The medial papillary muscle complex and its related septomarginal trabeculation. A normal anatomical study on human hearts*

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INTRODUCTION

The tension apparatus supporting the antero-septal commissure of the tricuspid valve has been the subject of several investigations. The prominent papillary muscle typically found at the base of the sub-pulmonary infundibulum was originally noted by Lancisi as quoted by Tandler (1913). Nominated as the papillary muscle of the conus by Luschka (1863), the fact that it is constantly supported by several ancillary muscles was emphasised by Wenink (1977), who coined the term 'medial papillary complex' to describe the overall group of muscles. Despite this, to the best of our knowledge, there has been no detailed study of the entire commissural area, particularly with regard to the support of the septal as opposed to the antero-superior leaflet and to the relationship of the medial muscle to the septomarginal trabeculation ('septal band'). The present study was designed to remedy these deficiencies.

MATERIALS AND METHODS

Eighty one normal hearts were taken from the anatomical collection of the Institute of Child Health, Royal Liverpool Children's Hospital Alder Hey, University of Liverpool. The material included two different groups. The first was made up of fetal material (47 cases). These ranged from 20 weeks of gestational age to full term. The second group of hearts came from infants (34 cases), aged from one day to 13 months. Among the first group, 7 fetuses were of unknown age. The most common causes of death in the liveborn infants were bronchopneumonia, brain haemorrhage, hyaline membrane disease, pulmonary haemorrhage and septicaemia. The specimens had been fixed in 10% formalin and opened in the conventional way. In order to study accurately the morphology of the postero-basal division of the septomarginal trabeculation, the tendinous cords of the septal leaflet of the tricuspid valve were divided in most of the cases, thus permitting complete exposure of the inlet septum. Similarly, after studying the medial papillary complex in its entirety, its tendinous cords were divided to permit full examination of the sub-pulmonary infundibulum.

Morphology of the perimembranous region of the normal heart

In order to understand fully the structure of the tension apparatus supporting the antero-septal commissure of the tricuspid valve, it is essential to know the arrangement of structures surrounding the membranous part of the septum, particularly the postero-basal division of the septomarginal trabeculation. The general configuration of this area is shown diagrammatically in Figure 1. The main muscle of the medial papillary complex is termed Lancisi's muscle. It has a free-standing belly which is rooted to the septum at the point where the septomarginal trabeculation bifurcates into antero-basal and postero-basal limbs. The postero-basal limb terminates beneath the membranous septum, with more or less clearly defined upper and posterior edges tending to form a right angle. The antero-basal division extends in cephalad direction and reinforces the surface of the sub-pulmonary infundibulum. Between these limbs is inserted the septal root of the supraventricular crest. The crest itself, defined as the muscular fold separating the tricuspid and pulmonary valves in the root of the right ventricle, also has two components. By far the larger part extends parietally to become the free wall of the right ventricle. The smaller part, as described above, inserts as the septal root between the limbs of the septomarginal trabeculation, overlying that small part of the muscular septum separating the ventricular outflow tracts and being continuous posteriorly with the inlet septum. The antero-septal commissure extends between the septal and antero-superior leaflets of the tricuspid valve to the area of the membranous septum. Its tension apparatus is derived from the medial papillary complex but the septal leaflet receives additional support from further groups of septal papillary muscles or cords arising directly from the septum.

Morphology of the medial complex

The medial papillary complex is represented by a main muscle belly, Lancisi's muscle, along with a variable number of adjacent minor papillary muscles and/or isolated cords. Lancisi's muscle was seen to vary in terms of the direction of angulation of its belly. The anterior edge of its root was found in a constant position in the angle between the antero-basal and the postero-basal limbs of the septomarginal trabeculation (Fig. 2a). A discrete line of junction between the supraventricular crest and the antero-basal division of the septomarginal trabeculation was observed inconstantly running in an antero-superior direction from the root of Lancisi's muscle (Fig. 2b). The belly of Lancisi's muscle was found to occupy various positions. These could be grouped into three major varieties. In the first, the belly of the muscle lay at the posterior extremity of the septomarginal trabeculation (40 cases). In a second variety, the belly of the muscle occupied much the same position as its root (18 cases). The third variant was intermediate between these extremes (23 cases).

