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Morphological relationships between the oval fossa and neighboring structures

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SUMMARY

Morphometric data are potentially useful in guiding paediatric cardiac surgery to correct atrial septal defects and as an aid to diagnosing prenatal narrowing or closure of the oval foramen. The purpose of this study was to find correlations between a series of morphometric parameters in the developing human oval fossa and body weight in fetuses and newborns. All specimens were from southern Spain, and are preserved in formaldehyde at the Department of Morphological Sciences, School of Medicine, University of Granada in Granada, Spain. We studied 95 fetal and neonatal hearts (50 male, 45 female, body weight 501-4000 g, 26-40 weeks of gestation). Morphometric techniques were used to measure the distances from the centre and rim of the oval fossa to neighbouring structures in the right atrium (craneal and caudal caval veins, coronary sinus, tricuspid valve orifice), and the distances from the rim and centre of the primary septum to neighbouring structures in the left atrium (right pulmonary vein, mitral valve orifice). The vertical and transverse diameters and area of the oval fossa were measured, and the relationships between area of the oval fossa and area of the atrial septum were calculated. These data were correlated with log fetal and neonatal body weight in kilograms. All morphometric parameters were significantly related to log fetal or neonatal body weight ($p < 0.001$). The values were not affected by the shape (oval or circular) of the oval fossa. The data can be used to calculate blood flow through the oval foramen with Doppler echocardiographic techniques. They can also enhance the success of surgical techniques such as double-umbrella closure of atrial defects.

Key words: Fetal - neonatal - oval foramen - oval fossa.

INTRODUCTION

Few morphometric studies have centered on the anatomy of the oval fossa, oval foramen and neighboring structures such as the caudal and craneal caval veins, coronary sinus, tricuspid and mitral valve orifices, and right pulmonary vein. Doppler imaging techniques provide information on these heart structures, which are vital to fetal circulation and help guarantee competence of the left heart chambers and their corresponding blood vessels (Fouron, 1991). Metric data obtained from autopsied hearts can be compared by fetal echocardiographers with the values found during intrauterine life (St John Sutton et al., 1993).

The present study was designed to provide morphometric data on the distances between the rim of the oval fossa, and from the center of the oval fossa to the right and left atrium. In addition, we measured the vertical and transverse diameters and the area of the oval foramen, and calculated the relationship between oval foramen area and atrial septum area during fetal development from week 26 to week 40 of gestation.

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Materials and Methods

A total of 95 fetal and neonatal human hearts were studied (50 male, 45 female, body weight 501-4000 g). Postnatal survival times were 0 (n = 77), < 24 h (n = 14) and > 24 h (n = 4), and ages ranged from 26 to 40 weeks of gestation. Internal and external anatomical malformations were ruled out in all hearts, which were diagnosed as normal (concordant atrioventricular and ventriculoarterial connections). None of the 95 cases had continuity between the orifice of the caudal caval vein and oval fossa, and in no case was the cause of death related to congenital cardiac malformation. Table 1 shows the distribution of these specimens according to body weight, sex and age.

Body weight (g)	No. Cases	Age (weeks)
501-1000	9	26-29
1001-2000	45	29-36
2001-3000	22	36-40
3001-4000	19	> 40

Table 1.– Distribution of body weights in 1000-g intervals and referred to gestational age in 95 fetal and neonatal normal human hearts (50 male, 45 female).

A set of linear measurements was taken (Figs. 1a-d) in all hearts with a millimeter ruler and compass (Alvarez et al., 1995; Chan and Goodman, 1993). When a curved surface made it impossible to use these tools, dampened string was laid across the specimen between the two endpoints and then measured in millimeters.

