Dynamic Morphologic Changes in the Normal Aortic Annulus during Systole and Diastole

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Background and aim of the study: **The three-dimensional motion of semilunar attachment of the leaflet 'annulus' remains obscure. It has been suggested that the aortic root is distensible and moves during the cardiac cycle. In the present study, the aortic root was evaluated using two dimensions. The aortic root, notably motion of the aortic annulus, was evaluated using multidetector computed tomography (MDCT), and a three-dimensional reconstruction of the aortic annulus was performed.**

Methods: **Twenty-five patients (17 males, eight females) underwent MDCT. None of the patients had aortic root disease, aortic valve disease, bicuspid valve, myocardial infarction or atrial fibrillation. The aortic annulus was measured in systole and diastole, and divided into three parts: the right coronary cusp (RCC), left coronary cusp (LCC) and non-coronary cusp (NCC). The lengths of the aortic annulus, sinus of Valsalva and sinotubular junction (STJ) were also measured in systole and diastole on longitudinal views.**

Results: **The lengths of each aortic annulus part in systole and diastole were as follows. In systole: RCC 41.8 ± 8.1 mm; LCC 39.3 ± 5.9 mm; NCC 43.7 ± 7.1 mm. In diastole: RCC 42.4 ± 7.0 mm; LCC 38.6 ± 7.8 mm; NCC 41.5 ± 7.8 mm. No statistically significant differences were observed between lengths in systole and diastole. The longitudinal lengths of aortic annulus, sinus of Valsalva and STJ at each period were as follows. In systole: aortic annulus 22.5 ± 2.2 mm; sinus of Valsalva 34.9 ± 4.3 mm; STJ 28.1 ± 3.2 mm. In diastole: aortic annulus 22.1 ± 2.2 mm; sinus of Valsalva 34.4 ± 4.7 mm; STJ 27.2 ± 3.1 mm. The length of the STJ in systole was significantly greater than that in diastole.**

Conclusion: **In the normal aortic root, no part of the aortic annulus changed length during the cardiac cycle. According to changes in aortic root dimensions, the commissures move outwards during the systolic phase.**

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During recent years, aortic valve repair, including aortic valve-sparing surgery, has received much attention (1-3). An understanding of the dynamic mechanism of the aortic annulus may be important for establishing aortic valve repair techniques and new artificial materials, much in the same way that mitral valve annuloplasty has improved mitral valve repair. Unlike the mitral valve, the aortic valve does not have a clear annulus (4). In the present study, the semilunar attachment of the leaflets was defined as the 'annulus'. The aortic annulus consists of a fibrous skeleton and muscular outlet portion of the left ventricle, and has a crown-shaped structure which makes the evaluation of motion during the cardiac cycle in vivo very difficult.

In the past, studies have focused on the opening and closing characteristics of the aortic valve and aortic root (5), the anatomy of the aortic root (6), and leaflet stress and sinuses (7). However, to the present authors' knowledge, no investigations have been conducted on the motion of the aortic annulus during the cardiac cycle in humans. Here, the aortic annulus was evaluated using multidetector computed tomography (MDCT), and a three-dimensional reconstruction of the aortic annulus was performed. The study aim was to clarify the motion of the aortic annulus, in order to assist in the development of repair techniques.

