From the Department of Surgery and the Emergency Trauma Center, Harborview Medical Center, Seattle, Washington.

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Address for reprints: Kaj Johansen, M.D., Ph.D., Department of Surgery, ZA-16, Harborview Medical Center, 325 Ninth Avenue, Seattle, WA 98104.

The current study evaluated demographic variables, mechanism of injury, initial symptoms and signs in the injured extremity, results of Doppler API determinations, outcome of early or late contrast arteriography, and findings at the time of early or late surgery. Followup in the Vascular Clinic (whether the patient appeared and the results of his or her examinations) was tabulated. The total number of arteriograms performed at HMC and the proportion of these studies performed for extremity trauma were calculated for the 12-month period of time preceding this study and compared with the period during which this study was accomplished. Differences between results were compared using Student's *t*-test, with significance assigned to *p* values less than 0.05.

## RESULTS

This study analyzed 100 limbs in 96 consecutive trauma patients. These patients were seen from 1 July 1989 to 14 January 1990 (representing a noteworthy acceleration in the prevalence of blunt, and especially penetrating, extremity trauma in metropolitan Seattle compared with our previous study [10], which required almost 2 years to accomplish).

Demographic and wounding characteristics are noted in Table I. As in all recent such analyses, including our own prior study, most subjects were young men who had suffered penetrating trauma.

Seventeen limbs with clinically normal perfusion had an API less than 0.90, and 16 of these (94%) had positive arteriographic findings (Table II). Seven patients underwent operations for vascular repair.

In four patients, an attending trauma surgeon elected to violate the study protocol by performing contrast arteriography because of concerns about wound "proximity" to underlying vessels despite a normal physical examination and an API greater than 0.90 in each case. All four arteriograms were normal, and each patient remained asymptomatic during followup.

The remaining 79 limbs, all with an API greater than 0.90, were initially evaluated solely by clinical examination and Doppler API. Subsequently, 64 limbs were scanned using duplex sonography. During followup for from 5 days to 2 weeks postinjury, five minor arterial lesions [four small pseudoaneurysms, one arteriovenous fistula (AVF)] were discovered by duplex scanning and confirmed by contrast arteriography. In the next year one of these patients, a 14-year-old youth, underwent elective dismantling of a traumatic AVF between the right profunda femoris artery and vein; no other patients required operative intervention.

Nineteen limbs were not studied by duplex scanning, usually because the patient failed to return for followup examination. Eighty-eight (92%) of the total study group appeared at the Vascular Clinic at least once; except as noted, none of this cohort later returned to HMC with the delayed appearance of an arterial injury appropriate to the original trauma.

In the prior 12-month period, 121 arteriograms were performed at HMC to rule out extremity vascular

trauma—a rate of ten per month. During the current 6.5-month study 21 such arteriograms were performed—a rate of 3.2 per month. During this period "exclusion" arteriograms were reduced from 14.0% to 5.2% of all angiographic studies performed at Harborview ( $p < 0.001$ , Chi-square).

Charges for API determination by Doppler pressure measurement are not billed separately at HMC; however, an estimated cost for 5 minutes of emergency department care, plus the amortized cost of a hand-held Doppler probe (\$500 every 2 years), is \$25. At an average cost of \$850 for a single extremity arteriogram at HMC during this time, substitution of Doppler API determination for "exclusion" arteriography in 79 of these 100 patients led to a net savings of \$65,175 during this 6.5-month period. As part of a study protocol, duplex sonography was not billed; a standard extremity arterial duplex scan would cost \$60–150.

On average, an "exclusion" extremity arteriogram requires 2.4 hours to complete in our trauma center (10). Because substitution of Doppler API (0.1 hours) permitted arteriography to be avoided in 79 of these 100 patients, each patient's management was expedited by 2.3 hours—a net total of 181.7 hours of patient care management time saved during the study period.

