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The morphology and distribution of the tendinous chords and their relation to the papillary muscles in the tricuspid valve of the human heart

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The tendinous chords of the tricuspid valve are the predominant type of connection between the papillary muscles and the tricuspid valve. Studies describing the evolutionary line of these connections are well known. The flexibility of particular leaflets of the tricuspid valve varies, as does the tension of the blood stream in particular cusps.
The present study was performed on a group of 96 formalin-fixed adult human hearts, which ranged in age from 18 to 90 years and gave no evidence of congenital malformations or pathological changes. The valves were divided into five types according to earlier studies and analysis was made in terms of these types. The tendinous chords and their ramifications were counted. The surfaces of particular leaflets were measured. The ratio of marginal to ventricular leaflets was counted for each type of leaflet in particular types of valves. The parts of the main leaflets supported by specific papillary muscles were counted for types 1, 2 and 3.
The number of tendinous chords decreased in leaflets in particular types of tricuspid valve, but the ratio of chords attached to the margins and ventricular surfaces was similar. The number of chords for the surface of leaflets (measured in mm^2) was similar in particular types of valve for all cusps.
The most differentiated were commissural chords in all types of valve. The ratio of chords attached to the margins and ventricular surfaces does not depend on the surface area of the leaflets.

Key words: tricuspid valve, tendinous chords

INTRODUCTION

The tendinous chords (*chordae tendineae cordis*) of the tricuspid valve are the predominant type of connection between the papillary muscles and the tricuspid valve. The evolutionary line of these connections is well known and includes straight connections, membranous connections and tendinous chords [6, 12, 14, 22, 25, 26]. Muscular and membranous connections

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are present in the hearts of humans and other primates as atavistic features [22, 25, 26]. The tendinous chords are attached to the margins of the leaflets, ventricular surface and commissures. Chords anchored in the margin have come to be known as primary tendinous chords, while chords attaching to the ventricular surface of leaflets are termed secondary tendinous chords. The functions of the two groups are different [8], a division which was recognised in the Renaissance in the pictures of Leonardo da Vinci and Vesalius [8, 13].

There are 5 types of tricuspid valve, and these depend on the number of leaflets.

The compliance of particular leaflets varies, as does the tension of the blood stream in particular leaflets of the tricuspid valve [11, 16, 17]. Studies of the relationship between the geometry and function of the right ventricle usually involve electrophysiological research [4]. In the light of this, and with the rapid progress in the field of interventional cardiology and the introduction into cardiosurgery of new valvuloplastic methods, study of the morphology of the tendinous chords is now required [4, 5, 7, 9, 18, 24].

MATERIAL AND METHODS

A group of 96 formalin-fixed adult human hearts (78 male, 28 female) was examined. The hearts ranged in age from 18 to 90 years and showed no congenital malformations or pathological changes. They were opened from the side of the right atrium; the line of the cut led from the ostium of the vena cava superior right to the atrioventricular orifice. The right ventricles were opened with a classic cut along the right margin and across the anterior wall of the right ventricle. The group studied consisted of 11 valves of type 1 (7 male, 4 female), 45 valves of type 2 (36 male, 9 female), 39 valves of type 3 (27 male, 12 female), 8 valves of type 4 (5 male, 3 female) and 3 valves of type 5 (2 male and 1 female). The valves were divided into 5 types according to earlier studies [20–22, 24] and investigations were performed in terms of these five types. In addition separate study was made of the subtypes of types 2 and 3, type 2 having three subtypes and type 3 — six subtypes.

The tendinous chords were counted for the main and accessory leaflets with respect to their position in the leaflet, whether in the margin, ventricular surface or commissural area [9, 14], and their ramifications were counted for the main and accessory leaflets. The fields of the surfaces of particular leaflets were measured using planimetry. For the main leaflets of types 1, 2 and 3 the fields of the surface provided by particular papillary muscles were measured and the ratios calculated as a percentage. The ratio of marginal and ventricular chords was counted for each particular leaflet and its surface. The results obtained were statistically analysed by one-way analysis of variance (ANOVA) for independent variables ($p < 0.05$).

