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Morphological and Clinical Analysis of Extra-Intracranial Bypass

2. Histological and Histometrical Evaluation with Correlation of Angiographical Findings

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Summary. Rest segments of superficial temporal arteries obtained during STA-MCA anastomoses were studied histologically and histometrically. Aging was found to be associated with thickening of the intimal layer and thinning of the medial layer. In comparison with the young patients, the old patients showed a larger internal diameter of the superficial temporal artery and a larger ratio of the thickness of the intimal layer to the medial layer. The internal diameter calculated angiographically and the internal diameter estimated histologically correlated well. The dilatation ratio of the superficial temporal artery did not correlate with dimensional data assessed histologically.

Key words: Superficial temporal artery – STA-MCA anastomosis – Atherosclerosis – Hypertension – Light microscopy – Cerebral angiography

Introduction

The superficial temporal artery is commonly used as a donor artery for extra-intracranial arterial bypass surgery because its use is anatomically feasible. Despite the considerable volume of literature on superficial temporal artery-middle cerebral artery (STA-MCA) anastomosis only a few reports have centered on this artery [4, 5, 6, 8, 15] and none have dealt with the relationship between its angiographical and histological features with special reference to STA-MCA anastomosis. We have described separately [10] the results of preoperative and postoperative angiographical analysis. Here we report a study on the histological and histometrical features of the superficial temporal artery and on the correlation of angiographical and histological findings.

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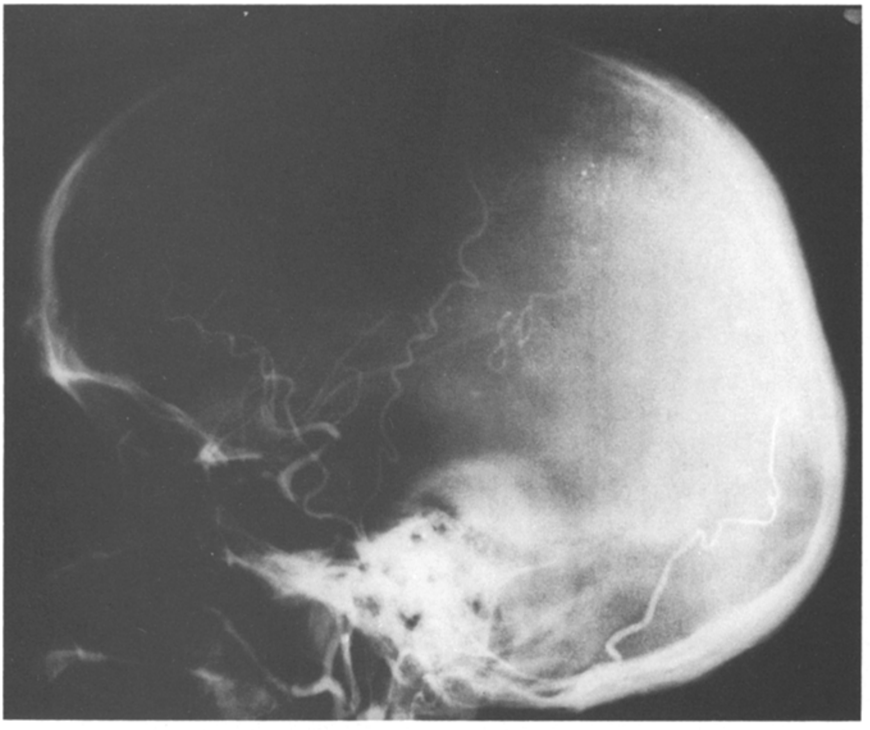

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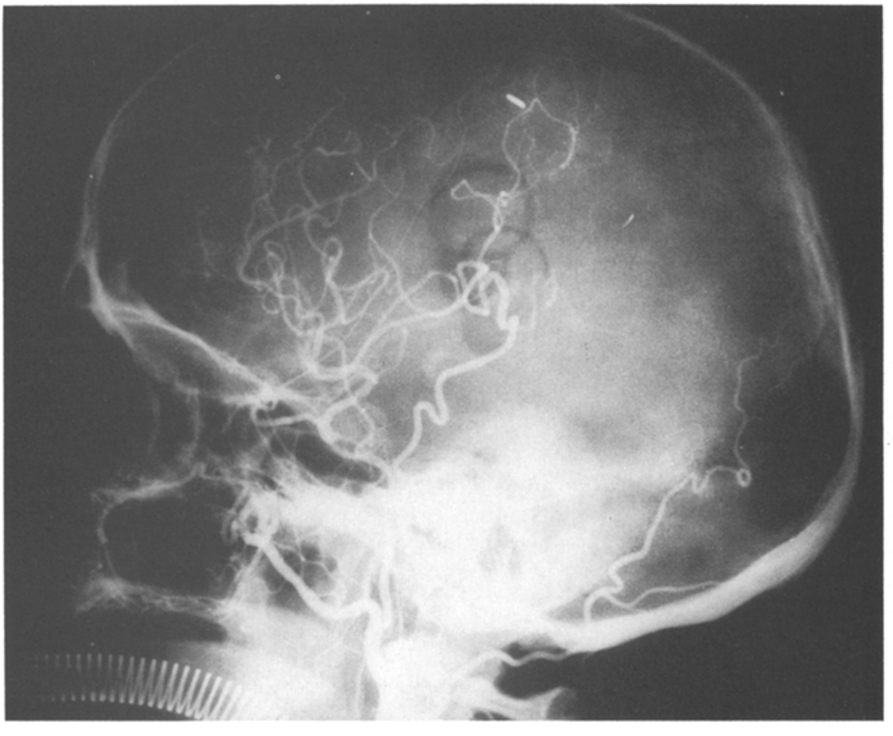

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Materials and Methods

During 46 consecutive STA-MCA anastomoses for cerebral ischemia in the Department of Neurosurgery, Klinikum Grosshadern, University of Munich, performed between January and October 1977, 52 rest segments of the superficial temporal artery were obtained when the artery was trimmed for anastomosis. In 6 cases the operation was performed bilaterally. The patients, 36 men and 10 women, were divided into three age groups, "young" (under 40-years-old), "middle-aged" (41 to 60) and "old" (over 61). Each group was divided into hypertensive and non-hypertensive subgroups. Details of these cases including angiographical events have been reported elsewhere [10].

