Original Article

Histological Study on the Influences of an Ultrasonic Scalpel on Skeletonized Vessel Wall

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Objective: The objective of this study was to histologically clarify the difference of vascular wall damage when an ultrasonic scalpel is used in varied ways in the vicinity of a vessel.
Subjects and Methods: 1) The surface of sodium carbonate-containing jelly was manually brushed with the edge of a dissecting hook type Harmonic Scalpel (HS), and the thickness of the air bubble layer was measured to investigate the range to which the vibrations of the instrument reached. 2) The internal thoracic artery (ITA), radial artery (RA) and vein skeletonized were cut bluntly or brushed using HS ex vivo, and tissue damages were observed histologically. 3) The depth of thermal degeneration (TD) of residual stumps of ITAs skeletonized by HS using an output power level (level) of 2 and the quick touch method at the time of coronary arterial bypass grafting (CABG) were investigated histologically.
Results: 1) The mean thickness of the air bubble layers by single brushing was 3.7, 3.7 and 3.1 mm at level 4, 3 and 2, and no significant difference. When brushed 5 times, it was 6.9, 5.5 and 6.7 mm, respectively, showing marked increases compared with single brushing. 2) A: One side of the RA stump cut with a dissecting hook at level 2 was nicely occluded by a degenerated protein coagulum, but the contralateral had no coagulum. An ITA cut by a shear type blade at level 3 showed that both stumps were nicely occluded, but the vessel wall was introverted and fragmented. B: ITAs brushed 5 or 10 times at level 2 showed that TD occurred in tunica externa, the mean depth of 100 or 203 μm , and never exceeded the external elastic lamella. RAs brushed 10 times at level 2 and 3 showed that TD and air bubble generation occurred in the tunica externa, and the mean depth was 203 and 203 μm. However, TD exceeded the external lamella in some cases at level 3. Veins brushed 10 times at level 3 showed that TD spread to all layers. 3) The depth of TD in ITAs skeletonized clinically by HS was 400 to 530 μm, and apart from the external elastic lamella.
Conclusions: 1) Though the air bubble layer was very thick in jelly, it was observed only in tunica externa ex vivo. 2) For coagulation and cut of small blood vessels, it is vital to press an HS blade edge onto the vessel so as to press equally both portions to be cut. There is a possibility of a fragmented and invtroverted vessel wall into the lumen. 3) By dissecting ITA and RA using HS at level 2 and the quick touch method, TD can be limited to the depth of the connective tissue of tunica externa. (Ann Thorac Cardiovasc Surg 2002; 8: 291–7)

Key words: ultrasonic scalpel, skeletonization, thermal degeneration (TD), internal thoracic artery (ITA), radial artery (RA), coronary artery bypass grafting (CABG)

Background

Recently, skeletonization is increasingly used for the dissection of internal thoracic and radial arteries as grafts for coronary artery bypass grafting (CABG), and an ultrasonic scalpel has been reported to be useful for the dissection. Conventionally, these arterial grafts have been skeletonized by a method to bluntly dissect the arteries using the blade edge of an electric cautery or a mosquito clamp and to coagulate arterial branches using bipolar-cautery. However, since electric cautery has the problem of causing strong thermal damage due to its very high temperature, it could not be used directly for the skeletonization of an internal thoracic artery (ITA). On

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the other hand, the ultrasonic scalpel (Harmonic Scalpel (HS); Ethicon Endo-Surgery, Cincinnati, Ohio), which became available recently, can dissect peri-vascular tissues and coagulate and cut vascular branches owing to mechanical incision by vibrations, cavitational fragmentation and protein coagulation. Regarding the problems associated with use close to a blood vessel, it has been reported on one hand that the ultrasonic scalpel least damages the vessel owing to a low temperature, whereas it has also been reported on the other hand that the damage reaches the depth of vascular walls. These opposing opinions on influences on vascular walls are thought to result from deficient information on differing influences on vascular walls depending upon the method in using an ultrasonic scalpel in the vicinity of a blood vessel. Thus, how the vascular wall is differently affected by varied usages of an ultrasonic scalpel in the vicinity of an artery was investigated experimentally, ex vivo histologically, and clinically in the present study.

