ORIGINAL COMMUNICATION

Comparison of Human and Porcine Aortic Valves

EUGENE K.W. SIM,[1*] SANJEEV MUSKAWAD,[2] CHU-SING LIM,[2] JOON HOCK YEO,[2] KHEE HIANG LIM,[2] ROBERT T. GRIGNANI,[1] A. DURRANI,[1] GILBERT LAU,[4] AND CARLOS DURAN[3]

[1]*Division of Cardiothoracic Surgery, National University Hospital, Singapore*
[2]*School of Mechanical and Production Engineering, Nanyang Technological University, Singapore*
[3]*Section of Cardiac Surgery, The International Heart Institute of Montana, Missoula, Montana*
[4]*Department of Pathology, Singapore General Hospital, Singapore*

We compared the anatomy of human and porcine aortic valves. Porcine hearts were collected from the abattoir. Human hearts from patients who had died of non-cardiac causes were examined in the mortuary; only undamaged and anatomically normal hearts were used. Silicon casts were prepared by injecting engineering silicon at 80 mm Hg into the aortic arch. Various features of the aortic valve were measured: circumference, length between the commissural end point and central point of coaptation, surface diameter, and surface area. In total, 12 porcine and 12 human aortic valves were studied. The average circumferences of the human and porcine aortic valves were 8.00 ± 0.2 (SD) cm and 7.90 ± 1.0 cm, respectively. The central point of coaptation in human valves was skewed toward the left coronary cusp, whereas in porcine valves it was skewed toward the non-coronary cusp. In human aortic valves, the non-coronary cusp had the largest surface diameter and surface area with mean measurements of 3.6 ± 0.2 cm and 1.230 ± 0.228 cm^2, respectively; the left coronary cusp was smallest for the same variables with measurements of 3.1 ± 0.3 cm and 0.898 ± 0.357 cm^2. In porcine valves, the right coronary cusp had the largest surface diameter and surface area with mean measurements of 3.9 ± 0.7 cm and 1.716 ± 0.81 cm^2, respectively; the non-coronary cusp was the smallest for the same variables with measurements of 2.9 ± 0.5 cm and 1.023 ± 0.659 cm^2. These differences suggest that when using porcine valves as transplant material (e.g., stentless valves), geometric considerations, such as commissural length, may be important. Clin. Anat. 16:193–196, 2003.

Key words: aortic valve cusp; silicon cast; valve morphology; human; porcine; valve geometry

INTRODUCTION

The mechanical heart valve is the most commonly used valve prosthesis; however, because of problems related with anticoagulation, there has been renewed interest in the use of biologic valves (Fisher and Wheatley, 1987; Bernacca et al., 1992; Love, 1998). Some studies have suggested that pericardial tissue would be suitable biologic material for fashioning replacement heart valves (Frater and Bodnar, 1992; Love, 1998).

Despite such interest in biologic grafts, there has been little research into the morphologic differences between porcine and human valves. Variations in the anatomy of the human aortic valve have been described by Swanson and Clark (1974), Vollebergh and Becker (1977), Kunzelman et al. (1994), and Silver and Roberts (1985). We recently studied the morphology of the human aortic valve and found that the non-coronary cusp was the largest and the left coronary cusp the smallest. We compare the morphology of aortic cusps between porcine and human valves. This information may be useful in both the design of pericardial reconstructed valves and in considering the feasibility of porcine valve transplantation. Anatomical differences might have important consequences in the flow hemodynamics of the valve.

*Correspondence to: A/Prof. Eugene Sim, Division of Cardiothoracic Surgery, National University Hospital, 5 Lower Kent Ridge Road, Singapore 119074. E-mail: sursimkw@nus.edu.sg

Received 5 September 2001; Revised 29 November 2002

Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/ca.10149

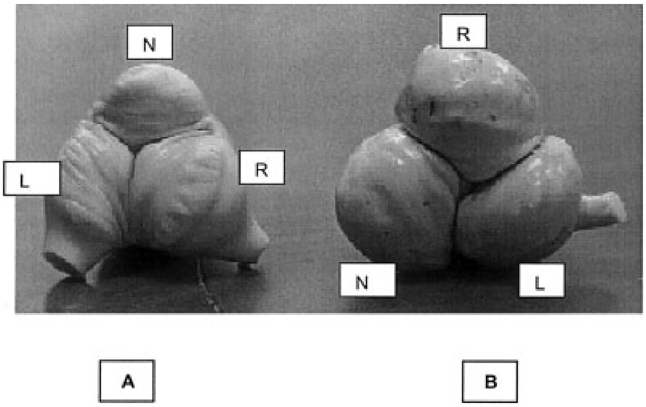

Fig. 1. Silicon casts of a porcine (**A**) and human (**B**) aortic valve. L, left coronary cusp; R, right coronary cusp; N, non-coronary cusp.