Clinical material and methods

Patients

A total of 25 patients (17 males, eight females; mean

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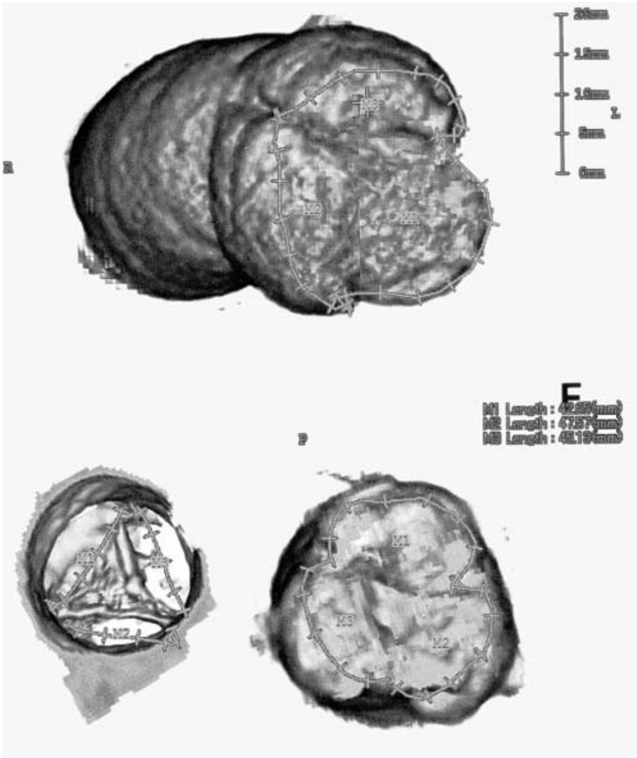

Figure 1: Volume rendering 40%. Systolic phase data measured at the T-wave of the electrocardiogram. The aortic annulus was measured by tracking many points to ensure that the correct semilunar attachments were traced.

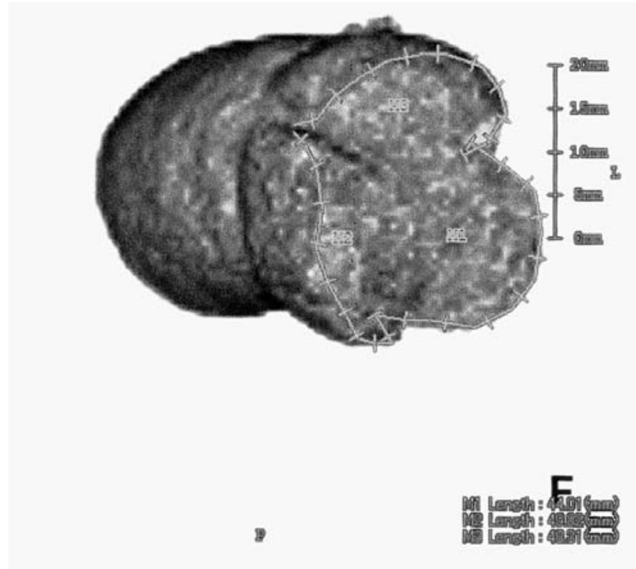

Figure 2: Volume rendering (VR) 80%. Diastolic phase data measured at the P-wave of the electrocardiogram. The measuring method was identical to that used for VR 40%.

age 60.1 ± 14.8 years) underwent MDCT at the authors' institution. Patient demographic data are listed in Table I. None of the patients had aortic root disease, aortic valve disease, congenital bicuspid valve, myocardial infarction or atrial fibrillation.

MDCT investigations

The MDCT system (Aquilion 16 Super Heart; Toshiba, Tokyo, Japan) was used in the study, with acquired data being processed with commercially available software (ZIO M900 QUADRA; Ziosoft Inc., Tokyo, Japan).

The aortic annulus, which represents the semilunar attachment of the leaflets, is divided into three portions, each of which corresponds to three leaflets of the right coronary cusp (RCC), left coronary cusp (LCC) and non-coronary cusp (NCC). The acquired data were processed into three-dimensional images by volume rendering (VR). The semilunar attachment of the leaflet was tracked in order to measure the lengths of each part of the annulus (see Figs. 1 and 2). The lengths of the anatomic ventriculoarterial junction, sinus of Valsalva and sinotubular junction (STJ) were also measured on longitudinal views, using multiplanar reformation (MPR) (see Figs. 3 and 4). The length of each portion was measured at the systolic and diastolic phases of the electrocardiogram (ECG). Systolic phase data were acquired at the T-wave of the ECG (VR and MPR 40%), while diastolic phase data were acquired at the P-wave (VR and MPR 80%).

Table I: Patient demographic data (n = 25).