Minor (or accessory) medial papillary muscles were also found to be located in three main areas. The first area was at the posterior extremity of the septomarginal trabeculation. Papillary muscles in this position were always tiny and short. In some cases the extremity of the postero-basal division of the septomarginal trabeculation was solely occupied by the minor papillary muscles (Fig. 2a), whilst in others both the minor muscles and the belly of Lancisi's muscle were located in this area. The minor muscles were then always more posterior and slightly cranial (Fig. 2c). The second group of minor papillary muscles was found on a line between the apex of the membranous septum and the postero-basal division of the septomarginal trabecula-tion. This oblique line represents the junctional line between the inlet septum and the
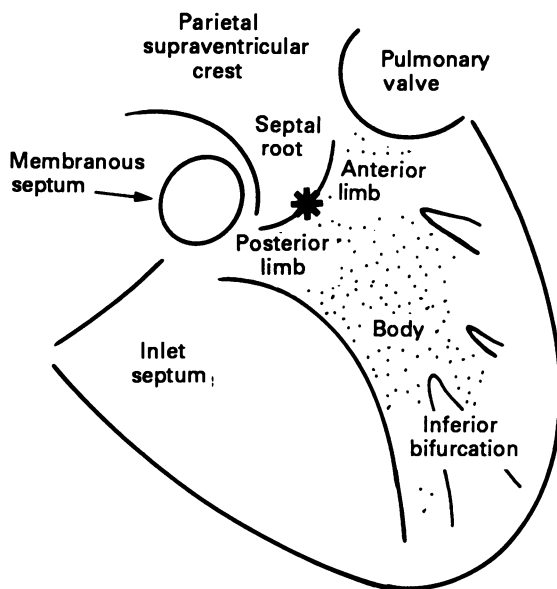
Fig. 1. Diagram of the right side of the intraventricular septum showing the septomarginal trabeculation and the supraventricular crest. The asterisk represents the anterior aspect of the root of Lancisi's muscle. This was found in a constant position throughout the series at the point where the septomarginal trabeculation bifurcated into basal anterior and posterior limbs (the superior bifurcation). An inferior bifurcation of the septomarginal trabeculation is also present. The diagram also includes the membranous septum.

septal root of the supraventricular crest (Fig. 3*a*, *b*). In those cases where the postero-basal division of the septomarginal trabeculation extended behind the membranous septum, the minor papillary muscles, when present, occupied its upper edge. The third area occupied by minor medial papillary muscles lay on the posterior edge of the trabeculation immediately below Lancisi's muscle (Figs. 2*c*, 3*c*, *d*). Other papillary muscles which were not part of the medial papillary complex continued more caudally along the posterior edge of the septomarginal trabeculation. These formed a separate group of septal papillary muscles (Fig. 3*d*). The data concerning the distribution of the minor medial papillary muscles are given in Table 1. The three positions occupied by the minor medial papillary muscles are shown diagrammatically in Figure 4. The septal group of muscles, discrete from the medial complex, was observed to support the midportion of the septal leaflet of the tricuspid valve. The posterior portion of the leaflet was supported by cords arising from the posterior papillary muscle. Overall, there was marked variability in the anchorage of the midportion of the septal leaflet of the tricuspid valve (compare Figs. 3*d*, 5*a–c*).

The postero-basal division of the septomarginal trabeculation itself also showed variable morphology. In those situations where the belly of Lancisi's muscle was located in an anterior or intermediate position, the extremity of the postero-basal division usually gave rise to a minor medial papillary muscle. When the belly of Lancisi's muscle extended to the posterior extremity of the postero-basal division, the minor medial papillary muscle (if present) was located postero-cranially.