RESULTS

The total average number of chords was 72.71 ± ± 13.38. Specific leaflets of the tricuspid valve differ in the number of chords attaching to the margin, ventricular surface and commissures, depending on the particular type of valve (Table 1). The fields of the measured surfaces in particular leaflets ranged from 610 ± 204 to 151 ± 59 mm^2. The ratio of chords to surface varied from 5.2 ± 4.4 (posterior leaflet in type 3 C) to 1.18 ± 0.17 (anterior leaflet in type 3A) (Table 2). The ratio of marginal and ventricular chords in particular leaflets and the total ratio in several types of tricuspid valve showed no statistical differences in the total number of chords. There were fewer chords attaching particular leaflets when there was an increase in particular types of valve. The number of chords attaching to main leaflets was higher than to accessory ones. Commissural chords were the most differentiated in all types of valve. The number of marginal chords was very similar in the anterior and septal cusps (CA — 12.03 ± 2.09 and CS — 11.99 ± 3.35) but statistically higher in the posterior cusps (CP — 9.47 ± 1.41). There were no statistical differences between the ratios of marginal and ventricular chords, which were similar in all types of valve. In the main cusps the ratio was statistically lower ($p < 0.05$) than in the accessory cusps. The number of chords for the surface of leaflets (measured in mm^2) was not statistically different ($p > 0.05$) in any type of valve or cusp (Table 1).

The fields of the surface provided by particular papillary muscles as part of the main cusps, measured and calculated as a percentage, were similar for types 1, 2 and 3. The measurements were not performed for types 4 and 5 because of the small group of valves in particular subtypes and the high variability in the number and position of the accessory cusps. The anterior leaflet was provided by chords which originated in the anterior and posterior papillary muscles (anterior papillary muscle 86.19 ± ± 11.66%, posterior 13.09 ± 1.74). The posterior leaflet was provided by chords coming from the posterior and septal papillary muscles (posterior 85.67 ± 11.48%, septal 14.33 ± 1.83%). The septal cusp was provided by chords from the septal and anterior papillary muscles (septal 19.0 ± 2.55, anterior 80.99 ± 10.85%).

Table 1. The average number of chords in particular leaflets of tricuspid valve with regard to their position and surface of leaflet

