

# The existence of the vomeronasal organ in postnatal chimpanzees and evidence for its homology with that of humans

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## ABSTRACT

It is currently thought that New World monkeys, prosimians, and humans are the only primates to possess vomeronasal organs (VNOs) as adults. Recent studies of the human VNO suggest that previous investigations on Old World primates may have missed the VNO. We examined nasal septa from the chimpanzee (*Pan troglodytes*) grossly and histologically for comparison with nasal septa from humans, Old World monkeys (*Macaca fascicularis*, *M. nemistrina*) and prosimian primates (*Microcebus murinus*, *Otolemur garnettii*). Grossly, chimpanzees had depressions on the nasal septum similar to fossae reported anterior to the VNO openings in humans. Histologically, chimpanzees and humans had bilateral epithelial tubes which were above the superior margin of the paraseptal cartilages (vomeronasal cartilage homologue). The epithelial tubes had a homogeneous ciliated epithelium. These structures were thus positionally and structurally identical to the human VNO and unlike the well-developed prosimian VNOs which were surrounded by vomeronasal cartilage. Macaques had no structures which resembled the VNO of either the prosimians or humans. The results demonstrate that the VNO is present postnatally in the chimpanzee and is almost identical to the human VNO in its anatomical position and histological structure. This in turn suggests that the reported absence of the VNO in at least some adult Old World primates is artifactual, and that further study may provide evidence for its existence in other species.

*Key words*: Jacobson's organ; paraseptal cartilage; vomeronasal cartilage.

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## INTRODUCTION

Recent studies suggest a nearly universal presence of the vomeronasal organ (VNO) in humans (e.g. Moran et al. 1991; Smith et al. 1998), although the structure is located in a more superior position compared with other mammals (Smith et al. 1998; Smith & Bhatnagar, 2000). The homology, potential function (e.g. as a pheromone receptor), and even existence of the human VNO have been the focus of renewed debate within the last 15 y (Johnson et al. 1985; Monti-Bloch et al. 1998; Smith et al. 1998; Preti & Wysocki, 1999). In part, this uncertain status is due to a lack of

evidence that the VNO exists postnatally in any other Old World primate. From a phylogenetic standpoint, this is problematic: why would only one species (*Homo sapiens*) possess the VNO, presumably a primitive feature (Wysocki, 1979; Bhatnagar & Meisami, 1998; Preti & Wysocki, 1999; Wysocki & Preti, 2000)?

Detailed descriptions of the nasal cavity in Old World primates have failed to mention the VNO (Spurgat, 1896; Cave & Haines, 1939; and see Wysocki, 1979, for a review). Attempts to locate the VNO in prenatal, perinatal, and/or postnatal macaques (Zingesser, 1984), gibbons (Loo, 1973; Maier,

1997), and gorillas (Maier, 1997) have failed, although some early prenatal 'vestiges' have been identified in macaques (Frets, 1914; Zingesser, 1984) and chimpanzees (Starck, 1960). Nonetheless, the finding that all adult humans possess a VNO has arisen based on more rigorous efforts using endoscopy (Moran et al. 1991) or serial sectioning techniques (Smith et al. 1998, 1999). Furthermore, Smith & Bhatnagar (2000) provided evidence that there are embryonic similarities between human and nonhuman primate VNOs, and that positional and histological differences arise during fetal development. It is therefore possible that some previous attempts to locate the VNO in postnatal Old World primates may have missed the organs due to their small size, nonchemosensory epithelium, and unique anatomical location.

