Alternative venous drainage of heart ventricles in rabbits

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Abstract: The objective of this study was to describe the uncommon connections between cardiac veins, alternative pathways within cardiac venous circulation and complex variability of the venous system in the heart ventricles. The study was carried out on 30 adult New Zealand White rabbits. The arrangement of the cardiac veins was studied by using the corrosion casts prepared with the Spofacryl[®] and by perfusion of coloured latex. The presence and organization of principal veins of the heart ventricles was relatively constant with a great variability in the mode of opening and forming a common trunk. The highest variations were observed in the region of the paraconal interventricular vein, the left and right marginal vein and the left distal ventricular vein. The left proximal ventricular vein was an inconstant tributary of the left circumflex vein and was seen in 17% of cases. The left distal ventricular vein was visible as one (13% of cases) or two veins (87% of cases). Angular vein was observed in 20% of cases. Numerous anastomosis were found among cardiac veins.

Key words: anastomosis; rabbits; heart ventricles; corrosion casting

Introduction

Cardiac venous circulation has become the subject of considerable interest in recent years (Duda et al. 2003). Utilization of New Zealand White rabbits for experiments can be suitable including cardiologic procedures, in vitro as well as in situ testing of myocardial infarction, or in a series of electrophysiological interventional procedures (Ytrehus et al. 1994; Yoldas & Nur 2012). The anatomical relations between the heart and its venous system in rabbits are very similar to humans and other mammals (Yoldas & Nur 2012). The cardiac venous system has a wide anastomosis and the main veins of the heart are characterised by significant variability (Duda et al. 2003) with an eventuality for the existence of secondary connections and alternative venous pathways.

The morphology of the cardiac veins has been documented in some domestic animals (McKibben & Christensen 1964; Nickel et al. 1981; Besoluk & Tipirdamaz 2001; Aksoy et al. 2009), rodentia (Halpern 1953; Chiasson 1980; Cizek et al. 2007), porcupines (Atalar et al. 2004), and in the North American beaver (Bissaillon 1981). Several studies about the distribution of the cardiac veins in rabbits have been pub-

lished in the literature (Bahar et al. 2007; Yoldas & Nur 2012).

The following study aimed at showing the anatomical configuration of the cardiac veins with regard to the variability and possible uncommon connections within the cardiac venous circulation, using corrosion cast methods and latex injections.

Material and methods

The cardiac venous system was studied in 30 adult, healthy New Zealand White rabbits (*Oryctolagus cuniculus*) of both sexes (20 females, 10 males) with an average weight of 3.5 kg. The study was carried out in an accredited experimental laboratory at the University of Veterinary Medicine and Pharmacy in Kosice, Slovakia. The investigation was performed with the approval of the institutional ethics committee (serial No. 2647/07-221/5). Anaesthesia of animals was established by intravenous injection of embutramide (T-61, 0.3 ml/kg). Under anaesthesia and after heparin administration (50,000 IU/kg), lateral thoracotomy was performed, *v. cava caudalis* was cannulated and the heart was perfused manually with 0.9% physiological saline (Mazensky et al. 2011). A continuous perfusion of a saline solution was up to the casting, in order to remove the fixative state and make resin penetrability easy. The *v. cava cranialis*, pulmonary

Fig. 1. Several variations of the left surface of the heart. Pt – pulmonary trunk, As – atrium sinistrum, Vd – ventriculus dexter, Vs – ventriculus sinister, 1 – the left conal vein, 2 – the paraconal interventricular vein, 3 – the left circumflex vein, 4 – the angular vein, 5 – the left marginal vein, 6 – the left distal ventricular vein, 7 – the collateral veins, 8 – the left proximal ventricular vein.

Fig. 2. Veins of the the right surface of the heart and some observed uncommon connections. Lcvc – left cranial vena cava, Ad – atrium dextrum, Vd – ventriculus dexter, 1 – the middle cardiac vein, 2 – the right distal ventricular vein, 3 – the right marginal vein, 4 – the right proximal ventricular vein, 5 – the right conal vein, 6 – the right circumflex vein.

trunk and aorta were ligated. The Coloured latex and the Corrosion casts methods were used for the visualization of the coronary venous system.

The Coloured latex was injected into the *v. cava caudalis* after perfusion, the heart was removed and cleaned of connective tissue. Cardiac vein courses were analyzed macroscopically and microscopically (Leica M 320).