Vascular segments were first immersed in saline solution at room temperature for approximately 30 min to release the vasoconstriction induced by mechanical manipulation on surgery, then in buffered 10% formalin solution for approximately 24 h. After embedding in paraffin, they were sliced circumferencially into 8 μ sections and stained with hematoxylin-eosin or elastic van Gieson stain.

All suitable specimens were subjected to the following histometrical assessment on the basis of microphotographs taken using a microscope fitted with a calibrated lens: internal diameter, D_i; external diameter, D_e; thickness of intimal layer, T_i; and thickness of medial layer, T_m. Using the shrinkage ratios reported by Wolinski and Glagov [16], who found that fixation with buffered 10% formalin solution reduced the arterial diameter by an average of 14% and subsequent histological processing including paraffin embedding resulted in a further reduction of approximately 16%, we corrected our data to probable unfixed dimensions. Circularly arranged cell layers in the media were counted in specimens stained with hematoxylin-eosin. Intimal proliferation was graded according to the relative thickness of the intima of the media: grade 1, the overall intimal thickness does not exceed half that of the media; grade 2, the overall intimal thickness exceeds half that of the media but does not exceed the thickness of the media; and grade 3, intimal thickness exceeds that of the media. Fragmentation of internal elastic lamina, herniation of the intima into the media and intimal dissection from the medial layer were graded arbitrarily, also into three degrees.

Before and after surgery the diameter of the superficial temporal artery was measured on lateral view angiographs at the site of anastomosis of the parietal or frontal branch. The real value of the internal diameter, $D_{i\,(ang)}$, was then calculated by use of the angiographical magnification ratio. The change in diameter of the superficial temporal artery was expressed as dilatation ratio: the ratio of the postoperative to preoperative diameter of the superficial temporal arterial branch, measured at the same point. Figure 1 shows the preoperative and postoperative left carotid angiograms of a patient with bilateral internal carotid occlusion who underwent bilateral STA-MCA anastomosis. Figure 2 shows a microphotograph of a specimen of the left superficial temporal artery taken from the same patient.

Results

Aging changes in almost all specimens were in agreement with those reported by Lie et al. [8], who classified them into four basic patterns: infantile, youth, adult and senile. Our specimens showed youth, adult or senile patterns. With advancing age the intimal layer tended to thicken and the medial layer become thinner. In specimens from young patients intimal proliferation began with the apparent reduplication of the internal elastic lamina into two or more tiers of irregular

Fig. 1A, B. Preoperative (**A**) and postoperative (**B**) left carotid angiographs of 48-year-old man with bilateral internal carotid occlusions who underwent bilateral STA-MCA anastomoses. The parietal branch of the superficial temporal artery was used as the donor artery for left STA-MCA anastomosis. Postoperative angiography was performed 7 months after surgery and the dilatation ratio of the donor artery was 3.4

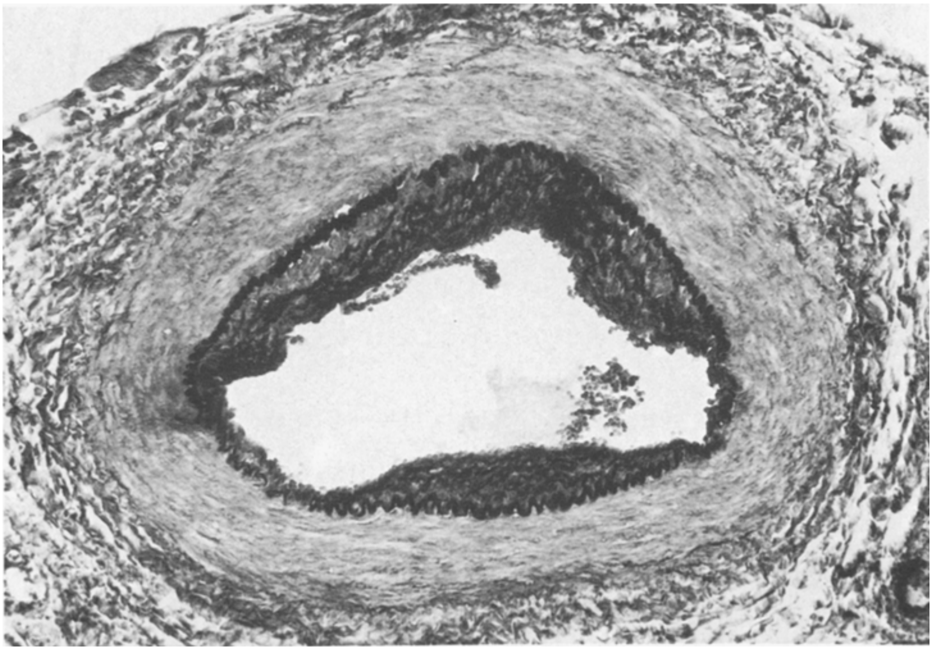
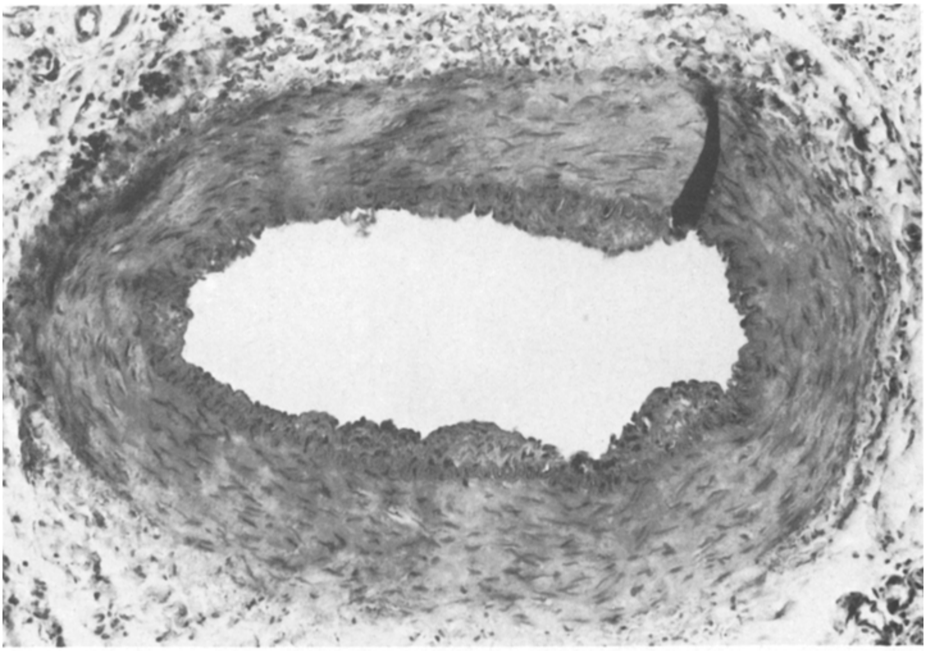