Type	Parameter	Leaflets															
		CA				CP				CS				Cac			
		Margin	Surface	Commi-ssure	Total	Margin	Surface	Commi-ssure	Total	Margin	Surface	Commi-ssure	Total	Margin	Surface	Commi-ssure	Total
1	Average ± ± SD	14.09 ± ± 4.86	9 ± ± 5.79	0.27 ± ± 0.46	23.36 ± ± 7.60	11.91 ± ± 4.30	5.82 ± ± 3.34	0	17.73 ± ± 6.8	17.18 ± ± 6.11	11.91 ± ± 5.45	0.27 ± ± 0.47	29.36 ± ± 10.07				
	Surface [mm^2] ± SD				609.66 ± ± 203.89				332.48 209.16				419.89 ± ± 101.76				
	Surface/chord ± SD				26.09 ± ± 8.01				18.75 ± ± 6.02				14.3 ± ± 6.4				
2	Average ± ± SD	14.13 ± ±5.16	9.58 ± ± 4.68	0.13 ± ± 0.40	23.84 ± ± 8.19	10.73 ± ± 5.92	4.93 ± ± 3.76	0.02 ± ± 0.15	15.69 ± ± 7.83	15.73 ± ± 5.37	8.91 ± ± 3.74	0.24 ± ± 0.48	24.89 ± ± 7.54	6.04 ± ± 2.85	2.42 ± ± 2.61	0.11 ± ± 0.32	8.41 ± ± 3.1
	Surface [mm^2] ± SD				466.8 ± ± 143.72				330.74 ± ± 183.65				432.81 ± ± 186.95				145.74 ± ± 65.12
	Surface/ /chord ± SD				19.58 ± ± 2.01				21.08 ± ± 0.99				17.39 ± ± 1.09				8.66 ± ± 0.05
2A	Average ± ± SD	14.54 ± ± 5.1	8.83 ± ± 4.67	0.25 ± ± 0.53	23.62 ± ± 8.8	11.67 ± ± 5.66	5.5 ± ± 3.74	0	17.17 ± ± 7.34	15.08 ± ± 4.17	9.42 ± ± 3.89	0.25 ± ± 0.44	24.75 ± ± 6.47	6.5 ± ± 2.98	2.67 ± ± 3.12	0.083 ± ± 0.28	9.25 ± ± 4.24
	Surface [mm^2] ± SD				247.42 ± ± 167.03				328.36 ± ± 192.62				419.24 ± ± 149.55				137.93 ± ± 59.58
	Surface/ /chord ± SD				10.48 ± ± 0.17				19.13 ± ± 0.09				16.94 ± ± 0.89				14.91 ± ± 0.09
2B	Average ± ± SD	14.8 ± ± 6.42	11.2 ± ± 5.88	0	26 ± ± 9.04	11.1 ± ± 6.71	6 ± ± 4.22	0.1 ± ± 0.03	17.2 ± ± 9.08	17.7 ± ± 6.57	8.3 ± ± 4.52	0.4 ± ± 0.02	26.2 ± ± 9.94	4.9 ± ± 1.59	1.3 ± ± 0.95	0.3 ± ± 0.08	6.5 ± ± 1.84
					492.72 ± ± 105.78				323.98 ± ± 155.05				466.08 ± ± 250.63				122.26 ± ± 57.94
					18.95 ± ± 0.1				18.84 ± ± 0.09				17.79 ± ± 1.01				18.81 ± ± 1.2
2C	Average ± ± SD	12.64 ± ± 4.13	9.73 ± ± 3.35	0	22.36 ± ± 6.02	8.36 ± ± 5.61	2.73 ± ± 2.61	0	11.09 ± ± 6.39	15.36 ± ± 6.58	8.36 ± ± 2.66	0,27 ± ± 0,65	24 ± ± 7.87	6.09 ± ± 3.36	2.91 ± ± 2.30	0	9 ± ± 4.31
					453.54 ± ± 125.43				342.07 ± ± 203.06				432.16 ± ± 210.4				184.13 ± ± 71.82
					20.28 ± ± 1.09				30.84 ± ± 2.34				18.01 ± ± 2.09				20.46 ± ± 1.59

