

3D models related to the publication: Pushing the boundary? Testing the ‘functional elongation hypothesis’ of the giraffe’s neck

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Abstract

This contribution contains the 3D models analyzed in Müller et al. (2021) “Pushing the boundary? Testing the ‘functional elongation hypothesis’ of the giraffe’s neck”. Evolution.

Keywords: cetartiodactyla, comparative anatomy, neck, vertebrae, vertebral column

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INTRODUCTION

The long neck of giraffes has fascinated comparative anatomists for centuries. Despite its extraordinary length, it maintains the usual count of just seven cervical vertebrae common in mammals. In the associated paper, we test the ‘functional elongation hypothesis’ of the giraffe neck which has been put forward by Lankester in 1908 and posits that the first thoracic vertebra is functionally incorporated into the giraffe neck. We tested this hypothesis using a combination of a three-dimensional (3D) geometric morphometric analysis and 3D modelling of range of motion at the cervicothoracic transition in a broad sample of Cetartiodactyla (fig. 1, table 1). As predicted by the ‘functional elongation hypothesis’, the first thoracic vertebrae of the giraffe converges in its shape with the 7th cervical of the other species. Moreover, we documented an increased range of motion at the cervicothoracic transition in giraffes. All analyzed 3D models are published here.

METHODS

Digital 3D surface models of specimens were acquired using either micro-computed tomography (μ CT) or photogrammetry (PH). One specimen was laser scanned and made available for the study (see table 1). The raw data obtained by the μ CT (YXLON FF35 CT-scanner) were further edited with Fiji plugins for Image J (version 1.51k; Schneider et al., 2012, Schindelin et al., 2012). Scans were cropped to reduce the amount of data and the contrast was increased before being saved as 16-bit binary tiff stacks (image sequences). The created tiff stacks were imported into Amira (Thermo Fisher Scientific, version 6.0.0), a software for visual data analysis (Stalling et al., 2005), and 3D bone surface models were created using the software’s segmentation editor. The number of polygons was reduced to 1.000.000 consistent for all specimens. For PH, high-resolution images were taken using a Canon EOS 1200D digital camera with 18 – 55 mm standard zoom lens. Specimens were individually fixed to a flat surface using modelling clay and photos were taken

from all around the specimen. Afterwards, the vertebra was turned upside-down and the process was repeated. The images (in total ca. 70 images per specimen) were uploaded in Agisoft Metashape (version 1.5.2), an image-based 3D modelling software creating 3D objects from still images (Reljić et al., 2019). Using the commands ‘align photos’, ‘build dense cloud’, and ‘build mesh’, surface models were generated. The two resulting models (e.g., top and bottom aspects of the vertebra) were loaded into MeshLab (version 1.3.4 beta), an open source software for processing triangular meshes (Cignioni et al., 2008) and merged using the ‘alignment’ function. Unfortunately, some of the PH models are unscaled (see table 1). The 3D surface models are provided in .ply format, and can therefore be opened with a wide range of freeware”.