To address this dilemma, we examined nasal septa from the chimpanzee, *Pan troglodytes*. This ape was selected since a previous report noted VNO-like structures in a chimpanzee fetus (Starck, 1960), although this was subsequently questioned (Maier, 1997). This material was compared with previously sectioned nasal septa from Old World primates and prosimians. These species were included for a comparison with the known extremes of VNO variation seen in adult primates (Bhatnagar & Meisami, 1998). Prosimian primates exhibit well-developed VNOs, with a relatively thick, medial chemosensory epithelium, and a thinner, ciliated, lateral nonsensory epithelium (Hunter et al. 1984; Evans & Schilling, 1995). In prosimian primates and many other mammals, vomeronasal cartilages form a tubular shell around the VNO (Hunter et al. 1984; Evans & Schilling, 1995). Humans possess VNOs which have a homogeneous (i.e. no medial versus lateral differentiation), ciliated epithelium (Smith et al. 1998, 1999; Smith & Bhatnagar, 2000). In humans, a distinction is also seen in the spatial separation of the VNO and paraseptal cartilages (Smith et al. 1998), the homologue of the vomeronasal cartilages. In contrast, no studies have reported presence of VNOs in any species of *Macaca*. We hypothesised that if postnatal chimpanzees possess VNOs, they would resemble those seen in humans, rather than the more distantly related prosimian species.

#### MATERIALS AND METHODS

We examined nasal septa from 3 chimpanzees (*Pan troglodytes*, 2 juveniles; 1 adult). This material was compared with nasal septal tissues from 20 humans (19 adults, 1 2-y-old), 2 pig-tailed macaques (*Macaca nemistrina*, 1 neonate, 1 juvenile), 2 adult long-tailed

macaques (*Macaca fascicularis*), 1 adult Garnett's galago (*Otolemur garnettii*), and 3 adult mouse lemurs (*Microcebus murinus*). Most tissues were obtained from archival collections of formalin-preserved specimens in the Department of Anthropology, University of Pittsburgh (2 chimpanzees, 2 long-tailed macaques), from human cadaver laboratories, or from captive animals which died of natural causes at the Cleveland MetroParks Zoo (1 chimpanzee) and Duke University Primate Center (3 mouse lemurs). The heads of the galago and pig-tailed macaques were obtained from research laboratories where the animals were killed after use in other studies that were unrelated to our investigation. Adult/subadult status was known based on recorded age or based on radiographic examination of teeth with comparison with published eruption sequences (Mooney et al. 1991).

The nasal septum from each chimpanzee was removed using instrumentation. Each was examined with the unaided eye during dissection, and then under the dissecting microscope. Grossly, the nasal septum of each chimpanzee was examined for the presence of the nasopalatine duct, which in prosimian primates and New World monkeys, has a direct communication to the VNO (Hunter et al. 1984; Evans & Schilling, 1995). Each chimpanzee septum was also examined for the presence of putative VNO openings on the nasal septum itself, a characteristic of humans (Johnson et al. 1985; Smith et al. 1998) but not previously described in any other primate. The location of putative VNO openings was recorded, and the septa were then prepared for serial sectioning. Septa were trimmed and the location of any putative VNO opening was measured relative to the anterior border of the block. Tissues were decalcified using a formic acid/sodium citrate solution and then processed for paraffin embedding. Each septum was sectioned coronally at 10–14 µm and alternately stained with the Gomori trichrome procedure and haematoxylin-eosin. Humans, macaques, mouse lemurs, and the galago had been previously sectioned at 10–25 µm and stained using the same protocols. The sectional series were examined for the presence of the VNO using a Leica photomicroscope.

#### RESULTS

Grossly, the nasal septum of each chimpanzee had vestiges of the paired nasopalatine ducts. These openings were found in an anteroinferior recess of the nasal fossa on each side, and were partially patent, just proximal to the nasal cavity. Each chimpanzee

