POTENTIALITY OF CONSTRUCTION OF AN AKINETIC SEPTUM
IN SINGLE VENTRICLE AS A RADICAL CORRECTION

Part I: Septal Analysis of the Normal Canine Heart

SHUJI SEKI M.D.*, SEIKI SUGIMOTO M.D.**, YASUHIRO SHIMIZU M.D.**, SHIGERU TERAMOTO M.D.***
AND TERUTAKE SUNADA M.D.****

To determine a possibility of success in construction of an akinetic septum as a radical correction for single ventricle, seven normal canine hearts were spatially analyzed to obtain ratios which would enable to reconstruct the heart by awaring only the maximum external circumference of the ventricles (the left and right free walls on cross section). Then, those data obtained were employed to construct single ventricle to analyze the possibility of the septal construction in it in Part II of this study.

On determining the volumes of the right and left ventricles, which was madantory, in Part II of this study, in discussion of cardiac function required in the single ventricle corrected with an akinetic septum, two methods were employed, one being with planimetry on photographs of the hearts cross-sectioned, the other being with planimetry on drawings that were obtained from equations. The equations employed were based on a postulation that both the ventricles were round on cross-section and that they overlapped partly each other. Thereby, one circle was complete and was assumed the left ventricle. The volumes determined by the equations were very close to the volumes measured on the photographed heart.

A long axis employed in the analysis of the normal heart was from the apex to the center of the mitral orifice with a reason that this axis would be more beneficial to a surgeon because of easier accessibility to the atrioventricular groove as a landmark on operation. The cross-section in this study was perpendicular to the long axis.

It could be stated that single ventricle still remained in an inoperable group of the congenital heart diseases even with the advent of the modern cardiovascular surgery, although there are a few reports1 - 3 in which the radical correction was successfully attempted.

In our laboratory construction of the interventricular septum has been thought to be one of radical corrections for single ventricle and a series of experiments have been conducted, as an experimental model, by replacing the septum with an akinetic prosthesis in dogs3 - 7 It was

Key Words:
Left ventricular long axis
Ventricular configuration
Ventricular volume,
Ventricular reconstruction

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Department of Surgery, Okayama University Medical School, 2-5-1, Shikata-cho, Okayama Japan.
* Instructor in surgery
** Resident in surgery
*** Associate professor in surgery
**** Professor in surgery

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<table>
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<th>Dog No.</th>
<th>Distance from apex (%)</th>
<th>Total circumference (external cm)</th>
<th>Free Ventricle wall (cm)</th>
<th>Interventricular septum (cm)</th>
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</table>

The table shows the dimensional parameters of the heart perpendicular to the long axis for different dog numbers. The values include total circumference, free ventricular wall, and interventricular septum lengths for both external and center measurements.

Shown in these experiments that a large portion of the septum was replaceable with an akinetic septum and that the most important finding obtained was to replace the septum as to maintain a volume ratio of both the ventricles normal. However, it is unknown whether the entire septum could be constructive in patients with single ventricle, because septal prosthesis available at present were not synergistically contractile so that only the septal prosthesis remains unchanged on systole in length which would result in relative increase of the prosthesis in the circumference of the heart and in compromising the right ventricular volume by bulging of the prosthesis.

In this study a possibility will be theoretically searched in the construction of the septum with an akinetic prosthesis in single ventricle. In the 1st part of this study data were obtained in 7 normal canine hearts to realize the heart spatially. In a second part of this study cardiac performances, which the single ventricle must
perform after the construction of the septum, were determined with the data obtained in the 1st part.

METHODS AND RESULTS

Seven normal hearts were harvested from the adult dogs after all the vessels from the heart were dissected and tared through right thoracotomy with intravenous anesthesia of pentobarbitol. An end of I.V. set was separately cannulated in the right and left atrial appendages. As soon as all the vessels were doubly ligated, the right side of the heart was inflated with 10% formalin solution of 15cm H₂O hydrostatic pressure. The left side was with 30cm H₂O. After the fixation with formalin the hearts were embedded in polyethylene glycol to prevent distortion of the hearts on section. The section was performed by a saw on a plane perpendicular to the long axis (from the apex to the center of the mitral orifice). The hearts were intended to be equally divided into 5 perpendicular to the long axis, but actually it was somewhat deviated so that an actual distance ratio of a given plane from the apex to the whole long axis was determined by measurement. In each plane the followings were measured: total external circumference of the heart (external right and left free ventricular walls), the right, and the left free ventricular walls (external and center of the wall thickness), the interventricular septum (between the external circumferences, and between the center lines of the circumferential wall thickness), and the circumferences of both the ventricles (Table 1). Graphs were drawn with the data obtained to determine an average of the variables described above at a plane, every 10% apart in the long axis. Ratio of each variable to that of the plane nearest to the mitral orifice were plotted in the vertical line and distance ratios of the plane from the apex to the long axis were in the abscissa. Average ratios of each variable at a plane every 10% difference in the long axis distance in the 7 hearts were calculated and shown by heavy dots in the graphs. As the variables of the plane nearest to the mitral orifice were maximum, the variables drawn in the graphs were ratios of the total circumference at a given plane to the maximum total circumference (Fig. 1), ratios of the septal length to the left ventricular circumference (Fig. 2), and ratios of the free wall of the left ventricle to the total circumference of the heart (Fig. 3).