→

Type	Parameter	Leaflets															
		CA				CP				CS				Cac			
		Margin	Surface	Commi-ssure	Total	Margin	Surface	Commi-ssure	Total	Margin	Surface	Commi-ssure	Total	Margin	Surface	Commi-ssure	Total
3	Average ± ± SD	12.38 ± ± 4.78	8.36 ± ± 3.54	0.13 ± ± 0.34	20.87 ± ± 6.99	11 ± ± 4.80	5.44 ± ± 3.8	0.20 ± ± 0.41	16.64 ± ± 7.19	14.38 ± ± 6.70	8.72 ± ± 4.44	0,23 ± ± 0,43	23.33 ± ± 8.91	5.49 ± ± 3.07	3.17 ± ± 3.67	0.17 ± ± 0.41	8.82 ± ± 4.60
					453.55 ± ± 152.39				342.07 ± ± 165.89				432.16 ± ± 190.76				154.97 ± ± 107.27
					21.73 ± ± 3.09				20.56 ± ± 2.98				18.52 ± ± 1.98				17.57 ± ± 1.87
3A	Average ± ± SD	13.25 ± ± 2.99	11.25 ± ± 2.06	0	24.5 ± ± 4.79	13.25 ± ± 2.22	4.75 ± ± 2.06	0	18 ± ± 1.41	7.5 ± ± 1.29	5 ± ± 2.45	0	12.5 ± ± 3.41	2 ± ± 1.19	0.75 ± ± 0.71	0.12 ± ± 0.35	2.87 ± ± 1.44
					451.48 ± ± 68.94				261.29 ± ± 110.65				580.84 ± ± 330.59				125.23 ± ± 105.03
					18.43 ± ± 1.1				14.52 ± ± 1.67				46.47 ± ± 3.99				43.56 ± ± 3.73
3B	Average ± ± SD	11.73 ± ± 4.67	7.64 ± ± 2.69	0.36 ± ± 0.50	19.73 ± ± 5.95	13.91 ± ± 5.45	6.45 ± ± 4.39	0.27 ± ± 0.07	20.64 ± ± 7.83	17.64 ± ± 6.02	9.82 ± ± 3.31	0.36 ± ± 0.5	27.82 ± ± 8.81	5.54 ± ± 3.1	1.91 ± ± 1.48	0.4 ± ± 0.21	7.5 ± ± 2.67
					430.51 ± ± 199				378.46 ± ± 240.44				416.99 ± ± 159.01				137.3 ± ± 116
					21.82 ± ± 2.98				18.33 ± ± 2.05				14.99 ± ± 2.63				18.3 ± ± 2.01
3C	Average ± ± SD	13.43 ± ± 6.45	7.43 ± ± 3.87	0.14 ± ± 0.38	21 ± ± 7.83	7.86 ± ± 2.48	2.42 ± ± 1.39	0.48 ± ± 0.28	10.57 ± ± 2.3	20 ± ± 8.37	6.86 ± ± 3.62	0.14 ± ± 0.38	27 ± ± 7.12	4.71 ± ± 2.27	3.57 ± ± 3.37	0.54 ± ± 0.36	8.43 ± ± 3.24
					461.9 ± ± 207.4				229.99 ± ± 98.66				242.11 ± ± 118.95				131.87 ± ± 63.51
					34.4 ± ± 3.04				29.27 ± ± 2.97				12.10 ± ± 1.76				15.64 ± ± 1.48
3D	Average ± ± SD	9.17 ± ± 3.97	6.67 ± ± 2.42	0	15.83 ± ± 6.149	11 ± ± 5.21	5.83 ± ± 2.32	0	16.83 ± ± 6.97	11.17 ± ± 4.96	12.67 ± ± 6.22	0.33 ± ± 0.52	24.17 ± ± 10.85	5.67 ± ± 2.39	5.08 ± ± 6.39	0.25 ± ± 0.45	11 ± ± 7.13
					409.9 ± ± 23.82				168.08 ± ± 117.18				385.31 ± ± 128.07				157.81 ± ± 99.47
					44.71 ± ± 4.02				15.28 ± ± 1.74				34.50 ± ± 2.01				14.35 ± ± 1.97