### A Possible Diagnostic Algorithm for Extremity Trauma

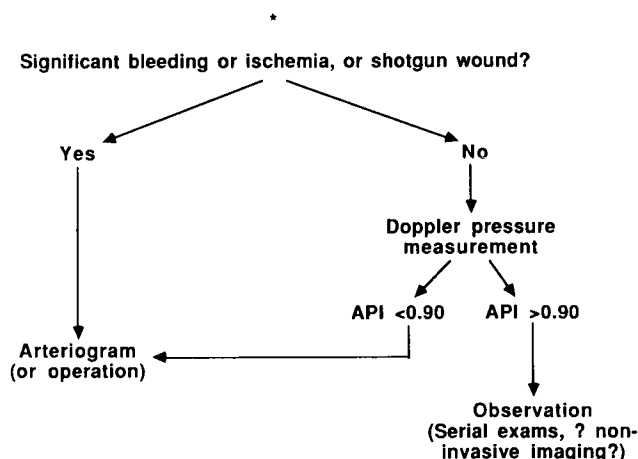


FIG. 1. Proposed diagnostic algorithm for extremity trauma (API = arterial pressure index) (10).

TABLE I  
Study population

Patients	96
Male	86
Female	10
Age (years)	28.2 (11–62)
Injuries	100
GSW	66
Stab wounds	18
Fx/dislocations	15
Other	1

TABLE II  
Arteriographic findings in limbs with API < 0.90 (n = 17)

Finding	Management	Outcome
Segmental narrowing, left brachial artery	Observation	Normal API
"Spasm," left radial artery	Observation	Normal API, duplex scan
Diffuse narrowing, all 3 tibial arteries	Fasciotomy	Normal duplex scan
"Spasm," right brachial artery	Observation	Normal API
AVF between superficial femoral artery, vein	Reconstruction	Normal
Intimal flap, proximal brachial artery	Observation	Normal API, duplex scan
Segmental spasm, right radial artery	Observation	Normal API, duplex scan
Spasm, anterior and posterior tibial arteries	Observation	Normal API
Normal brachial artery	Observation	Normal API, duplex scan
Pseudoaneurysm, anterior tibial artery	Resection	Normal
AVF between posterior tibial artery and vein	Embolization	Recurrence: successfully re-embolised
Intimal flap, left brachial artery	Observed	Normal API, duplex scan
Occluded left brachial artery	Vein graft	Normal API
Pseudoaneurysm, proximal left brachial artery	Resection, vein graft	Normal API
Segmental spasm, superficial femoral artery	Observation	Normal API, duplex scan
Pseudoaneurysm, left brachial artery	Resection, vein graft	Normal API
Diffuse spasm, all tibial arteries	Fasciotomy	Normal API

## DISCUSSION

Physical examination cannot, by itself, reliably discriminate between injured limbs that contain an occult arterial injury and those that do not (14). As a consequence, so-called "exclusion" arteriography became the standard of practice in order to ensure the absence of occult arterial injuries in such patients (4, 14, 18-20). Recently, however, it has become clear that the use of screening arteriography in this setting, already recognized to be invasive, expensive, and time-consuming, is also only rarely positive—perhaps in as few as 10%–15% of cases. And the number of patients in whom the results of contrast arteriography significantly alter subsequent management is even smaller—from 0% to 3.5% (1, 2, 5, 7, 8, 15, 17, 21, 23). These numbers approximate the likelihood of a false-positive or false-negative arteriogram in such a setting (16, 18).

Furthermore, the definition of what constitutes a "significant" arteriographic finding has evolved. Contrast arteriography will define a constellation of findings—intimal flaps, thrombi, areas of spasm or stenosis, small pseudoaneurysms, or even arteriovenous fistulas, most of which have previously been considered indications for operative repair. However, recent studies by Stain et al. (21), and Dennis, Frykberg, and colleagues (5, 7) have suggested that the vast majority of such arteriographically manifest lesions are benign and need only be observed. In other words, besides the other shortcomings of "exclusion" arteriography, it appears to be too sensitive for use as a screen for occult arterial injuries in traumatized extremities.

