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IDENTIFICATION OF A NASOCONCHAL PARANASAL SINUS IN THE WHITE RHINOCEROS (*CERATOTHERIUM SIMUM*)

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Abstract: African rhinoceros are poached for their horns using indiscriminate and aggressive methods. Rhinoceros that survive these attacks often have severe facial trauma, and treatment is limited by a lack of understanding and published information of the normal anatomy. This study was performed to investigate and describe the anatomy of the most commonly injured area of the head of the white rhinoceros (*Ceratotherium simum*). Two white rhinoceros cadaver heads were imaged by computed tomography and grossly dissected. A combined dorsal conchal sinus and nasal sinus (named the nasoconchal sinus) was identified and confirmed to be readily exposed by horn removal. The nasoconchal sinus communicates via a relatively large opening with the middle nasal meatus of the nasal cavity. Awareness of the combined sinus space and its single communicating pathway will assist with accurate assessment and treatment of trauma to the dorsal facial region of the white rhinoceros.

Key words: Anatomy, *Ceratotherium simum*, nasal sinus, nasoconchal, white rhinoceros.

BRIEF COMMUNICATION

Since 2008, African rhinoceros have suffered alarming population loss from escalating rates of poaching for their horns.[3] In South Africa alone, more than 5,000 animals have been killed in the last 5 yr.[3,5] Currently, white rhinoceros (*Ceratotherium simum*) and black rhinoceros (*Diceros bicornis*) are listed as "near threatened" and "critically endangered," respectively.[7] White rhinoceros exist in greater numbers and are more frequently targeted by illegal hunting. The rare rhinoceros that survives poaching incidents sustains varying degrees of facial trauma, with frequent and sometimes severe disruption to the dorsal and lateral margins of the face, involving soft tissue, bone, and upper respiratory tract structures. Large defects in the regional paranasal sinuses and nasal cavity are common findings.

There is a concerted effort to provide veterinary care and rehabilitation to rhinoceros found alive after poaching attacks. Medical and surgical management of facial trauma is currently being attempted without a fundamental understanding of the affected anatomy. Scant information is available regarding the anatomy of the rhinoceros head and, in particular, the upper respiratory tract.[1,2] There is a need to describe and understand this anatomy to facilitate optimal treatment of injured rhinoceros. The aim of this study was to investigate the paranasal sinus anatomy of the white rhinoceros and specifically to focus on the commonly traumatized dorsorostral region of the head under both horns.

Two white rhinoceros cadaver heads (from 6-yr-old and 3.5-yr-old female subadults) were disarticulated at the atlanto-occipital joints and stored at –20°C before thawing for dissection. The nasal (rostral) and frontal (caudal) horns from the older individual (rhino A) had been previously removed at the dermal junction without disrupting the underlying facial bones. The horns of the younger rhinoceros (rhino B) had been removed by saw 10 cm above the base. Each head was imaged via computed tomography prior to dissection. A bandsaw was used to section the heads in transverse, dorsal, and midline planes to visualize anatomy from different perspectives. For each section, the surfaces were mapped to determine related paranasal sinus and nasal cavity spaces with particular attention to the dorsal nasal cavity and associated paranasal sinuses. The nasal horn stump was further removed by saw in rhino B, exposing the underlying cavity and simulating injury associated with relatively conservative horn poaching.

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Polypropylene catheters and a flexible video endoscope were used to investigate cavities and communications within and between paranasal sinuses and the nasal cavity. Sinus communications and the extent of cavities were demonstrated by selective injection of new methylene blue (NMB) and observing over the subsequent 10 min for evidence of flow of the colored solution between spaces.

The nasal septum; dorsal and ventral nasal concha; and dorsal, middle, ventral, and common nasal meatuses were identified in the computed tomography images and the cadaver specimens (Fig. 1). The dorsal nasal concha was smooth-walled along its entire medial surface and enclosed a single cavernous, dorsal conchal sinus (Figs. 1–3). The nasal bone had a large space between the internal and external cortices, particularly as a rostral bulbous expansion, under the nasal (rostral) horn attachment (Figs. 2, 3). The space was consistent with a paranasal sinus (the *sinus nasalis* or nasal sinus). Caudolaterally, a large elongate opening, occupying approximately half the length and width of the floor of the sinus, marked the transition from bone sinus to conchal sinus (Fig. 2). The nasal sinus appeared to be directly continuous with the dorsal conchal sinus, thus forming an extensive combined space, the *sinus nasoconchalis* or nasoconchal sinus (NCS) (Figs. 2, 3). A midline septum (*septum sinuum nasalium* or nasal sinus septum) separated left and right nasal sinuses (Fig. 2D) and osseous plates (*lamellae intrasinuales*) projected into the nasal sinus primarily from the rostral, lateral, and septal