In 37 hearts (Fig. 2*c*), the end of the postero-basal division faced the apex of the membranous septum but did not approach it closely. In a second group of specimens (5 cases – Fig. 2*b*) this area was not well defined, the postero-basal division merging with adjacent structures. In a third category, made up of 14 hearts, the postero-basal
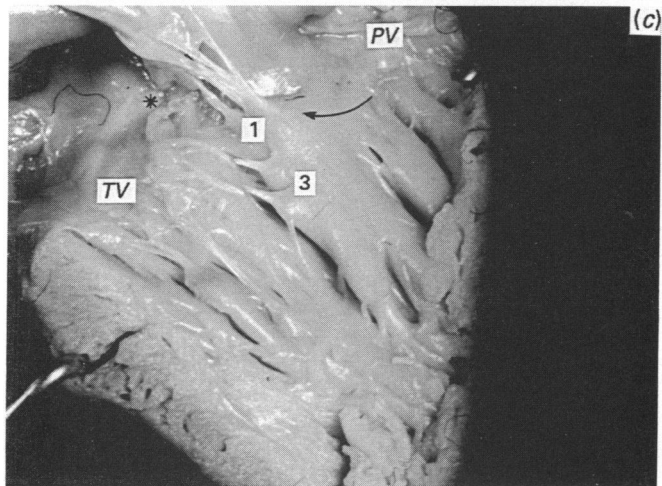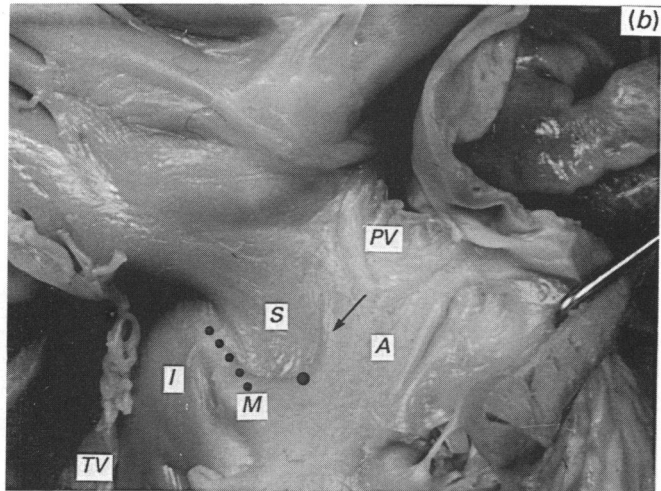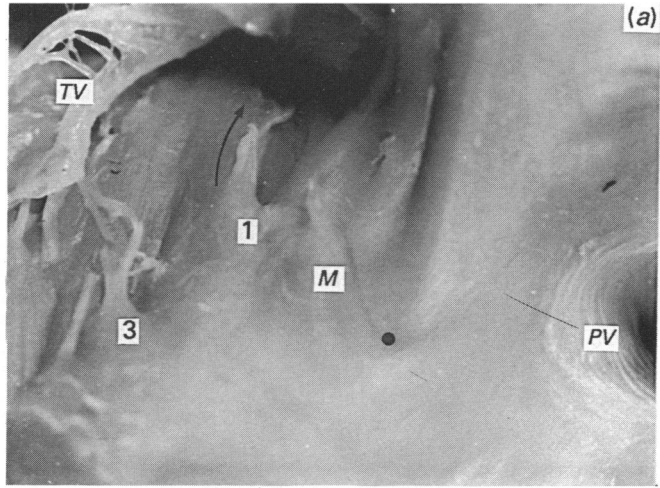
division extended to the apex of the membranous septum along the line of junction between the inlet septum and the supraventricular crest (Fig. 6a). A fourth group of hearts (10 cases) showed more marked cranial deviation with the postero-basal division interposing itself between the membranous septum and the supraventricular crest (Fig. 6b). In the fifth variety of 13 hearts (Fig. 6c), the postero-basal division ran postero-caudally to the membranous septum. Finally, in two cases, similar in most respects to the last category, the postero-basal division of the septomarginal trabeculation was incompletely defined, being poorly delaminated from the surrounding inlet septal musculature (Fig. 2a).

<div align="center">DISCUSSION</div>

The medial papillary complex is that group of muscles or tendinous cords that supports the antero-septal commissure of the tricuspid valve. Its most prominent muscle is that originally described by Lancisi, as quoted by Tandler (1913). The concept of a medial papillary complex was preferred by Wenink (1977) because he noted multiple small papillary muscles around Lancisi's muscle itself which contributed to commissural support. Indeed, although the muscle has long been described, knowledge of its anatomical variations and, more generally, of the medial complex has been very limited (Poirier, 1902; Holl, 1912; Tandler, 1913; Verduyn Lunel, 1964). We have observed marked variations in the disposition of Lancisi's muscle along with its supporting minor medial papillary muscles and we have correlated this with the morphology of the postero-basal limb of the septomarginal trabeculation. In addition, we have distinguished three areas of support for the septal leaflet of the triscuspid valve.

The medial papillary complex is located in an immediate sub-infundibular position. Both Lancisi's muscle and minor papillary muscles are intimately related to the postero-basal division of the septomarginal trabeculation. They support the antero-superior portion of the septal leaflet of the tricuspid valve. In contrast, those more peripheral papillary muscles found along the more caudal posterior border of the

