Digital reconstruction of the skull of *Sarmientosaurus musacchioi*, a titanosaur (Sauropoda, Dinosauria) from the Upper Cretaceous of Argentina

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Abstract

The study of titanosaur paleobiology has been severely hampered by the incomplete nature of their fossil record, particularly the scarcity of well-preserved and relatively complete cranial remains. Even the most complete titanosaur skulls are often fractured, incomplete, or deformed, which has resulted in a limited knowledge of the paleobiology related to cranial anatomy, especially functional morphology. In this context, we present the digital restoration of the skull of the Argentinean titanosaur *Sarmientosaurus musacchioi*, created using the open-source 3D modeling software Blender. The digitally restored model is freely accessible to other researchers, facilitating broader research and comparative studies.

Keywords: 3D reconstruction, Blender, Sauropoda, Titanosaur skull

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INTRODUCTION

Titanosauria represents the most abundant sauropod record from the Cretaceous period worldwide, with over 50 species discovered in South America alone (Mannion and Calvo, 2011; de Jesus Faria et al., 2015). However, the titanosaurian records are predominantly limited to postcranial remains. Although numerous cranial fragments have been found globally (e.g., Díez Díaz et al., 2012; Martinelli et al., 2015; Poropat et al., 2021), only five species have preserved skulls complete enough to yield palaeobiological insights: *Nemegtosaurus mongoliensis*, *Rapetosaurus krausei*, *Tapuiasaurus macedoi*, *Sarmientosaurus musacchioi* and most recently, *Diamantisaurus matildae* (Wilson, 2005; Rogers, 2009; Zaher et al., 2011; Martínez et al., 2016, Poropat et al., 2023). Here, we present the digital restoration of *Sarmientosaurus. musacchioi* (Figures 1-6; see also Table 1), a titanosaur from the Upper Cretaceous Barro Barreal Formation in Argentina. To date, no biomechanical studies involving titanosaur skulls have been conducted, and much of their paleobiology has been inferred through comparisons with closely related taxa (e.g., Young et al., 2012; Button et al., 2014, 2016). As such, this digital restoration provides a valuable tool for future biomechanical analyses, with potential to offer new information into the feeding strategies, skull mechanics, and overall physiology of titanosaurs.

METHODS

3D acquisition

The 3D surfaces of the skull, as well as the left and right mandibles, of the holotype MDT-PV 2, as published on the original article (Martinez et al., 2016), were provided in .STL format by one of the authors, Gabriel Casal. *Institutional abbreviation:* Museo Desiderio Torres, Sarmiento, Chubut, Argentina

Preservation and reconstruction of the skull and mandible

The 3D surfaces (mesh models) of the skull and mandibles were imported to Blender 4.1.1 (available at https://www.blender.org). All the reconstructions were based on studies of phylogenetically close species to *S. mussacchioi* (Rogers and Forster, 2004; Zaher et al., 2011; de Jesus Faria et al., 2015; Wilson et al., 2016). In general, some cracks or edges were removed and the mesh surface was smoothed. A visit to the "Universidad Nacional de la Patagonia San Juan Bosco" in Comodoro Rivadavia, Chubut, Argentina by one of the authors GGB to assist the digital reconstruction. The in loco analysis of the cranial elements of *S. mussacchioi* guided several aspects of the digital restoration of the morphology of the fossil and the identification of remaining rock matrix. In the skull, the dorsomedial portion is fragmented/missing, which includes the nasal bone, medial and posterior portion of the premaxilla, and dorsomedial portion of the maxilla, which also contributes to part of the palate (Fig. 1C, D, E). This entire dorsomedial region of the skull was digitally reconstructed by sculpture of digital surface (Fig. 2A, B, C, D, E). The neurovascular foramina present in the right maxilla (Fig. 1A, C, E) were duplicated and mirrored to the missing left maxilla (Fig 2B, C e E). The medial anterior portion of the left pterygoid is fragmented and preserved on the right side (Fig. 1A, B, D), so the anterior part of right pterygoid was duplicated and mirrored to the left opposite side (Fig. 2A, B, D). The posterior medial part of the pterygoid and the basiptery-

