ORIGINAL ARTICLE

# Inner ventricular structures and valves of the heart in white rhinoceros (*Ceratotherium simum*)

Serkan Erdoğan · Martin Lima · William Pérez

**Abstract**  In this study, we describe the internal structures of both ventricles and the valvular apparatus of the heart of the white rhino. In the right of the heart, three papillary muscles were found in septal and marginal walls and m. papillaris magnus was the biggest. There was only one m. papillaris parvus in the right ventricle. The right atrioventricular valve was tricuspid, and the parietal cusp was longest. In the left of the heart, two papillary muscles were found on the septal wall and the subauricular was the biggest. The left atrioventricular valve was bicuspid and the parietal cusp was longest. There were no nodules in the valves of the pulmonary trunk and aorta, and the semilunar valves had many fibrous folds and transparent parts. Within the cardiac skeleton there was a cartilago cordis which occupied a small part of the right fibrous trigone. While the right ventricle included only one septomarginal trabecula, there were many trabeculae in the left ventricle. In both ventricles, the endocardium was thin and the subendocardial network was visible, also their continuation with the septomarginal trabeculae. We also found many trabeculae carneae in the dorsal part of the ventricles.

**Keywords**  Heart · Rhinocerotidae · Ventricle · Wild animal

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## Introduction

Previous studies on cardiac anatomy were conducted mostly in domestic animals and humans (Truex and Warshaw 1942; Depreux et al. 1976; Miller and Holmes 1984; Ozbag et al. 2003; Deniz et al. 2004; Pérez et al. 2008a, b). Anatomical characteristics of the rhino heart were described by Bhattacharya et al. (1987) in *Rhinoceros unicornis*, by Matoussi (1998) in *Diceros bicornis*, and by Cave (1981) in *Dicerorhinus sumatrensis*, but these studies focussed mostly on some aspects of the heart. The present study was conducted in view of the limited number of literature reports available on the ventricular anatomy and valvular system in wild animals, as well as these studies having been conducted mostly on some aspects of heart anatomy. Another concern was the lack of descriptive and comprehensive information on the internal features of heart and characteristics of valvular system in the rhinoceros.

The two African species of rhinoceros are the black (*Diceros bicornis*) and white rhinoceros (*Ceratotherium simum*). According to IUCN (Emslie 2012) there were an estimated 20 170 white rhino in the wild and an estimated 750 in captivity worldwide. The majority (98.8 %) of white rhino occur in just four countries (South Africa, Namibia, Zimbabwe, Kenya). This species is considered as Near Threatened by the IUCN due to the continued and increased poaching threat and increasing illegal demand for horn (Emslie 2012).

We used the opportunity of dissecting a white rhino heart to describe the internal structures of both ventricles and the valve apparatus, with the aim of increasing the existing anatomical knowledge in this species.

## Materials and methods

The heart of a white rhino (*Ceratotherium simum*) obtained from necropsy at a local zoo was dissected after fixation in a solution of 10 % formaldehyde. The animal bodyweight could not be obtained. We removed the atrial mass and both ventricles were opened by sections parallel to the coronary and interventricular grooves. The chordae tendineae of each papillary muscle were counted in origin and the destination of cusps was determined. The length and width of papillary muscles and lengths of cusps and semilunar valves were measured with digital calipers and pictures were taken with a digital camera (Nikon D7000; Nikon Corporation, Tokyo, Japan). The terms were used according to the Nomina Anatomica Veterinaria (2012).

## Results

The right ventricle was triangular in form and extended from the right atrium to near the apex of the heart. The three right ventricular papillary muscles originated in ventricular wall and were attached to septal, parietal and angular cusps of the tricuspid valve via chordae tendineae (Fig. 1a–c). The papillary muscles found on the septal wall were the m. papillaris subarteriosus and the m. papillaris parvus, while the papillary muscle found on the right marginal wall was the m. papillaris magnus. The three papillary muscles of the right ventricle had a highly variable size. The biggest papillary muscle was m. papillaris magnus (Fig. 1a) and its length and width were measured as 56.66 and 39.04 mm. The lengths and widths of the m. papillaris subarteriosus and m. papillaris parvus were 19.50 and 24.15 mm, and 28.63 and 22.62 mm, respectively.

The right atrioventricular orifice was the large oval aperture of communication between the right atrium and ventricle and was surrounded by a fibrous ring, covered by the lining membrane of the heart. The right atrioventricular orifice was guarded by a tricuspid valve and this valve was composed of septal, parietal and angular cusps (Fig. 1a, c). The parietal cusp was the longest cusp, and the length of the free border was 220.38 mm. The free borders of the angular and septal cusps were measured as 68.85 and 67.95 mm in length, respectively.