→

Type	Parameter	Leaflets															
		CA				CP				CS				Cac			
		Margin	Surface	Commissure	Total	Margin	Surface	Commissure	Total	Margin	Surface	Commissure	Total	Margin	Surface	Commissure	Total
3E	Average ± ± SD	14.89 ± ± 3.89	10.22 ± ± 4.58	0	25.11 ± ± 7.06	9.55 ± ± 4.64	5.67 ± ± 4.74	0.22 ± ± 0.44	15.44 ± ± 8.62	11.89 ± ± 3.92	9 ± ± 3.43	0.44 ± ± 0.22	21.11 ± ± 6.01	7.5 ± ± 3.53	3.83 ± ± 2.89	0.17 ± ± 0.38	11.5 ± ± 3.39
					463.05 ± ± 138.07				311.94 ± ± 116.39				360.35 ± ± 165.92				159.32 ± ± 149.09
					18.44 ± ± 5.07				20.2 ± ± 5.98				17.07 ± ± 4.78				13.85 ± ± 7.99
3F	Average ± ± SD	9 ± ± 4.24	6.5 ± ± 2.12	0	15.5 ± ± 6.36	8 ± ± 0.6	9.5 ± ± 3.53	0.5 ± ± 0.71	18 ± ± 4.24	11.5 ± ± 3.53	3.5 ± ± 3.3	0	15 ± ± 7.07	5.25 ± ± 0.5	4.75 ± ± 5.85	0.75 ± ± 0.95	10.75 ± ± 7.42
					452.33 ± ± 58.06				400.95 ± ± 49.7				323.89 ± ± 196.92				296.01 ± ± 165.79
					29.18 ± ± 4.56				22.27 ± ± 2.15				21.59 ± ± 3.98				27.53 ± ± 8.07
4	Average ± ± SD	10.25 ± ± 2.91	8 ± ± 3.82	0.38 ± ± 0.74	18.62 ± ± 4.4	8.12 ± ± 3.83	5.37 ± ± 2.87	0	13.5 ± ± 2.14	14 ± ± 5.21	5.62 ± ± 2.06	0.12 ± ± 0.35	19.75 ± ± 6.73	4.33 ± ± 2.74	2.12 ± ± 1.87	0.8 ± ± 0.28	6.54 ± ± 1.82
					405.68 ± ± 90.42				250.64 ± ± 90.34				399.25 ± ± 99.23				111.44 ± ± 61.26
					21.78 ± ± 4.01				18.57 ± ± 3.59				20.21 ± ± 4.04				17.03 ± ± 3.89
5	Average ± ± SD	9.33 ± ± 0.58	5.67 ± ± 2.89	0.58 ± ± 0.33	15.33 ± ± 2.31	10.33 ± ± 1.15	5 ± 2	0	15.33 ± ± 1.15	14.33 ± ± 6.65	4.67 ± ± 2.89	0.58 ± ± 0.33	19.33 ± ± 5.51	3.33 ± ± 2.1	1.5 ± ± 1.1	0.62 ± ± 0.2	5.08 ± ± 0.88
					161.28 ± ± 58.6				357.39 ± ±127.42				282.01 ± ± 17.75				109.04 ± ± 72.08
					23.31 ± ± 8.97				10.52 ± ± 3.69				14.59 ± 2.09 ± 2.09				21.45 ± ± 9.98

CA — anterior leaflet; CP — posterior leaflet; CS — septal leaflet; Cac — accessory leaflet; Margin — average number of chords attaching to margin of leaflet; Surface — average number of chords attaching to surface; Commissure — average number of chords attaching to commissure; Total — total number of chords in leaflets of tricuspid valve; SD — standard derivation, Surface of leaflet measured in mm^2; Surface/chord — quotient of leaflet surface to number of chords; Surface/chord — quotient of number of chords to leaflet surface, ant-anterior papillary muscle, post, posterior papillary muscle; sept — septal papillary muscle; origin — number of chords departing papillary muscle; end — number of chords attaching to leaflet

Table 2. The ratio of marginal and ventricular chords in several types of tricuspid valve

Type	Leaflet				
	CA Quotient	CP Quotient	CS Quotient	Cac Quotient	Total Quotien
1	2.44 ± 1.84	2,85 ± 2,18	1.63 ± 0.81		1.73 ± 0.55
2	1.87 ± 1.29	3.23 ±2.28	2.29 ± 1.99	3.59 ± 2.85	1.96 ± 0.84
2A	2.05 ± 1.33	3.04 ± 2.06	2.04 ± 1.93	4.10 ± 3.45	1.98 ± 0.9
2B	1.79 ± 1.43	2.16 ± 0.96	3.1 ± 2.64	3.45 ± 1.71	2.03 ± 0.88
2C	1.55 ± 1.09	4.62 ± 3.01	2.09 ± 1.32	2.62 ± 2	1.85 ± 0.7
3	1.74 ± 1.24	3.38 ± 3.06	2.21 ± 1.95	2.88 ± 2.27	1.81 ±0.63
3A	1.18 ± 0.17	3.68 ± 2.91	1.8 ± 0.86	2.92 ± 2.75	1.68 ± 0.17
3B	1.59 ± 0.7	3.37 ± 3.07	1.88 ± 0.71	3.46 ± 1.88	2.01 ± 0.51
3C	2.48 ± 2.53	5.21 ± 4.38	4 ± 2.85	1.82 ± 1.26	2.29 ± 0.88
3D	1.36 ± 0.37	1.98 ± 0.61	0.92 ± 0.28	3.20 ± 3.03	1.25 ± 0.38
3E	1.87 ± 1.28	2.69 ± 2.08	1.52 ± 0.73	2.20 ± 1	1.66 ± 0.55
3F	1.35 ± 0.21	0.90 ± 0.33	5.67 ± 4.71	3.12 ± 2	1.38 ± 0.37
4	3.5 ± 2.4	3.89 ± 3.01	2.6 ± 0.92	2.24 ± 1.08	1.91 ± 1.91
5	1.92 ± 0.8	2.37 ± 1.2	4.08 ± 3.06	4.37 ± 4.06	2.3 ± 0.76