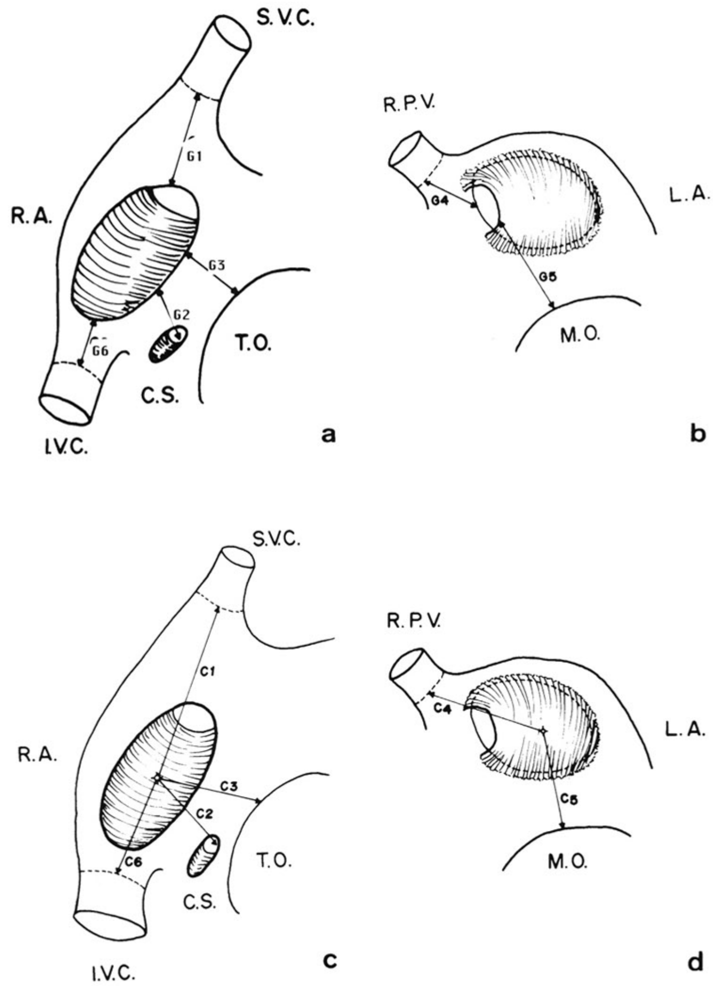

Fig. 1.– a: Diagram of the linear measurements in the oval fossa. SCV, craneal caval vein; ICV, caudal caval vein; C.S., coronary sinus; TO, tricuspid valve orifice; RA, right atrium. Morphometric parameters are the distances between the orifice of the craneal caval vein and the ventral rim (limbus) of the oval fossa (G1); the caudal rim of the oval fossa and the orifice of the coronary sinus (G2); the ventral-caudal rim of the oval fossa and the tricuspid valve orifice (G3); the orifice of the caudal caval vein and the dorsalrim of the oval fossa (G6).
b: Diagram of the linear measurements in the oval foramen. MO, mitral valve orifice; RPV, right pulmonary vein; LA, left atrium. Morphometric parameters are the distances between the orifice of the right pulmonary vein in the ventral rim of the oval foramen (G4); the dorsal rim of the ovalforamen and the mitral valve orifice (G5).
c: Diagram of the linear measurements in the oval fossa. SCV, craneal caval vein; ICV, caudal caval vein; CS, coronary sinus; TO, tricuspid valve orifice; RA, right atrium. Morphometric parameters are the distances between the orifice of the craneal caval vein and the central point of the oval fossa (C1); the orifice of the coronary sinus and the central point of the oval fossa (C2); the tricuspid valve orifice and the central point of the oval fossa (C3); the orifice of the caudal caval vein and the central point of the oval fossa (C6).
d: Diagram of the linear measurements in the oval foramen. MO, mitral valve orifice; RPV, right pulmonary vein; LA, left atrium. Morphometric parameters are the distances between the orifice of the right pulmonary vein and central point of the primary septum (C4); the mitral valve orifice and the central point of the primary septum (C5).

