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Remarks on the morphology of the papillary muscles of the right ventricle

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In addition to the papillary muscles of right ventricle referred to in anatomical nomenclature, namely the anterior, posterior and septal, we have distinguished the "conal papillary muscle" and the "papillary muscle of the posterior angle of the right ventricle". The conal papillary muscle was described by Luschka in the 17th century as the most constant of the septal papillary muscles. We have distinguished the muscles of the posterior angle of the right ventricle as muscles which would not be clearly classified as either septal or posterior muscles. Moreover, the muscles of the posterior angle of the right ventricle are probably associated with the transfer of the papillary muscles from the septum to the posterior wall of the right ventricle during phylogenetic evolution. Some researchers have classified them with the septal papillary muscles [11, 12], while others have assigned them to the posterior group [5]. The morphology of the muscles was classified using earlier categories for the posterior papillary muscles only. We have adopted the concept of multi-apical and multi-segmental muscles [5].

Key words: papillary muscle, right ventricle, human heart

INTRODUCTION

In this study we have used the classification of the papillary muscles of the right ventricle established by Grochowski [5] for describing the morphology of the posterior papillary muscles of the right ventricle. This classification was extended by us to include types not previously described. As well as presenting the anterior, posterior and septal papillary muscles recognised in anatomical nomenclature, we have distinguished the "conal papillary muscles" and the "muscles of the posterior angle of the right ventricle". The conal papillary muscle was described by Luschka in the 17th century [13] as the most constant of the papillary muscles of septum. This muscle probably plays a different role in stabilising the position of the tricuspid valve, since the direction of the vector of the bloodstream is different over the anterior angle of the right ventricle from that in other parts of the septum [6].

The muscles of the posterior angle of the right ventricle were distinguished as muscles which would not be clearly classified as septal or posterior muscles. Moreover, the muscles of the posterior angle of the right ventricle are probably associated with the transfer of the papillary muscles from the septum to the posterior wall of the right ventricle during evolution [11, 12].

For plain description of the forms of the papillary muscles of the right ventricle we have used the concept of multi-apical and multi-segmental muscles [5].

MATERIAL AND METHODS

The study material consisted of 107 formalin-fixed human adult hearts of both sexes (30 female and 77 male) from 18 to 90 years of age, in which no macroscopic developmental failures or pathological changes had been found.

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The hearts were opened from the side of the right atrium, with the line of the cut running from the ostium of the superior cardinal vein to the right atrioventricular ostium. The right ventricles were opened by a V-shaped cut along the right margin and across the anterior wall of the right ventricle below the root of the papillary muscles. The valves were usually cut in the region of the connection between the posterior and anterior leaflets.

The papillary muscles were designated anterior, posterior and septal muscles, according to anatomical nomenclature [14]. We distinguished 2 groups which do not exist in *Nomina Anatomica*: the conal papillary muscles and the papillary muscle of the posterior angle of the right ventricle. Some researchers classify the latter as septal papillary muscles [11, 12], while others assign them to the posterior group [5].

We used the concept of the conal papillary muscle after Szostakiewicz-Sawicka and Grzybiak [11], Szostakiewicz-Sawicka [12], and Dudziak [2], assigning to this group the most anterior muscle of the septal papillary muscles located in the region of the *conus arteriosus*. The conal papillary muscle was described by Luschka in the 17th century. It was given a different name by Frick — *musculus subarterialis* and the muscle was defined by him as located in the septal margin of the supraventricular crista. The decision to exclude this muscle from the septal group of muscles is also based on its phylogeny [8, 9, 12]. It seems that the attachment of tendinous chords in this location is important for the geometry of the right ventricle because of the irregularity of shape of the right atrioventricular ostium in this region.