The Corrosion casts were prepared with Spofacryl® (SpofaDental a.s., Jičín, Czech Republic) as described Supuka et al. (2014). Following the plastic cannula was inserted and fixed into the *v. cava caudalis* and the casting medium in a quantity 5 ml was injected. After vascular casting with the resin is completed, it must not be manipulated with animals for 30 min and then they have to be submersed in water at a temperature ranging from 40 to 60 °C for a period between 30 min and 24 h for full polymerization of the resin (Lametschwandtner et al. 1990). Maceration of soft tissue was done in KOH solution (2–4%), for 3–6 days, at temperature 60–70 °C (Mazensky & Danko 2010). Prior to the outset of the drying process, the corroded specimens were submersed in water and dried at room temperature. The cardiac veins were investigated macroscopically and microscopically (Leica M 320). Anatomical nomenclature of the coronary veins was performed in accordance with Nomina Anatomica Veterinaria (Danko et al. 2011) and previous reports.

Results

The great cardiac vein (*V. cordis magna*, VCM) was the largest vein that drained the heart and opened into the left cranial vena cava (*V. cava cranialis sinistra*, VCCS). The VCM, partly covered by the left auricle, runs towards the left in the coronary groove. It received very fine branches from the left atrium and the proximal portions of the left ventricle. The VCM consisted of two main branches, the left circumflex vein and the paraconal interventricular vein (Fig. 1). The left circumflex vein collected the left proximal atrial and ventricular vein, left marginal vein and left distal ventricular vein. The left proximal ventricular vein was an inconstant tributary of the left circumflex vein and was observed in 17% of cases. The left distal ventricular vein was identified as one (13%) or two veins (87%).

The paraconal interventricular vein (*V. interven-tricularis paraconalis*, VIP) was constituted by the union of numerous branches from the wall of the left ventricle in the middle third of the paraconal sulcus. Along its course, VIP received cranially the left conal vein from the conus arteriosus, septal veins and few fine branches from the right and left ventricle. In 17% of

Fig. 3. Cardiac veins of the left surface of the heart. The presence of the angular vein, corrosion cast, lateral view. 1 – the left conal vein, 2 – the interventricular paraconal vein, 3 – angular vein, 4 – the left proximal ventricular vein, 5 – the left marginal vein, 6 – the great cardiac vein, TP – *truncus pulmonalis*, VCCS – *v. cava cranialis sinistra*.

cases there were observed collateral veins between the VIP and the left marginal vein (Fig. 1B) and between the VIP and the right marginal vein in 4 cases (13%). Two paraconal interventricular veins were recorded in 3% of cases. In fact, they ran simultaneously with the sulcus interventricularis paraconalis and merged into one trunk in the coronary groove.

In 20% of cases, one vein was observed in the angle where the VIP became the left circumflex vein, which could be the equivalent of the angular vein presented in the cat, donkey or sheep. This vein was located between the VIP and the left proximal ventricular vein, or if it absented – between the VIP and the left marginal vein with the blood drainage from the left ventricle (Fig. 1A, Fig. 3).

The left conal vein (*V. coni arteriosi sinistra*, VCoS) ran on the left circumference of the pulmonary root. It is a tributary of the VIP in the proximal third of the sulcus interventricularis paraconalis (Fig. 1). 17% of cases showed that it was located in the coronary groove and emptied into the VIP. Its terminal branches were seen to anastomose with the right conal vein in 3% of cases of investigated hearts. The VCoS was mostly created with a confluence of 3 small branches.

The left proximal ventricular vein (*V. proximalis ventriculi sinistri*, VPVS) is a branch of the left circumflex vein and was recorded only in 17% of cases (Fig. 1C). It was not observed in others, in which

Fig. 4. The left surface of the rabbit heart. The left marginal vein originated as two veins in distal third of the heart. Coloured latex, lateral view. As – *atrium sinistrum*, 1 – the interventricular paraconal vein, 2 – the left marginal vein.

the related region was drained by branches of the left marginal vein and collateral veins of the VIP.

The left marginal vein (*V. marginis ventriculi sinistri*, VMVS) was formed as a strong vein by the union of numerous branches from the wall of the left ventricle and apex cordis. Often originated as two veins in the distal third of the heart (Fig. 4). Branches of the VMVS were observed to anastomose with the collateral branches of the VIP in 17% of cases (Fig. 1B) and with the MCV in 3% of cases. A double vein was seen in 3% of cases. The VMVS opened into the left circumflex vein in 87% of cases, into the VCCS in 10% of cases. In 3% of cases the VMVS was emptying into the VIP in the middle third of the left ventricle.

The left distal ventricular vein (*V. distalis ventriculi sinistri*, VDVS) usually originated from the lower part of the proximal third of the heart as two veins in 87% of cases (Fig. 1A). In 3% of cases these two veins formed a common trunk. The VDVS were opened into the left circumflex vein in 77% of cases. In 7% of cases both veins emptied into the VCCS and in 3% of cases the first vein entered the VCCS and the second the left circumflex vein. Only the one large vein coming from the distal part of the rabbit heart was seen in 13% of cases (Fig. 1B). One vein located between the second VDVS and the middle cardiac vein was found in 3% of cases. It was formed in the distal third of the heart and emptied into the VCCS.