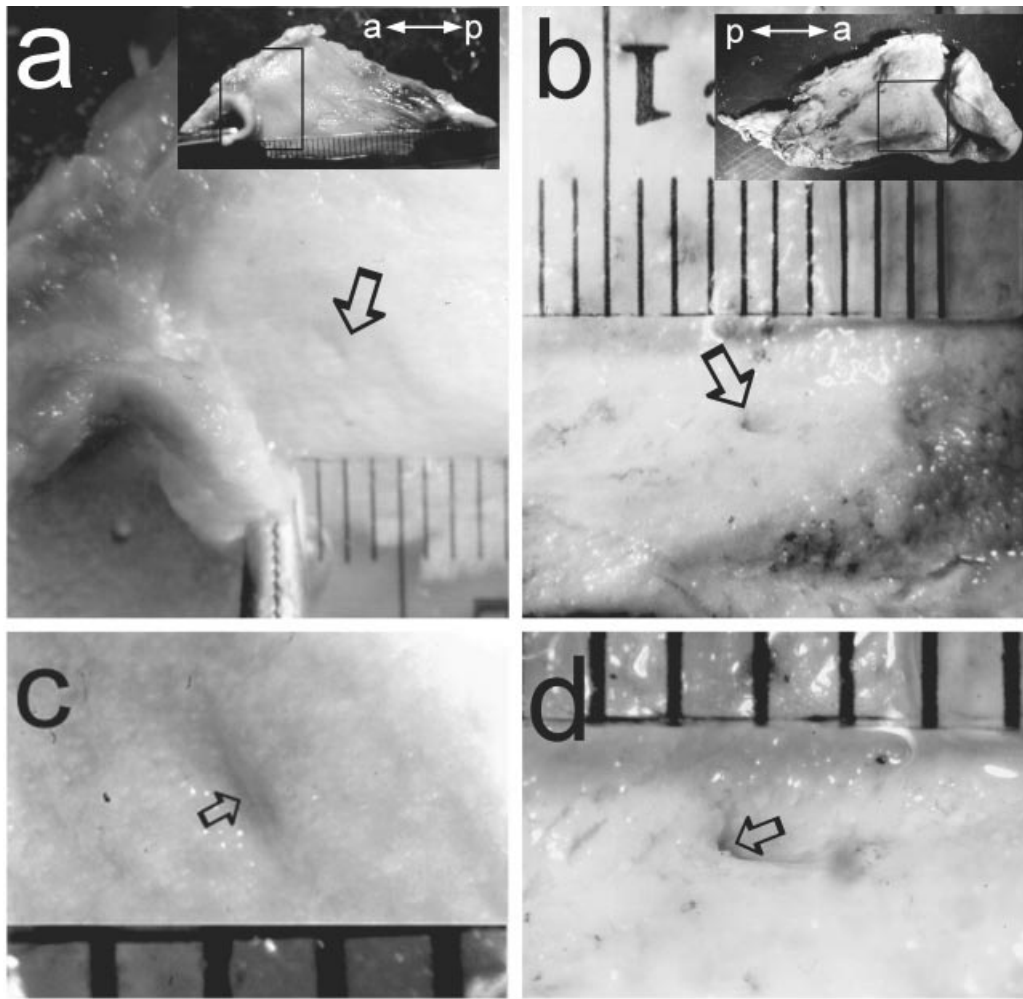


Fig. 1. Chimpanzees exhibited grossly visible evidence for the existence of the VNO, which matched previous descriptions in humans. (a) Left side of the nasal septum in a juvenile chimpanzee (septal region is indicated by inset; anteroposterior axis indicated). This specimen shows a grossly visible depression (note the shadow indicated by the open arrow) on the anteroinferior surface of the septum. (c) When examined under magnification, this depression corresponds to a small slit-like opening in the mucosa (open arrow). (b) Right side of the nasal septum in a 76-y-old male human (septal region is indicated by inset). A small depression is seen on the anteroinferior surface of the septum (open arrow). (d) Under a microscope, this depression corresponds to a small crescent-shaped fossa, with the opening to the VNO at the posterior aspect (open arrow).

also exhibited evidence of VNO openings on the nasal septum itself. On one or both sides of the nasal septum of all chimpanzees (except on the right side of 1 septum that had mucosal destruction), small depressions were visible macroscopically on the anteroinferior surface,  $\sim 5\text{--}9$  mm from the floor of the nasal cavity. Under magnification, these depressions corresponded to minute pits (Fig. 1).