Fig. 2(a–c). (a) The root of the Lancisi's muscle (indicated by the dot) lies at the bifurcation of the septomarginal trabeculation. This case shows a postero-basal division of the septomarginal trabeculation in which the limb (arrow), caudal to the membranous septum (dark area), is incompletely delaminated from the underlying trabeculations of the inlet septum (compare with Fig. 6c). The belly of Lancisi's muscle (M) occupies an intermediate position between its root (dot) and the extremity of the postero-basal division of the septomarginal trabeculation. The extremity of the postero-basal division is in this case occupied by the minor medial papillary muscle (Position 1). Note also one minor medial papillary muscle and one cord in Position 3. PV, pulmonary valve; TV, tricuspid valve. (b) The septal root (S) of the supraventricular crest is clasped between the antero-basal division (A) of the septomarginal trabeculation anteriorly and the inlet septum (I) posteriorly. This case shows a peculiar postero-basal division with an excavation in the posterior edge of the septomarginal trabeculation. Lancisi's muscle (M) expands, with its belly, to the extremity of the postero-basal division. The oblique dotted line shows the junctional area between the inlet (I) and the infundibular (S) septa. Note that the line goes approximately from the apex of the membranous septum (dark triangular area) to the upper edge of the postero-basal division of the septomarginal trabeculation. The 'raphe' is indicated by an arrow. The dot represents the root of Lancisi's muscle. (c) The medial papillary complex is shown. The belly of Lancisi's muscle (arrow) is near the extremity of the postero-basal division which is occupied by a minor papillary muscle (Position 1). Note that this minor papillary muscle is postero-cranial to Lancisi's muscle. Two minor papillary muscles are also present at the uppermost posterior edge of the septomarginal trabeculation (Position 3) supporting the anterior portion of the septal leaflet of the tricuspid valve. Note that these two papillary muscles are in an immediate sub-infundibular position closely related both to Lancisi's muscle and to the postero-basal division of the septomarginal trabeculation. In this case the postero-basal division of the septomarginal trabeculation shows a right angle configuration, between the upper and the posterior edges, with its extremity facing the membranous septum (asterisk).
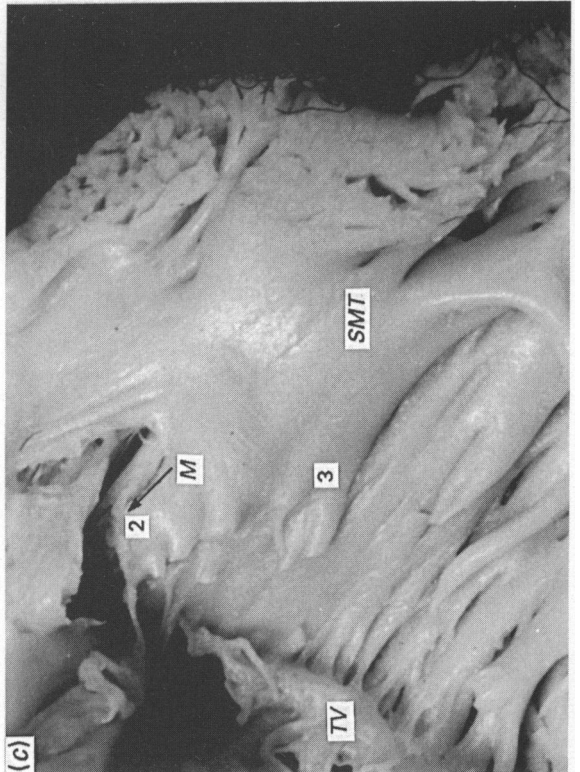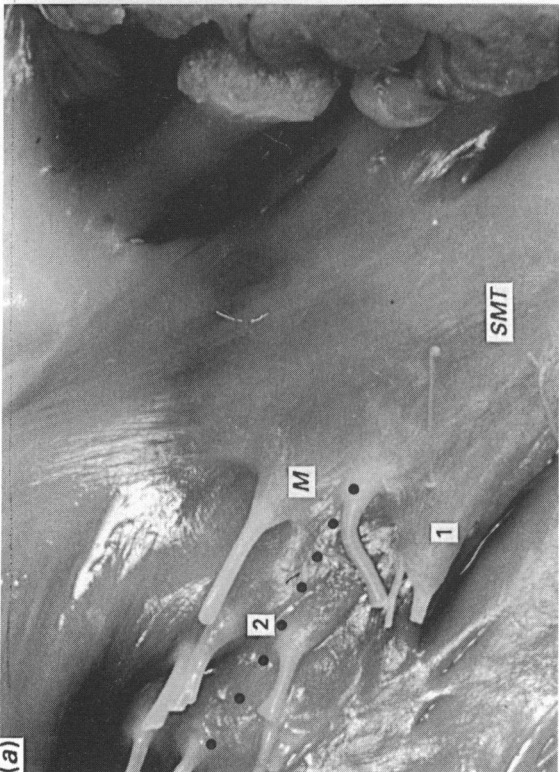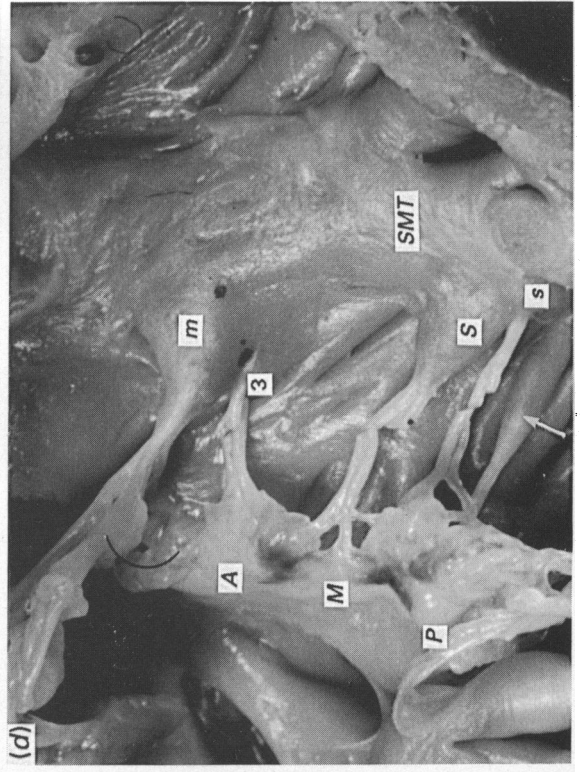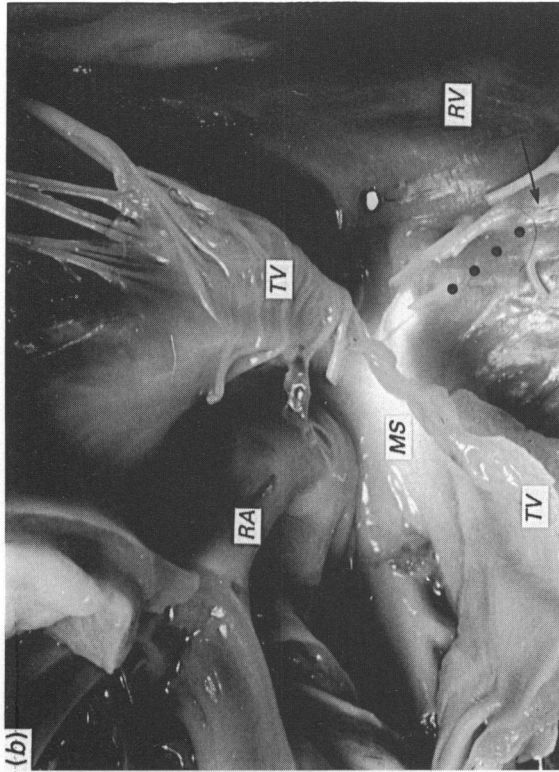
Table 1. *Topography of the medial papillary complex*