CA — anterior leaflet; CP — posterior leaflet; CS — septal leaflet; Cac — accessory leaflet

Table 3. Fields of surface provided by particular papillary muscles as part of the main cusps as a percentage of the total surface in types 1, 2 and 3

Type	Leaflets					
	CA		CP		CS	
	Anterior p.m. Average (%)	Posterior p.m. Average (%)	Posterior p.m. Average (%)	Septal p.m. Average (%)	Septal p.m. Average (%)	Anterior p.m. Average (%)
1	86.54 ± 12.98	13.46 ± 2.02	84.63 ± 12.69	15.37 ± 2.31	80.01 ± 6.4	19.99 ± 1.6
2	86.55 ± 12.13	13.45 ± 1.86	84.04 ± 11.57	15.96 ± 2.17	79.78 ± 10.57	20.21 ± 2.68
2A	85.01 ± 11.05	14.99 ± 1.95	79.08 ± 10.28	20.92 ± 2.72	79.94 ± 10.39	20.06 ± 2.61
2B	87.88 ± 16.7	12.12 ± 2.30	86.77 ± 16.47	13.23 ± 2.5	78.99 ± 11.85	21.01 ± 3.15
2C	86.77 ± 7.81	13.23 ± 1.19	85.67 ± 6.85	14.33 ± 1.15	80.19 ± 13.63	19.81 ± 3.37
3	87.15 ± 11.34	12.84 ± 1.65	86.76 ± 11.42	13.24 ± 1.61	81.8 ± 11.03	18.2 ± 2.46
3A	88.19 ± 7.06	11.81 ± 0.94	84.63 ± 11	15.37 ± 1.2	84.46 ± 10.98	15.54 ± 2.02
3B	86.25 ± 11.21	13.75 ± 1.79	87.91 ± 13.17	12.09 ± 1.81	82.77 ± 9.93	17.23 ± 2.07
3C	88.03 ± 13.20	11.97 ± 1.79	84.92 ± 14.44	15.08 ± 2.56	81.69 ± 7.35	18.31 ± 1.65
3D	90.32 ± 15.35	9.68 ± 1.65	85.77 ± 7.72	14.23 ± 1.28	80.97 ± 12.14	19.03 ± 2.85
3E	84.04 ± 10.92	15.96 ± 2.07	90.44 ± 11.76	9.56 ± 1.24	79.52 ± 10.34	20.48 ± 2.66
3F	86.09 ± 10.33	13.91 ± 1.67	86.91 ± 10.43	13.09 ± 1.58	81.39 ± 15.46	18.61 ± 3.53
Total	86.19 ± 11.66	13.09 ± 1.74	85.67 ± 11.48	14.32 ± 1.84	80.99 ± 10.85	19.0 ± 2.55

CA — anterior leaflet; CP — posterior leaflet; CS — septal leaflet; p.m. — papillary musculе

The anterior and posterior leaflets were provided by papillary muscles located in the corresponding walls of the ventricle in statistically higher percentages ($p < 0.05$) than were the septal leaflets (Table 3).

