DILATION OF THE INTERNAL MAMMARY ARTERY BY EXTERNAL AND INTRALUMINAL PAPAVERINE APPLICATION

Three methods for prevention of perioperative spasm of the internal mammary artery were compared in 78 patients undergoing coronary artery bypass grafting. In group 1, internal mammary artery pedicles were divided distally, clamped, and placed under the upper sternum submerged in papaverine solution (1.5 mg/ml). In group 2, as in group 1 but before clamping, 2 ml of heparinized blood with 1.5 mg/ml papaverine added was injected into the vessel lumen. In group 3 treatment was as in group 2, but heparinized blood with papaverine was injected a second time just before extracorporeal bypass was begun. In a univariate analysis free flow from dilated internal mammary arteries was not significantly different among the groups (group 1, 58 ml/min; group 2, 82 ml/min; group 3, 68 ml/min; $p < 0.1$). When free flow from dilated internal mammary arteries was the dependent variable in a regression analysis, the use of intraluminal papaverine, high blood pressure during flow measurement, and high initial blood flow were predictors of high flow (all $p < 0.01$). Morphometric measurements on the resected distal portion of the dilated internal mammary arteries disclosed less folding of the internal elastic lamina and a larger luminal area in groups 2 and 3 compared with respective findings in group 1 (1.21 mm^2 and 1.42 mm^2 versus 0.77 mm^2 ; $p < 0.02$). Mechanical vessel wall injury occurred in 8 of 52 internal mammary arteries treated with intraluminal papaverine. Intraluminal papaverine solution injected once or twice in addition to external papaverine exposure therefore provides a better blood flow rate and distal dilation than mere submersion in papaverine solution, but at a considerable risk of mechanical wall injury. (J THORAC CARDIOVASC SURG 1995;110:697-703)

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Although the internal mammary artery (IMA) is considered the preferable conduit for myocardial revascularization,¹⁻⁴ spasm of this vessel can cause inadequate flow, which may be detrimental during periods of increased nutritional demand such as

weaning from cardiopulmonary bypass⁵ or during hypovolemia after operation.⁶ Also, IMAs with poor perioperative flow rates are more likely to occlude.⁷ An adequately dilated IMA graft facilitates placement of anastomotic sutures.⁸ To promote dilation of the IMA, vasodilating substances have been applied to the outside of the pedicle⁹⁻¹¹ or injected intraluminally with or without hydrostatic dilation.^{8,12} Hydrostatic dilation with papaverine dissolved in saline solution provides good dilation but carries a potential risk of mechanical damage to the media and intima caused by cannulation and overstretching and by chemical damage as a result of the acidity of the solution.¹³⁻¹⁸ Hillier and associates¹⁹ found, however, that 5 minutes of papaverine exposure does not seem to damage the endothelial function. Because saline solution and papaverine are both acidic, a vehicle of higher pH and with a greater buffer capacity than saline solution may be

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Table I. Characteristics of patients and IMAs