Similarly, the anatomic proximity of a wound to limb vessels has frequently led to the performance of contrast arteriography to exclude occult injuries. However, recent studies (1, 2, 5, 6, 8, 9, 12, 15, 17, 23), suggest that, with the possible exception of shotgun injuries (5, 22), clinical

estimation of "proximity" is insensitive, and such arteriograms are only rarely positive.

Just as the clinical assessment of a limb with *chronic* arterial disease can be quantified by Doppler arterial pressure measurement and the calculation of ankle/brachial indices, we have previously shown that a normalized Doppler arterial pressure index (API) is as accurate as contrast arteriography at defining the presence or absence of an occult extremity arterial injury (10). In that arteriography-controlled study an API less than 0.90 had a sensitivity of 95% and a specificity of 97% for arterial disruption, suggesting that determination of API might be substituted for "exclusion" arteriography in traumatized extremities.

The current trial tested our hypothesis that Doppler API can discriminate between limbs with and without silent arterial injuries. Our patient population (predominantly young males), the distribution of injury mechanisms (84% penetrating trauma), the low prevalence of positive arteriographic findings (16%), and the even lower incidence of cases requiring arterial reconstruction (7%), all are consonant with other recent studies (1, 2, 5, 7-9, 15, 17, 21, 23), as well as our own (10). Our data suggest that Doppler arterial pressure measurements *can* safely be substituted for contrast arteriography in the diagnostic evaluation of patients with extremity trauma. Because such studies are rapid, noninvasive, and inexpensive, such a substitution is not only safe for the patients but may result in substantial savings in time and money for overburdened emergency rooms.

The validity of duplex sonography for evaluating patients with actual or potential arterial trauma is unproven, although it is a topic under evaluation in our center (24) and elsewhere (2, 13). The ability of duplex scanning both to provide ultrasonographic images of blood vessels and to quantitate flow disturbances in arterial trauma make it an exciting and potentially useful

tool for evaluating trauma victims. In the current series, among 64 patients with extremity trauma in whom duplex sonography was performed, five asymptomatic arterial lesions were discovered and their presence documented by contrast arteriography. Six months later the persistence of one such lesion, a profunda femoris AVF, resulted in its elective repair. The remaining arterial lesions, all of them small arterial pseudoaneurysms, were followed without reconstruction, a course validated by other studies (5, 21).

Certain limitations accompany the use of Doppler arterial pressure measurements as screening tests for arterial trauma. As noted elsewhere (10), such measurements will not discover injuries to the profunda femoris, profunda brachii, or peroneal arteries. Lesions that do not reduce flow (intimal flaps, small pseudoaneurysms, AVFs) will not necessarily be detected by this technique. In addition, Doppler pressure measurement is not useful for the diagnosis of venous injuries (lesions we suspect may potentially be better diagnosed by duplex sonography). Occasional severe extremity injuries will not permit API determination because of an inability to place a blood pressure cuff (because of the magnitude of the wound or the presence of splints or dressing). Hypovolemic shock may cause an initially low API value, which then becomes normal following restitution of normal perfusion (3). Finally, several patients in our two prospective studies had an initially abnormal API which subsequently became normal [presumably a manifestation of transient severe arterial spasm (5), another entity whose natural history may be best elucidated by serial duplex scanning].

We demonstrated modest (although by no means trivial) fiscal savings through substitution of Doppler arterial pressure measurements for routine screening contrast arteriography in extremity trauma. These savings would be dwarfed at trauma centers with a higher volume of victims of extremity trauma, especially when the charges for an extremity arteriogram at such centers may approach \$2,000 (personal communication, Albert Yellin, M.D.).