MATERIALS AND METHODS

Acquisition of Porcine Aortic Valve Casts

Hearts were acquired from the abattoir and refrigerated for not more than 12 hours before study. All fat and muscle around the ascending aorta were removed, allowing full access to the two coronary arteries. Seventy milliliters of Dow Corning 3110 silicon rubber was mixed with 7 ml of standard set catalyst in a beaker to activate the silicon to harden. Both coronary arteries were tied off to prevent the outflow of the silicon gel through them. During the early part of injection a small vent was produced by a probe at the central point of coaptation to release any trapped air that might distort the silicon cast. The silicon mixture was injected in a retrograde fashion into the aortic arch to a pressure of 80 mm Hg, which is the average end diastole pressure of a healthy pig (Swanson and Clark, 1974). Only anatomically normal and undamaged aortic valves were used, resulting in 12 casts (Fig. 1).

Acquisition of Human Aortic Valve Casts

At the mortuary, the hearts of adult patients who had died of non-cardiac causes were examined. Only anatomically normal and undamaged heart valves were used. The casts were made in the same way as for the porcine valves, with the same silicon mixture injected at 80 mm Hg. Twelve human aortic valve casts were made (Fig. 1).

Analysis of Aortic Valve Casts

Various surface features of the cast were measured using calipers. All measurements for a given valve were repeated five times by a single examiner and the means were calculated. The measurements made were of the aortic circumference, the length between the commissural end point and central point of coaptation (Lc), and surface diameter. The surface area of a cusp was calculated by counting the squares of a flexible grid cloth that was spread over the surface of the cusp.

Aortic Circumference

The aortic valve circumference was measured at the sino-tubular junction, which is represented by a subtle ridge at the level of the top of the three commissures.

Length Between Commissural End Point and Central Point of Coaptation

The length between the commissural end point and central point of coaptation was measured between the right coronary and left coronary cusps (RC–LC), the non-coronary and right coronary cusps (NC–RC), and the non-coronary and left coronary cusps (NC–LC) (Fig. 2).

Surface Diameter

The surface diameter is the length from the central point of coaptation to the nadir of the cusp, that is, the lowest point of the attached border of the cusp (Fig. 2).

Surface Area

The surface area of both the human and porcine heart valves was measured by counting the squares of the grid cloth spread over the cuspal surface.

RESULTS

Aortic Circumference

There was no significant difference between the mean circumferences of porcine and human aortic valves, which were 8.00 ± 0.20 (SD) cm (range = 7.1–9.1 cm) and 7.90 ± 1.00 cm (range = 6.9–10.2 cm), respectively. The mean aortic valve diameter was also similar for human and porcine valves, measuring 2.55 ± 0.13 cm (range = 2.26–2.90 cm) and 2.20 ± 0.32 cm (range = 2.20–3.25 cm), respectively.

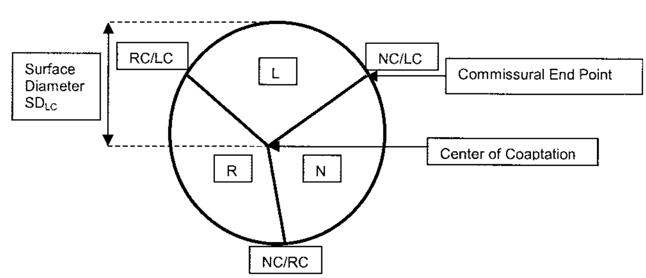

Fig. 2. Schematic diagram of an aortic valve showing the center of coaptation, commissural end point, and surface diameter of a cusp. The commissures are labeled as NC/RC, NC/LC, and RC/LC.