	Positions of the minor medial papillary muscles			
	1+2	1+3	2+3	3
Minor papillary muscles	2	11	4	41
Isolated cords	—	4	—	13
Minor papillary muscles and isolated cords	2	3	1	—
	4	18	5	54
Total = 81				

septomarginal trabeculation should not be considered as part of the medial papillary complex. They are not relative to Lancisi's muscle nor to the postero-basal limb of the trabeculation. Neither are they in an immediately sub-infundibular position. They mostly support the midportion of the septal leaflet of the tricuspid valve.

Van Mierop (1974) has emphasised the importance of distinguishing the uppermost papillary muscles of the posterior edge of the septomarginal trabeculation from Lancisi's muscle in the setting of certain congenital malformations where Lancisi's muscle itself is absent. He does not, however, consider such small papillary muscles as anatomically accessory to Lancisi's muscle.

In his study on the medial papillary complex, Wenink (1977) reported a large series of cases of different age groups presenting variations in the morphological arrangement of the complex. No positional variations of Lancisi's muscle were described in this study. Furthermore, no differential topographical criteria were proposed in the description of the minor papillary muscles. Indeed, the presence of separate groups of minor papillary muscles was not reported. As far as we are aware, no previous study had commented on the variations we observed concerning the muscle of Lancisi. We