Of even greater relevance, from the perspective of traumatologists, is the time saved by the activation of a diagnostic algorithm such as we have proposed. In our trauma center the overall management of trauma victims is delayed an average of 2.4 hours by performance of contrast arteriography (10). If, as we have demonstrated, four-fifths of such patients can safely be spared this diagnostic delay, management of their other life- or limb-threatening injuries can be expedited. Substitution of Doppler arterial pressure measurements for "exclusion" arteriography in 79 of 100 injured limbs saved more than 180 total hours in the early management of these 96 patients. The greatest benefit of adopting Doppler arterial pressure measurement for the screening of traumatized extremities for occult arterial injuries may ultimately

be the streamlining of the diagnostic workups of such patients and thus their overall care.

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### DISCUSSION

DR. DALE W. OLLER (Raleigh, North Carolina): Doctor Frykberg has established himself by his carefully designed studies presented previously to the A.A.S.T. and publications in the *Journal* as a serious student and observer of the problems of peripheral vascular trauma. His work and that of his colleagues presented today is one of three addressing the practical clinical approach to the knotty problem and circumstance of the penetrating lesion in the extremity near a vessel.

Because of the timely arrival of the manuscript, its extensive reference section, and the fact that there has been so great an interest over the last three decades expressed in the literature by many trauma centers, I candidly conclude that this is a topic upon which everybody has an opinion.

Pragmatically, we know that exploration has a high (64% or more) negative rate for discovery of arterial lesions, if that is the chosen approach. Doctor Feliciano has told us there was a 5% morbidity, a 0.4% mortality, and that even some of the lesions are missed on exploration.

Arteriography has become, because of its ability to exclude and characterize the nature of a vascular lesion, the standard. Doctors Reid and Weigelt indicate that in asymptomatic patients there may be anywhere from a 6% to a 21% incidence of arterial injury. Sensitivity for arteriography is very high. The quandary develops over the significance of a 10% positivity, not the less than 2% false negativity with arteriography.

Doctor Frykberg prospectively studied previously 135 patients with proximity penetrating extremity injury with arteriography and concluded that: 1) the natural history of clinical occult arterial lesions is predominantly benign; 2) arteriography could be safely delayed up to 24 hours; 3) soft signs were not clinically useful predictors of vascular injury; and 4) with the exception of shotgun wounds, arteriography did not appear to be cost effective as a screening modality.

This work is supported by that of groups at U.C. Davis and also at Miami. The efforts today presented here by Doctor Frykberg are a natural extension of his previous work—a prospective study of the accuracy and safety of physical examination, utilizing no adjuncts (no noninvasive techniques) but 24-hour hospitalization and patient counseling.

Clinically occult proximity wounds constituted 78% of 366 lesions in 310 patients. Patients with shotgun blasts were arteriogrammed, as were patients with thoracic outlet lesions. The study area was the delto-pectoral groove to the mid-forearm and the inguinal ligament to the mid-calf. Seventy-one per cent were lower extremity injuries. Twenty-one of the 23 extremity vascular lesions that required surgical intervention produced at least one hard sign. Two of these lesions developed hard signs on observation after initial negative or normal physical examination.

I think that the positive predictive value of 100% is stating the obvious. The negative predictive value of 99.3%, 284 of 286, makes the rather large assumption that significant extremity vascular lesions were detected. Based on Doctor Frykberg's previous work, I infer the proximity group to have approximately 28 undetected occult arteriographic lesions.

Less than 6 weeks ago, we explored this patient and opened the artery [slide]. The absence of the intimal defect and a minor wound complication were not offset by the teaching value and the fun of the resident placing a small vein patch.

I suggest we do not really know the negative predictive value. Please tell us more regarding the nature of the newly found and described physical evaluation, its frequency, and the role of the house staff in the evaluation equation. Why did you

arteriogram the patient who lost his popliteal pulse and developed distal ischemia while being observed?

Richard Gelberman wrote of nine patients with distal popliteal pulses with complete proximal artery transection in the *Journal* in 1980. Do you think that directional Doppler would have suggested this arterial lesion? Doctor Gelberman's work suggests so.