TABLE 1. Length from the Commissural End Point to the Central Point of Coaptation of Human and Porcine Aortic Valve Cusps*

Commisures	Human valve *n* = 12, (cm)	Porcine valve *n* = 12, (cm)
$Lc_{(NC/RC)}$		
Mean ± SD	2.1 ± 0.1	2.2 ± 0.4
Range	2.0–2.1	1.8–3.1
$Lc_{(NC/LC)}$		
Mean ± SD	2.2 ± 0.2	2.3 ± 0.3
Range	1.8–2.4	2.0–3.2
$Lc_{(RC/LC)}$		
Mean ± SD	2.4 ± 0.2	2.7 ± 0.3
Range	2.2–2.9	2.4–3.6

*$Lc_{(NC/RC)}$, length from the commissural end point to the central point of coaptation between the non-coronary and right coronary cusps; $Lc_{(NC/LC)}$, length from the commissural end point to the central point of coaptation between the non-coronary and left coronary cusps; $Lc_{(RC/LC)}$, length from the commissural end point to the central point of coaptation between the right and left coronary cusps.

Length Between Commissural End Point and Central Point of Coaptation

The Lc (RC-LC) was the longest of the three in 83.3% (10/12) of human valves and in 100.0% (12/12) of porcine valves (Table 1). Furthermore, porcine and human valves exhibited the same trends in their relative commissural lengths, with the $Lc_{(RC/LC)} > Lc_{(NC/LC)} > Lc_{(NC/RC)}$ in 75.0% (9/12) of both human and porcine valves. In human valves, however, $Lc_{(NC/LC)}$ did not vary much from the $Lc_{(RC/LC)}$, unlike porcine valves. The view of casts from below shows that the central point of coaptation for human valves is oriented toward the left coronary cusp, whereas in porcine valves it is toward the non-coronary cusp (Fig. 1).

Surface Diameter

The surface diameter of the non-coronary cusp was the largest in 83.3% (10/12) of human aortic valves; the right coronary cusp was the largest in 91.7% (11/12) of porcine valves (Table 2). The surface diameter of the left coronary cusp (SD_{LC}) was the smallest in 75.0% (9/12) of human aortic valves; the surface diameter of the non-coronary cusp (SD_{NC}) was the smallest in 91.7% (11/12) of porcine valves (Table 2).

TABLE 2. Surface Diameter of Human and Porcine Aortic Valve Cusps*

Valve cusp	Human valve (cm)	Porcine valve (cm)
NC		
Mean ± SD	3.6 ± 0.2	2.9 ± 0.5
Range	3.2–4.1	2.2–3.6
RC		
Mean ± SD	3.3 ± 0.3	3.9 ± 0.7
Range	2.6–3.9	3.0–5.5
LC		
Mean ± SD	3.1 ± 0.3	3.4 ± 0.7
Range	2.8–3.5	2.5–4.8

*NC, non-coronary cusp; RC, right coronary cusp; LC, left coronary cusp.

TABLE 3. Surface Area of Human and Porcine Aortic Valve Cusps*

Valve cusp	Human valve (cm^2)	Porcine valve (cm^2)
NC		
Mean ± SD	1.230 ± 0.228	1.023 ± 0.659
Range	1.070–1.675	0.471–2.831
RC		
Mean ± SD	1.070 ± 0.306	1.716 ± 0.810
Range	0.820–1.850	1.072–4.025
LC		
Mean ± SD	0.898 ± 0.357	1.364 ± 0.729
Range	0.419–1.850	0.868–3.522

*NC, non-coronary cusp; RC, right coronary cusp; LC, left coronary cusp.

Surface Area

The non-coronary cusp had the largest surface area in 83.3% (10/12) of human valves; the right coronary cusp had the largest surface area in 100.0% (12/12) of porcine valves (Tables 3,4). The left coronary cusp was smallest in 66.7% (8/12) of human valves, whereas the non-coronary cusp was smallest in 100% (12/12) of porcine valves (Tables 3,4). In 50% (6/12) of human valves the order of size was $SA_{(NC)} > SA_{(RC)} > SA_{(LC)}$, whereas in 100% (12/12) of porcine valves the order was $SA_{(RC)} > SA_{(LC)} > SA_{(NC)}$ (Table 3).

DISCUSSION

The role of bioprosthetic valves for aortic valve replacement is well established. It is considered by many the valve of choice in elderly patients. There have been new developments recently in the process-

TABLE 4. Comparison of the Largest and Smallest Surface Area of Human and Porcine Aortic Valve Cusps*

	Human valve		Porcine valve	
Valve cusp	*n*	%	*n*	%
Largest Cusp				
NC	10	83.3	0	0
RC	1	8.3	12	100
LC	1	8.3	0	0
Smallest Cusp				
NC	2	16.6	12	100
RC	2	16.6	0	0
LC	8	66.7	0	0

*NC, non-coronary cusp; RC, right coronary cusp; LC, left coronary cusp.

ing of bioprosthetic valves, such as the use of anticalcification agents, zero pressure fixations and the development of stentless valves. The most common bioprosthetic valve used today is the porcine valve; however, no comparative studies have been carried out comparing the morphology of the porcine aortic valve to that of the human valve.

