Annals of Anatomy 205 (2016) 60–64

Contents lists available at ScienceDirect

Annals of Anatomy

journal homepage: www.elsevier.com/locate/aanat

Research article

Anatomy of the true interatrial septum for transseptal access to the left atrium

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ARTICLE INFO

Article history:
Received 6 January 2016
Received in revised form 23 January 2016
Accepted 25 January 2016

Keywords:
Transseptal puncture
Septal pouch
Patent foramen ovale
Fossa ovalis

ABSTRACT

Clinical anatomy of the interatrial septum is treacherous, difficult and its unfamiliarity can cause many serious complications. This work aims to create an anatomical map of the true interatrial septum. An appreciation of the anatomical situation is essential for safe and efficacious transseptal access from the right atrium to the left heart chambers. Examination of 135 autopsied human hearts (Caucasian) of both sexes (28% females) aged from 19 to 94 years old (47.0 ± 18.2) with BMI = 27.1 ± 6.0 kg/m^2 was conducted. Focus was specifically targeted on the assessment of the fossa ovalis, patent foramen ovale (PFO), and right-sided septal pouch (RSP) morphology. Mean values of cranio-caudal and antero-posterior fossa ovalis diameters were 12.1 ± 3.6 and 14.1 ± 3.6 mm, respectively. The fossa ovalis was situated an average of 10.1 ± 4.4 mm above the inferior vena cava ostium, 20.7 ± 5.2 mm from the right atrioventricular ring, and 12.6 ± 5.2 mm under the right atrium roof. Four types of fossa ovalis anatomy have been observed (smooth-56.3%, PFO-24.4%, RSP-11.9%, net-like formation-7.4%). The PFO mean channel length was 10.5 ± 5.2 mm. The tunnel-like PFO (channel length ≥12 mm) was observed in 8.9% of specimens. The RSP was observed in 11.9% of specimens (with mean depth = 6.3 ± 3.8 mm) and was directed apex upward in all observed specimens (may imitate the PFO channel). The fossa ovalis/interatrial septum surface area ratio was 18.3 ± 9.0%. In conclusion: (1) An anatomical map of the interatrial septum from the right atrial side was presented. (2) The RSP may imitate the PFO channel. (3) The "true" interatrial septum represents only about 20% of the whole interatrial septum area. (4) There is wide variation in the location and geometry of the fossa ovalis. (5) We could distinguish four different types of the fossa ovalis area.

1. Introduction

It has been over half a century since Ross, Braunwald, and Morrow provided the first description of the transseptal left atrial puncture technique, which permits a direct route to the left atrium via the systemic venous system, right atrium and interatrial septum (Ross et al., 1960). Prior to this development, obtaining percutaneous access to the left atrium was one of the most difficult cardiac procedures. The left atrium was commonly reached by retrograde arterial cannulation via the left ventricle and mitral valve, although the manipulation of catheters proved problematic due to multiple required 90° turns (Zimmerman et al., 1950). Alternative techniques, such as: transbronchial (Facquet et al., 1952), transthoracic (Bjork et al., 1953), suprasternal (Radner, 1954) and direct ventricular (Brock et al., 1956) puncture have been proposed, but each has certain disadvantages. Another method of left atrial access utilized natural connections between the right and left atria, such as a patent foramen ovale (PFO) or other atrial septal defects. This access was new, still developed, and limited to a small number of patients with favorable anatomical conditions. Brockenbrough (Brockenbrough et al., 1962), and later Mullins (Mullins, 1983) refined the transseptal puncture procedure with several critical modifications. Today, both transseptal puncture and access through PFO are widely used cardiac techniques. Transseptal access is commonly employed during the following procedures: catheter ablation, pulmonary vein isolation, left atrial appendage closure, PFO and atrial septal defect repair, percutaneous mitral valvuloplasty, MitraClip catheter-based mitral valve repair, hemodynamic assessment of the mitral valve, paravalvular leak closure, and as

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http://dx.doi.org/10.1016/j.aanat.2016.01.009

an alternative access to the left ventricle in the presence of a prosthetic aortic valve (Earley, 2009; Jönsson and Settergren, 2010). For experienced operators, it is usually an uncomplicated procedure, however, in some cases it may be extremely difficult, with fatal complications (Katritsis et al., 2013).

An appreciation of the anatomical conditions is essential for safe and efficacious transseptal access from the right atrium to the left heart chambers. Clinical anatomy of the true interatrial septum is treacherous, difficult and its unfamiliarity can cause many serious complications. Thus, the aim of our study was to assess the regional morphology of the right atrium and interatrial septum for a deeper understanding.

2. Materials and method

The study was designed and conducted by the Department of Anatomy, Jagiellonian University Medical College in Cracow, Poland and approved by the Bioethical Committee of the Jagiellonian University Medical College, Cracow (KBET/51/B/2013).

Heart specimens were collected during routine forensic medical autopsies performed at the Department of Forensic Medicine, Jagiellonian University Medical College from July 2013 to October 2014. The hearts were removed together with the proximal portions of the great vessels: the ascending aorta, pulmonary trunk, superior vena cava (SVC), inferior vena cava (IVC), and all pulmonary veins. All specimens were randomly selected. Exclusion criteria include: severe anatomical defects, states after operations and grafts on the heart, obvious severe macroscopic pathology of the heart or vascular system found during the autopsy (aneurysms, storage diseases), heart trauma, and macroscopic signs of decomposition of cadavers. Other conditions such as: myocardial infarction, arterial and pulmonary hypertension, cardiomyopathy, heart failure, arrhythmias were not recognized as an exclusion criteria. After dissection all hearts were fixed in 10% paraformaldehyde for a maximum of 2 months until the time of measurement.