Inv nr.	Description
M3#1594	Restored model of specimen MDT-PV 02
M3#1599	Surface model provided by Gabriel Casal of specimen MDT-PV 02 before its virtual restoration

Table 1. List of cranium and mandible models of *Sarmientosaurus mussacchioi* (MDT-PV 02). Collection : Museo Desiderio Torres

goid process are absent on the left side (Fig. 1B, D, F) and have been duplicated and mirrored from the right side to the left side (Fig. 2B, D, F). On both sides, the jugal, lacrimal and the posterior portion of the inner surface of maxilla is covered by sediment, which was identified during the visit and removed digitally. The anterior portion of the nasal is absent (Fig. 1A, B, C, E), therefore, this part was reconstructed. We sculptured an elongated, curved and slender bone that extends to the anterior portion of the skull, separating the two nasal apertures (Fig. 2A, B, C, E), this is in accordance with other close related sauropod taxa *Nemegtosaurus mongoliensis*, *Rapetosaurus krausei*, *Tapuiasaurus macedoi*, *Diamantisaurus matildae* and *Camarasaurus lentus* (Wilson, 2005; Rogers, 2009; Zaher et al., 2011; Button et al., 2016, Poropat et al., 2023). The left quadrate and quadratojugal are also missing but their counterparts are preserved on the right side (Fig. 1A, B, F) and were duplicated and mirrored to the opposite side, resulting in a real morphology on both sides (Fig. 2B, F). In the original article, there is no comment on the presence of sediment covering the supratemporal fenestra (Martinez et al., 2016). However, in the fossil specimen and the original 3D surface, the supratemporal fossae are filled with sediment (Fig. 3A) and we edited this portion and opened the fenestrae (Fig. 3B). The original 3D model does not have all individualized elements along the tooth row, and all the preserved teeth are fused into a continuous ridge (Fig. 1A, D, E; Fig. 4A, B). The teeth were digitally individualized, and the preserved anterior teeth of the skull were duplicated and mirrored to fill empty alveoli(Fig. 2A, B, E; Fig. 5A, B, C; Fig. 6). The right hemimandible is fully preserved (Fig. 4A, B, E), while the left mandible lacks the posterior portion formed by the surangular, prearticular and articular bones (Fig. 4C, D, E). Therefore, the 3D surface (mesh model) of right mandible was duplicated and mirrored to replace the left mandible (Fig. 5). The final mesh (surface) model of the skull has 510,640 faces and the edited mesh (surface) model of the mandible has 433,322 faces. Finally, the restored model was tested for mesh errors on the Blender tool "3DPrint", to remove non-manifold edges and intersecting faces. After this step, the 3D model of skull and mandibles were exported in .PLY format (Fig. 6).

DISCUSSION

The virtual restoration and reconstruction of the skull of *Sarmientosaurus musacchioi* provides valuable new insights into this titanosaur, enabling detailed anatomical comparisons with other sauropods. This work serves as a foundational model for various biomechanical tests, such as finite element analysis, geometric morphometrics, and even physical models via 3D printing. Furthermore, with this publication, *S. musacchioi* becomes the first titanosaur skull available for use, significantly enhancing a group with limited cranial data. It is also the only titanosaur skull specimen freely accessible as a high-resolution 3D model to the broader scientific community.