The difficulty with this patient population is beautifully underscored by the fact that 22 patients refused admission and that no patient without clinically evident vascular injury returned. At our institution, as yours, a similar cost savings might be realized.

Finally, in the movie, "The Marathon Man," Dustin Hoffman had to endure dental drilling by Sir Laurence Olivier while being asked, "Is it safe? Is it safe?" Eric, I believe you have constructed the best case yet with well defined terms.

I enjoyed the paper and appreciate the opportunity to discuss it. You know, Dustin Hoffman never could give a satisfactory response to, "Is it safe?" He needed to escape.

DR. DHIRAJ SHAH (Albany, New York): I would like to congratulate Doctor Francis for an excellent presentation and thank him and Doctor Thal for providing me a copy of their manuscript well in advance. In this study, the authors showed that routine angiography for detecting vascular injuries in patients without indication is nonrewarding. I completely agree with them in that context. I think, with careful clinical examination, noninvasive vascular laboratory testing, and duplex scanning, the question of the usefulness of so-called routine exclusion angiography may be a nonissue today.

Most critical arterial injuries can be diagnosed by vascular laboratory testing and clinical examination. Noncritical injuries may occasionally be missed, but they may not be of any consequence. Nowadays, many noncritical vascular injuries, such as intimal defects, may be observed without jeopardy to the patient.

At our institution, we use vascular laboratory testing extensively and do selective angiograms only when tests are abnormal. During the last 2-year period, we did 78 angiograms for extremity trauma only when it was indicated by vascular laboratory testing. Sixty of these patients had injuries that needed surgical repair. Others were minor and observed. There was no incidence of missed injuries during this time. This approach provided us with high yields.

Therefore I think that almost all vascular injuries can be picked up by careful physical examination and vascular laboratory testing, as is suggested by other papers this morning, and routine angiography may be unnecessary.

I have a few questions for the authors. In the four patients whom you observed for minor injuries, did you do followup angiograms to show whether the lesions healed or not?

Second, in the other group of patients in whom you have done selective angiograms for indications, do you have any data to show the incidence of true-positive, false-positive, and others for that group of patients?

Last, on the basis of this study, did you change your practice to selective angiography? If so, did you miss any major vascular injuries during that time?

Thank you for the privilege of the floor.

DR. ROBERT S. RHODES (Jackson, Mississippi): This morning's papers are the latest culmination of several years' work in evaluating the role of arteriography in penetrating trauma of the extremities. Two very separate issues have emerged: first, the low yield of arteriography for "proximity" wounds; and second, the possible benign natural history of occult injuries detected by such arteriography. Doctor Johansen and his co-workers, acting with the courage of their convictions, have not performed arteriography for proximity wounds and have demonstrated the relative safety of an alternative approach using

noninvasive techniques. They are to be congratulated for crossing this threshold.

The application of duplex scanning to clinical arterial trauma is an extremely important contribution of this paper. This technique provides both imaging and flow data and it substitutes a less expensive, less invasive, less risky, more mobile technique for arteriography. Duplex scanning also has the advantage of being able to detect possible venous injuries. However, the duplex scan is more dependent upon examiner experience and more subjective in its interpretation. I support the authors' conclusion and believe that the duplex scan, when available, should replace arteriography in the evaluation of those patients in whom there is no clinical evidence of arterial injury.

To further appreciate the value of the Doppler ratio, however, I would like to know the relationship of both normal and abnormal ratios with the hard and soft signs of arterial injury. Doctors Rose and Moore, in a paper several years ago, pointed out that there is an inverse relationship between the yield of arteriography and the number of clinical features used to determine proximity. Doctor Johansen appears to have used only hard clinical signs, and their Doppler pressure index really substitutes a semiquantitative measure for the qualitative assessment of just one of those hard signs, an abnormal pulse. I am concerned that the Doppler ratio, when used alone, missed four of seven pseudoaneurysms and one of three arteriovenous fistulas.