Objective

The objective of this study was to histologically clarify the difference of vascular wall damage when an ultrasonic scalpel is used in varied ways in the vicinity of an artery.

Subjects and Methods

1) In the experimental study, the ultrasonic scalpel, HS, was manually contacted with commercially available sodium carbonate-containing jelly, and the depth of the air bubble layer was measured. For this manual contact, the jelly surface was lightly and quickly brushed with the edge (5 mm in diameter) of a dissecting hook type blade similarly to its clinical use (quick touch method). This brushing was performed once or repeated 5 times, and the depth of the air bubble layer was measured at 5 sites at intervals of 1 cm to obtain the mean value. Unless otherwise stated, the same blade edge and the same portion of the blade edge were used in all the following experiments.

2) In the ex vivo study, residual portions of the peripheral ends of radial artery (RA), ITA and great saphenous veins (GSV), that were all harvested by blunt skeletonization using a mosquito clamp at the time of CABG, were cut and brushed by HS. (A) A dissecting hook type HS and a shear type HS were used for cutting to investigate the difference between these two types. The output power level (level) was 2 for a dissenting hook type HS, and a blood vessel was manually pressed with the blade edge. The level for a shear type HS was 3. (B) For brushing, the blade edge was manually operated by the quick touch method, the HS level was 2 or 3, and brushing was repeated 5 or 10 times to investigate influences on vascular walls. After the brushing, the blood vessel was promptly fixed in formalin, stained with hematoxylin-eosin and observed histologically. Five to seven tissue sections were observed for individual samples, and the maximum depth of thermal degeneration (TD) was measured to obtain the TD depth. The TD depth was measured at varied levels and varied repetition times for intergroup comparison. The statistical significance of the difference between observed values were tested using the Mann-Whitney test taking $p<0.05$ as significant.

3) In the clinical study, the residual stumps of the ITAs that had been skeletonized by the quick touch method at the time of CABG were stained with hematoxylin-eosin, and the depth of TD was measured.

Individual patients had consented to the use of clinical residual tissues for the purpose of the present research, and the study had been approved by the clinical study ethics committee of our institute.

Results

1) The depth of the air bubble layer in the sodium carbonate-containing jelly

A: Figure 1A, C and E shows the results obtained by a single brushing at levels of 4, 3 and 2, respectively, and the observed depth of the air bubble layer was 3.65±0.59, 3.65±0.73 and 3.06±0.61 mm, respectively, as shown in Table 1. There was no significant difference among the three groups. B: The results obtained by 5 times brushing at levels 4, 3 and 2 are shown in Fig. 1B, D and E, respectively, and the depth of the air bubble layer was 6.90±1.32, 5.45±0.76 and 6.68±0.94 mm, respectively, as shown in Table 1. Although there was no significant difference among the three groups, the thickness was significantly greater in the 5 times brushing group than in the single brushing group.

2) Ex vivo influence of HS on vascular walls

A: Histological observation of the small blood vessels cut by HS

When an RA was strongly pressed with the blade edge of HS at level 2, the artery was easily cut within several sec-