Six chordae tendineae originated from the m. papillaris magnus and the first three chordae tendineae were directed to the parietal cusp of right atrioventricular valve, while the other three chordae tendineae directed to the angular cusp of the right atrioventricular valve (Fig. 1a, b). The first and the last chordae originating from m. papillaris magnus were located very close to each other on the medial side of the papillary muscle and distal to the other chordae tendineae (Fig. 1a).

Similar to the chordae tendineae of m. papillaris magnus, six chordae tendineae originated from the m. papillaris subarteriosus; the first two were directed exclusively to the angular cusp, the next chordae were terminated in both



Fig. 1 Right ventricle. **a** *MPM* m. papillaris magnus, *CP* cuspis parietalis of the right atrioventricular valve, *CA* cuspis angularis of the right atrioventricular valve. **b** *MPM* m. papillaris magnus, *RAV* right atrioventricular valve, *TC* trabeculae carneae, **c** *PPM* m. papillaris parvus, *CP* cuspis parietalis of the right atrioventricular valve, *CS* cuspis septalis of the right atrioventricular valve
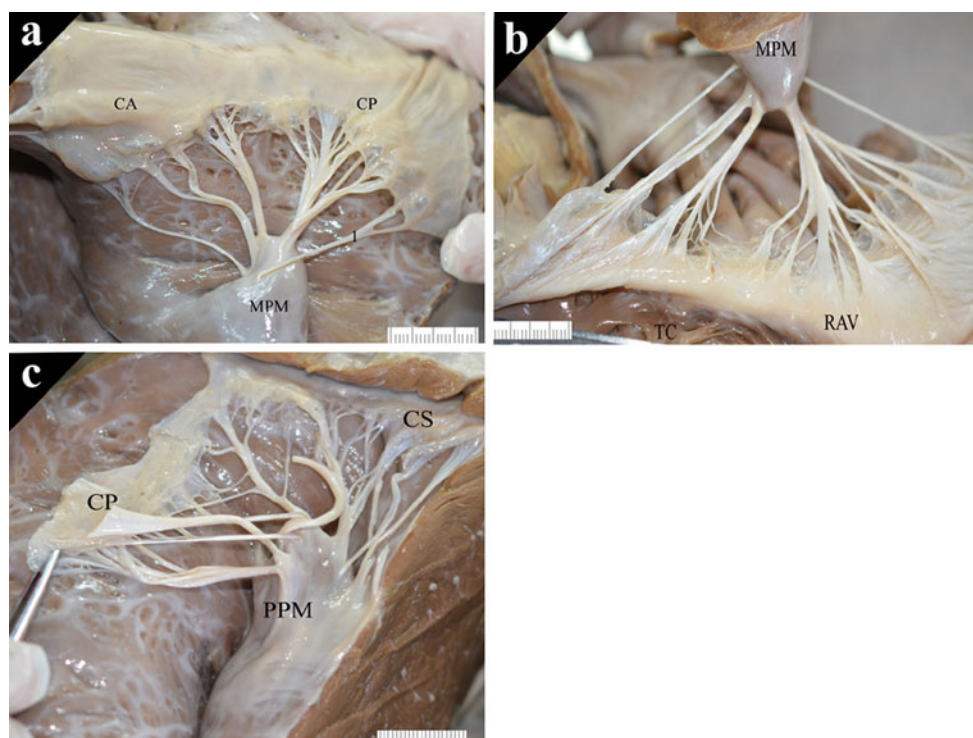
angular and septal cusps by different small branches. The rest of the cords were directed to the septal cusp of right atrioventricular valve.

Nine chordae tendineae originated from the m. papillaris parvus; the first four attached to the septal cusp and other chords reached to the parietal cusp (Fig. 1c). Five chordae tendineae were directly originated from the septal wall of the right ventricle and were also directed to the septal cusp. In the right ventricle there was a small trabecula septomarginalis.

Within the left heart two papillary muscles were found (Fig. 2a, b). The papillary muscle found on the septal wall, the m. papillaris subauricularis, was the biggest and its length and width were 74.91 and 48.06 mm. The other papillary muscle was the m. papillaris subatrialis and was located in the left marginal wall. Its length and width were closer one to another and were 69.42 and 64.14 mm.