No single test appears capable of achieving all our goals. If we move away from arteriography, we should do so for the right reason. In this litigious era certain arguments should be avoided and, in particular, we should avoid the term "unnecessary." Arteriography for "proximity" injury may be relatively unproductive, but it should not be labeled unnecessary.

The possible benign nature of some types of injury is another rationale used to justify not performing arteriography. The benignity of arteriographic catheter site lesions is cited in support. While these lesions may be benign, the analogy to trauma may only be appropriate for stab wounds. Other mechanisms of trauma and types of injury should not be considered equivalent. Segmental narrowing and small nonstenotic intimal flaps increasingly appear to be benign and resection with an arterial anastomosis may actually add more trauma than primarily inflicted by the injury. Some intimal flaps were associated with low pressure ratios, however, and I know of no data that relate the natural history of these lesions to physiologic or anatomic criteria. On the other hand, pseudoaneurysms and arteriovenous fistulas are less likely to be benign. Both of these latter types of injuries are more difficult to manage when detected late, and therefore should not be considered minor. Doctor Johansen operated on one arteriovenous fistula and three pseudoaneurysms that were associated with low Doppler ratios, but did not operate on those that were discovered late. It is not clear why these late lesions were considered minor. I am particularly concerned because these lesions have an unpredictable natural history and occur predominantly in patients whose followup is difficult.

It is conceivable that the natural history of these occult lesions may be related to the mechanism of trauma. "Occult" injuries from stab wounds may have a different natural history from those of gunshot wounds, etc. Since these missed injuries are relatively infrequent, I would ask President Blaisdell to consider having the Multi-Institutional Trial Committee conduct a survey to assess the Association's cumulative experience. Much larger experience is required before we can safely advocate a broad nonoperative approach for pseudoaneurysms or arteriovenous fistulas.

Last, we should de-emphasize the monetary issue. Specifically, we must distinguish costs from charges. Reduced charges

should not be considered savings. Savings only exist for the supplies that are not consumed, medical personnel that are not otherwise paid, or equipment that is not bought. Considering the poor reimbursement from trauma patients, particularly for those with penetrating trauma, the allure of cost savings is likely to be a mirage. The right reason for adopting this non-invasive approach is that it appears to provide the same information at less risk and in a more timely fashion.

Doctor Johansen is to be congratulated for bringing these important new ideas to us. I also want to thank the Association for the opportunity to discuss this important paper.

DR. THOMAS PANETTA (Bronx, New York): Just a quick question relating to the six intimal flaps that were reported in this paper. Duplex scanning can be an adjunct to arteriography. Would you consider using it to differentiate, in minimal injuries that are picked up angiographically, the difference between the partial- and the full-thickness injuries, with implication for the need for surgical repair?

DR. JOSEPH VAN DE WATER (New Hyde Park, New York): We as surgeons seem to be guided by anatomy and by the axiom that if it's broke, fix it. But the degree of broke and the consequent impairment of function must be defined. Remember that 1) all organs have a certain reserve; 2) we do not know the natural history of a minimally damaged vessel, for example, an intimal flap; 3) should arterial insufficiency occur downstream later, we can usually correct that without any sequelae.

I urge that you think more in terms of function, and I congratulate Doctor Johansen in bringing physiology to this problem. We are indebted to Doctor Frykberg and the group in Jacksonville, who at last year's meeting and again this year questioned the need for an anatomic or angiographic examination of all penetrating extremity trauma cases.

Doctor Johansen, did you compare the difference in pressure between injured and normal extremities in your study and how did that value compare with the ankle-brachial index as an injury predictor? What would you estimate is the pressure difference that indicates a definite functional difference, and hence the need for an arteriogram? Thank you.