The aortic valve consists of three cusps that are attached to the aortic wall in a crescent-shaped or semilunar fashion, and that are composed of multiple layers of connective tissue of markedly varying density, composition, and function (Schoen, 1991). During the cardiac cycle these cusps open and close, and are subjected to pressure fluctuations that can result in deformations of surface area up to 40% (Clarke and Finke, 1974; Vesely and Lozon, 1993).

Until recently there was little detail available on the morphology of the aortic valve. Although Swanson and Clark (1974) observed that the non-coronary cusp was the largest in the human aortic valve, many current anatomy textbooks, including *Gray's Anatomy* and *Cunningham's Anatomy*, still describe the aortic valve as having symmetrical cusps. Navaratnam (1993) described the aortic valve cusps as being of equal size with the commissures radially symmetrical. Vollebergh and Becker (1977) measured the width and height of the aortic valve on 200 necropsy patients and found that the right coronary cusp was the largest, and the left the smallest. In contrast, Silver and Roberts (1985) observed that the non-coronary or posterior aortic cusp had a larger mean area and mean weight than either the right or the left cusp, and that the right coronary cusp was the smallest. In the present study, the non-coronary cusp was the largest and the left coronary cusp the smallest. Extensive anatomic studies have only been carried out in human aortic valves with little work on porcine valves.

The only study we have found on porcine valve morphology was published by Sands et al. (1969). They noted that in porcine valves the non-coronary cusp was disproportionately the smallest. Choo et al. (personal communication) have noted recently that the non-coronary sinus depth, height and cusp dimensions were smallest as compared with the other two sinuses in porcine valves. Their findings are similar to ours: in the porcine aortic valve the right coronary cusp was largest and the non-coronary cusp the smallest; in the human aortic valve the non-coronary cusp was the largest and the left coronary cusp the smallest.

This study shows geometrical differences of cusp size between human and porcine aortic valves. The significance of these differences at present is not known; however, they may play an important role in the hemodynamics and the long-term maintenance of the structural integrity of the valves.

REFERENCES

Bernacca GM, Mackay TG, Wheatley DJ. 1992. In vitro calcification of bioprosthetic heart valves: report of a novel method and review of the biochemical factors involved. J Heart Valve Dis 1:110–114.

Clarke RE, Finke EH. 1974. Scanning and light microscopy of human aortic leaflets in stressed and relaxed states. J Thorac Cardiovasc Surg 67:792–804.

Fisher J, Wheatley DJ. 1987. An improved pericardial bioprosthetic heart valve. Design and laboratory evaluation. Eur J Cardiothoracic Surg 1:71–79.

Frater RWM, Bodnar E. 1992. Towards understanding the pericardium as valve substitute. J Heart Valve Dis 1:213–215.

Kunzelman KS, Cochran RP, Verrier ED, Eberhart RC. 1994. Anatomic basis for mitral valve modeling. J Heart Valve Dis 3:491–496.

Love JW. 1998. Autologous pericardial reconstruction of semilunar valves. J Heart Valve Dis 7:40–47.

Navaratnam V. 1993. Design of heart valves: a review. Clin Anat 6:327–332.

Sands MP, Rittenhouse EA, Mohri H, Merendino KA. 1969. An anatomical comparison of human, pig, calf, and sheep aortic valves. Ann Thorac Surg 8:407–414.

Schoen FJ. 1991. Pathology of bioprosthesis and other tissue heart valve replacements. In: Silver MD, editor. Cardiovascular pathology. 2nd Ed. New York: Churchill Livingstone. p 1547–1605.

Silver MA, Roberts WC. 1985. Detailed anatomy of the normally functioning aortic valve in hearts of normal and increased weight. Am J Cardiol 55:454–461.

Swanson WM, Clark RE. 1974. Dimensions and geometric relationships of the human aortic valve as a function of pressure. Circ Res 35:871–882.

Vesely I, Lozon A. 1993. Natural preload of aortic valve leaflet components during glutaraldehyde fixation: effects on tissue mechanics. J Biomech 26:121–131.

Vollebergh FEMG, Becker AE. 1977. Minor congenital variations of cusp size in tricuspid aortic valves. Possible link with isolated aortic stenosis. Br Heart J 39:1006–1011.