The left ventricle was longer and more conical in shape than the right, and on transverse section, its concavity presented an oval or nearly circular outline. The left atrioventricular orifice was placed below and to the left of the aortic orifice. It was surrounded by a dense fibrous ring and guarded by the atrioventricular valve. The left atrioventricular valve was bicuspid and consisted of septal and parietal cusps (Fig. 2a). The cusps were of unequal size and were longer than those of the right atrioventricular valve. The parietal cusp was longer than the septal cusp; and the length of the free border of the parietal and septal cusps were measured as 206.31 and 114.61 mm in length, respectively.

Eight chordae tendineae originated from the subauricular papillary muscle and the first two chordae tendineae

reached to the septal cusp, while the rest of the chordae tendineae attached to the parietal cusp of the left atrioventricular valve (Fig. 2a). Six chordae tendineae originated from the m. papillaris subauricularis and the first three chordae tendineae reached to the septal cusp, and the other three chordae attached to the parietal cusp of the left atrioventricular valve (Fig. 2a).

While the right ventricle included only one trabecula, there were many septomarginal trabeculae in the left ventricle; one of them was bigger than the trabecula of the right side and the others were smaller and ramified into slim branches (Fig. 2a). In both ventricles, the endocardium was thin and the subendocardial network (Purkinje fibres) was visible, together with their continuation with the septomarginal trabecula (Figs. 1c, 2a). We found many trabeculae carneae which were rounded and irregular muscular columns not only in the bottom of the ventricles but also in the dorsal parts of the ventricles (Fig. 2b).

The atrial surfaces of the cusps were directed toward the blood current from the atrium and were smooth; their ventricular surfaces, directed toward the wall of the ventricle, were rough and irregular and gave attachment to numerous strong and slim chordae tendineae. Many chordae tendineae attached to the ventricular surfaces of the cusps, while some chordae tendineae terminated in the free borders of the cusps in both ventricles (Fig. 1b).

The opening of the pulmonary artery was circular or oval in form, and situated at the summit of the conus arteriosus, close to the ventricular septum (Fig. 3a). The inner diameter of the pulmonary trunk was 84.15 mm. It was placed above and to the left of the atrioventricular orifice and was guarded by the pulmonary semilunar



**Fig. 2** Left ventricle. **a** *SAPM* m. papillaris subauricularis, *SATPM* m. papillaris subatrialis, *PC* cuspis parietalis of the left atrioventricular valve, *SC* cuspis septalis of the left atrioventricular valve. *Arrows* trabecula septomarginalis. **b** The chordae tendineae to the left atrioventricular valve were sectioned. *SAPM* m. papillaris subauricularis, *SATPM* m. papillaris subatrialis, *TC* trabeculae carneae, *LAV* left atrioventricular valve
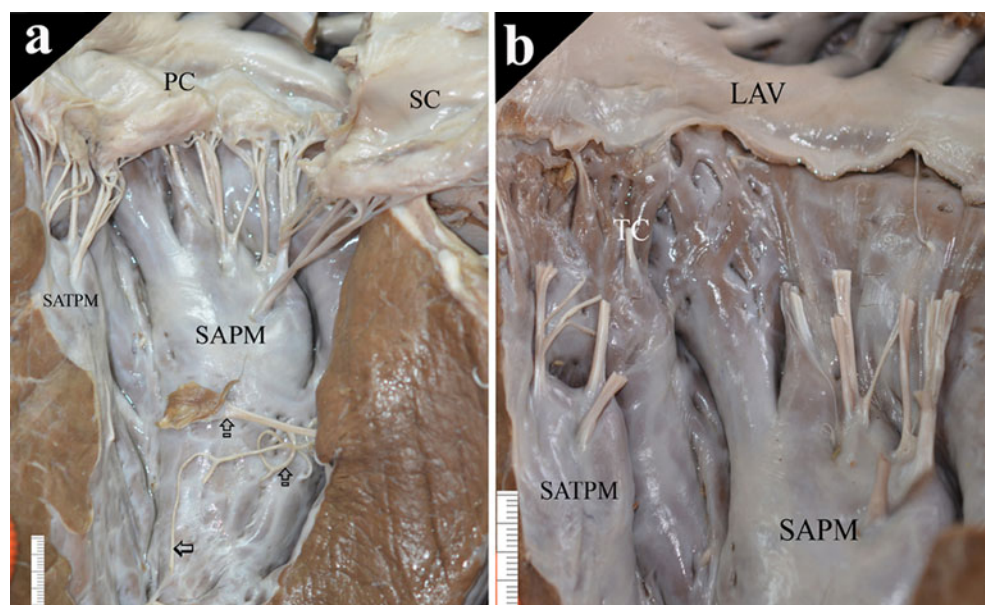
valves. The pulmonary valve had three semilunar valves, including the valvula semilunaris dextra, valvula semilunaris sinistra and the valvula semilunaris intermedia (Fig. 3a). It was determined that not all valves were of the same length. The valvula semilunaris intermedia was longer (109.81 mm) than the others and the lengths of the free borders of the valvula semilunaris sinistra and dextra were 105.81 and 90.0 mm, respectively.