Variable	Group 1		Group 2		Group 3		Kruskal-Wallis test (p value)
	Median	Range	Median	Range	Median	Range	
Patient age (yr)	63.1	41.2-71.0	62.8	42.6-73.4	63.3	37.7-75.7	0.94
Body weight (kg)	74.5	57-109	79.5	58-90	79.5	66-94	0.22
Height (cm)	176	153-190	173	160-186	176	160-187	0.20
Body surface (m ²)	1.90	1.54-2.30	1.90	1.60-2.11	1.96	1.69-2.11	0.39
IMA length (cm)	15.3	12-18.5	15.5	13-19	16	13-17	0.87
First MAP (mm Hg)	70.0	56.0-111.0	66.8	47.5-85.2	70.5	48.4-91.0	0.15
IMA blood flow 1	11.5	1.2-72.0	11.1	0.96-57.6	8.2	3.4-57.6	0.30
Second MAP (mm Hg)	57.5	27-93	66	38-86	65	27-96	0.15
IMA blood flow 2	58	6-150	82	24-288	68	20-384	0.08
Time of papaverine exposure (min)	66	25-101	57	29-125	73.5	27-142	0.17
Biopsy specimen length (mm)	18	11-25	18	9-43	19.5	12-32	0.21
Luminal area (mm ²)	0.77*	0.14-2.32	1.21	0.19-3.48	1.42	0.37-3.97	0.02
Media area (mm ²)	0.66	0.35-1.35	0.71	0.28-1.30	0.86	0.28-1.40	0.26
Intima area (mm ²)	0.06	0.02-0.16	0.06	0.02-0.16	0.08	0.03-0.43	0.21
IT index	0.09	0.04-0.18	0.08	0.02-0.26	0.11	0.04-0.81	0.59
Fold index	1.41*	1.01-2.27	1.18	1.03-2.00	1.16	1.01-1.56	<0.01
IEL length (mm)	5.04	3.49-6.49	5.03	3.58-6.90	5.70*	4.43-7.79	0.04

Treatment groups are shown in columns 2 through 4. Column 5 shows results of the Kruskal-Wallis test for differences among groups. MAP and IMA flow measured at two times as described in text. IT, Intimal thickening; IEL, internal elastic lamina.

*Different from both other groups.

preferable for intraluminal application.⁸ Mills and Bringaze⁸ found that blood with dissolved papaverine was less acidic and suggested that it might be used with confidence.

After a dilating agent is injected into the IMA and it is clamped, the intraluminal volume of the vessel increases. Blood entering from the subclavian artery thus dilutes or pushes distally the dilating agent. It is therefore not certain that intraluminal papaverine without hydrostatic dilation will dilate the vessel along its entire length, although a 20% diameter increase has been obtained distally.¹⁹ In the present study on IMA dilation all the IMA pedicles were kept immersed in papaverine solution. The additive dilating effect caused by the intraluminal injection of papaverine in heparinized blood once or twice was examined.

Patients and methods

Seventy-eight patients, 68 men and 10 women (median age 62.8 years, range 37.7 to 75.7), underwent coronary artery bypass grafting. Before the induction of anesthesia and until the start of cardiopulmonary bypass glyceryl nitrate was infused in an individualized manner to keep blood pressure at an acceptable level. The dosage varied considerably from 0.2 to 9 µg/kg per minute (median 2 µg/kg per minute). The left IMA was used as one of the bypasses, usually to the left anterior descending coronary artery. After heparinization of the patient and isolation of

the IMA, usually down to the fifth rib or fifth intercostal space, the mode of treatment of the pedicle was randomized to one of three treatment groups by drawing of one card from an envelope. The envelope contained 78 labeled cards, 26 from each group. IMAs in all groups were cut distally and free flow from the cut end was measured by recording the time required for 4.8 ml of blood to flow into an open syringe (IMA blood flow 1, Table I). Blood was allowed to run freely from the end of the IMA into the heparinized syringe to limit foreign surface contact of the blood. Simultaneously, radial artery pressure was recorded as an expression of central arterial pressure (first mean arterial pressure [MAP], Table I). The syringe had been filled with 0.3 ml of heparinized saline solution (33 U/ml). Eight milligrams of papaverine was added by injecting 0.2 ml papaverine solution (40 mg/ml) into the blood and mixed by turning the syringe upside down 10 times after inserting the piston.

Group 1 IMAs were clipped distally and placed inside a plastic bag containing papaverine (1.5 mg/ml in 0.9% saline solution). Group 2 IMAs were treated like those in group 1, and in addition 2 ml of the heparinized blood with papaverine was injected intraluminally with use of a 1 mm intravenous plastic cannula (Venflon, Viggo Spectramed, Helsingborg, Sweden). Group 3 IMAs were treated like those in group 2, and in addition they were injected a second time with the papaverine in heparinized blood just before extracorporeal bypass was begun.

