Original article

Anatomy of the left atrioventricular valve apparatus in landrace pigs

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Abstract

The aim of this study was to describe the structures and variations of the left atrioventricular valve apparatus in pigs' hearts. The valve apparatus elements were investigated using morphometric criteria such as the implantation base width, maximum cuspid depth and fibrous ring circumference, and using morphological criteria such as the numbers and sites of the cuspids, tendon cords and papillary muscles. We concluded that morphometric criteria such as the implantation base width and greater cuspid depth could be used to characterize the cuspids of the left atrioventricular valve apparatus; and that morphological criteria such as the number of papillary muscles, fibrous ring circumference and number of tendon cords were generally not associated with the variations in the number of cuspids. We can state that the number of cuspids in the left atrioventricular valve in pigs is variable and that commissural cuspids are frequently present.

Keywords: animal anatomy, veterinary, heart.

1 Introduction

The left atrioventricular valve apparatus of pigs has important applications in experimental, clinical and surgical fields. From reviewing the literature, some of these applications can be seen: use of the valve as a bioprosthesis in xenografts (GANDRA, RIVETTI, PINTO et al., 1992; PAVONI, BADANO, IUS et al., 2007; COHN, LAMBERT, CASTANEDA et al., 2009; JAMIESON, LEWIS, SAKWA et al., 2011); stent implantation (LOZONSCHI, BOMBIEN, OSAKI et al., 2010; ATTMANN, POKORNY, LOZONSCHI et al., 2011); experimental prolapse of the mitral valve (QUILL, BATEMAN, ST LOUIS et al., 2011); and surgical correction of mitral valve regurgitation (KIM, KOCATURK, OZTURK et al., 2009; GOETZENICH, DOHMEN, HATAM et al., 2010). Separately, the other components of the valve apparatus have also been subjects of specific investigations: mitral annuloplasty for surgical reconstruction of the valve (BHATTACHARYA and HE, 2009; NIELSEN, LOMHOLT, JOHANSEN et al., 2011); ablation of the papillary muscle without compromising mitral valve function (GUO, ZHOU, LI et al., 2010); and functional properties of the tendon cords of the mitral valve (LIAO and VESELY, 2003; CHEN, YIN and MAY-NEWMAN, 2004; RITCHIE, WARNOCK and YOGANATHAN, 2005; ESPINO, SHEPHERD, HUKINS et al., 2005).

Use of transgenic pigs' hearts with the resources of cloning (SAMIEC and SKRZYSZOWSKA, 2011) and genetic engineering (COOPER and TEUTEBERG, 2010) in xenotransplantation has garnered increasing interest (EKSER and COOPER, 2008; BYME et al, 2011; MANJI, MENKIS and COOPER, 2011; COOPER and AYARES, 2011; McGREGOR, CARPENTIER, LILA et al., 2011). The proven similarity between pigs' hearts and human hearts (WHITE et al, 1993; VAN RIJK-ZWIKKER, DELEMARRE and HUYSMANS, 1994; CRICK, SHEPPARD, HO et al., 1998) has prioritized their widespread use in heart research (HUGHES, 1986; CRICK, SHEPPARD, HO et al., 1998).

Given these extensive applications in clinical, surgical and experimental research, we believe that better anatomical knowledge of the left atrioventricular valve apparatus of pigs is likely to make these investigations more effective. However, published data on the anatomical constitution of the left atrioventricular valve apparatus of pigs are rare (WALMSLEY, 1978; CRICK, SHEPPARD, HO et al., 1998).

Thus, we think that it is important to provide anatomical descriptions of the components of the left atrioventricular valve apparatus of pigs using the same morphometric criteria used by Wafae, Hayashi, Gerola et al. (1990) in human hearts and by Alves, Wafae, Beu et al. (2008) in dogs' hearts.

2 Material and methods

Thirty hearts from Landrace pigs were used (16 males and 14 females), weighing between 192 and 401 grams.

