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Physics and Geometry of Heart Sound Quadrilateral

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ABSTRACT

Heart has been modeled as a sphere, a bullet as well as a deformed ellipsoid of revolution. Using the concept of standing waves the frequencies obtained in the fourier transform of phonocardiogram are related to the geometrical parameters of heart. Theses parameters may be obtained from "heart-sound triangle". Some preliminary studies of the geometry of heart-sound triangle have been conducted.

If one auscultates the chest maximum intensity of sound is obtained at four locations corresponding to the Aortic (A), Pulmonary (P), Tricuspid (T) and Mitral (M) valves. A photograph of the chest taken after stickers have been placed at these positions shall give a two-dimension projection of the body surface. The sides as well as angles of the heart-sound triangle, PTM or the heart-sound quadrilateral APTM, may be measured from this photograph.

Moiré fringe topography is a non-contact, non-invasive, three dimensional, optical–imaging technique, which is being used in industry and medicine to detect minor changes in surface gradient.

Using a photogrammetric technique, a three dimensional map of the chest surface may be obtained and if superimposed on a heart-sound quadrilateral APTM, one would obtain a three-dimensional heart-sound quadrilateral.

Deformed-ellipsoidal model of the human heart is developed, and validated by calculating frequency ratios from heart-sound triangle and comparing them with experimental ratios obtained from phonocardiogram for healthy individuals.
Reproducibility of three-dimensional, heart-sound quadrilateral is also established and its parameters are related to deformed-ellipsoidal model of the human heart. Experimental data used is obtained from healthy individuals.

This study is useful to develop artificial heart or heart valves, which could improve quality of life for heart patients.

Inspec Classification: A877OF, B7510, C3385, C733O

Keywords : Heart-sound quadrilateral, Aortic (A), Pulmonary (P), Tricuspid (T), Mitral (M).

1) INTRODUCTION

Heart may be considered as an engine performing work (Camron 1987, Berege l979,Chiavelo 1984, Glass 1991 and Guevara 1984).

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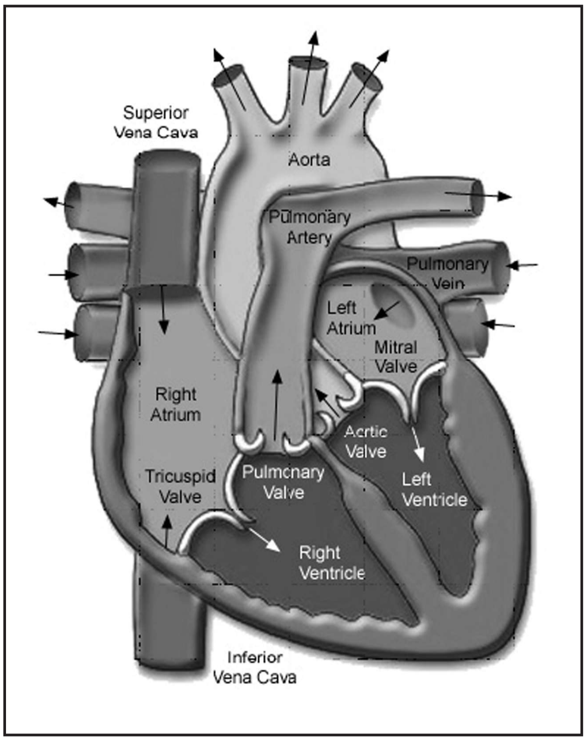
Heart is one of the most important organs of human body. Cardiac care occupies a very important role in the total well being of a person. However, the stressful life of the 21st century has also increased heart problems. Therefore, there is an increasing emphasis on the modeling of heart function.

Heart may be modeled as a vibrating system. One may be interested in the frequencies with which the heart may vibrate. The concept of the standing waves may be used to calculate the possible frequencies of vibration of the heart (Noble 2002). Previous models of the heart consider the heart as a sphere (Mazumdar 1984) or a bullet. However, shape of the heart may be better approximated if we consider it a deformed ellipsoid of revolution.