After construction of distal vein graft anastomoses and selection of the site for IMA anastomosis, while the patient was supported by cardiopulmonary bypass, it was decided at which level to cut the IMA. For this study, a 10

Fig. 1. Diagram shows distal, resected part of IMA pedicle. First clip was applied to prevent bleeding; second and third to fix steel rod to IMA to "splint" it and prevent its retraction. Second and third clip were applied while pedicle was stretched to its original length.

mm long segment of IMA (range 4 to 14 mm) just distal to this level was isolated between two clips, with the most distal applied first to maintain intraluminal pressure. A 15×0.4 mm steel rod was placed alongside the vessel segment by the clips to "splint" and prevent retraction of the vessel segment (Fig. 1). This closed IMA segment with trapped blood was then excised and immersed in 4% buffered formalin. The open end of the cut IMA was split in preparation for anastomosis and the lengths of the remaining IMA (IMA length, Table I) and removed parts of the pedicle (biopsy specimen length, Table I) were measured. The volume of blood bled into a beaker during 20 or 30 seconds was measured and free flow rate (in milliliters per minute) was calculated (IMA blood flow 2, Table I). Simultaneously, the radial artery pressure was recorded (second MAP, Table I).

After operation, the highest measured value of aspartate aminotransferase was recorded. The presence of any new electrocardiographic changes indicating possible septal or anterolateral infarction within the first month after the operation was also recorded.

The formalin-fixed segments of IMA were processed for light microscopy according to standard procedures. Sections $5 \mu\text{m}$ thick were cut from the midportion of the vessel segment that was splinted by the steel rod. At this site the lumen was nearly circular. The sections were stained with van Gieson elastin stain and used for morphometric analysis as described previously.²⁰ All morphometric measurements were made by one of us (K. H.) without knowledge of the group code. Eight specimens, four in each of groups 2 and 3, showed signs of mechanical damage and could not be evaluated morphometrically, leaving 70 for analysis. Fig. 2 shows the morphometric measurements made in each specimen. The perimeter of the media (PM), the length of the internal elastic lamina (IEL), the cross-sectional area of the media (M), the cross-sectional area of the intimal layer (IL), and the cross-sectional area of the lumen (LA) were measured as previously described.²⁰ The measurements were used to calculate a fold index that denoted the degree of folding of the internal elastic lamina as follows: Fold index = IEL/CC , where CC (length of the circle circumscribing the same area as the IEL) = $2\pi R_i$, where R_i = internal

Fig. 2. Diagram of measured and calculated variables. Perimeter of media (PM), area of media (M), area of intimal layer (IL) (equal to area between luminal circumference (LC) and folded internal elastic lamina [IEL]), length of folded internal elastic lamina, and luminal area (LA) were measured. Following variables were calculated: R_e , external radius = $\text{PM}/2\pi$; R_i , internal radius = $\sqrt{(\pi R_e^2 - M)/\pi}$; and CC, length of circle circumscribing same area as internal elastic lamina = $2\pi R_i$.

radius = $\sqrt{(\pi R_e^2 - M)/\pi}$, where R_e = external radius = $\text{PM}/2\pi$. The ratio between the area of the intimal layer (IL) and that of the media (M) was used as an index of intimal thickening as follows: Intimal thickening index = IL/M .

Differences among the three treatment groups were evaluated by the Kruskal-Wallis one-way analysis of variance with $\alpha = 0.05$. When multiple comparisons were done the probability α of making at least one false decision, that is, that two given treatments differed when in fact they did not, was ≤ 0.25 . When k represented the number of groups to be compared, $\alpha = 0.25/k(k - 1)$ for each comparison.²¹ Possible correlations between any two variables were examined by Kendall's test.²² The test was made two-sided. The variables IMA blood flow 1; second MAP; media area; and three dummy variables; D1, D2, and D3; were included as possible predictor variables in a stepwise regression analysis done with the 2R program in the 1993 version of the BMDP statistical software package (BMDP Statistical Software, Inc., Los Angeles, Calif.) to assess the technique of papaverine application independent of other potential predictors of flow. The dummy variable D1 was set to the value 1 in treatment group 1 and to 0 in groups 2 and 3; D2 and D3 were set to the value 1 in treatment groups 2 and 3 and to 0 otherwise. To correct for nonnormal distributions, IMA blood flow 1 and IMA flow 2 were entered in the analysis after logarithmic transformation.