The following parameters were measured: distances between the orifice of the craneal caval vein and the ventral rim (limbus) of the oval foss (G_1); the caudal rim of the oval fossa and the orifice of the coronary sinus (G_2); the ventral-caudal rim of the oval fossa and the tricuspid valve orifice (G_3); the orifice of the right pulmonary vein and the ventral rim of the oval foramen (G_4); the dorsal rim of the oval foramen and the mitral valve orifice (G_5); the orifice of the caudal caval vein and the dorsal rim of the oval fossa (G_6); and distances between the orifice of the craneal caval vein and the central point of the oval fossa (C_1); the orifice of the coronary sinus and the central point of the oval fossa (C_2); the tricuspid valve orifice and the central point of the oval fossa (C_3); the orifice of the right pulmonary vein and central point of the primary septum (C_4); the mitral valve orifice and the central point of the primary septum (C_5); and the orifice of the caudal caval vein and the central point of the oval fossa (C_6). The area of the oval foramen was calculated by finding the radius r with the formula $(x + y)/4$, where x is the largest diameter and y the smallest diameter, and then calculating r^2. The area of the atrial septum was also calculated, as was the ratio of the two areas.

We used minimum square regression analysis to calculate the correlations between the values of morphometric parameters and log fetal and neonatal body weight in kilograms. Descriptive statistics are reported as the mean ± standard deviation. All analyses were done with version 6 of the BMDP software package (Dixon, 1992).

Results

Table 2 gives the mean values of each morphometric parameter. All parameters were significantly related to log fetal or neonatal body weight ($p < 0.001$).

Parameter	Mean (mm)	Parameter	Mean (mm)
G_1	5.67 ± 1.44	C_1	8.56 ± 1.68
G_2	3.25 ± 0.75	C_2	6.24 ± 1.17
G_3	5.66 ± 1.22	C_3	8.96 ± 1.67
G_4	4.92 ± 1.16	C_4	8.07 ± 1.49
G_5	5.02 ± 1.03	C_5	7.83 ± 1.44
G_6	3.45 ± 0.90	C_6	6.18 ± 1.28
Oval foramen area (mm^2)	18.62 ± 7.28		
Atrial septum area (mm^2)	47.39 ± 16.96		
Body weight (Kg)	2.0831 ± 936.44		
Log body weight (Kg)	7.5299 ± 0.49		

For all parameters, $P < 0.001$.

Key to abbreviations: distances between (G_1) the orifice of the craneal caval vein and the ventral rim (limbus) of the oval fossa; (G_2) the caudal rim of the oval fossa and the orifice of the coronary sinus; (G_3) the ventral-caudal rim of the oval fossa and the tricuspid valve orifice; (G_4) the orifice of the right pulmonary vein and the ventral rim of the oval foramen; (G_5) the dorsal rim of the oval foramen and the mitral valve orifice; (G_6) the orifice of the caudal caval vein and the dorsal rim of the oval fossa; (C_1) the orifice of the craneal caval vein and the central point of the oval fossa; (C_2) the orifice of the coronary sinus and the central point of the oval fossa; (C_3) the tricuspid valve orifice and the central point of the oval fossa; (C_4) the orifice of the right pulmonary vein and central point of the primary septum; (C_5) the mitral valve orifice and the central point of the primary septum; (C_6) the orifice of the caudal caval vein and the central point of the oval fossa.

Table 2.– Mean values and standard deviations of morphometric parameters measured in 95 fetal and neonatal normal human hearts.