Histologically, the proximal portion of the nasopalatine duct did not communicate with any VNO-like structures in chimpanzees. However, the chimpanzees did possess bilateral epithelial tubes which were found posterior to the level of the nasopalatine ducts and were located from 2 (juvenile) to 5.2 mm (adult) superior to the superior margin of the paraseptal cartilages (Fig. 2a, b). These tubes resembled the VNOs found in the juvenile and adult

humans in anatomical position and histological structure (Fig. 2c, d). At their anteriormost extent, the epithelial tubes communicated with the nasal cavities through openings in the anteroinferior nasal septal epithelium. In position, these openings corresponded to the pits seen during gross examination. Posteriorly, the tubes were found parallel to the palate and to the paraseptal cartilages until they ended as epithelial culs-de-sac. The anteroposterior length of the right and left VNOs ranged from 2350 to 3540  $\mu\text{m}$  in the two juvenile chimpanzees and from 5320 to 6580  $\mu\text{m}$  in the adult.

The epithelial tubes differed from the VNOs observed in the prosimian species (Fig. 2e, f), which had well-delineated differences between sensory and nonsensory epithelia. In the chimpanzee, the tubes were pseudostratified columnar epithelium and had

cilia clearly visible on all apical surfaces (Fig. 2*b*), characteristics that were also seen in the human VNO (Fig. 2*d*). In contrast, macaques had numerous gland ducts in the septal mucosa, but these were nonciliated (Fig. 3*a*) and exhibited no communication with the nasopalatine duct nor any predictable relationship to the paraseptal cartilages. Thus, macaques had no epithelial structures that resembled the VNO of either humans (Fig. 3*c*) or prosimian primates.

#### DISCUSSION

The apparent absence of the VNO in adult Old World primates has yielded a phylogenetic dilemma, leading some authors to question the homology of the human VNO (Gegenbaur 1886; Maier, 1997; Preti & Wysocki, 1999). To date, the best evidence for the homology of the human VNO to that of other primates (and of mammals in general) is ontogenetic in nature, based on a common embryonic origin from a thickening (vomeronasal primordium) on the medial aspect of each olfactory pit (Smith & Bhatnagar, 2000). These authors have suggested that the salient histological and positional differences between the human VNO and that of prosimians and New World primates are manifested during fetal development. Here we show that postnatal chimpanzees possess bilateral, ciliated epithelial tubes in the anteroinferior portion of the nasal septum. Based on the anatomical position and histological characteristics, we conclude that the septal epithelial tubes observed in the postnatal chimpanzee are homologous to the VNOs described in humans.

It is noteworthy that the VNO-like structures observed in a 71 mm CRL fetal chimpanzee by Starck (1960) were positionally similar to our findings in postnatal chimpanzees and to previous reports on fetal (Smith et al. 1997) and adult humans (Smith et al. 1998). This suggests that the VNO may follow a similar course of development in *Homo sapiens* and *Pan troglodytes*, which remains to be verified by an examination of a complete prenatal chimpanzee sample.

The available data suggest that humans and their closest extant relative, the chimpanzee (Goodman et al. 1994), are similar in possessing a relatively superiorly positioned VNO, which lacks the clear sensory epithelium seen in prosimians and New World primates. Such findings may not be surprising in light of studies indicating that *Homo sapiens* and *Pan troglodytes* share approximately 99% of their DNA (Ki et al. 1999). If the first ancestral primates possessed a VNO (as do all extant prosimians), then retention of

the VNO may be a plesiomorphic trait in the chimpanzee and human (and other apes?), although the modification of this structure may represent a synapomorphy. At least some Old World monkeys (very few taxa have been carefully studied in this regard) may exhibit a synapomorphic prenatal regression of the VNO. This emerging picture is based on currently available data, but it is clear that previous studies on Old World primates may have missed the VNO if present. As material becomes available, it is especially critical that further investigations determine whether retention of the VNO occurs in other apes. The expectation that the chimpanzee possesses VNOs similar to humans is confirmed, but the functional status as a vestige, pheromone-receptor, or other alternatively evolved function, remains to be determined.