The classification of the papillary muscles in all groups follows that carried out earlier by Grochowski [5], enriched with types not described before. We have used after Grochowski the concepts of "multi-apical" and "multi-segmental" in describing muscles. We considered muscles seen as one structure and which can only be subdivided with difficulty to be multi-segmental. Where the parts are easily separated, the muscle is referred to as multi-apical.

RESULTS

The papillary muscles in all groups were classified according to Grochowski's [5] earlier classification. This consisted of 14 types (1–14), enlarged by us with the addition of types 15 and 16 (Fig. 1). Absence of a particular muscle during analysis was designated type 0.

We observed 467 papillary muscles belonging to types 1–16 and 67 muscles of type 0 (absence of muscle) in the study material taken as a whole. The number of muscles of each particular type was as follows: type 1 — 140, type 2 — 79, type 3 — 31, type 4 — 38, type 5 — 62, type 6 — 37, type 7 — 7, type 8 — 3, type 9 — 5, type 10 — 27, type 11 — 6, type 12 — 13, type 13 — 7, type 14 — 10, type 15 — 1, type 16 — 1 (Table 1).

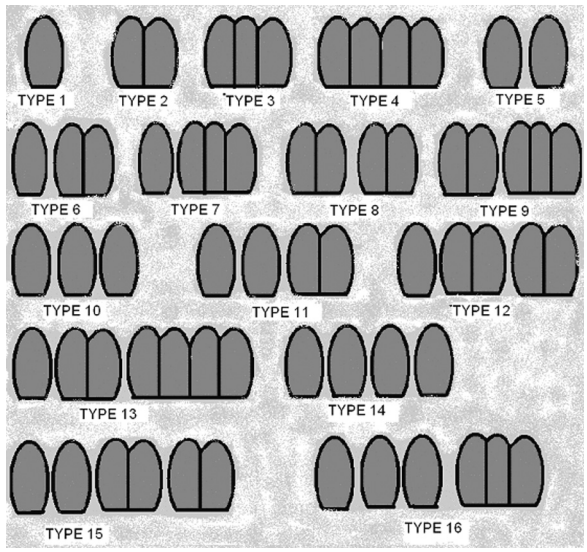

Figure 1. Classification of the papillary muscles of the right ventricle.

Table 1. Distribution of particular types of papillary muscles of right ventricle

Type of muscle	Number of frequency	Percentage of frequency
Type 0	67	12.55
Type 1	140	26.21
Type 2	79	14.79
Type 3	31	5.8
Type 4	38	7.12
Type 5	62	11.61
Type 6	37	6.93
Type 7	7	1.31
Type 8	3	0.56
Type 9	5	0.93
Type 10	27	5.06
Type 11	6	1.12
Type 12	13	2.43
Type 13	7	1.31
Type 14	10	1.87
Type 15	1	0.19
Type 16	1	0.19

The frequency of occurrence of the particular types of anterior papillary muscle in the group studied group was: type 0 — 0.94%, type 1 — 23.26%, type 2 — 11.32%, type 3 — 17.92%, type 4 — 31.13%, type 5 — 8.49%, type 6 — 3.77%, type 7 — 2.83%, type 9 — 2.83%, type 11 — 1.89%, type 12 — 2.83%, type 13 — 3.77%, type 15 — 0.94%. Types 8, 10, 14 and 16 did not appear in this group. The majority of this group fell within types 1–4 (72. 63%), which was in agreement with the form usually presented of a single massive anterior papillary muscle.

The frequency of occurrence of particular types of posterior papillary muscles in the group studied was: type 0 — 3.73% of hearts, type 1 — 19.62%, type 2 — 18.19%, type 3 — 4.67%, type 4 — 3.73%, type 5 — 18.19%, type 6 — 7.46%, type 7 — 0.94%, type 8 — 0.94%, type 9 — 1.88%, type 10 — 9.34%, type 11 — 0.94%, type 12 — 2.81%, type 13 — 0.94%, type 14 — 3.73%. Types 15 and 16 were not detected. The most frequent form of posterior papillary muscle was the double-segmental form (type 2 — 18.19%) and types 5, 10 and 14, the double, triple and quadruple-apical forms.