Parameter	Body weight (g) 501-1000 (*n* = 9)	1001-2000 (*n* = 45)	2001-3000 (*n* = 22)	3001-4000 (*n* = 19)
G_1 (mm)	4.05 ± 1.27	5.44 ± 1.06	5.95 ± 1.02	3.31 ± 1.55
G_2 (mm)	2.33 ± 0.47	3.08 ± 0.58	3.31 ± 0.46	3.92 ± 0.86
G_3 (mm)	4.16 ± 0.33	4.17 ± 1.35	6.09 ± 0.84	6.68 ± 1.21
G_4 (mm)	3.50 ± 0.70-	4.72 ± 0.87	5.36 ± 1.02	5.31 ± 0.92
G_5 (mm)	4.10 ± 0.70	4.82 ± 0.83	5.22 ± 0.79	5.52 ± 1.18
G_6 (mm)	2.60 ± 0.60	3.20 ± 0.78	3.63 ± 0.64	4.00 ± 0.79
C_1 (mm)	6.33 ± 1.33	5.62 ± 2.63	9.06 ± 1.13	9.89 ± 1.30
C_2 (mm)	5.59 ± 1.13	5.90 ± 0.80	6.56 ± 0.80	7.39 ± 1.27
C_3 (mm)	6.83 ± 0.88	8.18 ± 1.05	9.79 ± 1.18	10.76 ± 1.32
C_4 (mm)	6.05 ± 1.42	7.66 ± 1.09	8.75 ± 1.32	8.84 ± 1.24
C_5 (mm)	5.85 ± 1.09	7.23 ± 0.99	8.70 ± 1.37	8.76 ± 1.01
C_6 (mm)	4.70 ± 0.60	5.70 ± 0.87	6.88 ± 1.33	7.05 ± 1.01

See Table 2 for explanation of abbreviations.

Table 3.– Mean values of morphometric parameters measured from the rim (G) and center (C) of the oval fossa and the ventral and dorsal rim of the oval foramen (G) and center (C) of the septum primun in 95 fetal and neonatal normal human hearts.

Table 3 summarizes the mean values for all 12 parameters during fetal and neonatal development from week 26 to week 40, in specimens ranging in body weight from 501 to 4000 g. Table 4 gives mean values and standard deviations for vertical and transverse diameters and area of the oval foramen during development.

As fetal development progressed, the values of each parameter changed. In fetuses with a body weight of 501-1000 g (26-29 weeks of gestation), the area of the oval foramen was 11.98 ± 3.17 mm^2; this increased to 24.33 ± 8.20 mm^2 in fetuses weighing 3001-4000 g (> 40 weeks of gestation). The ratio of the oval foramen to the atrial septum area also changed as development progressed (Table 4). In fetuses with a body weight of 501-1000 g the ratio of the oval foramen to atrial septum area was 0.50 ± 0.22; this decreased to 0.41 ± 0.16 in fetuses weighing 3001-4000 g. The values of the morphometric parameters were not affected by the shape of the oval fossa (oval or circular); this is in agreement with an earlier study (Alvarez et al., 1995) showing that area of the oval fossa is little affected by shape.

We also considered the criteria established for patients subjected to double-umbrella closure of an atrial defect. In these cases we assumed that at least 4 mm separated the defect edges from important cardiac structures such as the atrioventricular valves, caval veins and pulmonary veins, as estimated by echocardiography (Rome et al., 1990).

Discussion

Our morphometric data, when considered in the light of echocardiographic studies, have immediate clinical applications in the treatment of atrial septal defects. Oval fossa defects, the most common type of interatrial communication, are true atrial septal defects (Anderson et al., 1987) which can now be treated with transcatheter closure and other surgical techniques in selected patients (Ferreira et al., 1992).

Chan and Goodman (1993) assessed the feasibility of closure by the clam-shell device by determining the size of the defect and the relationships between its edges and the contiguous arterial structures. According to these authors, the atrial structures that affect the feasibility of transcatheter closure are the craneal and caudal caval veins, the right pulmonary veins, and the coronary sinus. They found that the defect may be situated close to the coronary sinus, caudal caval vein, or right pulmonary vein. Because placement of the clam-shell device may obstruct these structures, they recommended double-umbrella closure of the atrial oval fossa defects as an alternative. Their list of criteria for this approach included a separation of at least 4 mm (estimated echocardiographically) between the edges of the defect and important cardiac structures such as the atrioventricular valves, caval veins and pulmonary vein.