Fig. 3 (*a–d*). (*a*) View of the medial papillary complex. The belly of Lancisi's muscle (*M*) is small and occupies a postero-inferior position. The extremity of the postero-basal division of the septomarginal trabeculation is occupied by a minor papillary muscle (1). A group of papillary muscles and/or isolated cords occupies the area (dotted line, 2) from the apex of the membranous septum (not transilluminated) to the upper edge of the postero-basal division. This line represent approximately the borderline between the inlet and the outlet of the right ventricle. In this case, the uppermost posterior edge of the septomarginal trabeculation (*SMT*) is devoid of papillary muscles and cords. (*b*) Transillumination of the membranous septum (same case as in Fig. 3*a*). As can be seen the oblique line (dotted line), which is the site of location of minor medial papillary muscles (Position 2), passes from the apex of the membranous septum (*MS*) towards the upper edge of the postero-basal division of the septomarginal trabeculation. The arrow indicates the belly of Lancisi's muscle which in this case occupies much the same position as its root. *RA*, right atrium; *RV*, right ventricle. (*c*) In this heart the postero-basal limb of the septomarginal trabeculation (*SMT*) shows marked cranial expansion (arrow), (compare with Fig. 5*b*). The medial papillary complex is shown. The belly of Lancisi's muscle (*M*) extends to the posterior edge of the postero-basal division of the septomarginal trabeculation. Minor papillary muscles are present cranially (Position 2). Note that this area is occupied by the cranial extension of the postero-basal division. Another group of minor papillary muscles are present caudally (Position 3) on the uppermost posterior edge of the septomarginal trabeculation. (*d*) The anchorage of the septal leaflet of the tricuspid valve. The midportion of the leaflet (*M*) is supported by septal papillary muscles (*S*) originating entirely from the lower posterior edge of the septomarginal trabeculation (*SMT*). Lancisi's muscle (*m*) and a group of minor medial papillary muscles (Position 3) are shown to be related to the antero-septal commissure of the tricuspid valve (bracket). The arrow indicates a septal papillary muscle supporting the ventricular surface of the septal leaflet. *A*, anterior portion of the septal leaflet; *P*, posterior portion of the septal leaflet.
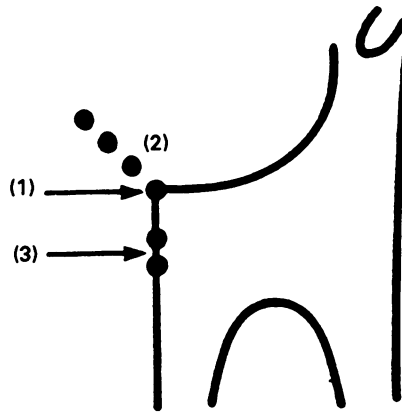
Fig. 4. Diagram showing three positions, arbitrarily numbered 1, 2 and 3 occupied by the minor medial papillary muscles and/or cords. Position 1 is the extremity of the septomarginal trabeculation. Position 2 is the inlet portion of the interventricular muscular septum. Position 3 is the uppermost posterior edge of the septomarginal trabeculation.

have differentiated the muscle in terms of its root and belly. The root was always found in a constant position at the angle between the antero-basal and the postero-basal limbs of the septomarginal trabeculation. When present, the 'raphe', which demarcates the line of junction between the supraventricular crest and the septomarginal trabeculation, also originated at this site. The belly of Lancisi's muscle, by contrast, was found to occupy positions which could be grouped into three types.

The basal portion of the septomarginal trabeculation, especially its posterior limb, was also found to be highly variable. The variability depended on whether the postero-basal limb was in front of or behind the membranous septum, or whether it supported its apex. In those cases where the postero-basal division expanded far posteriorly behind the membranous septum towards the atrioventricular junction, this posterior limb was fused with the most cranial trabeculation of the inlet septum. On the other hand, when the postero-basal limb expanded centrally to support the apex of the membranous septum or extended more cranially in front of the membranous septum, it retained its own identity as a muscle bar reinforcing the muscular septum. The limb was most prominent when it extended behind the membranous septum towards the inlet septum. Variations were also noted in the morphology of the supraventricular crest. Often it was clasped between the antero-basal and the postero-basal limbs of the