Areas of the right and left ventricles were measured with a planimeter by taking a photograph of each section (Fig. 4). The areas measured were those encircled by the external
Fig. 3. Ratio: Free Left Ventricular Wall/Left and Right Free Ventricular Walls.
Dotted lines are ratios of the length of the free wall in the left ventricle to the free walls of the left and right ventricles. Heavy dots are their averages.

free ventricular wall and the center line of the septum, by the evened internal circumference (unevenness of the internal circumference due to the trabeculae and the papillary muscles was neglected) and the septal center line, and by the internal circumference and the septal center line. After ratios of the areas measured to the maximal area among them were calculated and graphed in each heart, an average of the areas of these hearts at a given plane was determined with the manner described above (Fig. 5). When the maximum of the average percentages obtained did not reach 100 per cent, the average percentages were corrected to bring the maximum average to 100 per cent, which were labeled as δ and shown in Table 2. In the 7 hearts an average of the long axes was 5.39 cm in length and the maximal total circumferences was 21.04 cm. The long axis of the right ventricle was 5.06 cm. The maximum areas (A) of being circumscribed by the external and internal circumferences of the right and left ventricles with the septal center line

were 17.60 cm², 13.83 cm², 13.18 cm², and 8.05 cm², respectively. Then, the volumes (V) of the ventricles were calculated as follows

$$ V = 0.1 \times L \times \Sigma \delta i A $$

where L is a length of the long axis. The right ventricular volumes, encircled by the external ($V_{RE}$) or the internal ($V_{RI}$) circumference and the septal center line (Table II) were

$$ V_{RE} = 0.1 \times 5.06 \times 6.47 \times 17.60 = 57.62 \text{ (ml)} $$
$$ V_{RI} = 0.1 \times 5.60 \times 6.08 \times 13.83 = 42.55 \text{ (ml)} $$

The left ones, external ($V_{LE}$) or internal ($V_{LI}$), were

$$ V_{LE} = 0.1 \times 5.39 \times 7.91 \times 13.18 = 56.19 \text{ (ml)} $$
$$ V_{LI} = 0.1 \times 5.39 \times 7.82 \times 8.05 = 33.93 \text{ (ml)} $$

TABLE II  RATIOS OF THE CROSS-SECTIONAL AREAS TO THE MAXIMUM AREA

<table>
<thead>
<tr>
<th>% Distance from apex in long axis</th>
<th>Ratio of area to the maximum area (%) (δ)</th>
<th>External circumference</th>
<th>Internal circumference</th>
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<td></td>
<td></td>
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<td>lt. ventricle</td>
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<tr>
<td>Total (Σ δt)</td>
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<td>647.2</td>
<td>790.9</td>
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</table>

Planimetry was done on the photographed cross-sections and ratios of the areas measured to the maximum one were tabulated. 
δ: delta

Volume ratios of the left ventricle to the right ventricle were

\[
\frac{V_L}{V_R} = \frac{56.19}{57.62} = 0.98 \\
\frac{V_{LI}}{V_{RI}} = \frac{33.93}{42.55} = 0.80
\]

To determine the volumes of the right and left ventricles mathematically, the right and left ventricles were assumed to be a circle on the plane (perpendicular to the long axis), and they were overlapped in a part (Fig. 6). The radius of the left ventricle was calculated from the total of the left free ventricular wall (external) and the septum (center line). The circle (radius; x) of the right ventricle was determined by three known values, namely, the rising points of the septum and the length of the right ventricular wall. Then, an opening angle for the septum in the right ventricle became obtainable by the following equations (Fig. 6),

1. \[ r_p \sin \theta = x \sin \varphi \]
2. \[ (2\pi - 2\varphi) \times x = a \]
3. \[ x = \frac{a}{2(\pi - \varphi)} \]

Equation 2 was transformed

Fig. 5. Area Ratios of a Plane Perpendicular to the Long Axis.
Cross-sections of the hearts were photographed and cross-sectional areas of the right and left ventricles were measured with a planimeter. Then ratios of the cross-sectional areas to the maximum one were plotted in the vertical lines. Cross-sectional area of a sphere was also plotted for comparison.
Schema of obtaining areas of the right and left ventricles

Circle ac a : left ventricle, Circle ac a : right ventricle,
ac a : free wall of left ventricle, ac a : septum, ac a : free
wall of right ventricle, ra : radius of left ventricle, xa : radius
of right ventricle.

Fig.6. Schema of Obtaining Areas of the Right and
Left Ventricles.
See the text for details.

Drawing for Obtaining of a Half of Opening Angle
for the Septum in the Right Ventricle

\[ y = \frac{2r_D \sin \theta \cdot \pi}{a} \]

Fig.7. Drawing for Obtaining of a Half of Opening
Angle for the Septum in the Right Ventricle.
See the text for details.