The ramifications of tendinous chords were counted with regard to the papillary muscles in relation to the origin of chords attaching particular leaflets. There were no statistical differences ($p > 0.05$)

Table 4. Ramifications of tendinous chords with regard to the papillary muscles giving the origin of chords attaching particular leaflets

Type of valve	CA				CP				CS			
	Anterior papillary muscle		Posterior papillary muscle		Posterior papillary muscle		Septal papillary muscle		Septal papillary muscle		Anterior papillary muscle	
	Origin Average	End Average	Origin Average	End Average	Origin Average	End Average	Origin Average	End Average	Origin Average	End Average	Origin Average	End Average
1	5.08 ± 0.23	20.21 ± 0.47	1.19 ± 0.14	3.14 ± 0.23	3.67 ± 0.26	15 ± 1.54	2 ± 0.2	2.64 ± 0.26	6.08 ± 2.08	19.73 ± 2.02	1.23 ± 0.27	3.39 ± 0.45
2	4.99 ± 0.18	20.68 ± 3.15	1.05 ± 0.3	2.08 ± 0.16	2.78 ± 0.19	13.44 ± 0.94	1.77 ± 1	2.49 ± 0.17	5.68 ± 0.25	19.91 ± 1.39	1.76 ± 0.16	4.93 ± 0.34
3	3.67 ± 0.15	18.37 ± 1.28	1.4 ± 0.11	2.49 ± 0.19	2.86 ± 0.24	14.13 ± 0.99	1.07 ± 0.21	3.14 ± 0.22	4.74 ± 0.23	19.05 ± 1.69	1.98 ± 0.25	4.27 ± 0.38
4	3.88 ± 0.21	16.03 ± 0.78	1.33 ± 0.07	2.59 ± 0.15	2.98 ± 0.21	12.2 ± 0.05	1.56 ± 0.76	2 ± 0.23	3.99 ± 0.35	15.73 ± 0.87	1.03 ± 0.16	3.67 ± 0.25
5	2.88 ± 0.3	13.91 ± 0.09	1.29 ± 0.05	2.13 ± 0.55	3.14 ± 0.1	13.32 ± 0.73	1.9 ± 0.13	2 ± 0.2	3.68 ± 0.69	15.65 ± 0.86	1.56 ± 0.11	3.54 ± 0.19

CA — anterior leaflet; CP — posterior leaflet; CS — septal leaflet

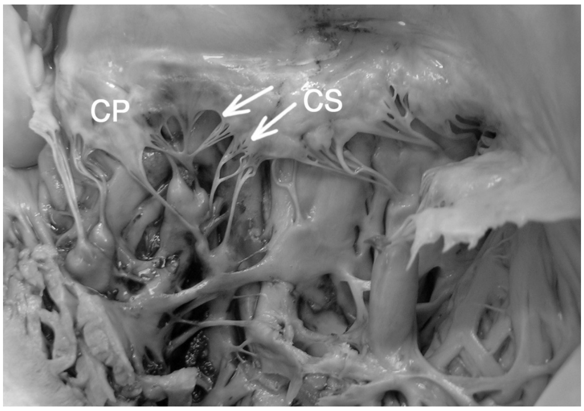

Figure 1. Atypical form of distribution of tendinous chords. Arrows show the tendinous chords arising from the posterior papillary muscle attached to the septal leaflet; CP — posterior leaflet; CS — septal leaflet