Fig. 2. Microphotograph of parietal branch of the superficial temporal artery taken from the same patient as in Fig. 1. Moderate intimal proliferation is seen. Estimated real internal diameter from this specimen, D_i, and other dimensional data are as follows: D_i, 0.43 mm; D_i/D_e, 45%; T_i/T_m, 68%. Elastic van Gieson, ×10

wavy accessory elastic fibrils lying between the internal elastic lamina and the endothelium (Figs. 3 and 4). The overall intimal thickness, however, seldom exceeded half that of the media, as shown in Fig. 4. Focal concentration of this proliferative activity, which Lie et al. [8] called "dome-shaped musculo-elastic cushion", was also noted (Fig. 4). In specimens from patients over 40-years-old, diffuse intimal thickening often attained or even exceeded the thickness of the media, as shown in Fig. 5, and fragmentation and fraying of the internal elastic lamina became apparent. In this adult pattern the medial layer contained an increased amount of collagen. The senile pattern was found in specimens taken from patients in the late sixth or seventh decades (Figs. 6 and 7). The intima was often more than twice as thick as the media, due to either a further increase of intimal connective tissue or atrophy of the media, or both. The internal elastic lamina was frequently so severely disrupted that it was difficult to single out this structure (Fig. 6). Organization of intimal fibrocollagenous tissue into two distinct zones, an inner dense collagenous layer with scanty elastic fibers and an outer elastic hyperplastic collagenous lays as described by Lie et al. [8], was also apparent (Fig. 7).

No significant difference was found in the number of layers of circularly arranged muscular cells in the media between hypertensive and non-hypertensive subgroups or between the three age groups (Table 1). The degrees of intimal proliferation, fragmentation of internal elastic lamina, herniation of the intima



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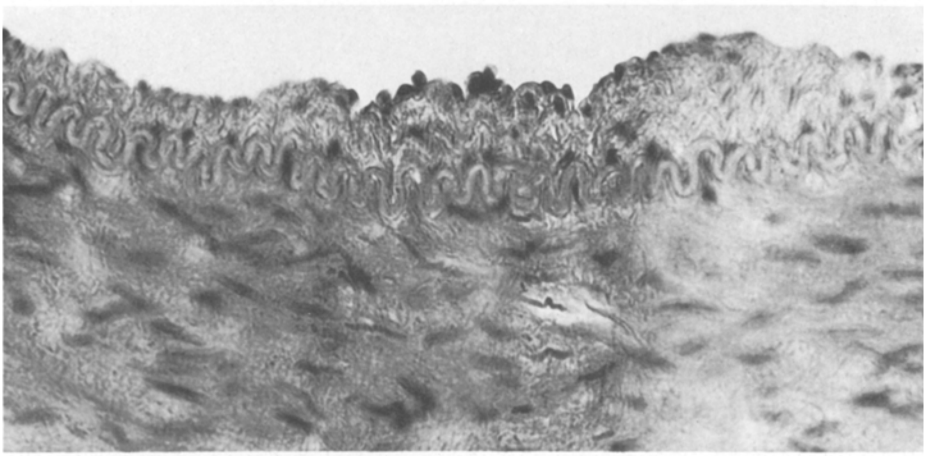

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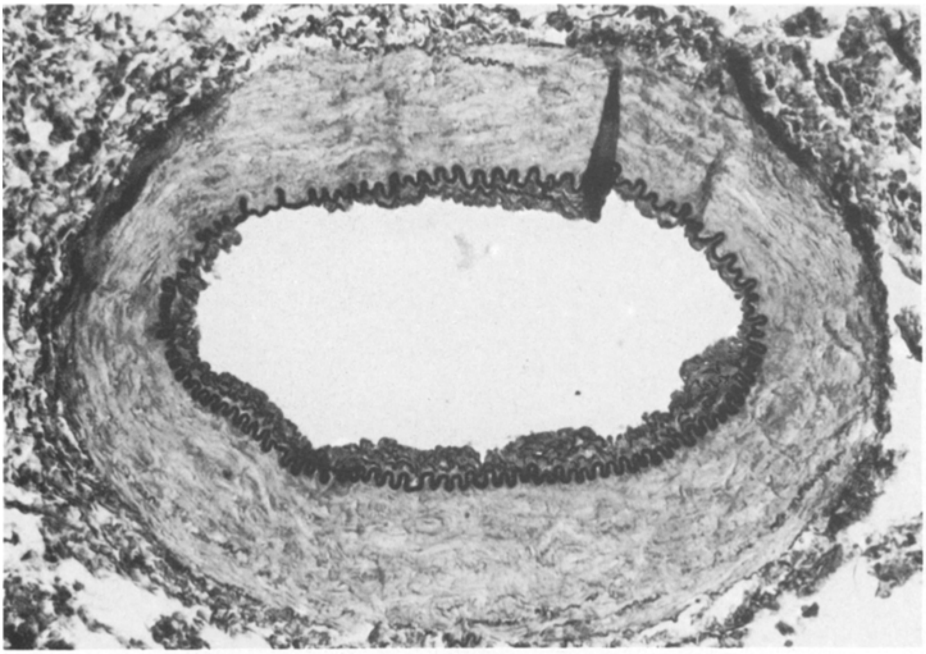
Fig. 3A, B. Parietal branch of the superficial temporal artery from a 23-year-old man. Intimal proliferation is mild. Muscle cell layers are arranged circumferentially in order. Hematoxylin-eosin: (**A**) ×12.6, (**B**) ×32

