Use of the internal mammary artery (IMA) as a conduit for coronary artery bypass has enhanced this procedure in terms of prolonged graft patency. The earlier warning by Arnold\(^1\) that use of both IMAs would devascularize the sternum was based on postmortem radiologic imaging. This was complemented by a subsequent animal study employing isotopic microspheres. In the present clinical study, laser Doppler flowmetry was adapted to identify changes in blood supply to the left half of the divided manubriosternal sternum during separation of the left internal mammary artery from its chest wall attachment. Our finding of continued blood flow after this event suggests that complete devascularization of the sternum does not take place. Quality of sternal bone and surrounding tissues and clinical indications should remain as factors influencing use of one or both internal mammary arteries.\(^{(Chest 1990; 98:878-80)}\)

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Employing isotopic microspheres. The conclusion of the latter work is that bilateral IMA harvesting, in effect, creates a free sternal bone graft. In our clinical study, laser Doppler flowmetry (LDF) was adapted to study changes in blood supply to cancellous bone of the manubriosternal sternum during separation of the left IMA from its chest wall attachment.

**Material and Methods**

Invitation to participate in the study was extended to a consecutive series of 13 patients who were undergoing their first coronary bypass operation and in whom the surgical plans called for use of the left IMA. Patients were counseled under guidelines of the institutional review boards of the participating hospitals.

A laser Doppler capillary perfusion monitor (MEDPACIFIC LD6000, MEDPACIFIC, Inc, Seattle, WA) with a 2-mW helium-neon light source was used. Use of this system has been previously well described.\(^2\) In summary, the laser light is brought to the measurement sample through an optical fiber. The light impinges on the tissue and is backscattered from both nonmoving tissue and from moving red blood cells. The light backscattered from the moving red blood cells is shifted in frequency according to the Doppler principle, whereas that from the nonmoving tissues is not. A second optical fiber returns the backscattered light to a photodetector and signal processor where the difference between the two frequencies, the Doppler frequency, is determined and a value for flow is determined. In skin, the laser light has been shown to penetrate in a generally hemispheric pattern to a depth of 1 to 1.5 mm, and the system has been calibrated against other methods for capillary perfusion measurement. Due to the fact that the calibration is not absolute, it has been customary to report the system output values in the electrical units of millivolts as the blood cell flux (BCF).

After confirmation of normal induction and stable arterial pulmonary artery and wedge pressures, a median sternotomy incision was performed and the left sternal edge was retracted with a table-mounted IMA retractor. Bone wax was applied to the open manubrial surface. At a level of 1 cm superior to the manubrial surface of the manubriosternal junction (MSJ), a 1.2-mm cylindrical bore into the cancellous bone of the manubrium, using a disposable 18-gauge needle, was created to a depth of 15 mm (Fig 1), and the space was irrigated with heparinized physiologic solution to remove bone and bone wax fragments. After establishment of zero-flow baseline, the flow probe was inserted into this space, with hydrostatic sealing by means of O-rings flush with the sternal surface (Fig 1, inset). A BCF baseline was established after retraction of the sternal edge, before beginning the dissection (Table 1, "Initial" column). Left IMA mobilization was performed, beginning at the terminal bifurcation of the vessel, serially dividing arterial and venous attachments to the chest wall using titanium vascular clips on the pedicle and electrocautery and vascular clips on the chest wall. The artery was thus mobilized to a level of 1 cm above the suprasternal notch. The operations progressed routinely, with an estimated ten minutes of operative time added to the procedures for probe placement.

A continuous display of BCF was established with 8-s recordings obtained at the following intervals (Table 1): (1) baseline, prior to beginning IMA dissection, (2) IMA mobilization to level of MSJ, and (3) complete IMA mobilization to 1 cm above the top of the manubrium. Mean flow values were used in the calculation of results. A paired Student's \(t\) test was used to determine if significant differences were present between flow values obtained initially, after mobilization of the IMA to the MSJ, and to the final level of 1 cm above the manubrium.

**Results**

Three studies were aborted or not used in the analysis of data. In one patient, the IMA was injured during dissection. In a second patient, a large phasic pattern of BCF related to mechanical ventilation was
noted, and in a third patient, a very porous sternal marrow prevented solid placement of the flow probe. Values obtained in ten patients are shown in Table 1. Initial flow values ranged from 111 to 30 mV with final values after IMA mobilization from 97 to 20 mV. After mobilization to the level of the MSJ, just inferior to probe location, mean flow actually increased significantly (p = 0.002). Complete mobilization to 1 cm above the top of the manubrium resulted in a decrease in mean flow compared with the value at MSJ which was close to, but did not achieve, statistical significance (p = 0.058). There was no statistical difference between the initial nonmobilized and the final fully mobilized values (p = 0.310). Postoperative courses were routine and all sternotomy wounds healed without complications.