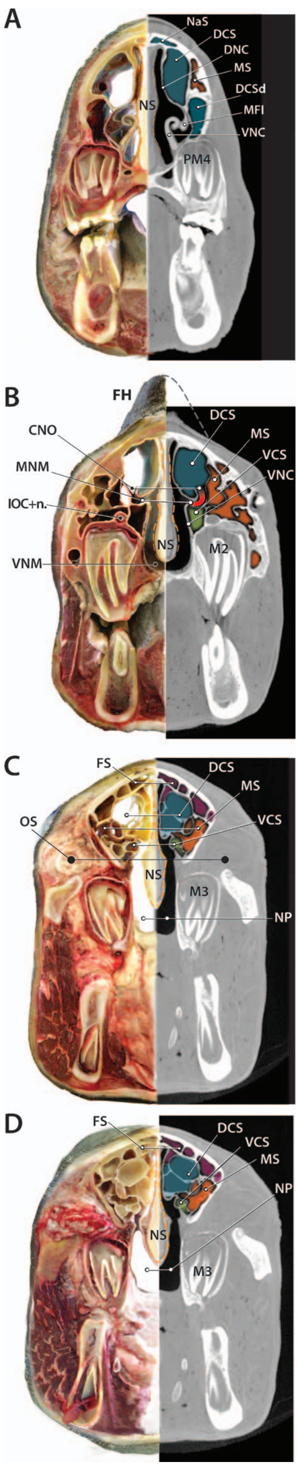

Figure 1. A–D. Sequential, rostral to caudal, matched transverse computed tomography, and photographic illustrations of rostral head anatomy of rhino B. The first cut (A) was made between the nasal and frontal horns. **A.** A ventrolateral diverticulum (DCSd) extending from the main space of the dorsal conchal sinus was identified in this cadaver. The location of the mucosal flap (MFl) is noted, lateral to which an endoscope is passed to reach the opening (CNO) into the dorsal conchal sinus. **B.** The CNO is visualized and its communication (shaded red) with the middle nasal meatus of the nasal cavity is apparent. **C, D.** The increasing complexity of the caudal extent of the DCS and surrounding paranasal sinuses is evident. CNO, conchonasal opening; DCS, dorsal conchal sinus (shaded blue); DCSd, diverticulum of dorsal conchal sinus (shaded blue); DNC, dorsal nasal concha; FH, frontal horn; FS, frontal sinus (shaded purple); IOC+n., infraorbital canal and nerve; MS, maxillary sinus (shaded orange); MNM, middle nasal meatus; MFl, mucosal flap; M2, permanent molar 2; M3, permanent molar 3; NS, nasal septum; NaS, nasal sinus (shaded blue); NP, nasopharynx; OS, ocular structures; PM4, permanent premolar 4; VCS, ventral conchal sinus (shaded green); VNC, ventral nasal concha; VNM, ventral nasal meatus.