into the media and intimal dissection were higher in the middle-aged and old groups than in the young group, whereas no significant difference in these pathological changes was found between the middle-aged and old groups (Table 2). The three age groups showed little difference in types of intimal proliferation (Table 2).



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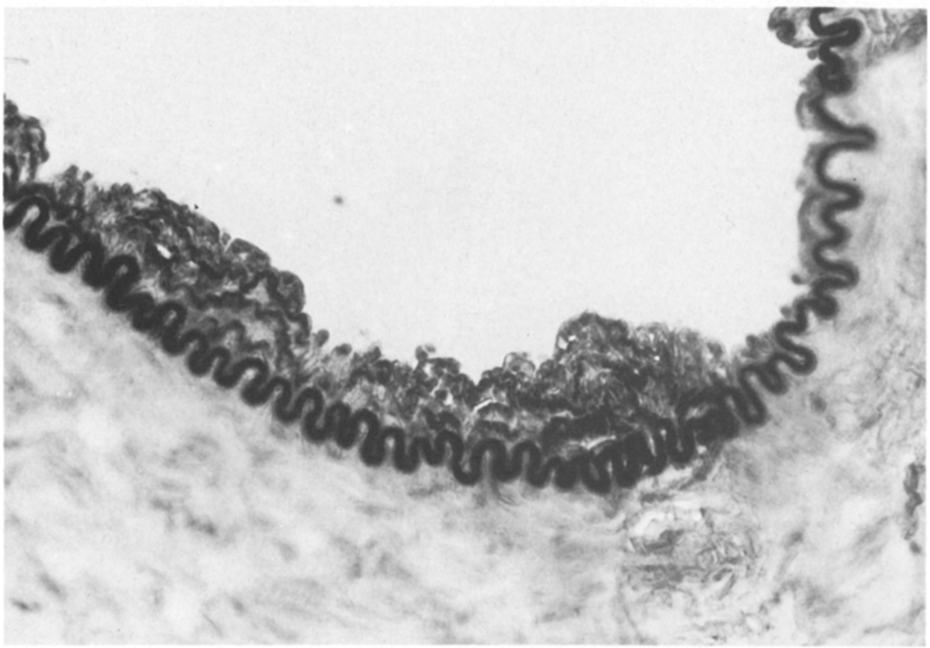

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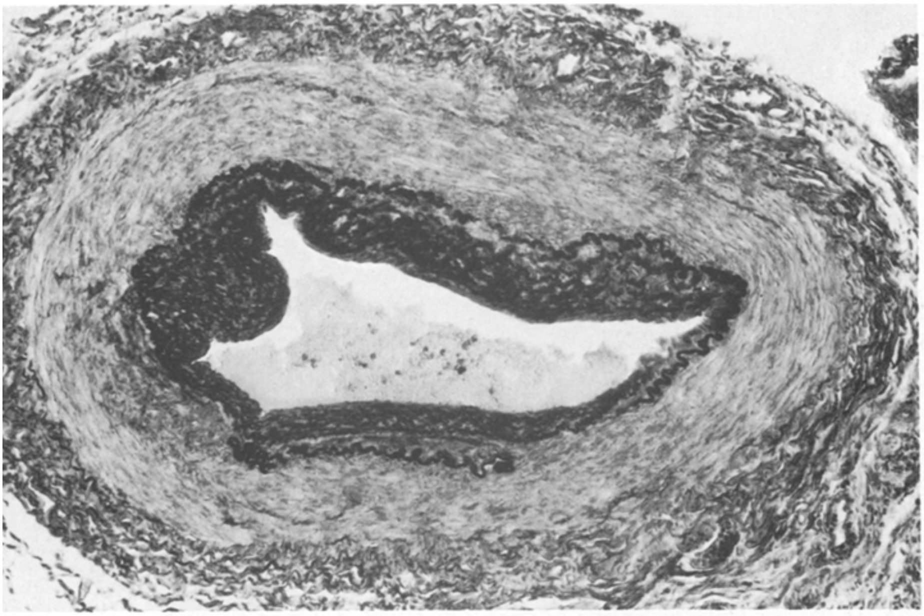
Fig. 4A, B. The same artery as in Fig. 1. Focal concentration of intimal proliferation, a "dome-shaped musculo-elastic cushion", is seen. Elastic van Gieson: (**A**) ×12.6, (**B**) ×32