The hearts were supplied by the Frigovino abattoir and cold storage plant in the city of Pirapozinho, state of São Paulo, Brazil, where the animals were slaughtered in accordance with the standard procedures in force in this country. The specimens were prepared by means of washing, removal of coagulum, filling of cavities with cotton wool and fixing in a 10% formaldehyde solution. The atria were then removed, along with the musculature of the left ventricular wall from the atrioventricular fibrous ring to the origins of the papillary muscles, while preserving all the components of the left atrioventricular valve apparatus. Following this, the hearts were subjected to Giacomini's conservation technique. The width of the implantation base on the fibrous ring and the greatest depth of the cuspids (distance from the most salient point of the cuspid to the fibrous ring) were measured using Mitutoyo digital calipers. The circumference of the fibrous ring was obtained by placing a metal wire on it and then straightening it for the measurement. The tendon cords were counted at their insertion into the ventricular face of the cuspids. The Kruskal-Wallis variance test, Pearson's correlation, the nonparametric Mann-Whitney test and Student's t test were used for the statistical analysis.

3 Results

3.1 Fibrous ring

The mean circumference of the left fibrous ring was 79.1 mm, with a range of sizes from 60.9 mm to 98.8 mm. There was a statistically weak correlation between the circumferential length of the fibrous ring and the number of cuspids in the valve apparatus ($p = 0.0528$; Pearson's correlation coefficient = 0.36). However, there was no relationship between the ring circumference and the number of tendon cords or papillary muscles (Figures 1 and 2).

3.2 Cuspids

In eleven hearts (36.7%), we observed that there were two cuspids (septal and parietal); in six hearts (20%) there were three cuspids (septal, parietal and one supernumerary; in

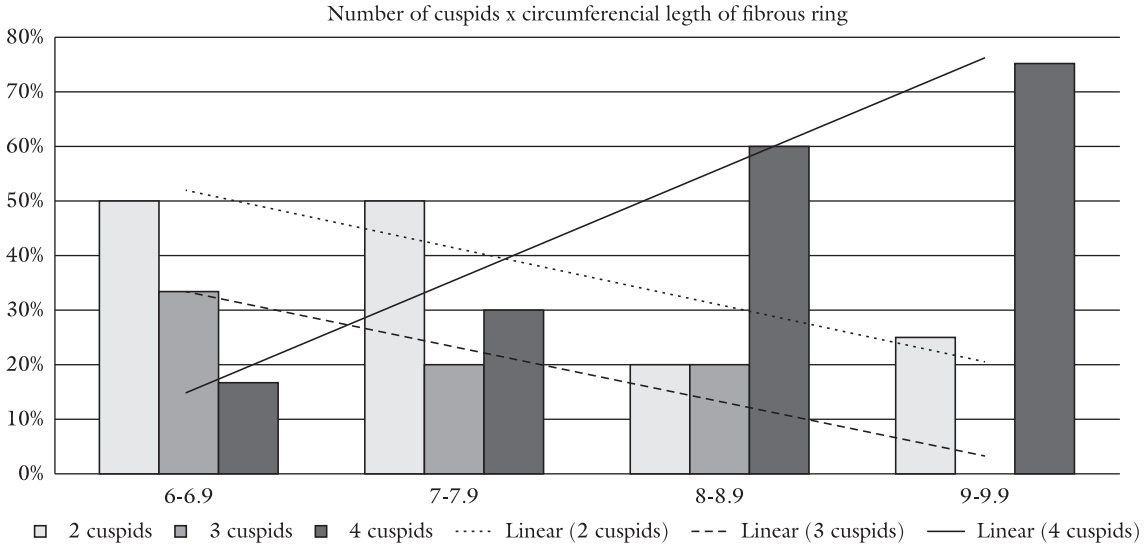

Figure 1. Number of cuspids in relation to the circumferential length of the fibrous rings.