The aortic opening had a circular or oval form and the inner diameter of the ascending aorta was 110.7 mm (Fig. 3a). Its orifice was guarded by the aortic semilunar valves. The aortic semilunar valves were three in number and surrounded the orifice of the aorta; two were anterior (valvula semilunaris dextra, valvula semilunaris sinistra) and one posterior (valvula semilunaris septalis; Fig. 3a). The valvula semilunaris dextra was longer than the others (104.32 mm) and the lengths of the free borders of the valvula semilunaris sinistra and septalis were 82.47 and 99.42 mm, respectively.

There were no nodules in the valves of the pulmonary trunk and aorta, but the semilunar valves had many fibrous folds and transparent parts (Fig. 3a). Within the cardiac skeleton there was a cartilago cordis which occupied a small part of the right fibrous trigone. There was no cartilage in the left fibrous trigone.

The left coronary artery emitted into the left sinus of the aorta and was divided into three branches: the paraconal interventricular branch, the circumflex branch and the diagonal branch (Fig. 3b). The paraconal interventricular branch gave off 10 branches to the right ventricle cranially; and the third one was a branch of the infundibulum. The first two directed to the branches of the pulmonary trunk. Caudal to the left ventricle, the paraconal interventricular branch emitted seven branches (Fig. 3b).

The circumflex branch gradually reduced in calibre and terminated near to the subsinusal interventricular sulcus. This artery emitted 10 arteries, distributed mostly into the left ventricle and the left ventricular border. The third branch of the left coronary artery or diagonal branch was also distributed exclusively to the left ventricle (Fig. 3b).

The right coronary artery originated from the right sinus of the aorta and had the same calibre as the left homologous one. It was continued as the subsinusal interventricular branch. The latter branch issued six small arteries to each ventricle and gradually terminated before reaching the apex. The interventricular septum was supplied by several branches that mostly originated from the interventricular, subsinusal and paraconal branches. Nowhere in the heart did we see anastomoses between the branches of the coronary arteries (Fig. 3b).

The main cardiac vein that drains most of the heart was the v. cordis magna (Fig. 3b). This vein was born near to the apex and presented two segments. One of these was named the interventricular, accompanied by the paraconal interventricular artery, and the other segment went through the coronary sulcus, with one part on the atrial surface and other part on the atrial side before reaching the coronary sinus. The interventricular segment received the tributaries of both ventricles and the coronary segment of the atria and ventricles; all are satellites of arterial branches. The v. cordis media ran through the subsinusal interventricular groove and accompanied the subsinusal interventricular artery.

The coronary sinus was the opening of the right atrium where jointly opened the v. cordis magna and v. cordis media. There was no left azygos vein in the heart of the white rhino, only a small vein which came off the left atrium and ended in the v. cordis media before the coronary