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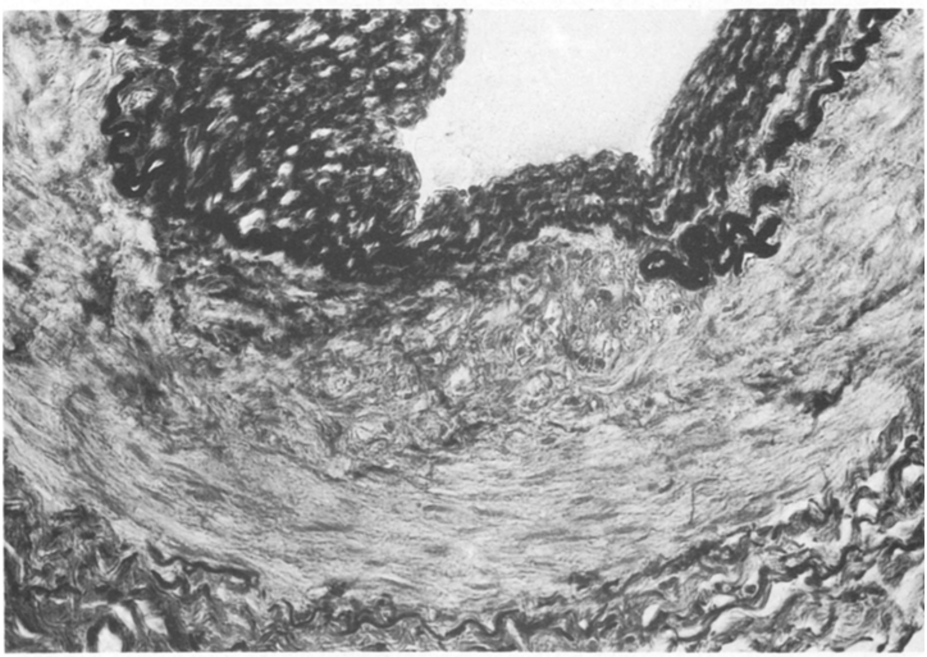

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Fig. 5A, B. Parietal branch of the superficial temporal artery from a 52-year-old man. Diffuse but uneven, "focal", moderate intimal proliferation and reduplication of the internal elastic lamina are seen. Fragmentation and fraying of the internal elastic lamina and intimal herniation into the media through a wide gap in the internal elastic lamina are observed focally. The medial layer contains an increased amount of collagen. Elastic van Gieson: (**A**) ×10, (**B**) ×20

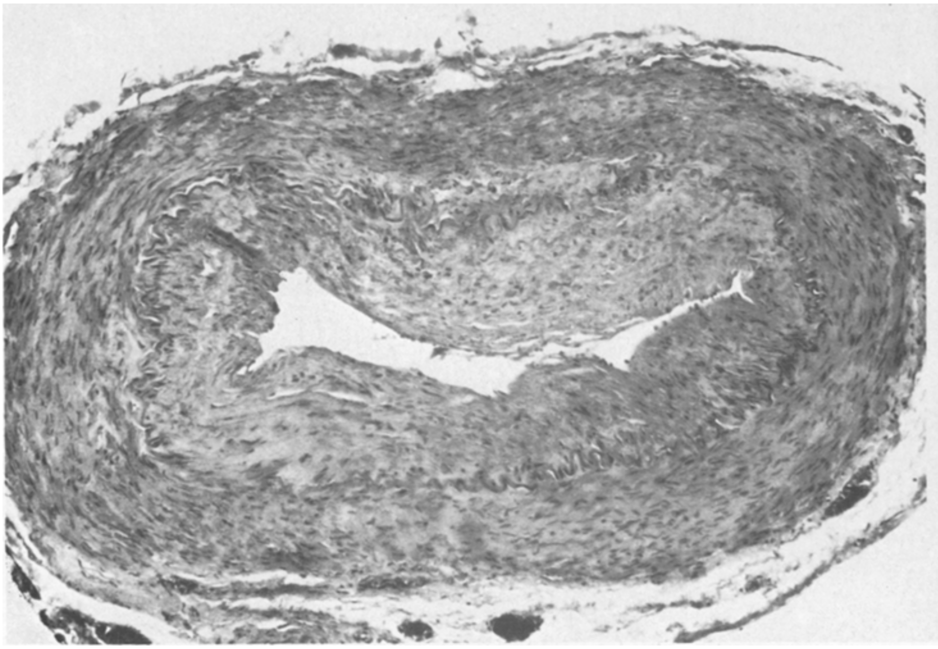

Fig. 6. Parietal branch of the superficial temporal artery from 65-year-old man. The intima is more than twice as thick as the media in most parts and the arrangement of muscular cells in the media is disordered. A tendency to intimal dissection from the medial layer is apparent between the internal elastic lamina and the media. Hematoxylin-eosin, ×7.9

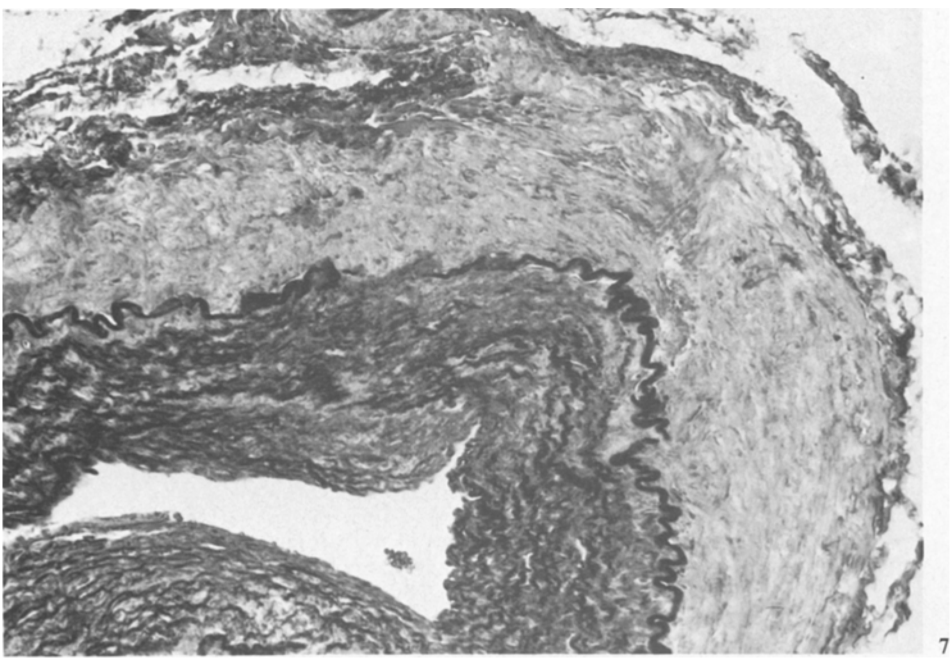

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Table 1. Numbers of medial cell layers in the superficial temporal arteries