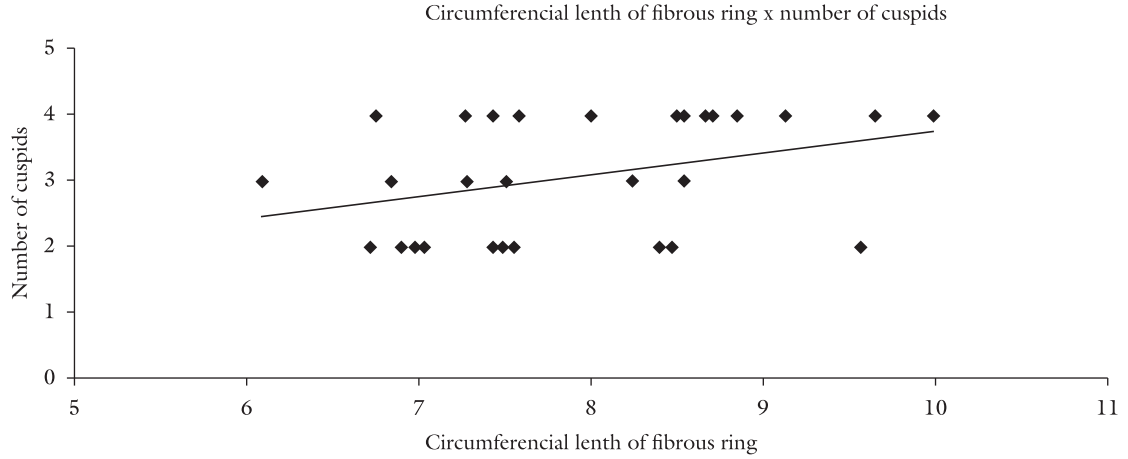

Figure 2. Relationship between the circumferential length of the fibrous ring and the number of cuspids.

twelve hearts (40%) there were four cuspids (septal, parietal and two supernumeraries) (Figure 3); and in one heart there were five cuspids (septal, parietal and three supernumeraries) (Figure 4). In the cases in which supernumerary cuspids were present, it was observed that their location between the septal and parietal cuspids could either be close to the septum (anteromedial; 53.3%) or be on the opposite side (posterolateral; 53.3%).

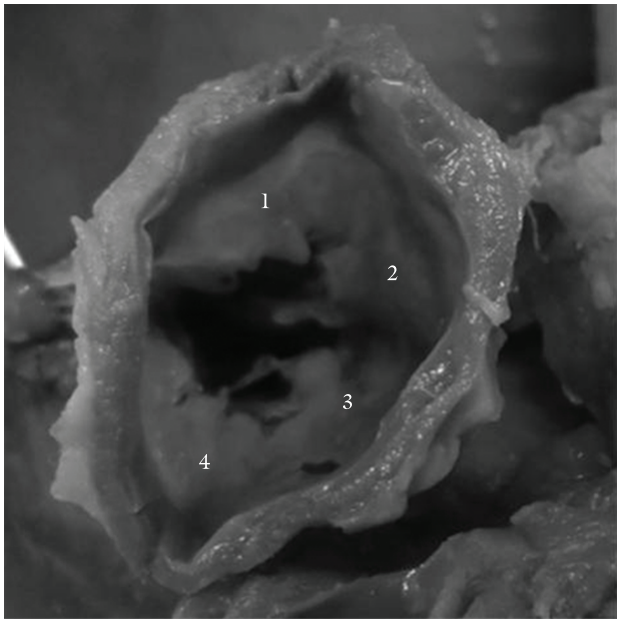

Figure 3. Left atrioventricular valve with four cuspids (1, 2, 3, 4).

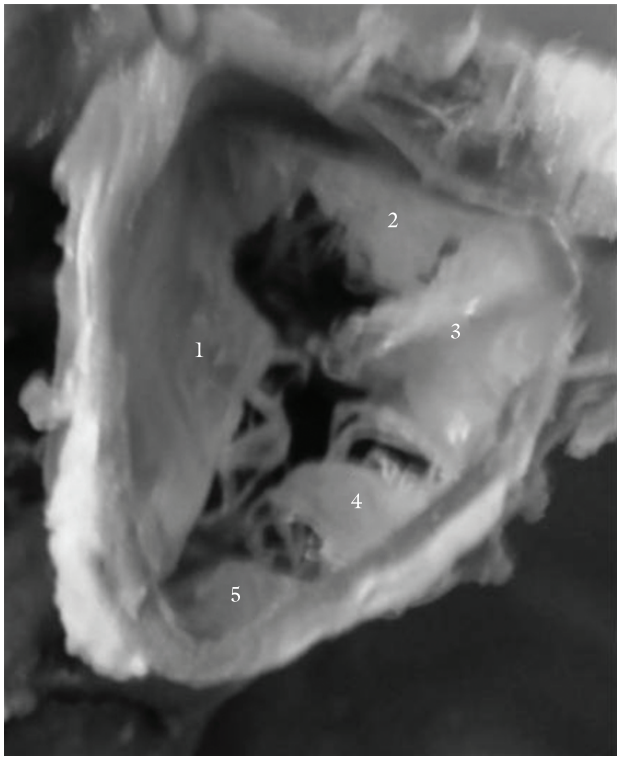

Figure 4. Left atrioventricular valve with five cuspids (1, 2, 3, 4, 5).