Our study included 135 randomly selected adult human hearts (Caucasian) of both sexes (28% females) aged from 19 to 94 years old (47.0 ± 18.2) with an average measured body mass index (BMI) of 27.1 ± 6.0 kg/m^2. All specimens were opened in a common manner. The right atrium was opened by an incision extending from the orifice of the SVC to the orifice of the IVC. The Eustachian valve associated with the orifice of the IVC however was not sectioned. The left atrium was opened by an incision extending between associated pairs of left and right pulmonary veins.

All descriptions and measurements were undertaken with the heart held in anatomical position. All measurements were conducted by 0.03 mm precision electronic caliper YATO (YT–7201). In order to reduce human error, two researchers obtained measurements. If the measurements of one parameter differed by more than 10% then they were not included in the database and the sample was measured again. The mean of the two measurements was calculated, rounding to the tenths decimal place. The following measurements were made: the shortest distance between the IVC and SVC ostia; width of the interatrial septum from the right atrium side (the longest antero-posterior diameter); cranio-caudal and antero-posterior diameters of the fossa ovalis as the largest lengths between opposite sides of the limbus of the fossa ovalis; and the shortest distances from the limbus of the fossa ovalis to the right atrioventricular ring, to the IVC ostium, and to the right atrium roof. The greatest distance from the limbus fossae ovalis to the edge of the infero-anterior rim (to the nearest point were the needle does not pass directly from the right to the left atrium) was measured. The approximate surface area of the fossa ovalis and the interatrial septum as well as the ratio of the fossa ovalis surface area to the entire interatrial septum surface area were calculated.

The appearance, location and morphology of the fossa ovalis, PFO, right-sided septal pouch (RSP), and muscle bridges within the right atrium were assessed. The positions of PFO and RSP orifices within the fossa ovalis were noted and the length of the PFO channel and RSP depth were measured. The floor of the fossa ovalis was transluminated from the left atrial side.

Hearts were weighed prior to paraformaldehyde treatment. The heart circumference defined as the smallest circumference of the heart at the atrio-ventricular groove (coronary grove) was obtained, and measurements of other main heart structures were performed to determine the presence of additional relative anatomic relationships.

Data are presented as mean values and corresponding standard deviations. StatSoft Statistica 10.0 for Windows was used for all statistical analyses. *P*-values less than 0.05 were considered to be statistically significant. Correlation coefficients were calculated to measure statistical dependence and the Student's *t*-tests and Mann–Whitney *U*-tests were performed for statistical comparisons.

3. Results

Minimum, maximum, median, and mean values with standard deviations of obtained anatomical measurements and calculations are presented in Table 1. The map of the interatrial septum from the right atrial side is shown in Fig. 1. The distance between the IVC and SVC ostia showed an increase with age ($r = 0.36$; $p = 0.00$), BMI ($r = 0.35$; $p = 0.00$), heart weight ($r = 0.39$; $p = 0.00$), heart circumference ($r = 0.28$; $p = 0.002$), IVC diameter ($r = 0.24$; $p = 0.006$), and cross-sectional area of the right atrioventricular ring ($r = 0.21$; $p = 0.01$). The interatrial septum width also showed an increase with age ($r = 0.27$; $p = 0.001$) and heart circumference ($r = 0.18$; $p = 0.04$).

The fossa ovalis is an oval or round depression in the lower posterior part of the interatrial septum and is composed primarily of thin fibrous tissue. It was oval in 55.6% and round in 44.4% of cases. The calculated ratio of the fossa ovalis surface area to the entire interatrial septum surface area was correlated with the heart weight ($r = 0.27$; $p = 0.002$). Mean values of cranio-caudal and antero-posterior fossa ovalis diameters were higher in heavier hearts ($r = 0.30$; $p = 0.001$ and $r = 0.21$; $p = 0.028$), and increased with age ($r = 0.234$; $p = 0.015$ and $r = 0.34$; $p = 0.000$, respectively). Cranio-caudal diameter also showed an increase with IVC diameter ($r = 0.28$; $p = 0.001$), while the antero-posterior diameter showed a direct correlation with diameter ($r = 0.19$; $p = 0.03$) and cross-sectional area ($r = 0.24$; $p = 0.005$) of right atrioventricular ring and IVC diameter ($r = 0.17$; $p = 0.04$). The fossa ovalis area was increased with age ($r = 0.2$; $p = 0.018$). The distance between the fossa ovalis limbus and the right atrium roof was increased with BMI ($r = 0.2$; $p = 0.017$), age ($r = 0.19$; $p = 0.025$), and heart circumference ($r = 0.28$; $p = 0.0015$). The sex showed no influence on any above-mentioned parameters.

The PFO (Fig. 2b) was present in 24.4% with a mean channel length of 10.5 ± 5.2 mm. The tunnel-like PFO (channel length ≥12 mm) was observed in 8.9% of all cases (36.4% of PFO cases). The PFO channel was directed superiorly and anteriorly in all observed cases. PFO channel length showed an inverse correlation with BMI ($r = -0.38$; $p = 0.034$) and increased with the length of the left atrial appendage ($r = 0.38$; $p < 0.05$). The PFO orifice was primarily located in the superior-central circumference of the fossa ovalis (78.8% of cases), and secondarily within the superior-posterior circumference of the fossa ovalis (21.2%). The frequency of PFO occurrence was higher in young adults than in elderly people ($p = 0.005$).

The septal pouch is defined as an invaginated portion of the septum formed in the absence of the PFO channel as a result of incomplete fusion of the embryological components of the