2) VALVES OF THE HUMAN HEART



Aorta
The aorta is the largest artery. It caries oxygenrich blood from hert to the rest of thebody

Superir Vena Cave
Oxygen poor blood front the upper parts of the body return to the heart through the superior vena cava

Pulmonary Arteries
The pulmonary arteries carry blood from the lungs to pick up oxygen

Right Ventricle
The right ventricle collects oxygen-poor blood from the right atrium and forces int into the lungs

Right Atrium
The chambers of the right Atrium collects de-oxygenated blood from the body and then force it through the tricuspid valve and into the right ventricle

Left Atrium
The chambers of the left Atrium collectsoxygenrich blood returning from the lungs and then force it through the mitral valve and into the ventrcle

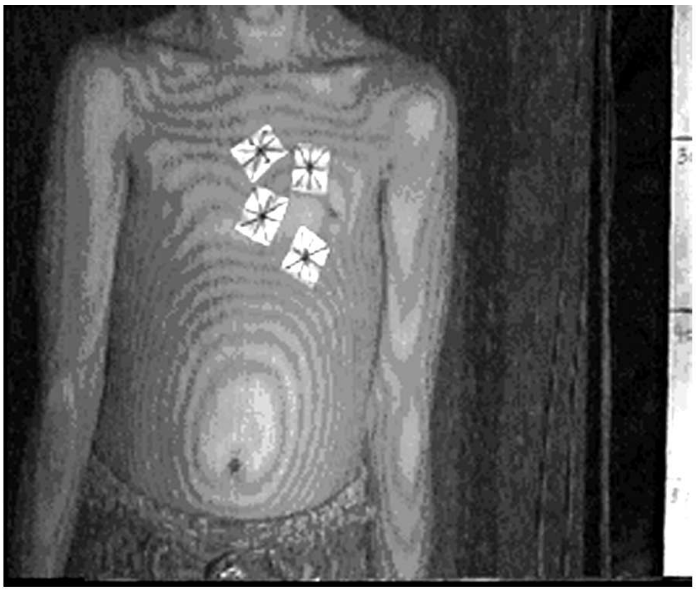
Left Atrium
It's the largest and strongest chamber of the heart. Its walls are about ½ inch thick, but have enough force to push blood through the arotic valve and into the body

3) STATEMENT OF THE PROBLEM AND TECHNIQUES USED

Using a photogrammetric technique (moir'e fringe topography) a three dimensional map of the chest surface may be obtained. If moir'e fringes are superimposed on a heart-sound quadrilateral, APTM, one would obtain a three-dimensional heart-sound quadrilateral.

Experimental data obtained from healthy individuals did not show any signs of spinal deformity. The reason is that presence of spinal deformity may change body triangles, and also effect the area of heart sound quadrilateral. 3 – 10 year's old male children are selected for this study. The heart sound observed and comparison was made, while the child was in sitting and standing possition

Figure-2.
Moir'e Fringe Topograpy



4) PURPOSE OF STUDY

i) To establish a technique to identify children with risk of cardiac problem.
ii) Test run to plan for further national studies.
iii) To discover the possible change in the heart-sound quadrilateral parameters in the age range of 3 – 10 years.
iv) To study the possible correlation between age and coefficient (ratios between area of heart-sound quadrilateral and area of the body), age and area of heart-sound quadrilateral, area of body and area of quadrilateral, age and standing height, age and weight.

5) HEART SOUND QUADRILATERAL (APTM)

Four types of valves regulate blood flow through human heart

i) The Tricuspid valve (T) regulates blood flow between the right atrium and right ventricle.
ii) The Pulmonary (P) valve controls blood flow from the right ventricle into the pulmonary

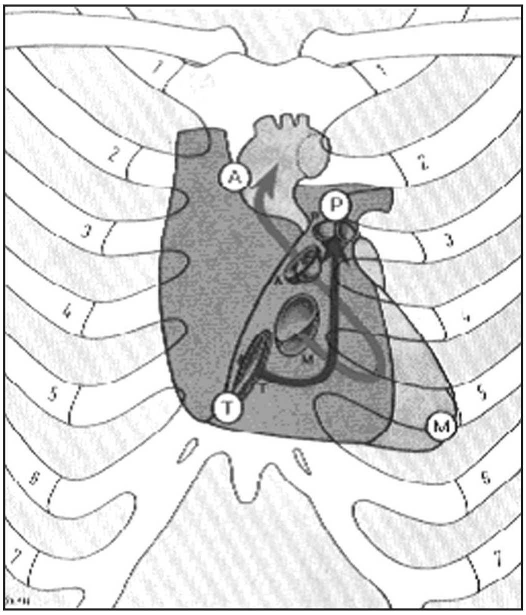
arteries, which carry blood to your lungs to pick up oxygen.

iii) The Mitral valve (M) lets oxygen-rich blood from your lungs pass from the left atrium into the left ventricle.

iv) The Aortic valve (A) opens the way for oxygen-rich blood to pass from the left ventricle into the aorta, your body's largest artery, where it is delivered to the rest of your body.

The points Aortic (A), Pulmonary (P), Tricuspid (T) and Mitral (M) form a quadrilateral. The quadrangular area may be completed by a line joining the upper ends of the right and left borders, and corresponds roughly to the upper limits of the atria. The left and right borders can be mapped out by heavy percussion.