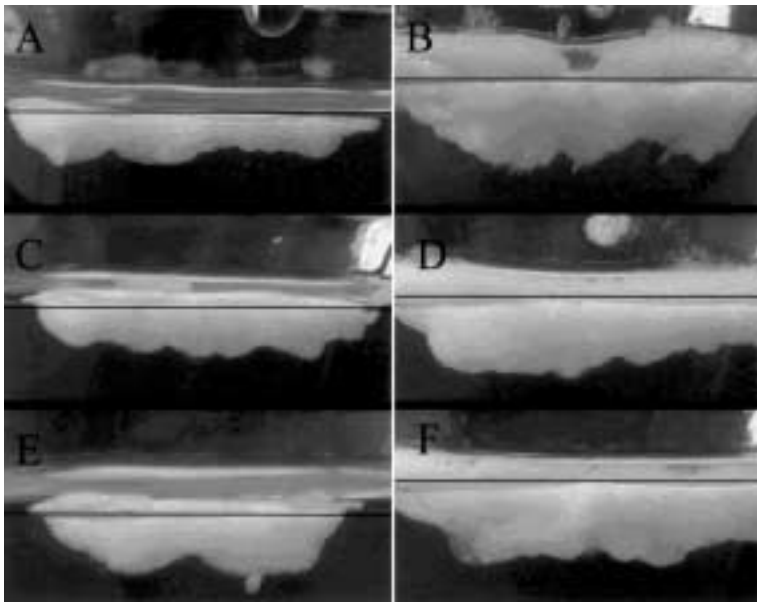

Fig. 1. The depth of the bubble layer in jelly.
The surface of the sodium carbonate containing jelly was brushed quickly by the edge of hook type blade. A, level 4, brushed once; B, level 4, 5 times; C, level 3, once; D, level 3, 5 times; E, level 2, once; F, level 2, 5 times. The depth was measured at 5 sites, with an interval of 1 cm. The mean values are summarized in Table 1.

Table 1. The depth of the bubble layer in sodium carbonate containing jelly according to the power level and brushing frequency

	Level	Frequency	N	Depth (mm) of bubble layer	
A	4	1	5	3.65±0.59	p<0.05
B	4	5	5	6.90±1.32	
C	3	1	5	3.65±0.73	p<0.05
D	3	5	5	5.45±0.76	
E	2	1	5	3.06±0.61	p<0.05
F	2	5	5	6.68±0.94	

The depth is dependent on the frequency of brushing. The influence of vibration of the tip reached to a depth over 6 mm. Level, output power level; frequency, brushing frequency.

onds. The tissue findings of both stumps are shown in Fig. 2A and B. In Fig. 2A, one stump was nicely coagulated and occluded by degenerated proteins. However, in Fig. 2B, the other side of the stump is perforated without coagulum and TD was strong, indicating that the direction of action is dependent upon the direction of the force applied to the blade edge. The ITAs sheared by a shear type blade edge at level 3 are shown in Fig. 2C and D. In this mode, TD occurred widely and the occlusion of stumps was satisfactory, but the whole vessel wall was rolled back and introverted into the lumen, and partly fragmented.

B: The depth of the vascular wall TD brushed by HS
As shown in Table 2, the mean depth of TD at level 2 was 100.0±31.6 μm in 5 times brushing and 202.8±75.7μm in 10 times brushing. The mean depth of TD at level 3 was 203.3±49.7 μm in 10 times brushing. Thus, the mean depth was significantly smaller in 5 times brushing at level 2 than in 10 times brushing at levels of 2 and 3, but no significant difference was observed when brushing was repeated 10 times at level of either 2 or 3.

Typical specimens are shown in Fig. 3. An ITA brushed 5 times at level 2 is shown in Fig. 3A. In this specimen, the depth of TD was 130 μm maximum and stayed at the outside of the external elastic lamella. An ITA brushed 10 times at a level of 2 is shown in Fig. 3B, in which the maximum depth of TD was 357 μm and thicker than that of 5 times brushing, but did not invade the external elastic lamella. Figure 3C shows the RA which was brushed 10 times at level 2, in which the maximum depth of TD was 333 μm and did not invade the external elastic lamella. An RA which was brushed 10 times at level 2 in a manner similar to Fig. 3C is shown in Fig. 3D, in which TD was mild, but many small air bubbles were formed inside the tunica externa. Figure 3E shows an RA brushed 10 times at level 3, in which both air bubble generation and TD were observed and the maximum depth of TD was 562 μm exceeding the external elastic lamella. A GSV brushed 10 times at level 3 is shown in Fig. 3F, in which tissue defect was observed in the tunica externa and TD