Fig. 5. The middle cardiac vein ascended towards the base of the heart in the subsinuosal interventricular sulcus and terminated to the VCCS. Coloured latex, lateral view. VCCS – *v. cava cranialis sinistra*, Ad – *atrium dextrum*, 1 – the middle cardiac vein, 2 – the right circumflex vein, 3 – the right distal ventricular vein.

The middle cardiac vein (*V. cordis media*; *The subsinuosal interventricular vein*, MCV) originated from a net that the collateral branches of the VMVS, VMVD and VIP made near the apex cordis. It ascended towards the base of the heart in the sulcus interventricularis subsinuosus and terminated to the VCCS in most of cases (Fig. 5). In 13% of cases the MCV emptied into the right circumflex vein. The MCV was observed to anastomose with the right marginal vein in 3% of cases and with the VMVS in 3% of cases. Along its course, the MCV received fine tributaries from the right ventricles, left ventricles and interventricular septum.

The right circumflex vein runs caudally to the coronary groove and opened into the VCCS. It received the right distal ventricular vein, the right marginal vein, the right proximal ventricular vein and the right conal vein (Fig. 2A).

The right distal ventricular vein (*V. distalis ventriculi dextri*, VDVD) was seen to start as a very thin vein from the proximal half of the wall of the right ventricle. This vein was opened into the right circumflex vein, in 3% of cases however, into the *v. cava caudalis*. In 3% of cases there was found anastomose between the VDVD and the MCV.

The right marginal vein (*V. marginis ventricularis dextri*, VMVD) runs from the apex of the heart to the right circumflex vein. In 13% of cases the VMVD was anastomosed with the VIP and in 7% of cases with the VPVD in the middle third of the heart. A common root

was determined in 7% of cases, which were formed by the VDVD, the VMVD and the VPVD. The VMVD was formed by the union of two branches in 13% of cases (Fig. 2A).

The right proximal ventricular vein (*V. proximalis ventriculi dextri*, VPVD) emerged from the sulcus interventricularis paraconalis near the apex cordis and distal third of the right ventricle. This vein was missing in 3% of cases. In 10% of cases there was determined, that the common root was formed by the VMVD, the VPVD and the VCoD (Fig. 2B). In 3% of cases the VPVD was anastomosed with the VIP.

The right conal vein (*V. coni arteriosi dextera*, VCoD) ran on the right circumference of the pulmonary root. It was formed by the confluence of 2–4 branches from the conus arteriosus and ended in the right circumflex vein (Fig. 2C). In 7% of cases the VCoD and VCoS linked together and were made as a semicircle round the conus arteriosus.

The smallest cardiac veins (*V. cordis minimae*) were noticed only on the right ventricular surface. The smallest cardiac veins collected blood from the interventricular septum and the wall of the right ventricle. These veins were opened into the cavity of the right ventricle.

Discussion

The major difference among rabbits and others animals refers to the presence of the VCCS, which ordinarily exists in the rabbit, in addition to the common right cranial *vena cava*. The existence of this vein was found in rodents such as rats (Halpern 1953) and mice (Ciszek et al. 2007). Only a few cases of the VCCS have been described in cats, cattle (Sekeles 1982) and marsupialia (Dowd 1974).

Sinus conarius is located immediately ventrally to the opening of the caudal *vena cava*, discharging the venous blood to the right atrium (Nickel et al. 1981). The coronary sinus present in most domestic animals (Nickel et al. 1981), was not observed in rabbits (Bahar et al. 2007; Yoldas & Nur 2012) and it does not exist in our study materials. The existence of *sinus coronarius* has been also reported in guinea-pigs (Popesko et al. 1990), porcupines (Atalar et al. 2004), rats (Halpern 1953) and mice (Ciszek et al. 2007). The great cardiac vein is the greatest vein of the rabbit heart. We found the same as the findings of Barone et al. (1973) and Yoldas & Nur (2012), that this vein is emptied into the VCCS. In a donkey, the VCM and the MCV form a common trunk which opens into the coronary sinus (Yadm 1993).