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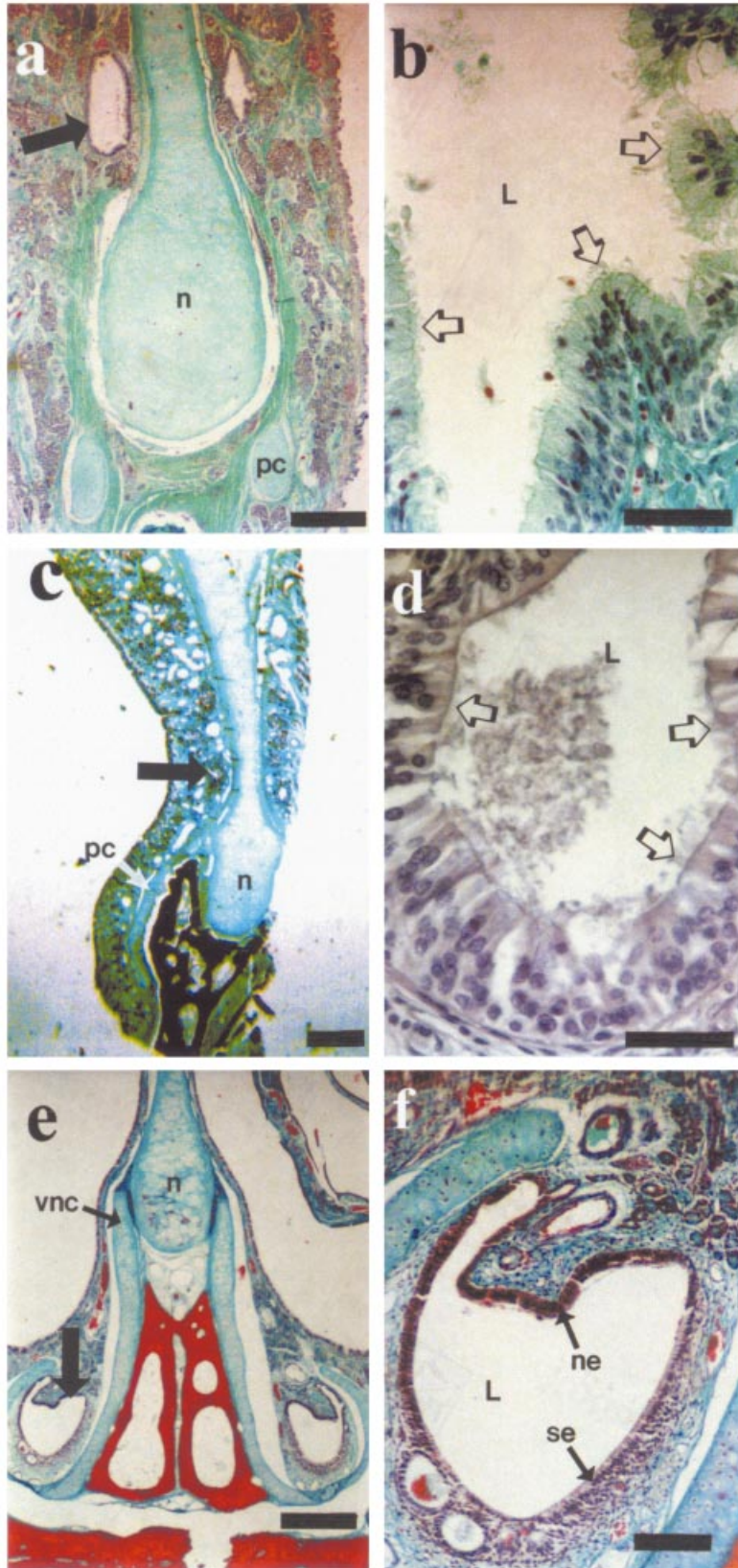


Fig. 2. Histological location and structure of the VNO in a juvenile chimpanzee (*a, b*) compared with a 2-y-old human (*c, d*) and adult galago (*e, f*). (*a*) The chimpanzee VNOs (arrow) are bilateral epithelial tubes, spatially separated from the paraseptal (vomeronasal) cartilages (pc). Bar, 500  $\mu$ m. (*b*) The VNO epithelium has a homogeneous epithelial morphology, ciliated, pseudostratified columnar; open arrows, cilia. Bar, 50  $\mu$ m. (*c*) The human VNOs (arrow) are in the identical anatomical location to that of the chimpanzee; open arrows, cilia. Bar, 800  $\mu$ m. (*d*) Human VNOs also have ciliated, pseudostratified columnar epithelium; open arrows, cilia. Bar, 50  $\mu$ m. (*e*) The VNO (arrow) of prosimian primates is well-developed, and located within a scroll of cartilage; vnc, vomeronasal cartilage. Bar, 500  $\mu$ m. (*f*) Such a VNO has clear functional characteristics including a sensory epithelium (se). Bar, 125  $\mu$ m. ne, nonsensory epithelium; L, lumen; n, nasal septum.