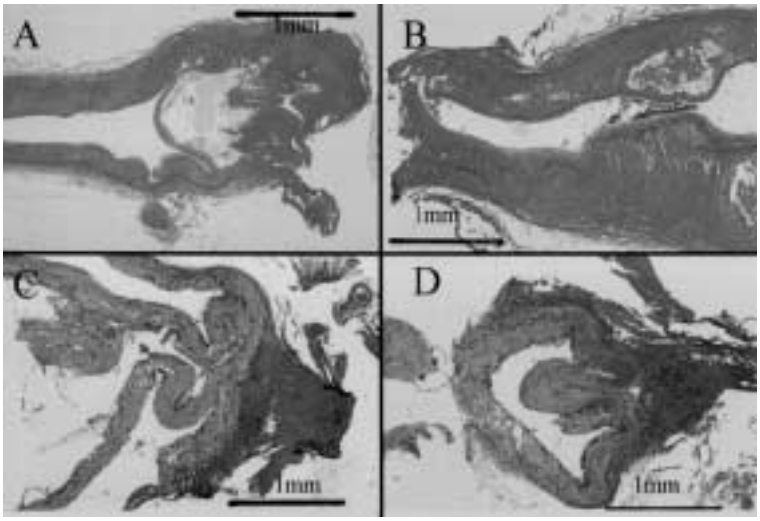

Fig. 2. Histological finding of the stumps of small artery cuts with an HS.
A and B: An RA cut using dissecting hook type, level 2. The stump of A was occluded by coagulum with TD by circa 1 mm long. However, in the stump of B there was no coagulum, but TD, indicating that formation of the coagulum is dependent on the direction of edge of hook type blade.
C and D: An ITA cut using shear type, level 3. Both stumps were well coagulated with TD and occluded by introverted vessel wall. The introverted and fragmented vessel wall was characteristic and might cause embolization.

Table 2. The depth of TD in the arterial wall according to power level and brushing frequency

	Level	Frequency	Sample	Depth (μm) of TD
A	2	5	4	100.0±31.6 (60.0-130.0)
B	2	10	15	202.8±75.7 (97.3-400.0)
C	3	10	9	203.3±49.7 (115.0-562.0)

A vs. B, $p<0.05$. A vs. C, $p<0.05$. B vs. C, n.s.
Bluntly skeletonized internal artery and radial artery were brushed quickly by the edge of hook type blade. The maximum depth of thermal degeneration was measured on every sample and the values were averaged. The averaged depth of thermal degeneration is dependent on the frequency of brushing. The maximum value was at level 3, brushed 10 times. Level, output power level; frequency, brushing frequency.

invaded the tunica intima.

3) Clinical study

The blood vessels were 3 to 5 mm in length, and 5 to 7 sections were prepared from each vessel. The specimen shown in Fig. 4A had low stainability at thermal degenerated portions and a depth of 529 μm maximum, but stayed within connective tissue outside the tunica externa. In the specimen shown in Fig. 4B, TD was strong, but the depth was 411 μm maximum and stayed within the external layer of fat tissue. In all ITA samples, the depth of TD was apart from the tunica externa, stayed within the connective tissue or fat tissue layer and never reached the external elastic lamella or the tunica media.

Discussion

A special issue in the dissection of the ITA and RA by means of skeletonization in CABG is how to fulfill the following delicate condition: good coagulation and cutting of arterial branches, and dissection of perivascular tissue without damaging the arterial wall itself. After graft anastomosis, it is also necessary not to induce vascular lumen stenosis due to spasm, cellular infiltration into vascular walls, the invasion of plasma constituents, hemorrhage, and thrombus formation. As the method fulfilling the above condition, Higami et al.[1] have proposed using a dissecting hook type HS at level 2 and to properly use the quick touch method and the close coagulation method, and reported that good dissection, good coagulation and abscission of arterial branches could be obtained. Problems concerning the coagulation and abscission of ITA branches by the close coagulation method have been histologically and physiologically investigated by Higami et al.[2] using the branches of pig ITAs. However, any histological report on the influence of the quick touch method on the main duct of ITA could not be found within the range of search. Therefore, we investigated the influence of the quick touch method on the vascular walls of ITA, RA and GSV in the present study.