We found commissural cuspids (Figure 5) in 17 hearts (56.7%), in varying numbers: one commissural cuspid in nine hearts (30%); two commissural cuspids in five hearts (16.7%); and three commissural cuspids in three hearts (10%). In the hearts with two true cuspids, seven (63.6%) also presented commissural cuspids; in the hearts with three cuspids, four (66.7%) were accompanied by commissural cuspids; and in the cases with four or five cuspids, six (50%) also had commissural cuspids.

The mean width of the septal cuspid was 25.4 mm, and this was wider than the parietal cuspid (mean of 15.5 mm), and these were both wider than the supernumerary cuspids (anteromedial: mean of 12 mm; and posterolateral: mean of 12.6 mm). In turn, the supernumerary cuspids were wider than the commissural cuspids (Figure 6). The depth of the septal cuspid (mean of 19.8 mm) was greater than the depths of the parietal cuspid (mean of 15.2 mm), posterolateral supernumerary cuspid (mean of 16.3 mm) and anteromedial supernumerary cuspid (mean of 13 mm), and these were deeper than the commissural cuspids (mean of 7.2 mm) (Figure 7).

To compare the cuspid measurements, the Mann-Whitney test and Student's t test were used (with $P < 0.0001$). The septal cuspid was bigger than the parietal, supernumerary and commissural cuspids, both in width and in depth. There were significant morphometric differences between the septal and parietal cuspids, the septal and supernumerary cuspids, the septal and commissural cuspids and the supernumerary and commissural cuspids. However, the parietal and supernumerary cuspids were morphometrically similar, especially regarding the depth.

3.3 Tendon cords

On average, the left atrioventricular valve apparatus had 78 tendon cords. The lowest number was 35 and the highest number was 118. The septal cuspids had 25.7 tendon cords on average and 40.4% of the total; the parietal cuspids, 22.4 tendon cords and 34.3% of the total; the, 14.7 tendon cords

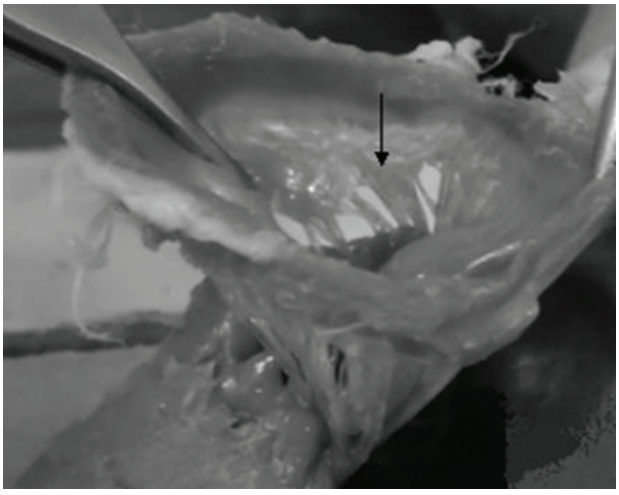

Figure 5. Left atrioventricular valve with commissural cuspid (arrow).