Parameter	Value
Age (years)*	60.1 ± 14.8 (30-82)
Gender ratio (M:F)	17:8
Body height (cm)*	161.2 ± 12.7 (135.0-184.6)
Body weight (kg)*	57.5 ± 10.7 (39.0-80.7)
Body surface area (m^2)*	1.59 ± 0.22 (1.18-1.95)

*Values are mean ± SD (range).

Statistical analysis

Data were analyzed using a paired *t*-test. Analysis of the aortic root was performed using a one-way ANOVA.

Results

The lengths of each portion of the aortic annulus in systole and diastole were as follows (Figs. 1 and 2). In systole: RCC 41.8 ± 8.1 mm; LCC 39.3 ± 5.9 mm; NCC 43.7 ± 7.1 mm. In diastole: RCC 42.4 ± 7.0 mm; LCC 38.6 ± 7.8 mm; NCC 41.5 ± 7.8 mm. No statistically significant differences were observed in portion lengths between systole and diastole, neither was any significant difference seen among cusp portion lengths in systole and diastole. Portion lengths (from longitudi-

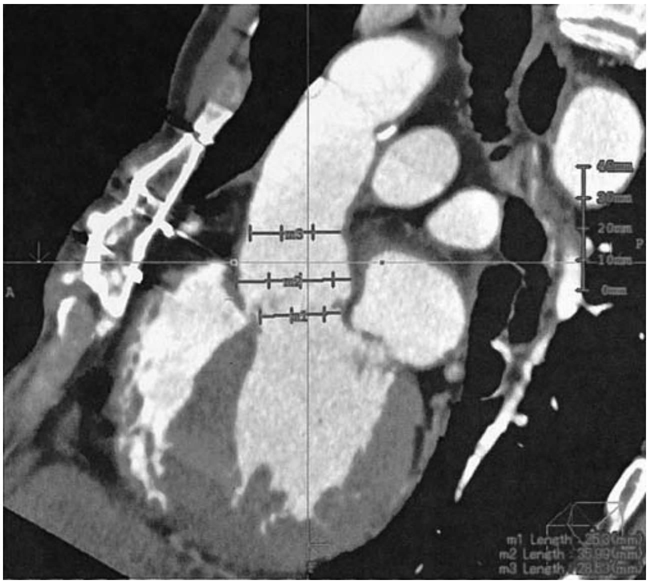

Figure 3: Multiplanar reformation 40%. Systolic phase data measured at the T-wave of the electrocardiogram. The lengths of the anatomic ventriculoarterial junction, sinus of Valsalva and sinotubular junction were also measured on longitudinal views.

Figure 4: Multiplanar reformation 80%. Diastolic phase data measured at the T-wave the electrocardiogram. The lengths of the anatomic ventriculoarterial junction, sinus of Valsalva and sinotubular junction were also measured on longitudinal views.

nal views) were as follows (Figs. 3 and 4). In systole: anatomic ventriculoarterial junction (base) 22.5 ± 2.2 mm; sinus of Valsalva 34.9 ± 4.3 mm; STJ 28.1 ± 3.2 mm. In diastole: anatomical ventriculoarterial junction (base) 22.1 ± 2.2 mm; sinus of Valsalva 34.4 ± 4.7 mm; STJ 27.2 ± 3.1 mm. Only the length of the STJ in systole was significantly greater than that in diastole. No difference was observed between the lengths of the other portions in systole and diastole.

Discussion

During recent years, the anatomy and physiology of the aortic root has attracted interest due to the increased attention on aortic valve repair. Indeed, several studies which have focused on the aortic root have provided extensive information on this subject.

In order to perform successful aortic valve repair it is important to understand the morphology of the normal aortic root, the components of which include the aortic annulus, aortic cusps and commissures, sinus of Valsalva and STJ. Many studies have been conducted on the aortic root components. For example, Kunzelmann et al. (6) showed that, anatomically, the root was of a consistent shape but of variable size, and that there was a definable mathematic relationship between the root diameter and clinically measurable leaflet dimensions. According to the data provided by these authors, the diameter at the sinus of Valsalva was maximum, that at the base (the anatomic ventriculoarterial junction) was medium, and that at the STJ was narrowest. Data obtained in the present study differed, however, with the sinus of Valsalva being maximum diameter, the STJ second-largest diameter, and the anatomic ventriculoarterial junction narrowest. Despite these differences, a theoretical relationship was still identified between the lengths of each component.