According to Kawabata,[3] the blade edge of HS vibrates at a frequency of 55,500 Hz with an amplitude of 50 to 100 μm, and when the blade edge contacts a tissue, intra-

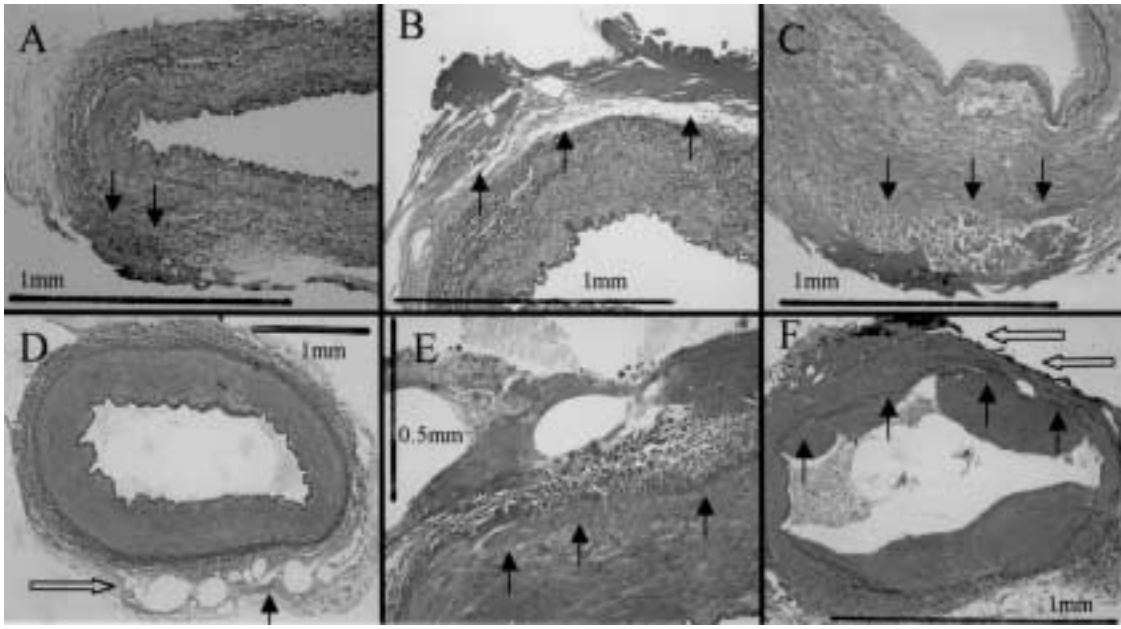

Fig. 3. Histological finding of a small vessel brushed with edge of a dissecting hook type.
Every vessel was skeletonized following blunt method without electric cautery.
A: ITA, level 2, brushed 5 times; the depth of TD (arrows) was 130 μm maximally.
B: ITA, level 2, brushed 10 times; the depth of TD (arrows) was 357 μm maximally.
C: RA, level 2, brushed 10 times; the depth of TD (arrows) was 333 μm and remained outside of the external elastic lamella.
D: RA, level 2, brushed 10 times; the depth of TD was minimal (arrow), but there were a lot of small bubbles in the connective tissues (open white arrow).
E: RA, level 3, brushed 10 times; the depth of TD (arrows) was 562 μm and beyond the external elastic lamella with small bubbles.
F: small vein, level 3, brushed 10 times; the TD (arrows) reached all layers and part of the tunica externa was defected (open white arrows).