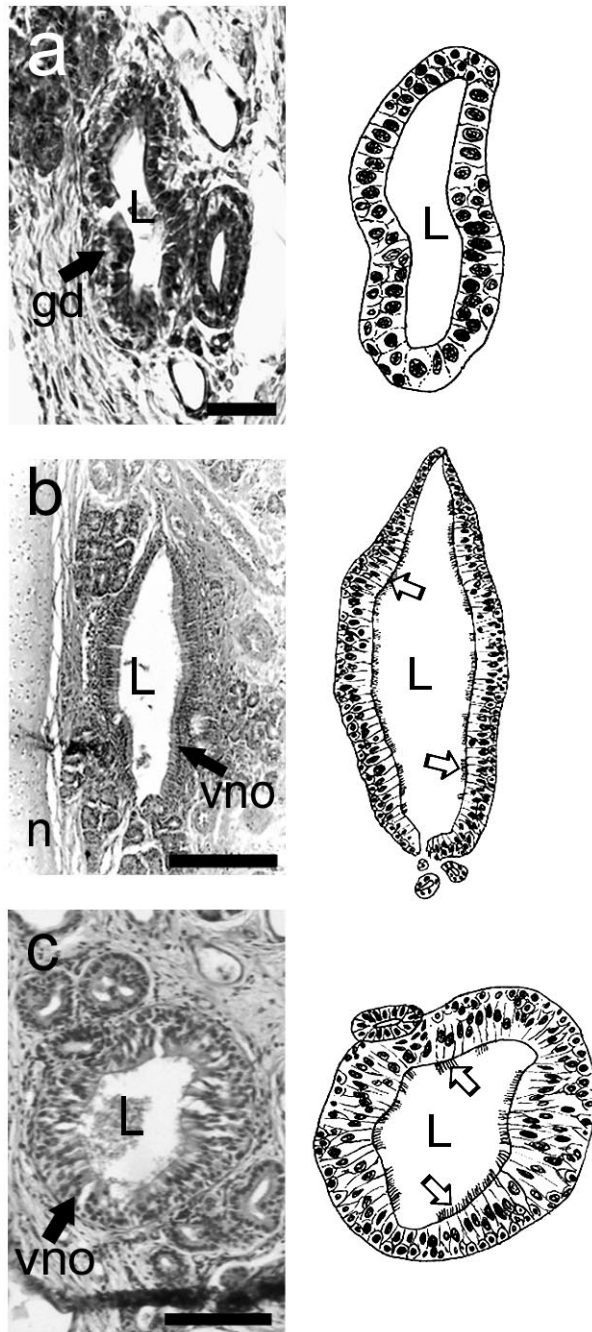


Fig. 3. Micrographs of septal tissues from the macaque (*a*, infant pig-tailed macaque), chimpanzee (*b*), and human (*c*) are shown on the left, stylised representations of each micrograph are shown on the right side. Macaques possessed numerous glandular ducts (gd, *a*), that showed some similarities to the vomeronasal organs (vno) of chimpanzees (*b*) and humans (*c*). However, the glandular ducts were nonciliated, and were usually simple or stratified cuboidal/columnar epithelium (*a*). In contrast, VNO epithelium of chimpanzees (*b*) and humans (*c*) had a ciliated, pseudostratified columnar epithelium; open arrows, cilia; L, lumen of duct or VNO. Bars: *a*, 50  $\mu$ m; *b*, 200  $\mu$ m; *c*, 200  $\mu$ m.

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