**Fig. 3** **a** Dorsal view of the pulmonary (*1, 2, 3*) and aortic (*4, 5, 6*) valves after section of the arteries and remotion of the atriums. *1* Valvula semilunaris intermedia, *2* valvula semilunaris dextra, *3* valvula semilunaris sinistra, *4* valvula semilunaris dextra, *5* valvula semilunaris sinistra, *6* valvula semilunaris septalis. **b** Auricular face of the heart. *1* Ramus interventricularis paraconalis, *2* ramus circumflexus, *3* ramus diagonalis, *4* v. cordis magna, *5* left ventricle, *6* left auricle, *7* truncus pulmonalis
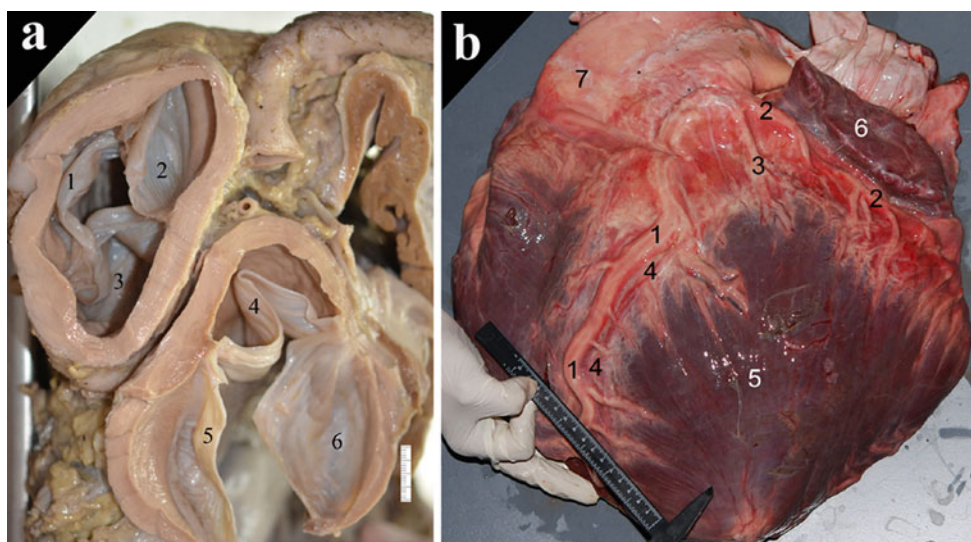
sinus was detected. The left atrial oblique vein (v. obliqua atrii sinistri) was formerly called the "Marshall vein". We found three veins (vv. cordis dextrae) that came from the right ventricle cranially. The minimal cardiac veins were opened in the four chambers of the heart.

## Discussion

There are only a few publications on the heart anatomy of different rhinoceros species and the available information is general, contains little detail and is limited to only some interests such as external anatomy and coronary arteries (Cave 1981; Bhattacharya et al. 1987; Matoussi 1998). Therefore, new and detailed studies of ventricular structures and valves anatomy in rhinoceros bear importance for the correct interpretation of the results of new research. To our knowledge, ventricular anatomy has not been studied before in the white rhinoceros (*Ceratotherium simum*).

The papillary muscles together with the chordae tendineae, trabeculae carneae and fibrous rings are important auxiliary structures of the so-called valvular apparatus of the left and right atrioventricular orifices (Ozbag et al. 2003). Similar to domestic mammals (Getty 1975; Barone 1996), we found all papillary muscles in the right ventricle, but the m. papillaris subarteriosus was the smallest papillary muscle. Similarly, m. papillaris subarteriosus was also the smallest papillary muscles in giraffe (Pérez et al. 2008a) and interestingly there were no m. papillaris parvi in the right ventricle of giraffe (Pérez et al. 2008a), as opposed to what is seen in domestic animals (Getty 1975; Barone 1996). In the white rhinoceros, the arrangement of the papillary muscles and tendinous cords distribution to the cusps was similar to the heart of *Diceros bicornis* (Matoussi 1998) and *Dicerorhinus sumatrensis* (Cave 1981), with the exception of m. papillaris parvi. While there were two papillary muscle parvi in *Diceros bicornis* (Matoussi 1998) and *Dicerorhinus sumatrensis* (Cave 1981), we described only one in our work (m. papillaris parvus). On the other hand, three papillary muscles were described in both the right and left ventricles of the Asian tapir (Rung-ruangkijkrai and Klomkleaw 2008) heart, in contrast to the result of two papillary muscles on the left side in our study and other reports of rhinoceros (Cave 1981; Matoussi 1998).

The topographic disposition of the atrioventricular and arterial orifices, as well as the constitution of the cardiac valves were similar to the descriptions done for the horse and domestic ruminants (Getty 1975; Barone 1996; Nomina Anatomica Veterinaria 2012). The disposition of the fibrous trigone and the cardiac cartilage was grossly the same as that described for horses (Barone 1996), and this occupied a small part of the right fibrous trigone in the white rhinoceros.

The septomarginal trabecula of the right ventricle was similar to that of domestic ungulates, where it has been studied in detail (Truex and Warshaw 1942; Depreux et al. 1976). Matoussi (1998) found three small trabeculae in the right heart of *Diceros bicornis*. In this study, there was only one septomarginal trabecula. Similar structures, although more complex because of their branching, were found in the left ventricle of the white rhinoceros, and these structures were similar to the trabeculae of the giraffe (Pérez et al. 2008a). In *Diceros bicornis*, Matoussi (1998) mentioned two trabecula septomarginalis in the left ventricle and there were many trabeculae in the left side in the white rhino. Similar to our study, one large trabecula septomarginalis was identified in the right ventricle and three small branching trabecula septomarginalis were found in the left ventricle of the Asian tapir heart (Rung-ruangkijkrai and Klomkleaw 2008). In the horse, the septomarginal trabeculae are variable; commonly, two large ones extend from the papillary muscles to the septum, and smaller ones may be found in various places, especially at the apex (Ghoshal 1975a).