Age group	Numbers of medial cell layers in the superficial temporal arteries	
Young		
Hypertensive	8.3±1.3 (n= 4)	10±5 (n=10)
Non-hypertensive	11 ±6 (n= 6)	
Middle-aged		
Hypertensive	11 ±4 (n=19)	11±4 (n=33)
Non-hypertensive	12 ±3 (n=13)	
Old		
Hypertensive	9.7±0.6 (n= 3)	11±3 (n= 8)
Non-hypertensive	11 ±4 (n= 4)	
Total		
Hypertensive	10 ±3 (n=26)	11±4 (n=51)
Non-hypertensive	12 ±4 (n=25)	

The internal diameter, D_i, of the superficial temporal artery was compared in the hypertensive and non-hypertensive groups and in the three age groups. Mean values and standard deviations of D_i were 0.40±0.11 mm in the young group, 0.46±0.12 mm in the middle-aged group and 0.53±0.09 mm in the old group. The difference between young and old groups is statistically significant ($P<$ 0.025). D_i was larger in the non-hypertensive than in the hypertensive subgroup in the young and old groups, but the difference was not statistically significant. No significant difference was found between the hypertensive and non-hypertensive subgroups in the ratio of internal diameter to external diameter or in the ratio of the thickness of the intimal layer to the medial layer (Table 3). The ratio of internal diameter to external diameter, D_i/D_e, was larger in the younger group than in the older groups, but the differences were not statistically significant. This ratio was also similar for hypertensive and non-hypertensive subgroups in each age group. The ratio of thickness of the intimal layer, T_i, to that of the medial layer, T_m, was larger in the older groups than in the young group and the difference between the young group and the old groups was statistically significant ($P<0.05$). Except in the old group this ratio was larger in the hypertensive than in the non-hypertensive subgroup.

Figure 8 shows the relationship between the internal diameter of the superficial temporal artery calculated from the value measured on postoperative angiograms just proximal to the site of anastomosis, $D_{i\,(ang)}$, and that calculated from histometrical analysis of the same specimen, D_i. The angiographically calculated

Fig. 7. The same artery as in Fig. 6. Fragmentation and fraying of the internal elastic lamina are prominent. Intimal fibrocollagenous tissue becomes organized into two distinct zones, an inner dense collagenous layer with scanty elastic fibers and an outer elastic hyperplastic collagenous layer. Elastic van Gieson, ×20

Table 2. Grading of histological changes in the superficial temporal arteries

Age group	No. of speci-mens	Intimal proliferation					IEL fragmentation			Herniation of intima into media			Intimal dissection		
		Relative thickness			Type										
		I	II	III	Focal	Diffuse	I	II	III	I	II	III	I	II	III
Young	10	3	6	1	3	7	9	1	0	9	1	0	8	1	1
Middle-aged	33	0	9	24	6	27	8	11	14	14	9	10	20	3	10
Old	9	0	1	8	2	7	2	4	3	2	4	3	4	0	5
Total	52	3	16	33	11	41	19	16	17	25	14	13	32	4	16
	(%)	(6)	(31)	(64)	(21)	(79)	(37)	(31)	(33)	(48)	(27)	(25)	(62)	(8)	(31)

Table 3. Dimensional data of the superficial temporal arteries (mean ± SD)

Age group	Internal diameter		Ratio of internal diameter to external diameter		Ratio of thickness of intimal layer to thickness of medial layer	
	D_i	(mm)	D_i/D_e	(%)	T_i/T_m	(%)
Young						
Hypertensive	0.35 ± 0.05 (n=3)	0.40 ± 0.11* (n=10)	50 ± 11 (n=3)	51 ± 9 (n=10)	64 ± 22 (n=3)	55 ± 24** (n=10)
Non-hypertensive	0.42 ± 0.13 (n=7)		52 ± 10 (n=7)		51 ± 24 (n=7)	
Middle-aged						
Hypertensive	0.47 ± 0.12 (n=19)	0.46 ± 0.12 (n=33)	44 ± 13 (n=19)	46 ± 13 (n=33)	108 ± 86 (n=19)	94 ± 70 (n=33)
Non-hypertensive	0.46 ± 0.12 (n=14)		49 ± 12 (n=14)		72 ± 30 (n=14)	
Old						
Hypertensive	0.49 ± 0.07 (n=3)	0.53 ± 0.09 (n=8)	45 ± 13 (n=3)	44 ± 9 (n=9)	88 ± 34 (n=3)	95 ± 30 (n=9)
Non-hypertensive	0.55 ± 0.10 (n=5)		44 ± 9 (n=6)		99 ± 30 (n=6)	
Total						
Hypertensive	0.46 ± 0.11 (n=25)	0.46 ± 0.11 (n=51)	45 ± 13 (n=25)	47 ± 12 (n=52)	102 ± 78 (n=25)	86 ± 56 (n=52)
Non-hypertensive	0.47 ± 0.12 (n=26)		49 ± 11 (n=27)		72 ± 33 (n=27)	

* Statistically significant difference ($P>0.025$) from old group
** Statistically significant difference ($P>0.05$) from old group