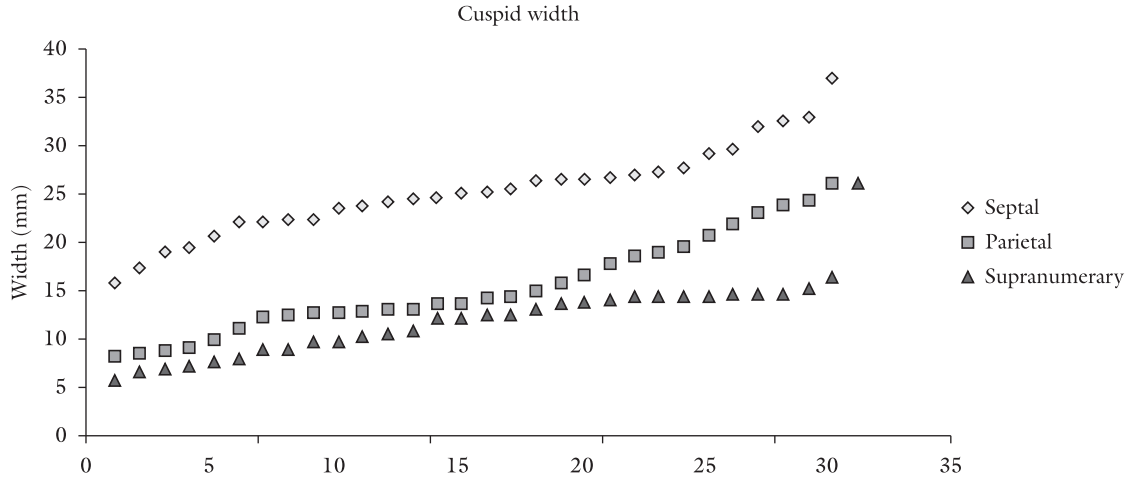

Figure 6. Comparison between cuspid widths.

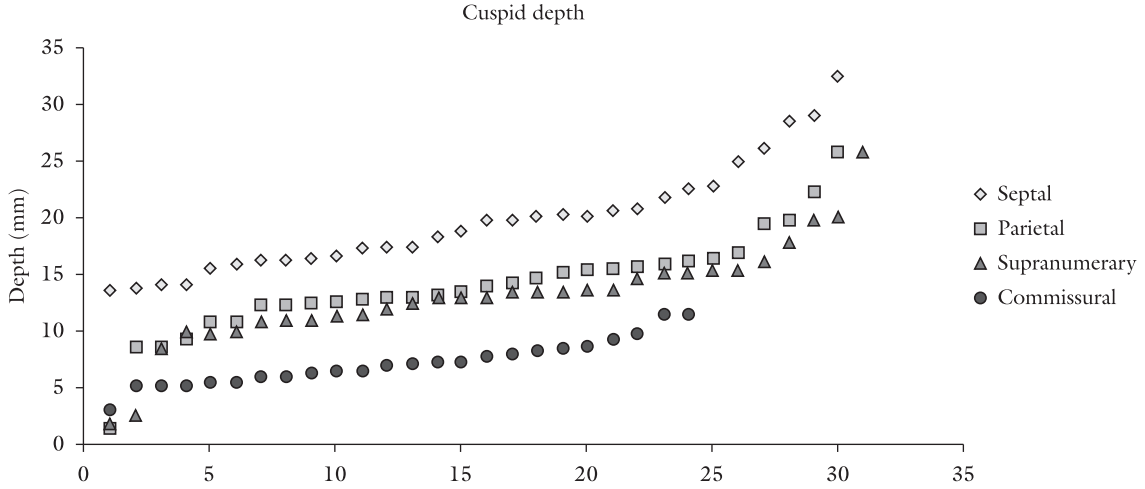

Figure 7. Comparison between cuspid depths.

and 12% of the total; the posterolateral supernumerary cuspids, 17.3 tendon cords and 14.1% of the total; and the commissural cuspids, 1.8 tendon cords and 10.9% of the total. Out of the total number of tendon cords, 49.4% came from the subauricular papillary muscle and 50.6% from the subatrial papillary muscle (Figure 8). The tendon cords were predominantly attached to the ventricular surface of the cuspids (48.1%).

3.4 Papillary muscles

The total number of papillary muscles ranged from two (90.0%) to four (10%). The subauricular papillary muscle can be single (96.7%) or double (3.3%), while the subatrial papillary muscle can be single (90%), double (6.7%) or triple (3.3%). There was no morphometric predominance between the papillary muscles, but the subatrial muscle was slightly larger. The mean height of the subatrial papillary muscle was 9.7 mm and the height of the subauricular muscle was 8.1 mm.

The tendon cords coming from the subauricular papillary muscle were attached to the septal cuspids (100%), parietal cuspids (53.3%) and supernumerary cuspids (100%). The tendon cords coming from the subatrial papillary muscle were attached to the septal cuspids (100%), parietal cuspids (100%), posterolateral supernumerary cuspids (56.25%) and anteromedial supernumerary cuspids (6.25%).

4 Discussion

In the literature, we found references to components of the left atrioventricular valve apparatus in animals (WALMSLEY, 1978; SCHUMMER, WILMUT, VOLLMERHAUS et al., 1981) and even in pigs' hearts (CRICK, SHEPPARD, HO et al., 1998). Nevertheless, the great volume of experimental and clinical applied research that uses pigs' hearts justifies conducting a more detailed study on the components of the valve apparatus in pigs.