Results

Table I shows that the following parameters did not differ among the groups: patient age, body weight, height, MAP at the time of flow measurement, IMA length, biopsy specimen length, media area, intima area, and intimal thickening index.

Table II*A. Correlation between IMA blood flow 2 after dilation and other variables*

	No. of data pairs	τ	<i>p</i> Value
IMA blood flow 1	78	0.2954	<0.0001
Second MAP	78	0.2845	0.0001
Media area	70	0.2481	0.001
Luminal area	70	0.1645	0.022
Body weight	78	0.1195	0.061
IT index	70	-0.1105	0.088
IMA length	78	-0.0913	0.118
Fold index	70	-0.0846	0.150
Patient age	78	0.0727	0.173
Bypass time	78	0.0580	0.226

B. Correlation between luminal area and other variables

	No. of data pairs	τ	<i>p</i> Value
Fold index	70	-0.7191	<0.0001
Media area	70	0.2671	0.0005
Second MAP	70	0.1429	0.040
IMA length	70	-0.1330	0.052
Patient age	70	0.0373	0.324
Bypass time	70	0.0251	0.379
IMA blood flow 1	70	0.0210	0.399
Body weight	70	-0.0152	0.426
IT index	70	-0.0108	0.447

τ , Kendall rank correlation coefficients; *p* value, significance probability using normal approximation; IT, intimal thickening; bypass time, time on bypass until IMA flow rate is measured.

Flow rate from the IMA did not differ among the groups either before or after dilation with papaverine. Luminal area was larger and the fold index smaller in groups 2 and 3 than the corresponding values in group 1. The internal elastic lamina was longer in group 3 than in groups 1 and 2.

The analysis showed positive correlation between IMA flow rate after dilation and the following parameters: IMA blood flow rate before dilation, simultaneous arterial blood pressure, media area, and luminal area (Table II, *A*). There was a positive correlation between media area and luminal area and between MAP at the time of flow measurement and luminal area. There was a strong negative correlation between fold index and luminal area (Table II, *B*). By multiple regression analysis, IMA blood flow 2 was related to IMA blood flow 1, second MAP, and the dummy variable D1, meaning that absence of intraluminal papaverine predicted low final blood flow (Table III).

Eight IMAs, four in each of groups 2 and 3 showed signs of mechanical damage. Consequently, the histologic sections could not be evaluated mor-

Table III. Predictors of ln (IMA blood flow 2)

Predictor	Coefficient $\pm$ SE	<i>p</i> Value
ln (IMA blood flow 1)	0.4305 $\pm$ 0.0766	<0.001
D1	-0.3841 $\pm$ 0.1305	<0.01
Second MAP	0.0114 $\pm$ 0.0039	<0.01

Intercept = 2.59; multiple $R \pm$ standard error (SE) = 0.66 $\pm$ 0.51.

D1, Dummy variable set to the value 1 in treatment group 1 and to 0 in groups 2 and 3.

phometrically. Closer examination of these sections showed (1) dissection between the media and adventitia ($n = 5$, Fig. 3, *A*), (2) disruption of the media ($n = 1$, Fig. 3, *B*), and (3) an invaginated media into the lumen at the site of a branch ($n = 2$, Fig. 3, *C*).

The groups did not differ with respect to maximum aspartate aminotransferase level measured after operation or with respect to the presence of electrocardiographic changes indicating possible septal or anterolateral infarction within the first month after the operation (by the χ^2 test).