Atkins and colleagues (1982), in their study of 51 specimens, considered the oval foramen as an indicator of transatrial blood flow in utero. They investigated 18 normal specimens from 5 months to 12 years of age (mean 4.3 ± 3.7 years) and 33 hearts with congenital cardiac anomalies from infants and children from 1 day to 11 years old (1.1 ± 2.4 years). Although their material differed from ours in age and the presence of abnormalities, these authors suggested that the size of the oval foramen is directly proportional to the relative volume of transatrial blood flow during cardiac morphogenesis. In their normal specimens the ratio of oval foramen area to atrial septum area was 0.19 ± 0.07, compared with a ratio of 0.43 ± 0.4 in our normal material. The difference in these values probably reflects the differences in the composition of the sample in each study; our material consisted of fetal and neonatal hearts from infants with postnatal survival times of 0 h (77 cases) or < 24 h (14 cases); only 4 infants in our sample survived for longer than 24 h after birth. At this stage the oval foramen is patent, and closure is normally complete only after 1 month of life.

	Body weight (g)			
Parameter	**501-1000 (*n* = 9)**	**1001-2000 (*n* = 45)**	**2001-3000 (*n* = 22)**	**3001-4000 (*n* = 19)**
Vertical diameter (mm)	4.20 ± 0.80	4.62 ± 0.87	5.66 ± 1.04	6.25 ± 1.39
Transverse diameter (mm)	3.33 ± 0.52	4.27 ± 0.73	4.69 ± 0.60	4.95 ± 0.861
Area (mm^2)	11.98 ± 0.33	15.61 ± 4.64	20.43 ± 7.36	24.33 ± 8.20
Ratio oval foramen/ atrial septum	0.50 ± 0.22	0.37 ± 0.12	5.44 ± 0.79	0.40 ± 0.16

Table 4.– Mean diameters and area of the oval foramen, and ratio of the oval foramen area to atrial septum area, in 95 fetal and neonatal human hearts.

The data in Table 4 are similar to the values from an earlier study by Hutchins and colleagues (1981), who found a mean diameter of 4.3 mm (range 3-6 mm) in the oval foramen at the end of gestation in 17 embryos and fetuses at 8-20 weeks of gestation, 11 fetuses of 21-39 weeks of gestation, and 26 newborns (birth 1 month). In our material, the mean vertical diameter of the oval foramen in all 95 hearts was 5.15 ± 0.8 mm; however, this parameter is more appropriately considered for smaller age intervals (see Table 4). Reliable figures for the diameters and area of the oval foramen in different stages of embryonic and fetal development should help clinicians to establish a diagnosis of prenatal narrowing or closure of this orifice (Naeve and Blanc, 1964; Sweeney and Rosenquist, 1982).

St John Sutton et al. (1993) used Doppler echocardiography to prospectively study 38 normal fetuses of 18-37 weeks' gestation, and reported that "direct assessment of flow through the foramen ovale is not possible as blood flow velocity across it is multiphasic and the cross-sectional area of the foramen ovale cannot be assessed because of its irregular shape." They also noted that "little is known on blood flow through the lungs and still less about interatrial shunting of blood in the normal human fetus during growth." Our morphometric data can potentially be used as an anatomical reference.

Like Sweeney and Rosenquist (1982), we found that in cardiopulmonary blocks preserved in formaldehyde, the anatomical relationships between structures were not affected by age or formalin fixation. In recording the transverse diameter of the oval foramen, we were aware of the flexibility of the primary septum; therefore these measurements are not entirely precise, although they are accurate enough for the purposes of the present study.

The morphometric data reported here for each of the 12 parameters in the oval fossa and oval foramen can provide surgeons and echocardiographers with a greater margin of safety in the management of atrial septal defects, especially when surgical treatment of the oval fossa is being considered.

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