cellular water-soluble substances are vaporized by cavitation. Suzuki et al.[4] investigated the generation of air bubbles by blade edge vibrations in agar and reported that there was directionality in air bubble generation depending upon the shape of the blade edge. In the present study, the mean thickness of the air bubble layer generated by instantaneous brushing of the jelly surface with an HS blade edge was 3.06 to 3.65 mm in single brushing, which increased to 5.45 to 6.90 mm in 5 times brushing, as shown in Fig. 1 and Table 1. Even when the lateral side of the blade edge sololy touched to the jelly, the thickness of the generated air bubble layer reached about 4.5 mm. As we had clinically manipulated the edge 5 to 8 times closer to the artery, there is a possibility that the influence of blade edge vibrations reached not only the vascular wall with which the blade edge contacted, but also the intravascular blood and the contralateral vascular wall as well. However, in our ex vivo studies, many air bubbles with a diameter of 50 to 400 μm were observed only in the tunica externa of RA as shown in Fig. 3D and E. Why air bubbles appeared only in the tunica externa of RA is not clear. This may be attributable to a difference in the amount of the gas dissolved in tunica externa tissues and to the absorption and buffering of vibrations by intact tissues. McCarus[5] and Kawabata[3] have reported that the cavitation action due to vibrations is secondary in tissue incision and destroys low-density tissues such as fat tissue.

Kawabata[3] has reported that HS is able to clinically coagulate and cut blood vessels with a diameter of 3 mm, and stated that ultrasonic vibrations destroy the tertiary hydrogen bonds to degenerate proteins to the adhesive coagulum which then occludes the blood vessel to induce hemostasis, and the heat generated secondarily facilitates coagulation. This study indicated that in abscission of a vessel by HS, the action of the HS blade edge is

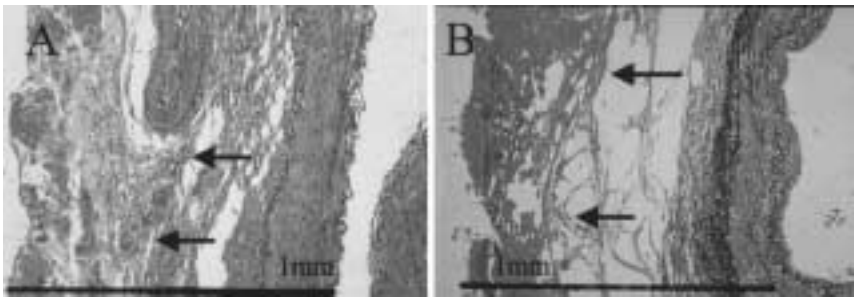

Fig. 4. Histological finding of TD in the ITA skeletonized clinically with a dissecting hook type, level 2.
A: case 1, 56-year-old man; the depth of TD (arrows) was 529 μm and remained outside of external elastic lamella and connective tissue.
B: case 2, 69-year-old man; the TD (arrows) was 411 μm and remained outside of external elastic lamella and fat tissue.

affected by the direction of pressuring and causes the introversion and fragmentation of vessel wall. Thus, it is necessary to press both sides of a planned stump as equally as possible when an ITA-branch is to be coagulated and cut using a dissecting hook type blade edge. Bahn et al.[6] observed a white coagulum in the lumen of ITA and recommended allowing the blood to flow out of a stump to prevent embolization. This coagulum was possibly a fragmented vessel wall.