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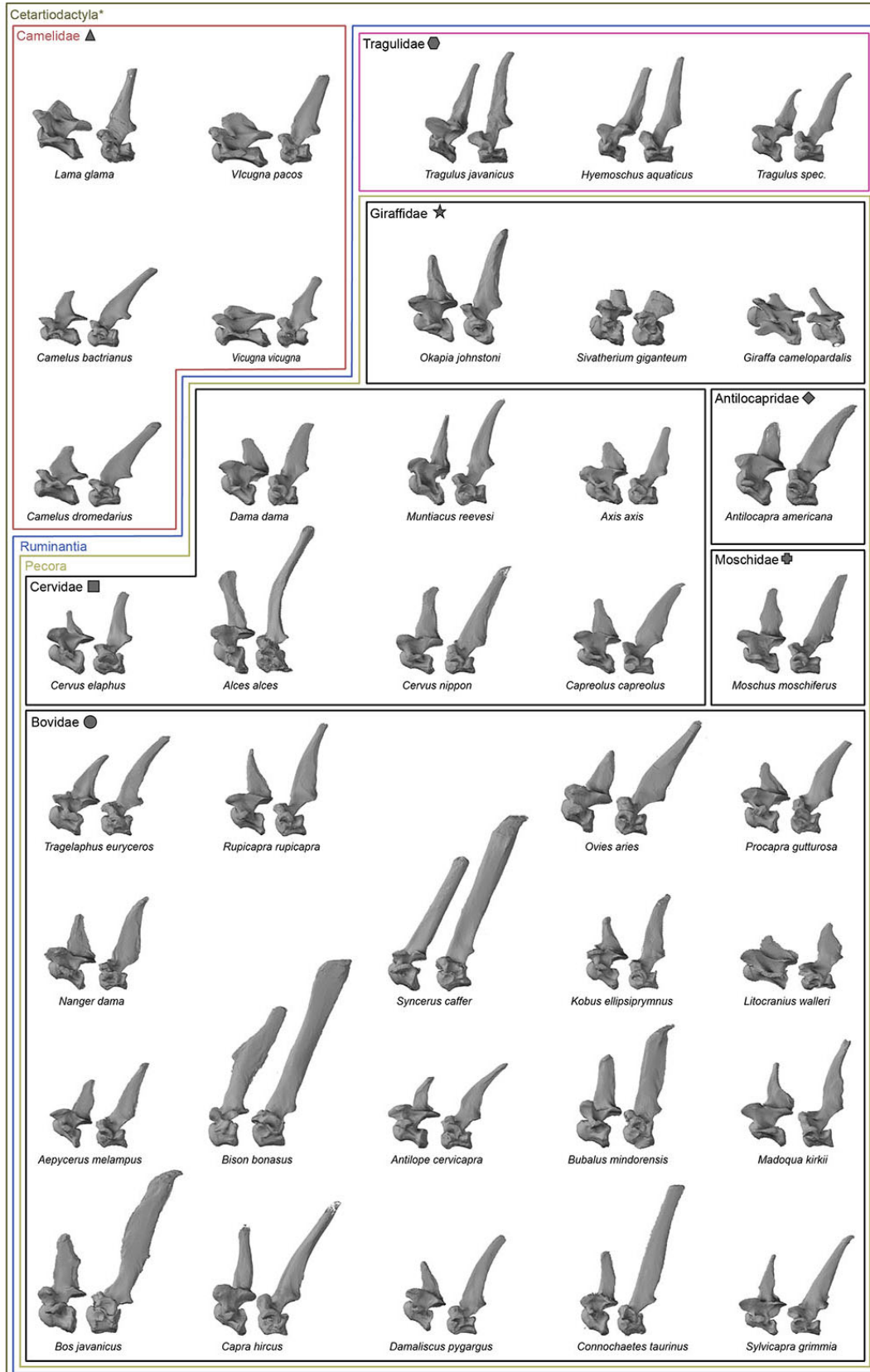


Figure 1. Overview of the C7/T1 pairs of vertebrae constituting the cervicothoracic transition in 38 cetartiodactyl species from a lateral perspective (cranial to the left). Images scaled to similar size of vertebral bodies. Note: The entire 3D dataset published here contains additional vertebrae.