Fig. 5 (a–c). (a) The midportion of the septal leaflet of the tricuspid valve (M) is shown to be supported by two papillary muscles which take origin from the lower posterior edge of the septomarginal trabeculation (SMT) and from the inlet septum (I) respectively. The probe has been placed behind the corresponding tendinous cords. The arrow indicates the anterior papillary muscle which was mutilated. (b) The midportion (M) of the septal leaflet of the tricuspid valve is anchored by two septal papillary muscles (oblique arrows) originating exclusively from the inlet septum. Note that the posterior portion (P) of the septal leaflet is in relation to the posterior papillary complex (PPM). The anterior portion (A) of the leaflet, on the other hand, is related to the medial papillary complex: note the rudimentary papillary muscle (vertical arrow) arising from the uppermost posterior edge of the septomarginal trabeculation. APM, anterior papillary muscle. (c) The midportion (M) of the septal leaflet of the tricuspid valve is supported by a single septal papillary muscle (arrow) which takes origin from the inlet septum and splits into multiple tendinous cords. The anterior (A) and posterior (P) portions of the septal leaflet are supported by the medial papillary complex (m) and the posterior papillary complex (PPM) respectively.
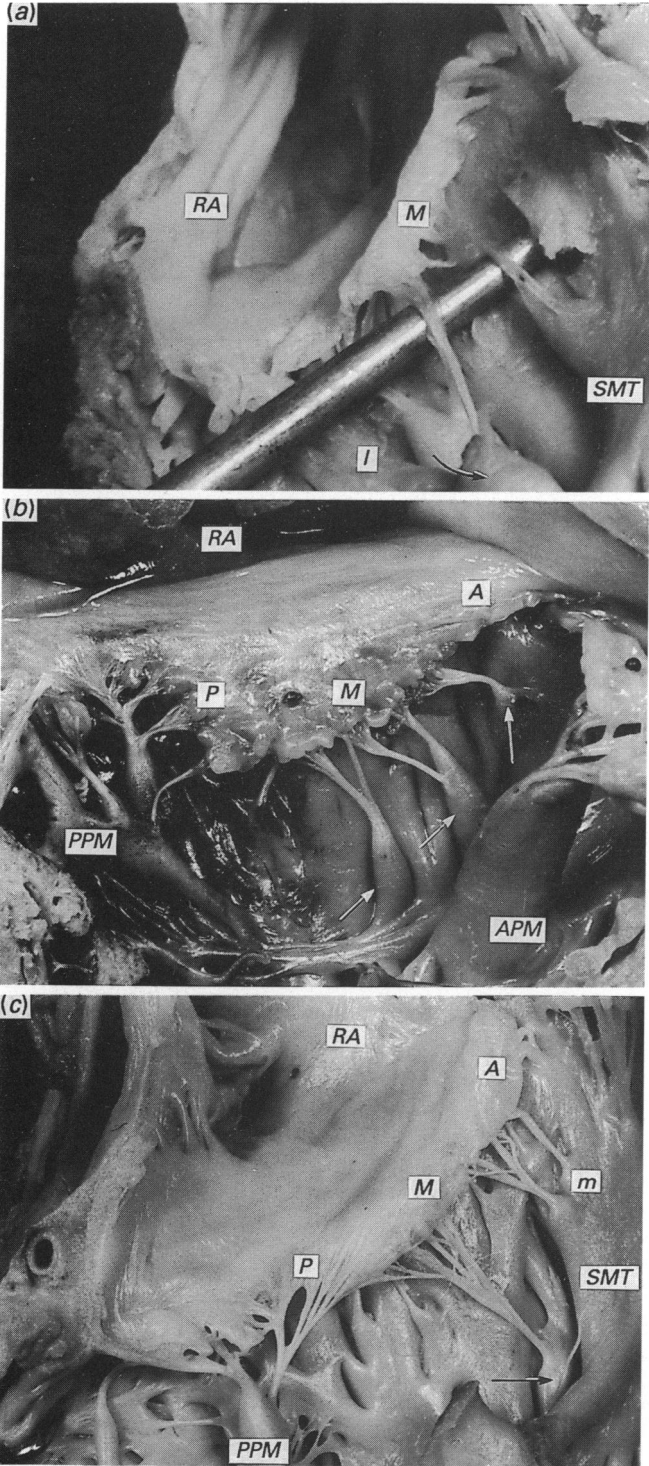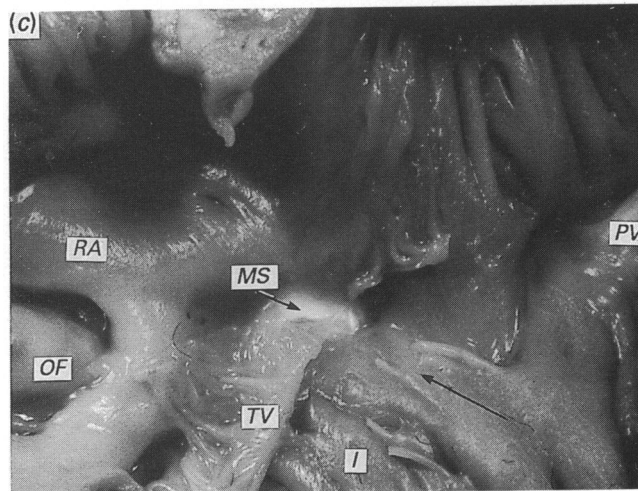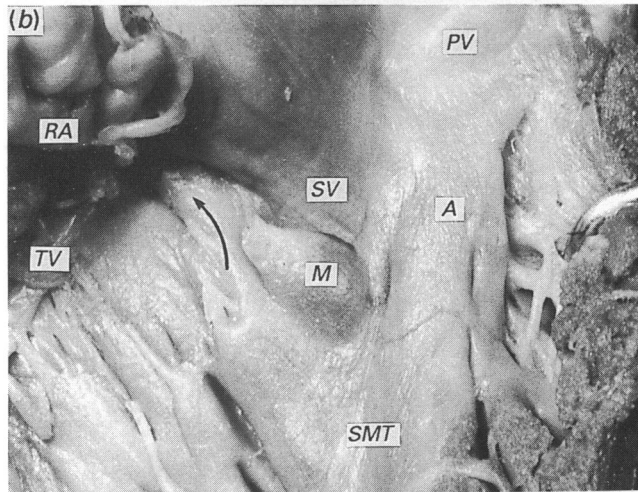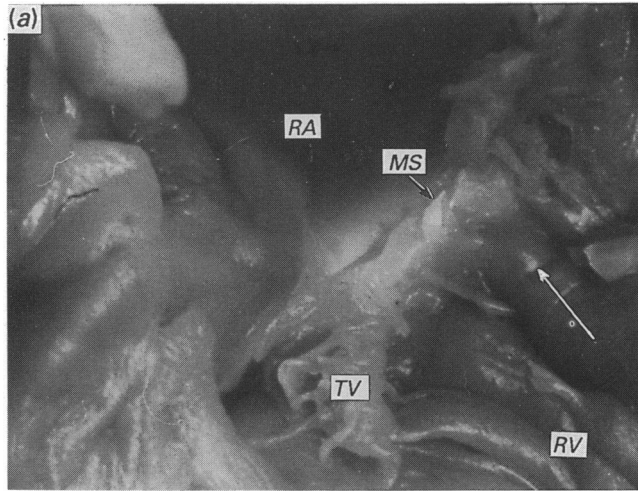
septomarginal trabeculation, being separated from the membranous septum. In other situations, the root of the supraventricular crest, though still clasped between the limbs of the septomarginal trabeculation, abutted directly on the membranous septum.