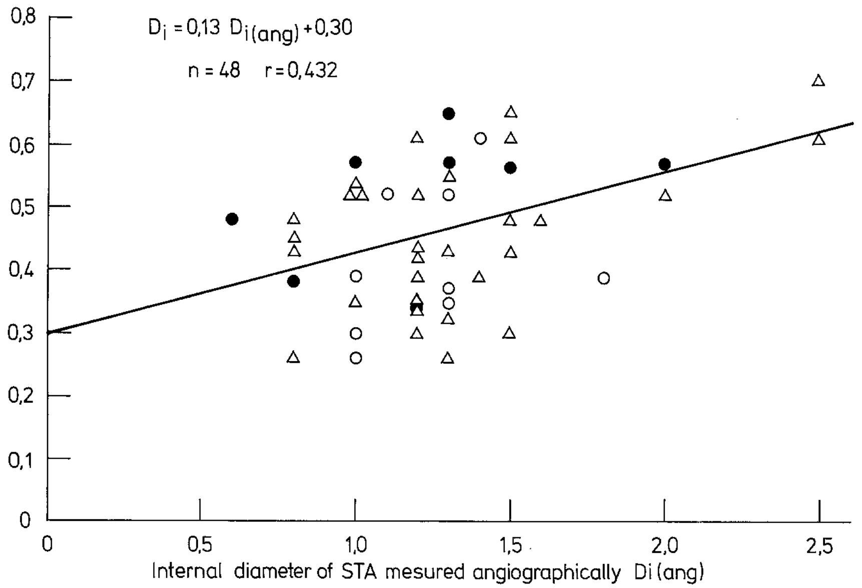


Fig. 8. Relationship between the internal diameter estimated by histometrical analysis, D_i, and that calculated angiographically, $D_{i\,(ang)}$. (○) young; (△) middle-aged; (●) old

Table 4. Ratio of internal diameter of the superficial temporal artery estimated from histological specimens to that measured angiographically

Age group	Ratio of histological to angiographical diameters (mean ± SD)		
	Hypertensive (%)	Non-hypertensive (%)	Total (%)
Young	34 ± 8 (n = 2)	34 ± 10 (n = 7)	34 ± 9 (n = 9)
Middle-aged	36 ± 10 (n = 18)	39 ± 13 (n = 14)	38 ± 11 (n = 32)
Old	53 ± 23 (n = 3)	45 ± 11 (n = 5)	48 ± 16 (n = 8)
Total	38 ± 12 (n = 23)	39 ± 12 (n = 26)	39 ± 12 (n = 49)

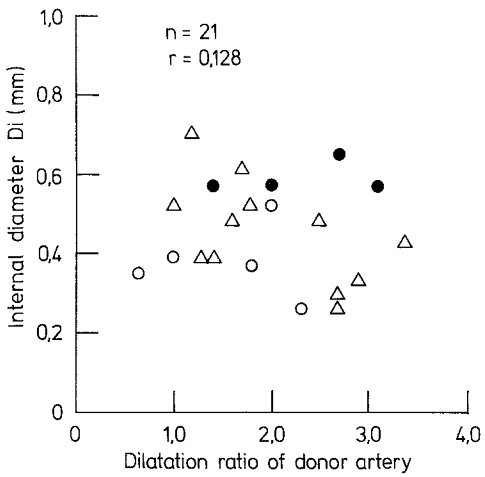
and histologically estimated values correlated well in statistical analysis (r = 0.432) and their relation was expressed by the following equation, $D_i = 0.13\ D_{i\,(ang)} + 0.30$.

The ratio of the internal diameter estimated histometrically to that measured by angiography, $D_i/D_{i\,(ang)}$, was compared in hypertensive and non-hypertensive patients and in the three age groups (Table 4). While no significant difference was found between hypertensive and non-hypertensive patients, a tendency was noted for this ratio to increase with age, although the differences between the age groups were also not significant statistically.

Dimensional data measured on histological specimens, internal diameter, D_i, the ratio of internal diameter to external diameter, D_i/D_e, and the ratio of intimal

Table 5. Dimensional data measured on histological specimens, grouped according to the postoperative bypass function of STA-MCA anastomosis

Postoperative bypass function	D_i (mm)	D_i/D_e (%)	T_i/T_m (%)
Good	0.47±0.14 (n=16)	44±10 (n=16)	101±93 (n=16)
Poor or none	0.43±0.08 (n= 5)	53±15 (n= 5)	52±20 (n= 5)



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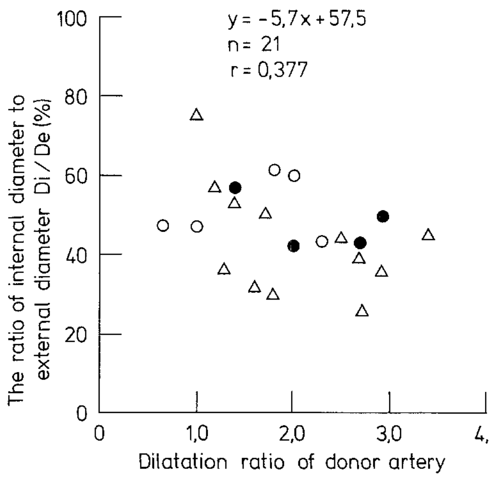

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Fig. 9. Relationship between the dilatation ratio and the internal diameter estimated histometrically

Fig. 10. Relationship between the dilatation ratio and the ratio of internal to external diameters calculated histometrically, D_i/D_e

thickness to medial thickness of arterial wall, T_i/T_m, were compared in patients with good postoperative bypass function and in those with poor or no bypass function (Table 5). D_i was comparable in the groups, whereas the mean value of D_i/D_e was smaller and that of T_i/T_m was larger in patients with good bypass function than those in patients with poor or no bypass function, although the differences were not statistically significant.

The relationship between the dilatation ratio calculated angiographically and the dimensional data estimated histometrically for the donor superficial temporal artery was also investigated. As Fig. 9 shows, the dilatation ratio calculated angiographically and the internal diameter estimated histometrically did not correlate (r=0.128). The dilatation ratio appeared to vary inversely with D_i/D_e (Fig. 10), but the correlation lacked statistical significance (r=0.377, P<0.1). A statistically significant correlation was also absent between the dilatation ratio and T_i/T_m (Fig. 11; r=0.07).