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Inv nr.	Taxon	Description	Method	Sex	Origin
Giraffidae					
ZMB 66393	<i>Giraffa camelopardalis</i>	C7-T1	CT	indet.	Wild caught, Namibia
ZSM 1967/17	<i>Giraffa camelopardalis</i>	C7-T1	CT	M	indet.
ZSM 1981/19	<i>Giraffa camelopardalis</i>	C3-T2	CT	M	indet.
KMDA M-10861	<i>Giraffa camelopardalis</i>	C3-T2	LS	F	Zoo Belfast/Antwerp
SMF 84214	<i>Giraffa camelopardalis</i>	C7-T1	PH	M	Wild caught, Kenya
SMF 78299	<i>Giraffa camelopardalis</i>	C7-T1	PH*	F	Zoo Kronberg
SMF o. N.	<i>Giraffa camelopardalis</i>	C7-T1	PH*	indet.	indet.
SMNS 19138	<i>Giraffa camelopardalis</i>	C7-T1	PH*	F	Wild caught, Tanzania
ZMB 62086	<i>Okapia johnstoni</i>	C3-T2	CT	indet.	indet.
ZMB 70325	<i>Okapia johnstoni</i>	C3-T2	CT	indet.	indet.
NHMUK 15707	† <i>Sivatherium giganteum</i>	C7	PH*	indet.	Nepal
NHMUK 15297	† <i>Sivatherium giganteum</i>	T1	PH*	indet.	Nepal
Cervidae					
ZMB 47502	<i>Cervus elaphus</i>	C3-T2	CT	indet.	indet.
SMF 1450	<i>Axis axis</i>	C7-T1	CT	F	indet.
SMF 4368	<i>Cervus nippon</i>	C7-T1	CT		SMF, Frankfurt, Germany
SMF 79852	<i>Capreolus capreolus</i>	C7-T1	CT	F	Wild caught, Germany
ZFMK 67.237	<i>Capreolus capreolus</i>	C7-T1	CT	F	Wild caught, Germany
SMF 92954	<i>Muntiacus reevesi</i>	C7-T1	CT	M	indet.
SMF 92332	<i>Muntiacus reevesi</i>	C7-T1	CT	indet.	Taiwan
SMF 35549	<i>Alces alces</i>	C7-T1	CT	M	Zoo Taunus
ZFMK 86.125	<i>Dama dama</i>	C7-T1	CT	F	Wild caught, Germany
Bovidae					
ZMB 78829	<i>Antilope cervicapra</i>	C3-T2	CT	indet.	indet.
SMNS 2998	<i>Bison bonasus</i>	C7-T1	PH*	indet.	Wild caught, Poland
SMF 74435	<i>Nanger dama</i>	C7-T1	CT	M	Zoo Frankfurt
SMF 23747	<i>Litocranius walleri</i>	C7-T1	CT	F	Zoo Frankfurt
SMF 23749	<i>Litocranius walleri</i>	C7-T1	CT	F	Zoo Frankfurt
SMF 95875	<i>Tragelaphus eurycerus</i>	C7-T1	CT	F	indet.
SMF 64934	<i>Bos javanicus</i>	C7-T1	CT	M	indet.
ZFMK 1982.338	<i>Ovis aries musimon</i>	C7-T1	CT	F	indet.
ZFMK 72.367	<i>Rupicapra rupicapra</i>	C7-T1	CT	M	Wild caught, Austria
ZFMK 2001.278	<i>Aepyceros melampus</i>	C7-T1	CT	M	Wild caught, Zimbabwe
SMNS 4443	<i>Kobus ellipsiprymnus</i>	C7-T1	CT	F	Wild caught, Tanzania
SMNS 15292	<i>Sylvicapra grimmia</i>	C7-T1	CT	F	Wild caught, Ethiopia
SMNS 7347	<i>Syncerus caffer</i>	C7-T1	PH*	indet.	Ethiopia
SMNS 5796	<i>Procapra gutturosa</i>	C7-T1	CT	F	Wild caught, China
SMNS 21617	<i>Damaliscus pygargus</i>	C7-T1	CT	F	Zoo Stuttgart
SMNS 4432	<i>Madoqua kirkii</i>	C7-T1	CT	M	Wild caught, Tanzania
SMNS 2054	<i>Bubalus mindorensis</i>	C7-T1	PH*	indet.	Wild caught, Philippines
SMNS 51328	<i>Capra hircus dom.</i>	C7-T1	CT	M	Germany
SMNS 4442	<i>Connochaetes taurinus</i>	C7-T1	PH*	M	Wild caught, Tanzania
Antilocapridae					
ZSM 1964/218	<i>Antilocapra americana</i>	C3-T2	CT	M	indet.
ZMB 77281	<i>Antilocapra americana</i>	C7-T1	CT	indet.	Zoo Hannover
Moschidae					
ZMB 62080	<i>Moschus moschiferus</i>	C3-T2	CT	M	Zoo Berlin
ZMB 60367	<i>Moschus moschiferus</i>	C7-T1	CT	F	Wild caught, Russia
ZMB 51830	<i>Moschus moschiferus</i>	C7-T1	CT	indet.	Zoo Berlin
Tragulidae					
SMF 82179	<i>Tragulus javanicus</i>	C7-T1	CT	F	indet.
ZMB 86222	<i>Tragulus javanicus</i>	C7-T1	CT	M	Zoo Berlin
ZMB o. N.	<i>Tragulus</i> sp.	C7-T1	CT	indet.	MNB, Berlin

ZMB 71071	<i>Hyemoschus aquaticus</i>	C7-T1	CT	indet.	Wild caught, Cameroon
ZMB 103235	<i>Hyemoschus aquaticus</i>	C7-T1	CT	indet.	indet.
Camelidae					
SMF 94752	<i>Vicugna vicugna</i>	C7-T1	CT	F	Zoo Frankfurt
SMF 70473	<i>Camelus dromedarius</i>	C7-T1	PH*	indet.	Zoo Darmstadt
SMF 25542	<i>Camelus bactrianus</i>	C7-T1	PH*	M	Zoo Frankfurt
SMNS 31175	<i>Lama glama</i>	C7-T1	CT	indet.	Zoo Hohenheim
SMNS 46255	<i>Vicugna pacos</i>	C7-T1	CT	M	Zoo Stuttgart
SMNS 7349	<i>Vicugna pacos</i>	C7-T1	CT	M	Zoo Stuttgart

Table 1. Complete specimen list. Institutions housing abbreviated collections sampled: KMDA, Koninklijke Maatschappij voor Dierkunde, Antwerp, Belgium; NHMUK, Natural History Museum, London, United Kingdom; SMF, Naturmuseum Senckenberg, Frankfurt, Germany; SMNS, Staatliches Museum für Naturkunde, Stuttgart, Germany; ZMB, Museum für Naturkunde, Berlin, Germany; ZFMK, Zoologisches Forschungsmuseum König, Bonn, Germany; ZSM, Zoologische Staatssammlung, Munich, Germany. CT, computed tomography; LS, laser scanning; PH, photogrammetry; M, male; F, female. *: unscaled photogrammetric models.