These arrangements of trabeculation and crest are directly analogous to the situation seen in hearts with deficiencies of the ventricular septum. In most instances, such defects abut directly on the central fibrous body (perimembranous defects). The posterior limb of the septomarginal trabeculation then stops short of the supra-ventricular crest, identified as the ventriculo-infundibular fold in the setting of a ventricular septal defect. In contrast, in a minority of hearts the postero-basal limb fuses with the ventriculo-infundibular fold in front of the membranous septum. This is as in some of the normal hearts as described above. In the presence of a septal defect it produces a muscular postero-inferior rim which overlies and protects the atrioventricular conduction axis.

SUMMARY

The morphology of the medial papillary muscle complex of the right ventricle was studied in 81 normal hearts from subjects ranging in age from 20 weeks of gestation to 13 months. The position of the main medial papillary muscle (of Lancisi) was differentiated in terms of a root and a belly. The anterior aspect of the root was found in a constant position at the basal bifurcation of the septomarginal trabeculation, whereas its belly showed considerable positional variation. Three groups of minor papillary muscles were identified and localised in specific areas in the base of the right ventricle. Taken overall, they formed part of the medial papillary complex. The complex itself was found to be constantly related to the antero-septal commissure of the tricuspid valve. A separate group of septal papillary muscles could be differentiated from the medial papillary complex.

The anchorage of the septal leaflet of the tricuspid valve to the ventricular septum was also studied. The antero-superior and postero-inferior portions of this leaflet were found to be supported by the medial and posterior papillary complexes, respectively. Its midportion was connected to the septal group of papillary muscles but much variability was evident. The portion of the septomarginal trabeculation supporting the medial papillary complex, namely the postero-basal division, was studied further. This showed considerable variability and did not form a continuous anatomical spectrum.

Fig. 6*a–c*. (*a*) The postero-basal division of the septomarginal trabeculation, indicated by the long arrow, is in this case cranially expanded towards the membranous septum (*MS*). (*b*) In this situation the postero-basal division (indicated by the arrow) shows further cranial expansion than that shown in Fig. 6*a*, interposing itself between the supraventricular crest (*SV*) and the membranous septum (dark areas). Note also the large size of Lancisi's muscle (*M*) which occupies, with its belly, an intermediate position. (*A*) indicates the antero-basal limb of the septomarginal trabeculation (*SMT*). (*c*) Postero-basal division (long arrow) which runs behind the membranous septum (*MS*). The postero-basal division has, in this situation, much the same morphology and orientation as the trabeculations of the inlet septum (*I*). Anatomically this seems to represent fusion of the uppermost inlet trabeculation with the posterior edge of the septomarginal trabeculation. *OF*, fossa ovalis.

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