The motion of the aortic valve during the cardiac cycle was studied by Higashidate et al. (8), who reported that: (i) the aortic valve opened before the aortic pressure began to increase, without detectable antegrade aortic flow; (ii) the maximum opening area of the aortic valve was affected by not only the aortic flow but also aortic pressure, and this resulted in aortic root expansion; (iii) the initial slow closure of the aortic valve was induced by cusp contraction from full round expansion to triangular opening; and (iv) the maximum aortic valve orifice area preceded the peak aortic blood flow. These findings - particularly the initial opening of the aortic valve without aortic blood flow and pressure gradient - were consistent with those of Thubrikar et al. (9), and suggested that the aortic valve opened before the onset of aortic blood flow due to an increase in the restoring force that tends to make the valve orifice triangular, owing to the increase in distance between the commissures without forward flow. In other words, the commissural 'pull-and-release' mechanism collaborated with expansible leaflet attachment (aortic root) (10).

In the present study, although only the STJ length increased during the systolic phase, the length of each part of the annulus was unchanged during the cardiac cycle. This suggested that each commissure moves outward at the systolic phase, consistent with the findings of others (8,9). Although it is difficult to assume that the aortic valve opens before the aortic pressure begins to rise, the outward motion of the commissures in systole plays a role in opening the aortic valve. This motion may be compared to a 'pull-and-release' mechanism. In the present study, the lengths of the anatomic ventriculoarterial junction (base) and sinus of Valsalva were unchanged during the cardiac cycle, with cusp lengths being unchanged during the cardiac cycle, and not differing one from another. Hence, the aortic annulus may have flexibility, but not distensibility.

As research into aortic root has progressed, the role of bulging of the sinus of Valsalva in normalizing leaflet stress, leaflet coaptation and coronary flow has become clearer, and this has led to refinements in aortic root repair (7,11,12). Advances in aortic root reimplantation have helped in the formation of a new sinus of Valsalva in order to satisfy the physiological characteristics of the normal aortic root (13). However, few reports have been made on the distensibility and motion of the sinus of Valsalva. Dagum et al. (14) reported that the change in the shape and torsion force of the anatomic ventriculoarterial junction and sinus of Valsalva caused a morphological change in the aortic root. However, these authors did not investigate the motion of the semilunar attachment of the leaflets - that is, the 'annulus'.

A previous study conducted by the present authors also showed that normal subjects with a normal aortic root did not change their diameter of anatomic ventriculoarterial junction, sinus of Valsalva and STJ during the cardiac cycle through the long axis dimension of echocardiography (15). However, Lansac et al. (16) obtained opposing results with a sheep model using three-dimensional sonomicrometry, showing that the aortic root expanded during systole. This difference may derive from evaluation points, however, as these authors observed each level of the aortic root (annulus, sinus of Valsalva and STJ) as round components. Moreover, while Lansac et al. used a three-dimensional evaluation, only two points in the long-axis view were used in the present study. Nonetheless, the true aortic annulus was considered to represent the semilunar attachment of the leaflets. It is possible that the semilunar attachments of the leaflets and the bulges of sinus of Valsalva might change their morphology differently during cardiac cycle. In fact, the results of a previous study showed that the length from the vertex of each cusp to the center of the aortic valve changed asymmetrically during the cardiac cycle (15). Thus, the lengths determined with the long-axis view might not reflect true motion of each aortic root component.

In the present study the aortic annuloplasty (subvalvular circular annuloplasty) was performed using a Gore-Tex strip (N.L. Gore & Associates, Arizona, USA) to plicate the subcommissural area and to deepen the zone of coaptation. With regards to preserving the normal motion of the aortic root, the technique was effectively natural as it preserved not only the morphology of the aortic root but also the motion of the commissures and the sinus of Valsalva (15).