Then equation 1 was transformed

\[ r_D \sin \theta = \frac{a}{2(\pi - \phi)} \sin \varphi \]

\[ \sin \varphi = \frac{2r_D \sin \theta \pi}{a} - \frac{2r_D \sin \theta \phi}{a} \]

Where \( r_D \): radius of the left ventricle,
a: the right free ventricular wall,
\( \theta \) and \( \varphi \): a half of an opening angle for the
septum in the left and right ventricles, respec-
tively,
x: radius of the right ventricle.

To obtain the opening angle of \( \theta \), the length
of the septum was determined as follows. The
circumferential length of a given plane was
obtained from Fig. 1, taking 21.04 cm as the
maximal circumference. The left free ventricular
wall (\( W_{LF} \)) was then determined by multiplying
the circumferential length with the ratio in Fig. 3
for that plane. The septum (\( W_S \)) was, then,
figured out by the following equations.

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TABLE III  VARIABLES FOR OBTAINING OF THE RIGHT VENTRICULAR VOLUME

<table>
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<th>%-distance</th>
<th>Free LV. wall (cm)</th>
<th>Septum (cm)</th>
<th>Radius of LV. (cm)</th>
<th>Free RV. wall (cm)</th>
<th>( \theta ) (cm)</th>
<th>Area of drawing (cm)</th>
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<td>114.6</td>
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After \( x \) was determined by variables in this table, the drawing (Fig.6) was made and the right ventricular areas were measured by planimetry.

\( \theta \): theta

\[
W_S = \frac{W_{LF} \times K}{1 - K}
\]

Where \( K \) was the ratio in Fig. 2 in that plane.

To obtain \( x \), the two following equations were drawn as shown in Fig. 7, and \( \varphi \) was obtained as a crossing point of the equations.

\[
Y = \sin \varphi
\]

\[
Y = \frac{2r_D \sin \theta}{a} = \frac{2r_D \sin \theta}{a} \varphi
\]

Then \( x \) was calculated with Equation 3 and the areas of the right ventricle in each cross-section were measured with planimetry on the drawings same as Fig. 6, but determined by the \( x \) obtained (Table III).

Then the volumes \((V_{LE}, V_{RE})\) were calculated as follows.

\[
V_{LE} = 0.1 \times 5.39 \times 117.1 = 63.1 \text{ (ml)}
\]

\[
V_{RE} = 0.1 \times 5.06 \times 114.6 = 58.0 \text{ (ml)}
\]

**DISCUSSION**

In analyzing possibility in construction of an akinetic interventricular septum as a radical correction for single ventricle, one of the easiest ways would be to assume the cardiac ventricle as a sphere. However this assumption was abandoned in the study, because the data obtained in
this analysis were so different from those of a sphere as shown in Fig. 1. and Fig. 5. Reasons of
the difference could be due to difference in the long axis employed in this study. In previous
studies by others an axis from the apex to the aortic valve was commonly used for this
type of studies, but in the study the axis used was from the apex to the center of the
mitral orifice. Because it was thought that the latter axis would be more beneficial to a surgeon
during operation for its easy accessibility. Another
reason of the difference could be caused by the
fixation itself of the heart with formalin and
difference in the hydrostatic pressures employed
for the ventricular fixation. In a preliminary
study (author: unpublished), however, the ven-
tricles were fixed by various intraluminal pres-
sures and it was found that the hydrostatic
pressures used in this study were suitable to
maintain the normal volume ratio of both the
ventricles.

As the hearts examined were different in size,
it was thought better to deal ratios rather than
actual values. Also, the hearts were sectioned
only into 4 or 5 planes so that an average of the
ratios in the 7 hearts at a given plane was not
obtained by averaging 7 measured values, but by
averaging 7 values, some of which was or were
cross point(s) of a line connecting the 2 nearest
measured values.

On each section a septal length measured and
a diameter calculated from the total external
circumference of the heart at a given plane as-
suming the circumference circular were compared
in Fig. 8. They were so close in the middle range
of the long axis, but at the ends the differences
were large. The difference near the mitral orifice
(the base) seemed to be due to elongation of the
septum for the aortic root and that near the apex
was due to difficulty in distinguishing the septum
from the free wall. It was an interesting finding
that the septum did not rise where the circum-
ference was equally divided into the left and
right free ventricular walls, but where the
circumference was divided into the short left
ventricular wall and the long right free ventric-
ular wall, in spite that the septum was equal to the
diameter of the circumference. Meaning of this
fact will be discussed in the following paper (Part
2).

The volume of the left ventricle (external
circumference) was 56.19 ml. with planimetry of
the photographs of the crossectioned ventricle
and 63.1 ml. with planimetry of the drawings,
which were determined by the equations de-
scribed earlier (Table III). The volume of the
right ventricle was 57.62 ml. with planimetry of
the photographs and 58.0 ml. with planimetry of
the drawings (Table III). It was surprising that
the volumes measured with planimetry of the
photographs and with planimetry of the drawings
were so close, especially those of the right
ventricle.

Difference of the volumes of the left ventricle
was 22.26 ml. between the external and the
internal circumferences, reflecting that mass of
the myocardium including the trabeculae and the
papillary muscles was 40 per cent of the volume
encircled by the external circumference of the
left ventricle.

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