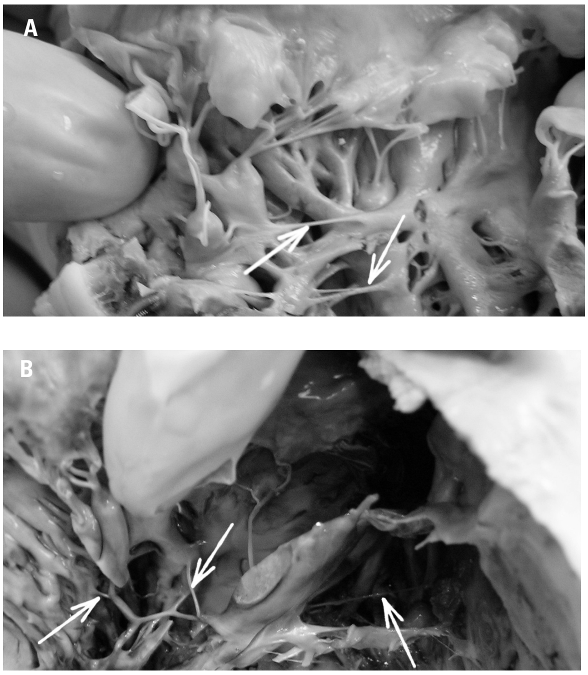

Figure 2. Spurious tendinous chords. Arrows show spurious tendinous chords in the right ventricle.

between the number of ramifications of the tendinous chords which originate from anterior (3.88 ± ± 0.45) and posterior (3.71 ± 0.31) papillary muscles, but this number was statistically higher ($p < 0.05$) than that for origin from septal muscles (3.15 ± 0.7) (Table 4). Atypical forms of tendinous chords were observed in the group studied, but their frequency was not statistically significant (Fig. 1, 2).

DISCUSSION

The study of the distribution of tendinous chords of the human tricuspid valve may be helpful in aspects of progress in cardiosurgical techniques, including tricuspid valve repair with chordal replacement after traumatic regurgitation, surgical repair of the mitral and tricuspid valves simultaneously using the De Vega method and invasive procedures with balloon valvuloplasty in cases of stenosis [5, 7, 9, 18, 24]. Studies of the tendinous chords performed in animal models of the mitral valve show the complexity of this problem. The function of the marginal chords, described in previous papers, differs from the role played by the ventricular chords [10, 13, 18].

We have studied the number of chords attaching to the margin of leaflets, to the ventricular surface and the commissural area in particular types of tricuspid valve. Additionally, for types 2 and 3 we studied each subtype separately. The number of chords in this study was lower than in the results of Łukaszewska-Otto [15] and Szostakiewicz-Sawicka [26], but the proportions between the marginal and ventricular chords are similar. We can hypothesise, that this inconsistency may be explained by the fact that these authors' studies were performed in a group of younger hearts (mean age 36 years and 30 years, respectively). Another study was performed in a group ranging from foetal to 52 year-old hearts, indicating that the number of chords increased with ageing [25]. Our results are similar to the group of hearts ranging from 39 to 52 used in the later Szostakiewicz-Sawicka study [25].

A similar subject was studied by Wafae et al. [27], but this author did not classify for study the tendinous chords in the main and accessory leaflets or in marginal, commissural and chords anchored in the ventricular surface of leaflets. His classification was based on the geometric form of the leaflets. In our previous work we did not classify the chords into types, because tendinous chords were only one type of connection joining the papillary muscles to the leaflets of tricuspid valve [21]. When the ratio of marginal and ventricular chords is taken into consideration, the results of Łukaszewska-Otto [15] and Szostakiewicz-Sawicka [25, 26] were similar to ours.

The number of chords attaching to the surface of leaflets was similar in particular types of valve for all cusps and was comparable to the results of Szostakiewicz-Sawicka [26], although her material was based on primates and a smaller number of human hearts. The ramification of chords attaching septal leaflets was higher than for the anterior and posterior leaflets. This, as well as the morphology of the septal papillary muscles, may be related to the lower mobility of the septal cusp than the anterior and posterior [16, 17, 23]. The anterior leaflets were provided by chords which originated in the anterior and posterior papillary muscles, the posterior leaflets by chords coming from the posterior and septal papillary muscles and the septal cusp by chords from the septal and anterior papillary muscles. The anterior and posterior leaflets were provided by papillary muscles located in the corresponding wall of the ventricle in statistically higher percentages than were the septal leaflets. The attachments of the papillary muscles are not parallel to those of the analogical leaflets of the tricuspid valve. This asymmetrical attachment, where it is in the "counter clockwise rotation" type of attachment, seems to be consistent with classical textbooks of anatomy and novel embryological studies [1–3, 6, 12, 14, 16].

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