Figure-3
Heart Sound Quadrilateral



6) MATHEMATICAL ANALYSIS

To find the relation between the ages of a child (A) and ratio of area of body and area of heart-sound quadrilateral (x) calculate correlation. It is very interesting that I have found correlation between A and x as 0.94 which shows that these variables A and x having very high relation with each other.

Similarly I calculated another correlation between A and heart sound quadrilateral (y) and again it is calculated as 0.94 shows again a high relation between A and Y.

6.1 Correlations

a. Definition of variables

A = Age of the child
x = Ratio of area of body and area of heart-sound quadrilateral
y = Area of heart-sound quadrilateral

b. Correlation between A and x

As Correlation = $r = \frac{\sum dAdx}{\sqrt{(\sum dA^2)(\sum dx^2)}}$ -------------------- (1)

After substituting the recorded values from Table2 we have $r = 0.94$

c. Correlation between A and x (Standardized variables)

$$r = \frac{\sum ZA\,Zx}{n} \quad \text{--------------------------------- (2)}$$

Where $ZA = \frac{A - \bar{A}}{S.D(A)}$ --------------------------------- (3)

And $Zx = \frac{x - \bar{x}}{S.D(x)}$ ---------------------------------- (4)

When $\bar{A} = \frac{\sum A}{n}$

And $\bar{x} = \frac{\sum x}{n}$

Similarly $S.D(A) = \sqrt{\frac{\sum (A - \bar{A})^2}{n}}$

And $S.D(x) = \sqrt{\frac{\sum (x - \bar{x})^2}{n}}$

Now equation (2) implies
(After substituting the recorded values from Table3) $r = 0.94$

d. Correlation between A and y

As Correlation = $r = \frac{\sum dAdy}{\sqrt{(\sum dA^2)(\sum dy^2)}}$ ----------------- (5)

After substituting the recorded values from Table4 we have $r = 0.94$

e. Correlation between A and y (Standardized variables)

$$= \frac{\sum ZA\,Zy}{n} \quad \text{--------------------------------- (6)}$$

Where $ZA = \frac{A - \bar{A}}{S.D(A)}$ --------------------------------- (7)

And $Zy = \frac{y - \bar{y}}{S.D(y)}$ ---------------------------------- (8)

When $A = \frac{\sum A}{n}$

$y = \frac{\sum y}{n}$

Similarly $S.D(A) = \sqrt{\frac{\sum (A - \bar{A})^2}{n}}$

And $S.D(y) = \sqrt{\frac{\sum (y - \bar{y})^2}{n}}$

Now equation (6) implies
(After substituting the recorded values from Tables2, 4 & 5) $r = 0.94$

6.2 Regression Lines

a. Regression Line between A and x

$x = a + bA$ --- (9)

Where '*a*' and '*b*' are arbitrary constants

As we know that

$a = \bar{x} + b\bar{A}$ -- (10)

$b = \frac{n\sum Ax - (\sum A)(\sum x)}{n\sum A^2 - (\sum A)^2}$ -------------------- (11)

After substituting the recorded values

We have $b = 18.65$ & $a = 68.29$

As $A = \frac{\sum A}{n} = 7.57$

And $x = \frac{\sum x}{n} = 209.64$

Now equation (10) implies

(After substituting the recorded values from Table2)
Now put the values of in equation (9) we have

$x = 68.29 + 18.65 A$ -------------------------------------- (12)

b. Regression Line between A and y

$y = a + bA$- --- (13)

Where '*a*' and '*b*' are arbitrary constants
As we know that

$a = \bar{y} - b\bar{A}$ --- (14)

$b = \frac{n\sum Ax - (\sum A)(\sum x)}{n\sum A^2 - (\sum A)^2}$ -------------------- (15)

After substituting the recorded values we have,

$b = 0.766$

As $A = \frac{\sum A}{n}$

And $y = \frac{\sum y}{n}$

Now equation (14) implies

(After substituting the recorded values from Table4) a = 6.64

Now put the values of in equation (13) we have

$y = 6.64 + 0.766A$ ------------------------------------- (16)

Table 1:
Genrate Data

Observations						
Case No	Initials	Date of Obs. (yy/mm/dd)	Date of Birth (yy/mm/dd)	Height (Standing) cm	Chest cm	Forward Bending
Case 01	J.I	01/08/25	97/08/06	101.1	15.7	+ve
Case 02	S.A	01/08/25	97/06/08	103.8	17.32	+ve

Table 2:
Calculation of Correlation between 'A' and 'x'