Moderator bands have been described in the left ventricle in human and many mammals (Truex and Warshaw 1942; Ghoshal 1975a; Gerlis et al. 1984). An excessive, abnormal number of these bands is associated with cardiac decompensation in cats (Liu et al. 1982). The bands usually extend from the papillary muscles to the interventricular septum in animal hearts (Ghoshal 1975a; Deniz et al. 2004). They are composed of muscle tissue in various proportions in human and dog hearts, and of connective and conductive tissue in sheep and goat hearts (Deniz et al. 2004). According to Truex and Warshaw (1942), they contain bundles of fibres derived from the left branch of the atrioventricular bundle.

In the white rhino we found many trabeculae carneae in the dorsal parts of the ventricles; these trabeculae are absent in domestic animals and the dorsal parts of the ventricles are smooth (Barone 1996), but in other animals we described a lot of trabeculae carneae in all parts of both ventricles (Pérez et al. 2008b).

According to Miller and Holmes (1984), there was variation between horses in the distribution of chordae tendineae between the two papillary muscles and their attachments on the cusps in the equine mitral valve. In future works on rhino hearts it will be necessary to register the possible variations of these structures. Moreover, the number of the chordae tendineae is highly variable among animal species. In contrast to wild animals such as white rhinoceros and Sumatran rhinoceros (Cave 1981), many chordae tendineae were detected in the left ventricle of domestic animals. The numbers of chordae tendineae vary between 6–18, 9–20, and 11–24 in sheep, goat and dog, respectively (Ozbag et al. 2003). In the Sumatran rhinoceros (Cave 1981), the papillary muscles of the left ventricle

include seven chordae tendineae for each papillary muscle. Whereas in our study, we counted eight chordae tendineae which originated from m. papillaris subauricularis and six chordae tendineae from m. papillaris subatrialis. In the right ventricle, six chordae tendineae were attached to m. papillary magnus in our study, similar to the Sumatran rhinoceros (Cave 1981).

Matoussi (1998) reported data on the length, size and distribution of major blood vessels in a black rhinoceros. In our study, the two coronary arteries had the same calibre as in the black rhinoceros (Matoussi, 1998). Unlike the black rhinoceros, the left coronary artery was divided into three branches in our study, and the diagonal branch was not mentioned in the black rhinoceros (Matoussi 1998). While the paraconal interventricular branch issued seven branches in the present study, the same vessel gave six branches in black rhino (Matoussi 1998).

Domestic animals can be divided into two groups according to the pattern of the distribution of the left and right coronary arteries. In group A, the interventricular subsinusal artery is a branch of the left coronary artery. This pattern is referred to as left coronary pattern and it constitutes the majority of cases in domestic animals, such as ox, sheep, goat, dog and cat (Barone and Colin 1951; Christensen 1962; Hoffmann 1975; Ghoshal 1975b, d; Barone 1996). In the giraffe (Pérez et al. 2008a), the left coronary artery is predominant; and in the dolphin (*Pontoporia blainvillei*), the left coronary artery is the most important vessel (Pérez and Lima 2006).

In group B, the interventricular subsinusal artery is a branch of the right coronary artery. This pattern is referred to as right coronary pattern, which is ascribed to horse and pig (Christensen 1962; Ghoshal 1975a, c; Hoffmann 1975) and the Egyptian water buffalo (George et al. 1969). This group also includes the dromedary camel (Kanan 1971; Ghazi and Tadjalli 1993; Taha and Abel-Magied 1996) and the Bactrian camel (Yuan et al. 2009). In *Arctocephalus australis,* the ramus interventricularis subsinosus proceeds in the majority of animals from the right coronary artery (Pérez et al. 2008b).

Since both coronary arteries are equal in size and similar in distribution in our study and black rhinoceros (Matoussi 1998), these animals are considered in group B, with subsinusal interventricular branch originated in the right coronary artery. This pattern is also presented in the horse (Ghoshal 1975a; Hoffmann 1975; Barone 1996) and seems to be characteristic of the *Perissodactyla* order.