**COMMENT**

Our clinical study of sternal blood flow after IMA mobilization was designed to introduce the fewest possible modifications to the conduct of a coronary bypass operation, and specifically to limit operating times, manipulations of the sternal halves, muscle trauma, and electrocautery to those processes normally occurring with IMA mobilization. It was considered more desirable to establish one stable recording point and to measure BCF as IMA mobilization approached and then passed this location than to introduce two or more recording points with the inherent difficulties of signal comparison between two probes. The nearly absolute immobility of the flow probe necessary to maintain a steady BCF value required probe location in the manubrium as opposed to the sternum proper. Illustrations provided with the injection studies of Arnold¹ appear to show equal spacing and size of IMA branches to both manubrium and sternum, and the single site for measurement was considered representative of IMA blood flow to both structures. Similarly, possible comparisons between the sternal halves before and after IMA mobilization and measurements later in the procedure prior to wound closure would have required modifying and prolonging the operations to preserve immobility of one or more probes.

Blood flow in bone has been studied experimentally, using ¹³³Xe washout and isotope-labeled microspheres,⁷ which are both indicators of blood flow in capillaries, and LDF⁸ which is sensitive to volume flow of red blood cells in a small area, irrespective of their containment. Lack of correlation between the methods is attributed to arteriovenous shunting, incomplete mixing and anesthetic effect with the former, and to bleeding artifact with LDF. In our study, bleeding was controlled hydrostatically by means of bone wax, and despite the disruption of bony trabeculae, capillaries, and other marrow structures, the BCF signal was typical of published accounts of bone blood flow.

The flow probe was located 1 cm superior to the MSJ. Our observation of significant increase in BCF after mobilization to the level of the MSJ was believed

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**Table 1—BCF Values at Three Levels of IMA Mobilization**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Initial</th>
<th>MSJ</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>86</td>
<td>107</td>
<td>44</td>
</tr>
<tr>
<td>2</td>
<td>62</td>
<td>95</td>
<td>88</td>
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<td>3</td>
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</tr>
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<td>28</td>
</tr>
<tr>
<td>10</td>
<td>53</td>
<td>60</td>
<td>46</td>
</tr>
</tbody>
</table>

Group mean ± SD: 63.20 ± 25.24, 78.70 ± 31.57, 51.90 ± 27.54

<table>
<thead>
<tr>
<th></th>
<th>p = 0.002</th>
<th>p = 0.058</th>
<th>p = 0.310</th>
</tr>
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*BCF = blood cell flux; IMA = internal mammary artery; and MSJ = manubrium-sternum junction.*
to be consistent with a progressive decrease in run-off as side branches were clipped below that level.

Cancellous bone heals directly from points of contact, with relative lack of callus formation. When one fragment is avascular, healing proceeds at a slower rate with ingrowth of periosteal capillaries from only one side. Our data and the observations of Grmoljez and Barner10 of prompt sternal healing after limited débridement both suggest that ipsilateral capillary ingrowth and blood flow occur after IMA mobilization.

We have been impressed with the variation in thickness and quality of the cancellous sternal bone and the persistent vascularity, through all phases of the operation, of the pectoralis major, transversus thoracis, and intercostal muscles that closely invest the sternum. Soft tissue blood flow does not appear to be affected by IMA mobilization; at the time of wound closure, active bleeding from muscle, periosteum, and the sternal wire sites does not appear to be decreased on the side of IMA mobilization. We have not established that blood flow is preserved at the periosteum where initial capillary ingrowth occurs. However, our finding of continuing BCF in adjacent cancellous bone after IMA mobilization leads us to the generalization that sufficient blood inflow and venous return remain through adjacent tissue to allow sternal union to occur after bilateral IMA mobilization. The decision to mobilize one or both IMAs should continue to be based on individual factors of coronary anatomy, age, ongoing ischemia under anesthesia, and local factors such as quality of the sternal bone and surrounding tissues.

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REFERENCES
2 Seyfer A, Shriver C, Miller T, Graeber C. Sternal blood flow after median sternotomy and mobilization of the internal mammary arteries. Surgery 1986; 104:899-904