The incidence of septal papillary muscles in the group studied was as follows: type 0 — 8.08%, type 1 — 20.2%, type 2 — 11.11%, type 3 — 3.03%, type 4 — 0.94%, type 5 — 18.19%, type 6 — 4.67%, type 7 — 1.88%, type 8 — 0.94%, type 10 — 15,15%, type 11 — 1.88%, type 12 — 5.05%, type 13 — 1.88%, type 14 — 5.05%, type 16 — 0.94%. Types 8, 9 and 15 did not appear in this group.

The conal muscles of right ventricle were represented only by types 1, 2, 3, 5 and 6. These occurred in 81 of the 107 hearts studied. In 24.53% they were absent (type 0). In these cases, additional external tendinous chords were present above the anterior angle of the right ventricle. The frequency of the particular types in this group was: type 1 — 44 muscles (54.32%), type 2 — 19 (23.45%), type 3 — 1 (0.94%), type 5 — 6 (7.41%), type 6 — 11 (13.8%).

The incidence of papillary muscles of the posterior angle of the right ventricle was as follows: type 0 — 23.36%, type 1 — 32.71%, type 2 in 18.69%, type 3 — 2.80%, type 5 — 10.28%, type 6 — 7.41%, type 10 — 1.86% and type 11 — 0.94%. The following types were not represented among the papillary muscles of the posterior angle of the right ventricle: 4, 7, 8, 9, 12, 13, 14, 15 and 16. The incidence of the particular types of papillary muscle in the groups referred to is set out in Table 2.

Table 2. Distribution of particular types of papillary muscles of the right ventricle according to muscle group

Type of muscle	Percentage of frequency of occurrence of particular types in muscle groups				
	Anterior muscles	Posterior muscles	Septal muscles	Conal muscles	Muscles of the posterior angle
Type 0	0.94	3.73	8.08	24.53	23.36
Type 1	23.26	19.62	20.2	54.32	32.71
Type 2	11.32	18.19	11.11	23.45	18.69
Type 3	17.92	4.67	3.03	0.94	2.8
Type 4	31.13	3.73	0.94	0	0
Type 5	8.49	18.19	18.19	7.41	10.28
Type 6	3.77	7.46	4.67	13.8	7.41
Type 7	2.83	0.94	1.88	0	0
Type 8	0	0.94	0	0	0
Type 9	2.83	1.88	0	0	0
Type 10	0	9.34	15.15	0	1.86
Type 11	1.89	0.94	1.88	0	0.94
Type 12	2.83	2.81	5.05	0	0
Type 13	3.77	0.94	1.88	0	0
Type 14	0	3.73	5.05	0	0
Type 15	0.94	0	0	0	0
Type 16	0	0	0.94	0	0

Figure 2. Atypical form of the papillary muscle of the right ventricle — the anterior and posterior papillary muscles are fused and "switched". Arrows in the photograph indicate the posterior (1) and anterior (2) papillary muscles, which are fused and "switched". The anterior papillary muscle supports the posterior and septal leaflets of the tricuspid valve in tendinous chords; the posterior papillary muscle supports the anterior leaflet.

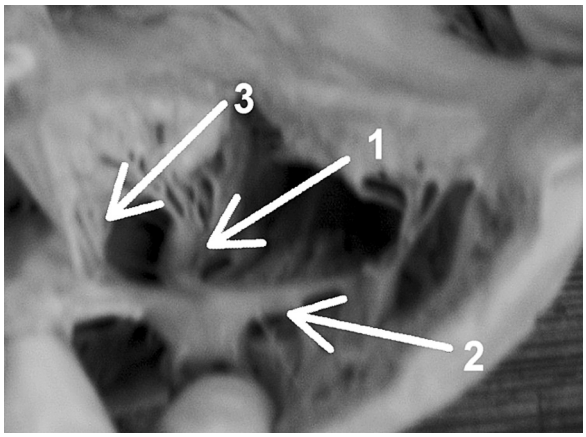

Figure 3. Atypical form of the posterior papillary muscle of the right ventricle. Figure 3 shows the posterior papillary muscle (1) arising from a muscular trabecule (2) which grows from the septum of the right ventricle and gives tendinous chords (3) to the septo-posterior leaflet of the tricuspid valve.