Case No	**Initials**	**Age (Years) A**	**Coeff (x)**	**dA=A-7.57**	**dx=x-209.64**	**dA^2**	**dx^2**	**dAdx**	**Ax**	**A^2**
Case 01	J.I	4.05	158.56	-3.52	-51.08	12.39	2609.1	179.80	642.16	16.40
Case 02	S.A	4.2	160.04	-3.37	-49.6	11.35	2460.1	167.15	672.16	17.64
$\sum$		265.29	7337.47	0.34	0.07	147.2606	57977.79	2760.803	58376.7	2158.07

Table 3:
Calculation of Correlation between 'A' and 'x' (Standardized variables)

(A - A')	**$(A - A')^2$**	**(x - x ')**	**$(x - x ')^2$**	**ZA =(A-A')/S.D**	**Zx =(x-x')/S.D**	**ZA . Zx**
-3.52	12.3904	-51.08	2609.166	-1.717073171	-1.255036855	2.154990112
-3.37	11.3569	-49.6	2460.16	-1.643902439	-1.218673219	2.003379877
0.34	147.2606	0.07	57977.8	0.165853659	0.001719902	33.08926788

Table 4:
Calculation of Correlation between 'A' and 'x' (Standardized variables)

Case No	**Initials**	**Age (Years) A**	**Area of Quadrilateral (y) cm^2**	**dA=A - 7.57**	**dy=y -1 2.44**	**dA^2**	**dy^2**	**Addy**	**Ay**	**A^2**
Case 01	J.I	4.05	10.01	-3.52	-2.43	12.390	5.9049	8.5536	40.540	16.40
Case 02	S.A	4.2	10.24	-3.37	-2.2	11.356	4.84	7.414	43.008	17.64
$\sum$		265.29	435.62			147.2606	112.9342	98.0644	112.9342	2158.0797

Table 5:
Calculation of Correlation between 'A' and 'y' (Standardized variables)

(A-A')	$(A-A')^2$	(y - y ')	$(y - y ')^2$	ZA =(A-A')/S.D	Zy =(y-y')/S.D	ZA . Zy
-3.52	12.3904	-2.43	5.9049	-1.717073171	-1.45508982	2.498495692
-3.37	11.3569	-2.2	4.84	-1.643902439	-1.317365269	2.16561998
0.34	147.26	0.22	98.0644	0.165853659	0.131736527	32.9879366

7) RESULTS

Correlations:

1. The correlation between age of the child and ratio of area of body and area of heart-sound quadrilateral is equal to 0.94
2. The correlation between age of the child and area of heart - sound quadrilateral is equal to 0.94

Regression Lines:

1. The regression line between age of the child and ratio of area of body and area of heart-sound quadrilateral is equal to:

$$x = 68.29 + 18.65A$$

2. The regression line between age of the child and area of heart - sound quadrilateral is equal to:

$$y = 6.64 + 0.766A$$

8) DISCUSSION AND CONCLUSION

In this work I have tried to look at the physical and the geometrical applications of heart-sound quadrilateral in 2-D as well as in 3-D. The heart sound quadrilateral has been studied in the contents of model of heart developed by Kamal (1992A). The technique consists of clinical observations of the child with respect to general nutritional status and presence/absence of spinal deformities. An attempt was made to include only those children in this study who presented having no major problems. The points of maximum intensity (PMI) corresponding to heart-sound generated from Aortic (A), Pulmonary (P), Tricuspid (T) and Mitral (M) valves were located using Lattmann Classic2 stethoscope with the child standing and points were marked on skin using a skin marker. A plastic sheet was placed vertically front of chest and points marked on the sheet. This gave us real dimensions of heart-sound quadrilateral. The data were analyzed using mathematical and statistical techniques. Regressions and correlations between various parameters were determined and plotted.

According to our analysis area of heart-sound quadrilateral is linearly dependent on age of the child with a correlation coefficient, coming out as 0.94. Ratio of the body area and the area of heart-sound quadrilateral is also strongly correlated with the age of child and as a linear dependence. We also studied the feasibility of using moiré technique to obtain 3-D positions of point of maximum intensity (PMI) corresponding to Aortic (A), Pulmonary (P), Tricuspid (T) and Mitral (M) valves. This may be helpful in diagnosis heart conditions in children, which may severely worsen the quality of life in later years. The method is inexpensive and easily accessible to all strata of population in all areas of the country. It may also be used to validate the proposed heart model by (1992B). Future studies may be conducted for separate sexes and somatotypes. Future studies must also incorporate effect of weight on heart shape and area of heart-sound quadrilateral.

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