Discussion

The most important finding of this study is that 8 (15%) of 52 IMAs injected with papaverine showed evidence of mechanical injury at microscopy. These injuries most likely were caused by the cannulation procedure that was used for injection of the papaverine solution. The cannula may have penetrated or ruptured the media or stripped the media off the adventitia, thereby possibly also avulsing side branches. It is conceivable that the risk of wall injury could be reduced by use of a specially designed cannula. The hazard of mechanical damage by cannulation of the IMA is illustrated by these findings although no obvious case of IMA hypoperfusion was seen among our patients. Postoperative IMA spasm is a recognized clinical problem.⁵ Our findings suggest that mechanical injury is a plausible cause when the lumen has been cannulated. Detrimental effects of IMA dissection can usually be avoided by discarding the distal cannulated portion. It may, however, be difficult to properly judge the extent of the dissection. At times, discarding damaged distal IMA may make the pedicle too short.

Morphometric measurements on the resected distal portion of the IMA pedicle disclosed a larger luminal area and less folding of the internal elastic lamina in groups 2 and 3 compared with respective findings in group 1. By univariate analysis, however, no significant differences in blood flow rate were found among the groups; by multiple linear regres-

Fig. 3. Photomicrographs of cross sections of distal IMA segments that could not be evaluated morphometrically because of vessel wall injury (original magnification $\times 30$). All these segments belonged to groups 2 or 3 (intraluminal papaverine). **A**, Advanced dissection between tunica media and external elastic lamina is shown. Some blood remains in dissected space (*star*). **B**, Rupture (*arrow*) of tunica media has taken place. Minor dissection between tunica media and external elastic lamina also appears (*star*). **C**, Shown are Minor dissection (*star*) and side branch (*arrow*) dislodged into IMA lumen indicating that dissection at more distal level has taken place.

sion, on the other hand, the use of intraluminal papaverine was a predictor of high flow. In all three groups there was a marked (fivefold to eightfold) increase in free flow from the first to the second flow measurement. Thus the addition of papaverine intraluminally provided better flow and distal dilation than mere submersion of the artery in papaverine solution, but at a considerable risk of vessel wall injury.

Another finding was that there was no correlation between intimal thickening and free IMA flow or between intimal thickening and luminal area. This held true within all specimens and also within each of the three treatment groups, which indicated that intimal thickening did not lead to a reduced luminal area. This may be explained by a compensatory enlargement of the lumen with increasing intimal

thickening as described for coronary arteries.²³ Both in the present study and in a previous study²⁴ we found a moderate amount of intimal thickening in most of the IMAs and only a few with considerable thickening. The most important predictors of IMA blood flow after papaverine treatment were initial IMA blood flow values, the use of intraluminal papaverine, and arterial blood pressure (Table III).

The IMA flow rate in group 1 when the IMA was submerged in 1.5 mg/ml papaverine solution (median 58 ml/min) was similar to the rate we found in a previous study when the method of treatment was equal, except for the papaverine concentration (0.8 mg/ml, 60 ml/min).²⁵ Increasing the concentration of papaverine from 0.8 to 1.5 mg/ml therefore does not seem to increase flow.

IMA patency is reported to be excellent after

external application of papaverine.^{4, 7, 10, 25} On the other hand, patency after intraluminal injection of papaverine and hydrostatic distension has to our knowledge not been examined. Many reports on clinical results of coronary bypass grafting with IMA have not stated exactly what method, if any, was used to prevent or treat IMA spasm. It is known from experimental studies of bypass operations with vein grafts that the mode of graft treatment may influence endothelial integrity²⁶⁻²⁹ and patency.³⁰⁻³¹

In conclusion, the use of intraluminal papaverine entails a high frequency of vessel wall injury. Intraluminal papaverine solution administered once or twice in addition to external papaverine exposure is a predictor of high flow compared with only external papaverine exposure and provides a more effective distal dilation. The lack of correlation between intimal thickening and blood flow suggests that intimal thickening in the IMA is of no concern for its use as a conduit in coronary bypass grafting.

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