Figure 4. Shows a typical distribution of the tendinous chords, which accompanies atypically connected anterior and posterior papillary muscles (arrow).

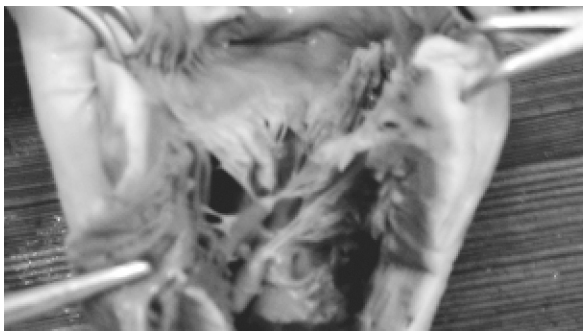

Figure 5. Atypical distribution of the tendinous chords caused by the absence of the anterior papillary muscle.

We also observed atypical forms of the papillary muscles. Figure 2 shows one such atypical form. The anterior and posterior papillary muscles are fused and "switched" — the anterior papillary muscle is located posteriorly to the posterior muscle. The anterior leaflet of the tricuspid valve is provided by tendinous chords from the posterior muscle. In addition, this muscle is connected to the anterior wall of the right ventricle by spurious tendinous chords. The septal and posterior leaflets have tendinous chords from the anterior muscle. We frequently observed an inward tendency of the tendinous chords in some hearts, but only in these cases were the muscles fused. This indicates that these rare anatomical variants of the papillary muscles may co-exist with an atypical distribution of the tendinous chords.

Figure 3 shows an example of a posterior papillary muscle arising from a muscular trabecule, growing from the septum of the right ventricle and giving tendinous chords to the septo-posterior leaflet of the tricuspid valve.

Figure 4 shows a typical distribution of the tendinous chords, which co-exists with atypically connected anterior and posterior papillary muscles. The second segment of the posterior papillary muscle arises from the base of the first segment. Figure 5 shows a further example of a rare form of anterior papillary muscle (type 0), which is often described as the most constant papillary muscle of right ventricle.

Figure 6 shows 3 photographs of atypical forms of the papillary muscles related to atypical muscular strands lying along the line of attachment of the tricuspid valve. The strand in Figure 6A gives tendinous chords to the septal leaflet. In Figure 6B the