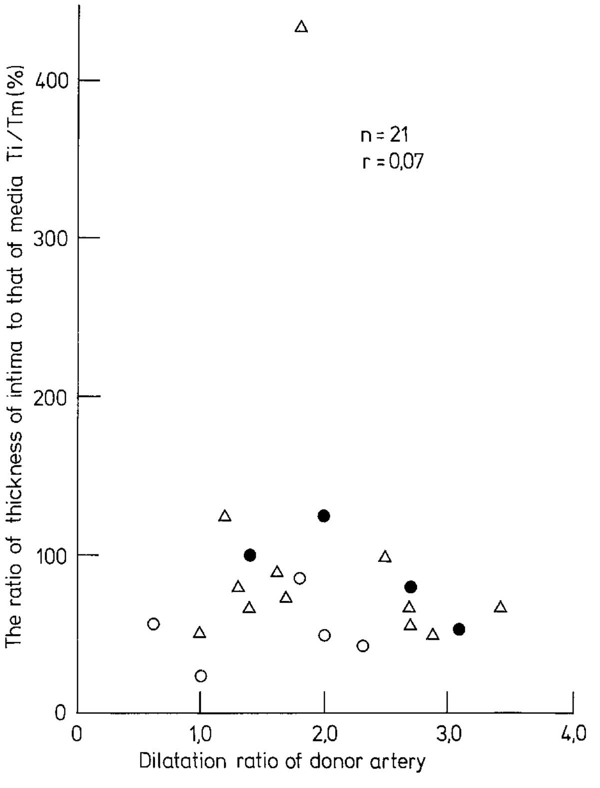

Fig. 11. Relationship between the dilatation ratio and the ratio of intimal thickness to medial thickness calculated histometrically, T_i/T_m

Discussion

Although other arteries such as the occipital and middle meningeal arteries [2, 3, 12, 13, 14] are sometimes used as the donor artery for extracranial-intracranial arterial bypass, the superficial temporal artery is commonly preferred because sufficient length for anastomosis is readily dissectable from its vascular bed and either of its two main branches can be chosen. Preoperative angiography usually supplies information on which the selection of suitable donor and recipient vessels can be based. But despite the common choice of the STA, few studies have been reported on the morphological aspect of this artery.

Based on a study of 150 cadaveric specimens, Lie et al. [8] classified the aging changes in the superficial temporal artery into four basic patterns, representing increasing severity of arteriosclerosis. Our histological findings were in accordance with those of Lie et al. [8]. The intimal layer tended to thicken and the medial layer to thin with age. Lie et al. could not find a constant relationship between medial thickness or the degree of fibrosis and the severity of hypertension, although herniation of the intima into the media through wide gaps in the internal elastic lamina was relatively prominent in specimens taken from patients with severe hypertension. We also found no significant difference in the number of layers of muscular cells in the media or in other histometrical values between hypertensive and non-hypertensive subgroups.

Kletter et al. [4, 5] have investigated the suitability of the superficial temporal artery for STA-MCA anastomosis by use of superficial temporal arteries, internal carotid arteries and the middle cerebral arteries taken from routine autopsy material. They found a difference in the form of atherosclerotic changes in the superficial temporal artery in comparison with other vessels, although these changes proceeded at the same rate as those in other vessels. Senile dilatation was significant in the superficial temporal artery, while calcareous infiltration was rare. They considered that the lumen of the superficial temporal artery changed remarkably little with increasing age because senile dilatation compensated for the reduction of the lumen and therefore that this artery is suitable for the operation. In our material, no calcium deposits could be demonstrated, and the internal diameter was found to increase with age, supporting the conclusion of Kletter et al. [4, 5].

Intimal dissection was found more frequently in the older groups than in the young group. Levinthal and Gregorius [7] reported three cases of STA-MCA anastomosis in which the intima had clearly separated from the media within the wall of the superficial temporal artery. They noted that this "anomaly" increased the likelihood of luminal compromise and occlusion and solved the problem by meticulous suturing, placing each stitch through both the media and intima of the artery. Our findings indicate, however, that intimal dissection is not an anomaly but the result of atherosclerotic changes, namely dissection of the intima. Nevertheless it must be remembered that more meticulous suturing is needed in older patients, in whom the intima tends to dissect from the medial layer.

Intimal proliferation and other atherosclerotic changes associated with aging might be an obstacle in performing anastomosis. However it is unknown whether they hinder the postoperative development of bypass function. This problem should be solved by our investigation of histological and angiographical correlations on the materials used in this study.

The internal diameter of the superficial temporal artery used as a donor artery in STA-MCA anastomosis has an important bearing not only on the technical difficulty of surgery but also on the postoperative functional development of the anastomosis. Preoperatively the donor artery is usually evaluated angiographically, and we found that the diameter measured angiographically correlated well with the real diameter encountered during operation. In this report we confirmed this correlation statistically, with the "real" diameter estimated from histological data. Our histometrical and angiographical data also suggest that the internal diameter encountered during the anastomotic procedure will not be dimensionally equal to that evaluated by preoperative angiography, but will be approximately one-third of that calculated angiographically in the young group, 40% in the middle-aged group and approximately one-half in the old group. This discrepancy can probably be explained by the fact that the artery expands during angiography under the intraluminal pressure, but collapses during the anastomotic procedure. The ratio of histological to angiographical diameters increased with advancing age, which accords with the increase of distensibility of the arterial wall with age [1, 9, 11].

The discrepancy between the value calculated angiographically and that estimated histologically or assessed during anastomosis should be remembered. Our data, particularly the ratio of histological to angiographical diameters, should be useful for preoperative estimation of the real internal diameter of the donor artery that will be encountered during anastomosis. There was no statistically significant difference in this ratio between hypertensive and non-hypertensive patients.

None of the dimensional data obtained from histological analysis, D_i, D_i/D_e and T_i/T_m, correlated with the dilatation ratio of the superficial temporal artery. Also no statistically significant differences were found between patients with good bypass function and those with poor or no bypass function.

Our data suggest that the histological aspects of the superficial temporal artery used as a donor artery for STA-MCA anastomosis, including internal diameter and atherosclerotic changes, do not have a major bearing on the bypass function. The most important determinant of postoperative bypass function of STA-MCA anastomosis, as mentioned in our earlier report, is the pressure gradient between the extracranial and intracranial arteries.

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