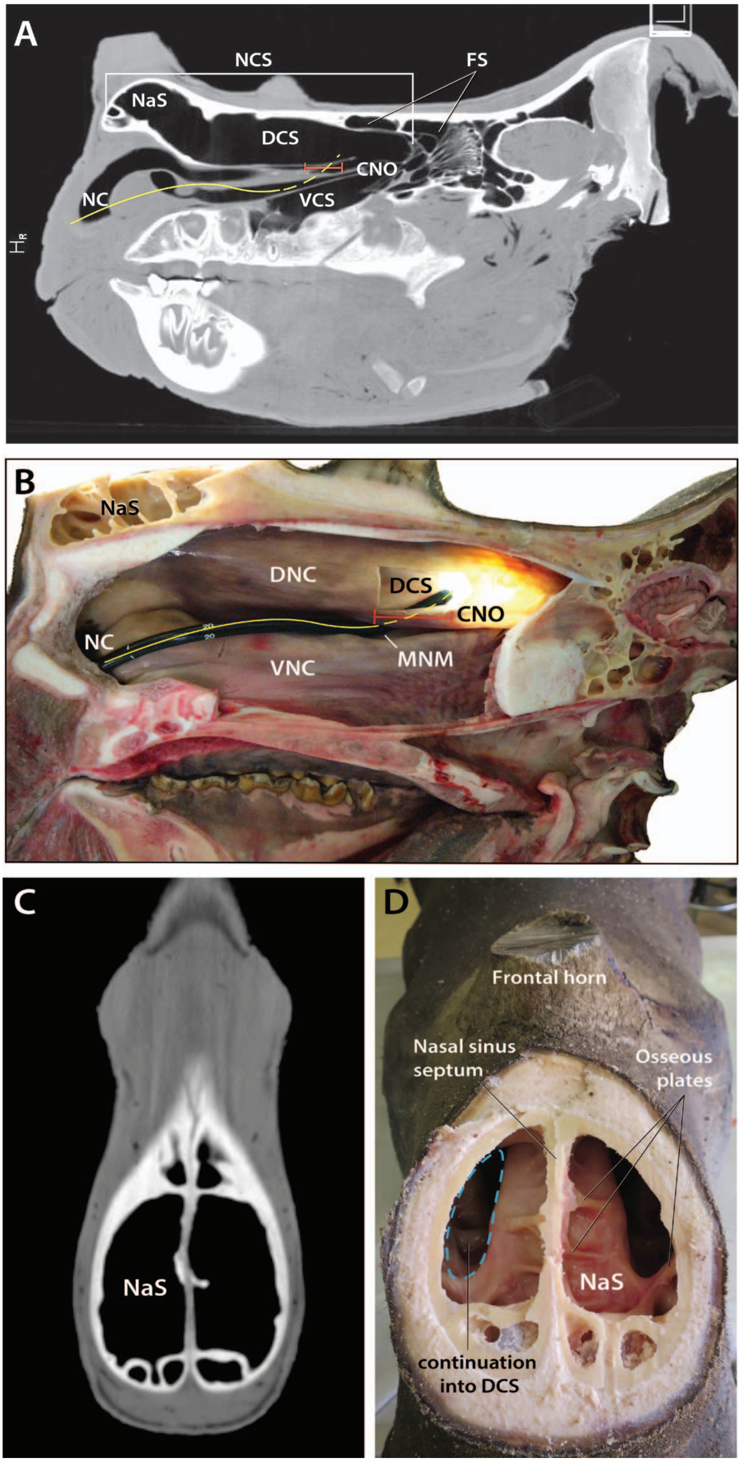

Figure 2. **A.** Right sagittal computed tomography image of rhino B showing the combined space of the nasal sinus (NaS) and dorsal conchal sinus (DCS) to form the nasoconchal sinus (NCS). The undulating line represents the path of a flexible endoscope through the nasal cavity (NC) and into the DCS via the conchonasal opening (CNO, defined by the bar). FS, frontal sinus; VCS, ventral conchal sinus. **B.** Photograph of the right nasal cavity of rhino B, medial to lateral view, the nasal septum has mostly been removed. The flexible endoscope path is shown