Great variability was observed in the region of *sulcus interventricularis paraconalis* and the left ventricle. Yoldas & Nur (2012) recorded, that VIP begins near the apex cordis. In porcupines, the VIP showed an intramyocardial course until the middle of the *sulcus interventricularis paraconalis*, and a subepicardial course after this point (Atalar et al. 2004). But in contrast to these reports, in our study the VIP started in the middle third

of this *sulcus*, which was the same pattern described in Angora rabbits (Bahar et al. 2007). It was reported, that the origin point of the VIP was in the middle of the *sulcus interventricularis paraconalis* in cats (Nickel et al. 1981) and beavers (Bissaillon 1981). Along its course we found collateral veins between the VIP and VMVS (17% of cases) or VMVD (13% of cases). In the angle, where the VIP became the left circumflex vein, there was observed one vein in 20% of cases, which could be the equivalent of the angular vein presented in the cat (Nickel et al. 1981), donkey (Yadm 1993), Tuj Sheep (Aksoy et al. 2009) and New Zealand White rabbit (Yoldas & Nur 2012). This vein was not mentioned in the Angora rabbit (Bahar et al. 2007). Besuluk & Tipirdamaz (2001) introduced that the VIP received the branches from the right and left ventricle and from the interventricular septum of Akkaman sheeps and Angora goats.

The VPVS, one to three in number, was seen in 81% Angora rabbits (Bahar et al. 2007) and 76% in New Zealand White rabbits (Yoldas & Nur 2012). In contrast to previous reports, the VPVS in our study was observed only in 16% as a single vein, but not found in others, in which the related region was drained by branches of the VMVS.

The VMVS often originated as 2 large veins in the distal third of the heart and in the middle third of the heart they formed a common root. The two veins are present in dogs (Maric et al. 1996). The VMVS terminated into the VCM in 87% of cases, in the VCCS in 10% of cases, as in others animals (Mc. Kibben & Christensen 1964; Nickel et al. 1981; Bahar et al. 2007), or in 3% of cases into the VIP. In porcupines, VMVS originated near the *apex cordis* and emptied into the *v. cava caudalis* by coursing subepicardially along the caudal side of the *ventriculus sinister* (Atalar et al. 2004). One uncommon vein was observed between the second VDVS and MCV. This vein arose in distal third of the heart and entered into the VCCS. We could not identify this vein because there was no such finding in the literature.

The MCV started from the *apex cordis* and drained into the VCCS. In 13% of cases it emptied into the right circumflex vein. Yoldas & Nur (2012) pointed that this vein opens into the base of the VCCS as in our study, although in 3% it opened in the *v. cava caudalis*. In marsupials, the MCV opens to the vessel which courses around the left atrium and then enters the right atrium below the orifice of the VCCS (Dowd 1974). In birds, the MCV is a prominent venous channel, which independently enters the right atrium (Lindsay 1967). Yoldas & Nur (2012) stated that the MCV and the right circumflex vein formed a common root in 32% of cases. On the contrary, it was not found in our study.

In this study, the VMVD, the VPVD and the VDVS formed a common root in 7% of cases. It was also found that in 10% of cases the VMVD, the VPVD and the VCoD merged into one trunk. According to Bahar et al. (2007) in 12.5% of cases the VMVD terminated in the medial face of the right auricle close to

the right cranial *vena cava* is joined together with the VPVD and the VCoD. In Angora rabbits the VMVD joined the right circumflex vein in 37.5% of cases or the caudolateral face of the right auricle in 50%. The VDVS in Angora rabbits ran into the right circumflex vein in 68.7% of cases and in the right auricle in 31.2% of cases. The present study showed that this vein emptied the right circumflex vein in all cases, and it is identical with the findings of Yoldas & Nur (2012). The VMVD in pigs was inconstant and was observed in 33% of the cases (Pakalska 1974). The VPVD was not found in porcupine (Atalar et al. 2004).

Generally, the venous drainage of the *conus arteriosus* is facilitated by the VCoS and VCoD in all cases. A similar situation was observed in porcupines and in the present study. In 7% of cases there was found a direct connection between the VCoS and VCoD. According to Ciszek et al. (2007), in many cases, there were observed an anastomosis between these two veins on the anterior surface of the truncus pulmonalis in mice. This is referred to as the prepulmonary conal venous arch and is similar to the arterial Vieussens anastomosis in humans (Ciszek et al. 2007).

The interventricular septum was drained by branches of the VCM and the MCV as reported in Mc. Kibben and Christensen (1964), Besuluk & Tipirdamaz (2001) and by small cardiac veins as stated in Bahar et al. (2007).

In conclusion, examination of cardiac vein in rabbit showed considerable variability manifested by differences in the presence, size and creation of anastomoses. The highest prevalence of variations in conformation and the mode of opening had been observed in the region of the VIP, the VMVS, VMVD and in the VDVS. Knowledge about the variability of major veins of the rabbit heart are important to understand the normal structure of the venous system. All informations concerning alternative drainage pathways are important in preoperative planning to identify the attention necessary for avoid destructions to the venous system of the heart and can also provide the required anatomical information for future experimental studies.

Acknowledgements

The present study was carried out within the project VEGA 1/0111/13.

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Received December 16, 2013

Accepted September 5, 2014