DR. KENNETH E. MCINTYRE (Tucson, Arizona): I have some generic comments about all of the papers, and I would like to congratulate Doctor Rhodes on his insightful discussion, because I think he is really the only discussant who has pointed out the problems with all these papers, that is, we do not know the natural history of some of these injuries. The followup in all of these studies is extremely short.

The other problem that I have noted is that some of the injuries that are found later may be very difficult to fix. Such a problem is the missed AV fistula; as the outflow resistance decreases, flow through the fistula increases. There are many large veins involved, and it becomes a difficult problem.

In addition, although most of this information is not new and most of us practice selective arteriography, this may not apply to blunt injury. For instance, we have all seen fractures that produce arterial vasospasm, thereby lowering the API, but it does not mean that any arterial injury exists, and once the fracture is reduced and the patient's shock is treated, then the API improves.

So I would like everybody to be aware of these caveats, because I think we should not throw the baby out with the bath water.

DR. JOHN R. HALL (Chicago, Illinois): At Cook County Pediatric Trauma Center, we have been following a selective approach now for several years, especially after having complications with angiograms in small children. Out of the 48 children with gunshot wounds (using an API of 0.9 as significant), we have had ten angiograms performed. Five of these were protocol violations. Of the remaining five, three injuries were seen on angiograms. In followup of 6 months on the majority

of the patients (with over half having duplex scans) we have had no complications. I believe this is the way to go.

DR. ERIC R. FRYKBERG (Closing Paper 52): I would like to thank Doctor Oller for his comments and for also a very good overview of the current issue as it stands.

Basically, the assumptions that we made in determining our accuracy rates may be challenged. As we explained in the manuscript, we do not have enough long-term followup to truly know our false-negative rate for physical examinations. So we agree with the concern expressed about our management of these injuries, and we do not at all mean to say that our study is the final word on this issue.

We do assume that there are arterial injuries not being detected. We know that from prior studies of our own and others. But these studies, as well as our present study, suggest the safety of not even detecting clinically occult arterial injuries. This represents the crux of our belief in the value of the physical examination as the sole means of evaluating penetrating extremity trauma.

Why arteriogram an injury after it has already developed signs of ischemia and pulse loss? Well, that is the standard approach currently used, and I agree that Doppler analysis may be just as effective.

Most of the concerns expressed today deal with followup. I would just like to make a couple of comments about followup. Long-term comprehensive followup is extremely desirable. It is the ultimate, optimal way of determining the answers that we seek. But something we know from the literature, from our experience, and from the experience of virtually all who have ever researched vascular trauma, is that the current state of the art does not permit a comprehensive long-term followup of the urban, financially indigent patient population, which almost exclusively constituted our study group.

Data from Louisville, from Dallas, from Miami, from Houston, and from New York at Downstate, have all documented the inability to comprehensively follow these patients. One day we may be able to do that, and we may be able then to confirm the true accuracy of the physical examination in this setting. But that should not mean that knowledge should stop, that we should not work with what we have to continue developing knowledge. That long-term comprehensive followup is not necessarily the sine qua non for acceptance of an idea is demonstrated by several widely accepted tenets, such as the value of arteriography in vascular injuries, the value of Doppler pressure monitoring to detect vascular injury, the value of one-shot emergency center arteriography in certain situations, and even the value of surgically repairing vascular injuries at all. Interestingly enough, virtually no long-term comprehensive followup data have ever been gathered in support of any of these concepts. In fact, if this were required, much of what we currently accept about vascular trauma would have to be discarded.

So, if we choose to apply these criteria, we ought to apply them consistently across the board, and not just to those ideas we do not happen to like.

There is some evidence that our method of followup does have merit. We know that patients do return when they develop signs of extremity vascular injury. We have documented that; several other centers have. We also know that these patients generally have nowhere else to return but to the trauma center they came from, because of their indigent status. A close rapport with the patients and counseling them to know what to look for and when to come back may further ensure their return if a vascular injury is initially overlooked.