The distribution of cardiac veins was similar to that described in domestic mammals (Getty 1975; Barone 1996). In the coronary sinus, the v. cordis magna and v. cordis media finished together in rhino, but both veins opened separately into the right atrium in giraffe (Pérez et al. 2008a) and horse (Barone 1996).

In the developing vertebrate embryo, the heart is the first functional organ (Christoffels et al. 2000; Miquerol and Kelly 2013). Organogenesis of the vertebrate heart includes a complex sequence of events initiating with the specification and differentiation of some cellular structures, followed by the formation of the early heart tube (Miquerol and Kelly 2013). In a complex morphogenetic progression, heart tubes transform into contracting atrial and ventricular chambers (Christoffels et al. 2000). Especially cardiac neural crest play an important role in dividing the arterial part of the heart into the aorta and pulmonary trunk in this process. The coronary vessels develop with cardiac septation simultaneously and supply oxygenated blood to the ventricular system (Miquerol and Kelly 2013). Heart development includes many stages, such as the formation and elongation of heart tube, rightward looping, formation of cardiac chambers and valves, and this morphogenesis was described as common in all vertebrates (Miquerol and Kelly 2013).

Many molecular and functional studies have been fulfilled on heart development in mammals (Christoffels et al. 2000; Miquerol and Kelly 2013). Some of these studies aimed to contribute to human medicine and some of them focused on the developmental problems of some structures of the heart (Icardo et al. 2002; Combs and Yutzey 2009). Furthermore, animal models have been developed for the understanding of developmental mechanisms of the heart and heart-related structures. According to Christoffels et al. (2000), no model which clearly describes these progressive processes has been articulated. Moreover, Combs and Yutzey (2009) reported that significant advances have been made in recent years in the definition of regulatory pathways that control normal and abnormal cardiac valve development. Sedmera (2007) also stated that it was not clear which mechanisms directed the fates of chamber myocytes to differentiate into the ventricular cardiac conduction system. Moreover, Sedmera (2007) reported that the formation and nature of connections between Purkinje fibres was unresolved. For that reason, we think that such explanatory and novel morphological information about heart can be useful for a better understanding for functional peculiarities of the heart in the first step and can pave the way for developmental and future advanced works in wild mammals.

In conclusion, the anatomy of the heart and its inner components in the white rhinoceros, other rhino species and horse, which are members of the same order (*Perissodactyla*), showed little differences; and overall their cardiac morphological features were immensely similar. The present study is considered to contribute to the determination of the macroanatomic and certain morphometric features of the ventricular structures. Furthermore, we also think that a precise information and collection of data

about wild animals will further influence our understanding of the different anatomy and functional peculiarities of inner ventricular structures and valves. The present study is also considered to aid in the evaluation of congenital malformations and macroscopic pathologies so that it presents the normal anatomical structure of the heart.

**Conflict of interest**    The authors report no conflict of interest.

## References

Barone R (1996) Anatomie comparée des mammifères domestiques, tome 5: Angiologie. Vigot, France

Barone R, Colin A (1951) Les arteries du coeur chez les ruminants domestiques. Rev Med Vet 102:172–181

Bhattacharya M, Baishya G, Chakraborty A, Baruah GK (1987) Gross anatomy of the heart of the Indian one horned rhinoceros (*Rhinoceros unicornis*). J Zoo Anim Med 18:105–108

Cave AJE (1981) On the cardiac anatomy of the Sumatran rhinoceros. J Zool 193:541–556

Christensen GC (1962) The blood supply to the interventricular septum of the heart—a comparative study. Am J Vet Res 23:869–874

Christoffels VM, Habets PEMH, Franco D, Campione M, de Jong F, Lamers WH, Bao Z, Palmer S, Biben C, Harvey RP, Moorman AFM (2000) Chamber formation and morphogenesis in the developing mammalian heart. Dev Biol 223:266–278

Combs MD, Yutzey KE (2009) Heart valve development: regulatory networks in development and disease. Circ Res 105:408–421

Deniz M, Kilinç M, Hatipoglu ES (2004) Morphological study of the left ventricular bands. Surg Radiol Anat 26:230–234

Depreux R, Mestdagh H, Houcke M (1976) Comparative morphology of the trabecula septomarginalis in terrestrial mammals. Anat Anz 139:24–35

Emslie R (2012) *Ceratotherium simum*. In: IUCN 2012. IUCN Red List of threatened species. Version 2012.2. http://www.iucnredlist.org (Downloaded 17 April 2013)