Study limitations

One limitation of the present study was that the points of length measurement during the cardiac cycle were limited, and consequently some changes in the aortic root may have gone undetected. The evaluation of torsion motion, or upward and downward motions of the aortic root, were difficult as MDCT is capable only of estimating lengths, though the error was considered to be only 2-3%. The credibility of the present study was based on subjects chosen in whom the aortic root was not calcified, though in these older patients (mean age 60.1 ± 14.8 years) the aortic root may have been stiffer than that of younger adults. As a consequence, the distensibility of the aortic root might have been underestimated.

In conclusion, in the normal aortic root none of the portions of the aortic annulus were seen to change in length during the cardiac cycle. According to changes in aortic root dimensions, the commissures move outwards during the systolic phase.

References

1. David TE, Feindel CM. An aortic valve-sparing operation for patients with aortic incompetence and aneurysm of the ascending aorta. J Thorac Cardiovasc Surg 1992;103:617-621;discussion 62.
2. Sarsam MA, Yacoub M. Remodeling of the aortic valve annulus. J Thorac Cardiovasc Surg 1993;105:435-438
3. El Khoury G, Vanoverschelde JL, Glineur D, et al. Repair of aortic valve prolapse: Experience with 44 patients. Eur J Cardiothorac Surg 2004;26:628-633
4. Anderson RH, Devine WA, Ho SY, Smith A, McKay R. The myth of the aortic annulus: The anatomy of the subaortic outflow tract. Ann Thorac Surg 1991;52:640-646
5. Leyh RG, Schmidtke C, Sievers HH, Yacoub MH. Opening and closing characteristics of the aortic valve after different types of valve-preserving surgery. Circulation 1999;100:2153-2160
6. Kunzelman KS, Grande KJ, David TE, Cochran RP, Verrier ED. Aortic root and valve relationships. Impact on surgical repair. J Thorac Cardiovasc Surg

1994;107:162-170
7. Grande-Allen KJ, Cochran RP, Reinhall PG, Kunzelman KS. Re-creation of sinuses is important for sparing the aortic valve: A finite element study. J Thorac Cardiovasc Surg 2000;119:753-763
8. Higashidate M, Tamiya K, Beppu T, Imai Y. Regulation of the aortic valve opening. In vivo dynamic measurement of aortic valve orifice area. J Thorac Cardiovasc Surg 1995;110:496-503
9. Thubrikar M, Bosher LP, Nolan SP. The mechanism of opening of the aortic valve. J Thorac Cardiovasc Surg 1979;77:863-870
10. Robicsek F, Thubrikar MJ, Fokin AA. Cause of degenerative disease of the trileaflet aortic valve: Review of subject and presentation of a new theory. Ann Thorac Surg 2002;73:1346-1354
11. Cochran RP, Kunzelman KS, Eddy AC, Hofer BO, Verrier ED. Modified conduit preparation creates a pseudosinus in an aortic valve-sparing procedure for aneurysm of the ascending aorta. J Thorac Cardiovasc Surg 1995;109:1049-1057;discussion 1057-1058
12. Yacoub MH, Kilner PJ, Birks EJ, Misfeld M. The aortic outflow and root: A tale of dynamism and crosstalk. Ann Thorac Surg 1999;68:S37-S43
13. David TE. Aortic valve sparing operations. Ann Thorac Surg 2002;73:1029-1030
14. Dagum P, Green GR, Nistal FJ, et al. Deformational dynamics of the aortic root: Modes and physiologic determinants. Circulation 1999;100:II54-II62
15. Kazui T, Izumoto H, Nasu M, Kawazoe K. Perioperative changes in dynamic aortic root morphology after Yacoub's root remodeling and concomitant aortic annuloplasty. Interact Cardiovasc Thorac Surg 2004;3:465-469
16. Lansac E, Lim HS, Shomura Y, et al. A four-dimensional study of the aortic root dynamics. Eur J Cardiothorac Surg 2002;4:497-503