We believe that one of the most compelling points about this issue is: where are all these missed vascular injuries that current dogma would predict to be occurring as a result of our current management approach? We have not seen them and neither have any other centers that have been managing patients in

this same way for a longer period of time (Frykberg, Ref. 31). You can say that 1 year is not enough followup to reliably see all missed vascular injuries, but in fact, the literature suggests that 1 year is indeed enough time to get a good approximation of the number of missed vascular injuries we are going to see. Generally, we know that most missed extremity vascular injuries that occur after a negative physical examination present within 3 months, the majority within 1 month.

So, further study is warranted, and I think skepticism is warranted, as it is for any idea that deviates from the established norm. But we believe that skepticism should consist of facts derived from appropriately designed studies. Until such facts exist, we feel our data should stand, and should at least prompt us all to question our current stance toward the value of physical examination for penetrating extremity trauma. Thank you.

DR. HUGH FRANCIS, III (Closing Paper 53): We would like to thank the discussants for their thoughtful remarks.

Doctor Shah, we have no followup arteriograms on the four nonoperated injuries. Further, we have no data on the arteriograms that were done in patients *with* signs of vascular injury.

Do we practice what we preach? Yes, we do. At Parkland, patients without signs of arterial injury are no longer subjected to proximity arteriography. So far, we know of no missed injuries.

Doctor Panetta, during this study period we did not use noninvasive techniques. This obviously seems to be the next step, and a prospective study is now under way using duplex imaging as an alternative to arteriography in evaluating clinically occult arterial injuries.

We would like to thank the Association for the privilege of presenting our data.

DR. KAJ JOHANSEN (Closing Paper 54): As usual, Doctor Rhodes has raised several cogent questions in his discussion of our paper. He asks whether there is a relationship between the Doppler pressure index that we calculated and the presence of "hard" or "soft" vascular signs. The answer is that, by definition, in none of these patients were there "hard" signs of vascular trauma. I cannot tell you about the exact relationship between the API and the presence or absence of "soft" vascular signs. As you have heard from another speaker this morning, that potentially may be a frail reed on which to lean.

It is indeed true that we had certain missed injuries. We believe that the missed injuries not managed operatively were clinically irrelevant.

I would, with all due respect, differ with you on a couple of points you have made, Doctor Rhodes. You have cautioned us about using the term "unnecessary," rather than "unproductive," in describing "exclusion" arteriography. I hope I did not say "unnecessary," but believe that there is a place for using it. When data prospectively collected and critically evaluated clearly demonstrate that a particular diagnostic or therapeutic technique is indeed obsolete, I believe we can then call it unnecessary. In fact, I think it is *incumbent* upon us to call it "unnecessary" when that technique—as is exclusion arteriography—is expensive, time consuming, and generally unhelpful.

Doctor Rhodes asked about why lesions found early were managed and those found late seemed to be watched. Those found early were managed in certain cases by other vascular surgeons. This was a diagnostic protocol, not a therapeutic protocol. We did not intend to tell other vascular surgeons how they should manage lesions that they found. On the other hand, the late lesions that were found, because of duplex scanning, were small and felt to be trivial.

Finally, I must disagree with two of the discussants somewhat that arteriovenous fistulas and pseudoaneurysms are necessarily more difficult to manage if diagnosed late. In some circumstances, that may be true, but it is not predictably so.

Also, if they are attacked early on they occasionally may be very difficult as well.

Doctor Van De Water, I believe, is asking what the specific basis for the selection of an API of 0.90 is. We chose that arbitrarily on the basis of the accepted normal values of the ankle-brachial index for chronic arterial disease.

In closing, I believe that our paper has, in a certain sense,

brought together what we have heard in the three prior papers here this morning. At Harborview, we no longer do routine exclusion arteriography. We believe very strongly in physical examination and in fact believe that the Doppler is an extension of our physical examination. Finally, we also believe that duplex scanning is the wave of the future for the evaluation of these interesting and complicated cases. Thank you very much.