Crick, Sheppard, Ho et al. (1998) mentioned the existence of two cuspids, but our results demonstrate that the valve apparatus may also have three, four or even five cuspids. Crick, Sheppard, Ho et al. (1998) did not cite the presence of supernumerary cuspids or commissural cuspids, while we found supernumerary cuspids in 63.3% of the specimens

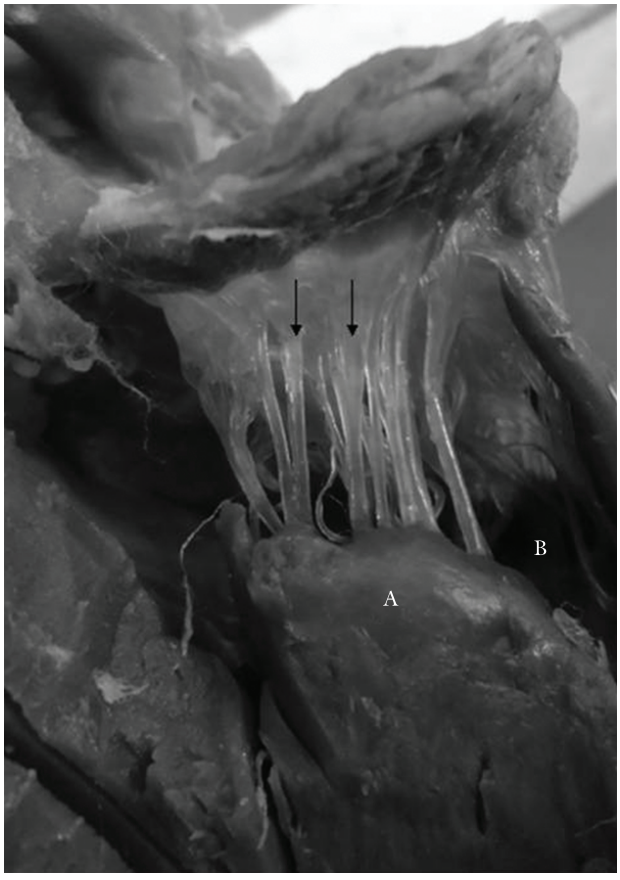

Figure 8. Tendon cords attached to the ventricular face (arrow); and papillary muscles: subauricular (a), subatrial (b).

and small commissural cuspids in 56.7%. Morphometrically, the supernumerary cuspids were smaller than the septal cuspid, equivalent to the parietal cuspid and larger than the commissural cuspids. They were located between the septal and parietal cuspids, either medially (53.3%) or laterally (53.3%). We demonstrated that the supernumerary cuspids were morphometrically different from the commissural cuspids. The number of cuspids did not present any relationship with weight, sex, circumferential length of the fibrous ring or the numbers of tendon cords or papillary muscles. The same occurred with the numbers of papillary muscles and tendon cords in relation to the parameters studied. According to Crick, Sheppard, Ho et al. (1998), the parietal cuspid is larger, but our investigation demonstrated that the septal cuspid was bigger, given that its mean width was 25 mm and its greatest depth was 19.8 mm, while the parietal cuspid presented a mean width of 15.5 mm and its greatest depth was 15.2 mm. The tendon cords of the subauricular and subatrial papillary muscles were attached to the septal, parietal and supernumerary cuspids. Attachment of tendon cords of the posterolateral supernumerary cuspid to the subatrial papillary muscle was infrequent.

We believe that the merit of this investigation consists of its use of morphometric criteria objectively differentiate the usual cuspids (septal and parietal) from supernumerary and commissural cuspids. Recommendations regarding the importance of making use of such measurements can also be found in Kunzelman, Cochran, Verrier et al. (1994) and Espino, Shepherd and Buchan (2007).

5 Conclusion

Morphometric criteria such as the width of the implantation base and maximum depth should be used to characterize the cuspids of the left atrioventricular valve apparatus.

Morphological criteria such as the number of papillary muscles, circumferential length of the fibrous ring and number of tendon cords generally do not correlate with the variations in the number of cuspids of the left atrioventricular valve.

Based on these criteria, we can affirm that the number of cuspids in the left atrioventricular valve is variable; that commissural cuspids frequently occur; and that the presence of commissural cuspids does not depend on the number of cuspids.

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