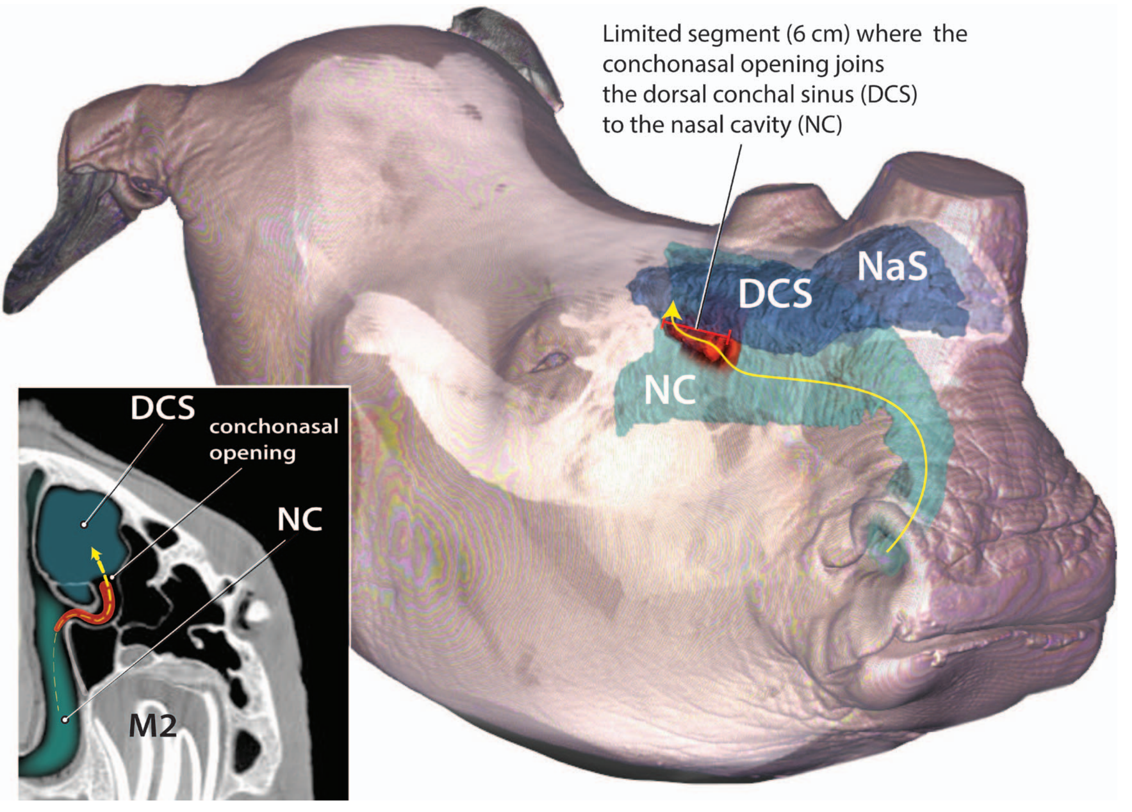

Figure 3. Three-dimentional illustration produced of rhino B showing the location of the nasoconchal sinus (combined nasal sinus, NaS, and dorsal conchal sinus, DCS, shaded blue) in relation to the nasal and frontal horns. The nasal cavity (NC) is shaded green and the red shaded area and red bar identify the location of the conchonasal opening. The yellow line marks the path of a flexible endoscope passed via the NC into the DCS. The inset of a transverse computed tomography image of Rhino B highlights the conchonasal opening between the DCS and the middle nasal meatus of the nasal cavity.

walls (Fig. 2D). The internal conchal sinus walls from rhino B (younger) were generally smooth while rhino A (older) had more irregular walls due to bone plate projections and numerous 3- to 5-mm conical bone projections, clustered dorsolaterally. A few thin septa and folds of variable height formed elongate troughs, mostly at the ventral aspect of the conchal sinus. Incomplete conchal cellulae and deep diverticula were located in the caudal 5–8 cm of the conchal sinus. Considerable variation in the internal wall architecture between left and right sides and between cadavers was noted. The caudal end of the dorsal conchal sinus was selectively flooded with NMB, with the rostrum elevated, and it was confirmed there was no drainage from the caudal conchal area.

A ventrolateral opening was identified at approximately the middle third of the dorsal conchal sinus (Figs. 1–3). The opening was 12–15 mm wide, rounded caudally, and narrowed to a point 6 cm rostrally, providing significant communication between the dorsal conchal sinus (and therefore the nasal sinus) and the middle nasal meatus of the nasal cavity. A 9-mm-diameter video endoscope could be freely passed through the opening,

←
in the NC, passing along the middle nasal meatus (MNM) and lateral to the mucosal flap to enter the DCS via the CNO (length defined by the bar). DNC, dorsal nasal concha; VNC, ventral nasal concha. **C, D.** Dorsal computed tomography view (**C**) of the nasal sinus matching the photograph (**D**) of rhino **B**. The nasal horn has been removed in **D** to reveal the underlying nasal sinus. Note the nasal sinus septum and osseous plates projecting from the septum and lateral and rostral walls. The large communication between the NaS and the DCS is identified by the dashed line in **D**.

via the ipsilateral nostril (Fig. 2A, B). The nasal cavity entrance to the opening was located dorsolateral to the ventral nasal concha, 32–35 cm caudal to the nares (as measured by the path of the endoscope) and was obscured from direct view by a vertical, 2- to 3-cm fold of mucosa continuous dorsally with the ventral margin of the dorsal conchal mucosa (Fig. 1A). Directing the endoscope along the lateral wall of the middle nasal meatus and lateral to this fold of mucosa, while angling dorsally, allowed visualization of the opening and successful entry into the overlying sinus (Fig. 2B). The sinus opening was bordered by a medial thin bony ridge, 6–7 cm long, with mild asymmetry and variation in this border between specimens. The nasal opening of the dorsal conchal sinus (*apertura conchonasalis,* the conchonasal opening) was the sole communication between the combined NCS and the nasal cavity. The approximate midpoint of the conchonasal opening was demarcated from the exterior by the medial canthus of the eye.