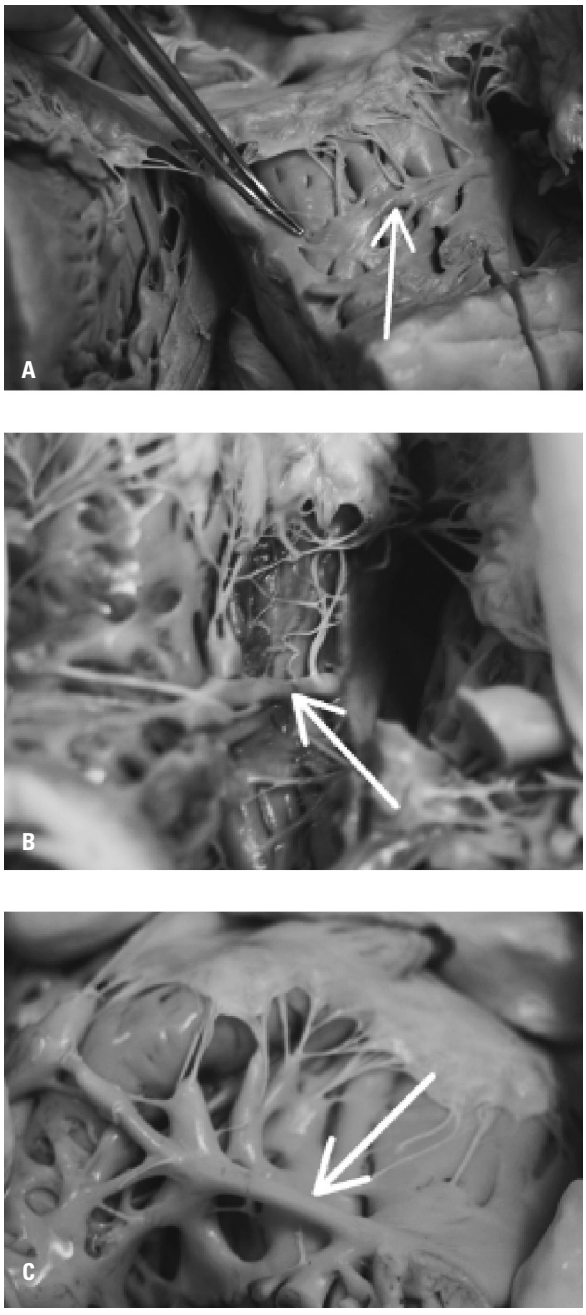

Figure 6. Atypical form of the papillary muscles of the septum and posterior angle of the right ventricle. The figure presents 3 photographs of atypical muscular strands (indicated by arrows) lying along the line of attachment of the tricuspid valve. The strand in **Figure 6A** gives tendinous chords to the septal leaflet. In **Figure 6B** papillary muscles arise from the strand. **Figure 6C** shows 2 apices of papillary muscle arising from the strand.

papillary muscles arise from the strand. Figure 6C shows 2 apices of the papillary muscle of the posterior angle of the right ventricle arising from the strand. The strand is partially connected with the posterior wall of the right ventricle near the posterior angle and partially set further out. Figure 7 shows

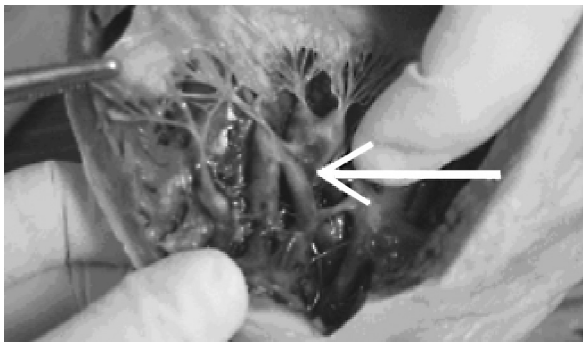

Figure 7. Atypical form of the single-apical papillary muscle with 2 "roots", indicated by the arrow.

an atypical form of the single-apical papillary muscle with 2 "roots". This case has been classified as type 1.

DISCUSSION

In this study we have used the classification of the papillary muscles of the right ventricle established by Grochowski [5]. This classification was enlarged by us with muscle types not previously described. As well as the anterior, posterior and septal papillary muscles present in anatomical nomenclature, we have distinguished the conal papillary muscle and the muscles of the posterior angle of the right ventricle. The conal papillary muscle was described by Luschka in the 17th century [13] as the most constant of the papillary muscles of the septum. The separate classification of the conal papillary muscle was based on its different morphology and the architecture of its musculature compared with other septal papillary muscles [12]. Recent studies [1] in cardiogenesis have shown a different origin of this muscle from other papillary muscles of the septum. This muscle probably plays a different role in closing the tricuspid valve during contraction of the ventricles, since the vector of the blood stream takes a different direction in this region [6]. If this muscle were absent, external chords would be found in this location in all hearts.