For investigating the influence of HS on the main duct walls of ITA and RA, we brushed the blood vessels harvested by blunt skeletonization with an HS blade edge as the most extreme example using HS in the vicinity of a blood vessel. The TD remained ouside external elastic lamina at level 2 in 5 and 10 times brushing. However when brushed 10 times at level 3 , the maximum depth was 562 μm and began to pass through the external elastic lamella, and reached the tunica intima layer in the veins. Kadesky et al.[7] histologically investigated the influences of HS when it was used in the vicinity of vessels of pigs in the same manner as the use of an electric cautery for the dissection of aorta of pigs, and reported that TD invaded 1/3 of all layers of the aorta wall. These results differ from ours, but this difference is thought to be due to different ways of HS usage. As the factors determining the degree of HS-induced TD, the following five factors may be raised: 1) the strength of compression on tissue by a blade edge, 2) the duration of contact between a blade edge and tissue, 3) output power level, 4) the direction of the pressure applied to a blade edge, and 5) the shape of a blade edge. Since the strength of tissue compression by a blade edge is dependent upon the feeling of an operator, very light brushing is vital. According to McCarus,[5] HS-induced tissue degeneration becomes deeper as the duration of contact between a blade edge and a tissue prolongs, and Higami et al.[1] have stated that HS should be contacted with an arterial wall for 0.1 to 0.2 sec in skeletonization of ITAs. Kinoshita et al.[8] investigated the relationship between the tissue temperature around a shear type blade edge and the duration of action, and reported that the tissue temperature stayed at levels lower than 80°C until 8 sec, then increased rapidly up to 150°C. Since HS is used continuously for several minutes clinically, the blade edge temperature possibly reaches 150°C.

The power to incise a tissue is reported to increase as the level is raised. Since there were risks to cut internal thoracic arterial branches more frequently at level 3, we use level 2 clinically. In the histological study of clinical cases, the tissue of tunica externa was preserved sufficiently, and the depth of TD was apart from the external elastic lamella by 300 μm or more. These findings indicate that, when level 2 and the quick touch method are used, HS-induced TD has a low possibility of reaching the tunica media.

Regarding the selection of a graft for CABG, Loop et al.[9] and Kitamura et al.[10] anastomosed the single ITA dissected by the pedicle method with the left anterior descending branch, and reported the usefulness of this method based on the survival rate and the rate of avoidance of cardiac accidents in their follow-up for 10 years. Calafiore et al.[11] reported that the skeletonization of bilateral ITAs showed such good results as a decrease in the occurrence of hypoperfusion syndrome and that of

sternal infections in diabetes mellitus-complicated cases. Thus, a method to dissect bilateral ITAs by skeletonization is thought to be more popular in the future. Very careful surgical manipulations are needed for the skeletonization of ITA using an electric cautery as pointed out by Cunningham.[12] Accordingly, the development of an instrument which is safer and with which skills can be acquired more easily than an electric cautery has been desired. The histological results of our ex vivo and clinical studies demonstrate the possibility that HS-induced TD stays at the depth of the connective tissue of tunica externa, and HS is thought to be able to dissect ITA more safely than an electric cautery. With respect to problems concerning the dissection of ITA by skeletonization using an electric cautery, associated in vivo reactions were investigated by Sasajima et al.[13] using experimental animals and by Gaudino et al.[14] electron microscopically, and both investigators reported good results. Regarding HS, on the other hand, the changes that cannot be detected by a light microscope, and problems such as cellular infiltration into vascular walls after starting blood reperfusion and infiltration with plasma constituents are still unsolved.

Conclusions

1) The thickness of an HS-induced air bubble layer is dependent upon the frequency of brushing of sodium carbonate-containing jelly.
2) In the ex vivo study, the air bubble layer stays at a depth of 500 μm and was observed only in the tissue of the tunica externa of the RA.
3) The close coagulation method is effective for the coagulation and cutting of arterial branches, but every precaution must be taken to make the edge contact the branch as rectangularly as possible, to press both sides of a stump equally and to allow a coagulum and fragmented vessel wall to flow out to prevent embolism.
4) When ITA and RA skeletonized bluntly were brushed with HS by the quick touch method, the TD never exceeded the external elastic lamella in 10 times brushing at level 2, but it exceeded the external lamella and damaged all venous layers in 10 times brushing at level 3.
5) When an ITA was skeletonized using HS clinically, induced TD stayed at the depth of the connective tissue of tunica externa and did not affect the tunica media and tunica intima.
6) Fine structural changes in ITA and RA affected by HS and in vivo reactions after anastomosis are to be investigated.

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