George AN, Berge R, Moustafa MS, El-Gaffary M (1969) The coronary vessels in the Egyptian water buffalo (*Bod Bubalus hubalis* L.). Zbl Vet Med 16:894–905

Gerlis LM, Wright HM, Wilson N, Erzengin F, Dickinson DF (1984) Left ventricular bands. A normal anatomical feature. Br Heart J 52:641–647

Getty R (1975) Sisson and Grossman's anatomy of the domestic animals, vols 1, 2, 5th edn. W B. Saunders Company. Philadelphia

Ghazi SR, Tadjalli M (1993) Coronary arterial anatomy of the one-humped camel (*Camelus dromedarius*). Vet Res Commun 17:163–170

Ghoshal NG (1975a) Equine heart and arteries. In: Getty R (ed) Sisson and Grossman's anatomy of the domestic animals, vol 1, 5th edn. W. B. Saunders Company. Philadelphia

Ghoshal NG (1975b) Ruminant heart and arteries. In: Getty R (ed) Sisson and Grossman's anatomy of the domestic animals, vol 1, 5th edn. W. B. Saunders Company, Philadelphia, pp 960–1023

Ghoshal NG (1975c) Porcine heart and arteries. In: Getty R (ed) Sisson and Grossman's anatomy of the domestic animals, vol 2, 5th edn. W. B. Saunders Company, Philadelphia, pp 1306–1342

Ghoshal NG (1975d) Carnivore heart and arteries. In: Getty R (ed) Sisson and Grossman's anatomy of the domestic animals, vol 2, 5th edn. W. B. Saunders Company, Philadelphia, pp 1598–1651

Hoffmann V (1975) Blood-vessel supply of the equine heart, also a comparative study of the topography of coronary vessels in domestic mammals (carnivores, swine and ruminants). Anat Anz 137(1–2):79–109

Icardo JM, Rincón JMG, Ros MÁ (2002) Congenital heart disease, heterotaxia and laterality. Rev Esp Cardiol 55(9):962–974

Kanan CV (1971) Observations on the pattern and distribution of the coronary blood vessels of the camel (*Camelus dromedarius*). Acta Morphol Neerl Scand 8(4):321–332

Liu SK, Fox PR, Tilley LP (1982) Excessive moderator bands in the left ventricle of 21 cats. JAVMA 180:1215–1219

Matoussi A (1998) Le coeur du rhinoceros bicorne d'Afrique (*Diceros bicornis*): elements d'anatomie. Rev Med Vet 149:407–416

Miller PJ, Holmes JR (1984) Observations on structure and function of the equine mitral valve. Equine Vet J 16:457–460

Miquerol L, Kelly RG (2013) Organogenesis of the vertebrate heart. WIREs Dev Biol 2:17–29

Nomina Anatomica Veterinaria (2012) International Committee on Veterinary Gross Anatomical Nomenclature (I.C.V.G.A.N.). Revised 5th edn. http://www.wava-amav.org/Downloads/nav_2012.pdf

Ozbag D, Kervancioglu P, Saruhan B, Tasdemir S, Yilmaz F (2003) The comparative investigation of the morphologic relationship of true chordae tendineae with false chordae tendineae of the left ventricle in different species. Turk J Vet Anim Sci 27:133–140

Pérez W, Lima M (2006) Cardiac anatomy of the *Pontoporia blainvillei*. Int J Morphol 24(3):351–356

Pérez W, Lima M, Pedrana G, Cirillo F (2008a) Heart anatomy of *Giraffa camelopardalis rothschildi*: a case report. Vet Med Czech 53:165–168

Pérez W, Katz H, Lima M (2008b) Gross heart anatomy of *Arctocephalus australis* (Zimmerman, 1783). Anat Sci Int 83:6–10

Rung-ruangkijkrai T, Klomkleaw W (2008) Macroscopic study of an Asian tapir heart. In: Proceedings, the 15th Congress of FAVA, Bangkok

Sedmera D (2007) Development of cardiac conduction system in mammals with a focus on the anatomical, functional and medical/genetical aspects. J Appl Biomed 5:115–123

Taha AA, Abel-Magied EM (1996) The coronary arteries of the dromedary camel (*Camelus dromedarius*). Anat Histol Embryol 25(4):295–299

Truex RC, Warshaw LJ (1942) The incidence and size of the moderator band in man and mammals. Anat Rec 82:361–372

Yuan G, Ma J, Ye W, Bai Z, Wang J (2009) Macroanatomy of coronary arteries in Bactrian camel (*Camelus bactrianus*). Vet Res Commun 33(4):367–377