The muscles of the posterior angle of the right ventricle were distinguished as muscles which would not be clearly assigned to the septal or posterior muscles. These muscles are probably associated with the transfer of papillary muscles from the septum to the posterior wall of the right ventricle during phylogenetic evolution [11, 12].

The most frequently occurring types of anterior papillary muscle were types 1–4 (83.99%), which confirms the recognised typical form of massive an-

terior papillary muscle referred to in the classic textbooks of anatomy as "major papillary muscle" [10]. Our results are in agreement with more recent studies on this subject [3]. In one heart we observed an absence of this muscle.

The types which represent uncomplicated forms (1, 2 and 3) or segmental forms (1, 2, 5 and 10) dominate among the posterior papillary muscles. The incidence of these types is a little lower than in Grochowski's study [5] among the hearts of young people and higher for the hearts of the elderly. We did not divide hearts into age-dependent groups as, according to earlier authors, they do not change in shape during ontogenesis [11, 12]. Absence of a posterior muscle occurred in 3.73% of the hearts studied by us and in 6% in Grochowski's study. The results of the two studies are similar, with segmental forms 1, 2 and 3 dominating in both.

The septal papillary muscles were most frequently represented by types 1, 2 and 10 (single and double segmental and double-apical) — 46.46%. Multi-segmental and multi-apical forms were more frequent in this group of papillary muscles than in others. Many external chords arising from the septal wall of the right ventricle were also observed. The distribution and form of tendinous chords will be the subject of a subsequent study. Our result is in agreement with the forms of septal papillary muscles described by Farb et al. [3].

The conal papillary muscle was inconstant. It was absent in 24.53% of the hearts studied, although in these cases external tendinous chords were present over the anterior angle of the right ventricle. The haemodynamic significance of this location of the papillary muscle has been demonstrated in a study using an imaging technique for hearts [6]. Type 1 was present in 54.32%, while other types presented in this group were 2, 3, 5 and 6. The muscles in this group were smaller than in others. It seems that the connection between the tricuspid valve and the wall of the right ventricle is more functional than the presence of large complex muscle. Frenula are often found as additional elements connecting the tricuspid valve with the wall of right ventricle in this location.

The muscles of the posterior angle of the right ventricle were present in 76.64%. The most frequently occurring were single and double-segmental forms represented by types 1 and 2 (51.4%). This group has been classified in some studies as septal papillary muscles [11, 12], and in others they have been assigned to the posterior group [5]. This group may represent an intermediate stage between the septal and posterior muscles, in accordance with the theory that anterior and posterior papillary muscles pass from the septum to the walls of the right ventricle during phylogenetic evolution [11, 12]. In some hearts of the group studied the muscles of the posterior angle of the right ventricle arose from a muscular strand lying along the line of attachment of the tricuspid valve. Grochowski [5] in his study also distinguished 7 topographical types of location of the posterior papillary muscles. Muscles distinguished by us as muscles of the posterior angle of the right ventricle were present in types 1, 2, 3 and 5 of this classification. Taken together, these types together occurred in 51% of young adults and in 82.3% of older adults in his study. In our study the incidence fell between the two, these types being observed in 76.64% of the group studied.

Classical textbooks of anatomy and embryology [8, 9, 13] describe the pattern of distribution of tendinous chords in relation to the papillary muscles of the right ventricle and the leaflets of the tricuspid valve. Recent studies in cardiogenesis [1, 7] bear this out, showing temporo-spatial differences in the origin of the muscles, leaflets and their connections. Among the hearts studied we found atypical forms of papillary muscles not always related to unusual patterns of distribution of the tendinous chords. Some of these forms have been described previously, such as the muscular strands lying along the interventricular septum described by Frick [4] as *musculi transversi*. Some of these are in fact rare variants. In the group under study all the atypical forms of papillary muscle, with one exception, co-existed with a rare atypical distribution of the tendinous chords.

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