In the two cadavers, the NCS dimensions were 35–40 cm rostrocaudally, 7–10 cm dorsoventrally, and 5–8 cm mediolaterally, with caudal tapering of the sinus. The nasal sinus walls varied from 5 to 10 mm thick. The nasal bone continued caudally as the frontal bone. The internal cortex of the frontal bone formed the dorsal and part of the lateral walls of the caudal half of the dorsal conchal sinus (Figs. 1, 2). The walls were up to 1 cm thick and were thinner where rostral portions of the frontal sinus overlapped the underlying dorsal conchal sinus. Internal walls of the maxillary sinus formed portions of the lateral wall of the dorsal conchal sinus (Fig. 1). The medial and ventral walls of the dorsal conchal sinus were 1–3 mm thick with a relatively thin mucosal lining compared with that covering the rostral ventral nasal concha. Caudally, the ventral and dorsal conchal sinuses were closely related via a common wall. The nasal horn was attached to dermal structures over the bulbous expansion of the rostral nasal bone with a similar formation at the frontal horn over the rostral aspect of the frontal bone.

Rhinoceridae and equidae are in the order Perissodactyla, and domestic horse (*Equus caballus*) anatomy provides a template for the paranasal sinus anatomy of the white rhinoceros. In the horse, the scrolled rostral dorsal nasal concha encloses a conchal bulla, which is further subdivided into cellulae.[4] A conchal septum separates the rostral portion from a caudal conchal sinus that is continuous with the frontal sinus. In the white rhinoceros, the entire dorsal nasal concha encloses a relatively vast dorsal conchal sinus, and there is no apparent communication with the frontal sinus. Furthermore, the cavernous nasal bone sinus and its dorsal conchal sinus continuation in the white rhinoceros contrasts with the long, flat, nasal bone of the horse. The combined paranasal sinus compartment has been named the nasoconchal sinus, and its communication with the nasal cavity the conchonasal opening, although these terms and nasal sinus are currently not listed in Nomina Anatomica Veterinaria.[6] A similarly named nasoconchal sinus has been described in a late Miocene American badger (*Chamitataxus avitus*).[9] The greater one-horned rhinoceros (*Rhinoceros unicornis*) skull has a central nasal bone protuberance, but internal skull features were not described.[2] The nasal cavity anatomy of the *R. unicornis* calf showed the standard structures, but direct extrapolation to the structures in other species was not possible.[1]

The specific function of the NCS in the white rhinoceros is unknown. Paranasal sinuses have been ascribed various roles, such as weight reduction of the skull, absorption of trauma, protection of underlying structures, aiding facial growth, increasing surface area for olfaction, as evolutionary vestigial remnants, and improving immune defense in the respiratory system by generating nitric oxide.[8] The nasoconchal sinus of the primitive American badger may have provided structural support to the skull or enhanced olfaction.[9] The design of the nasal bone and its associated sinus in the white rhinoceros may have developed to provide maximal biomechanical support for the horn and forces transmitted to the skull through the horn. The presence of the large communication between the combined NCS and the nasal cavity likely serves as an outflow pathway but may also provide a strategically placed inflow pathway for inspired air to be circulated through the sinus, possibly to enhance olfactory function.

The single opening between the NCS and the nasal cavity may have clinical significance as sinus fluid accumulation has to drain through this ostium. During the present study, a blood clot readily obstructed the opening, suggesting clinical efforts to open this communication may improve sinus drainage. One author (JM) observed sinusitis in 18 poached rhinoceros, resulting in mucopurulent exudate accumulation in the NCS. It is suggested that the visual assessment and treatment of the sinuses are possible via rhinoscopy and direction of the flexible endoscope through the opening of the dorsal conchal sinus.

An extensive NCS and its communication with the nasal cavity is described in the white rhinoceros. Facial trauma following poaching of nasal and frontal horns will expose the nasal and dorsal conchal sinuses. Frontal horn removal may expose the frontal sinus, and deeper, lateral wounds will expose the maxillary sinus. The entire nasal bone and its sinus may be lost with indiscriminate removal of both horns, along with portions of the frontal bone and maxilla, resulting in paranasal sinus disruption, nasal cavity exposure and partial loss of the nasal septum.

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