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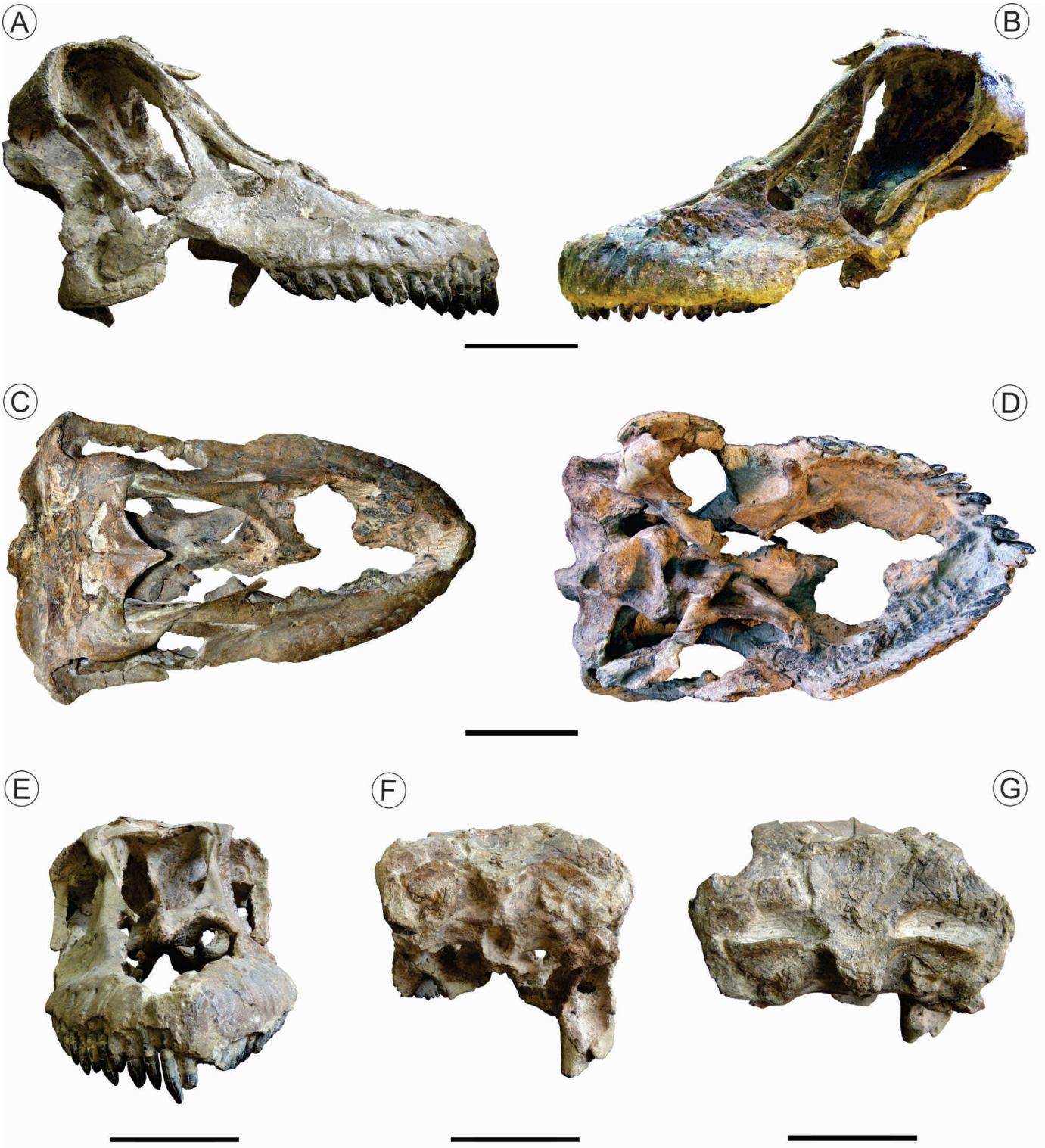

Figure 1. Original skull of *Sarmientosaurus mussacchioi* MDT-PV 2. In right lateral (a), left lateral (b), dorsal (c), ventral (d), anterior (e), posterior (f) and supratemporal fossa in focus (g) views. Scale bar = 10 cm.

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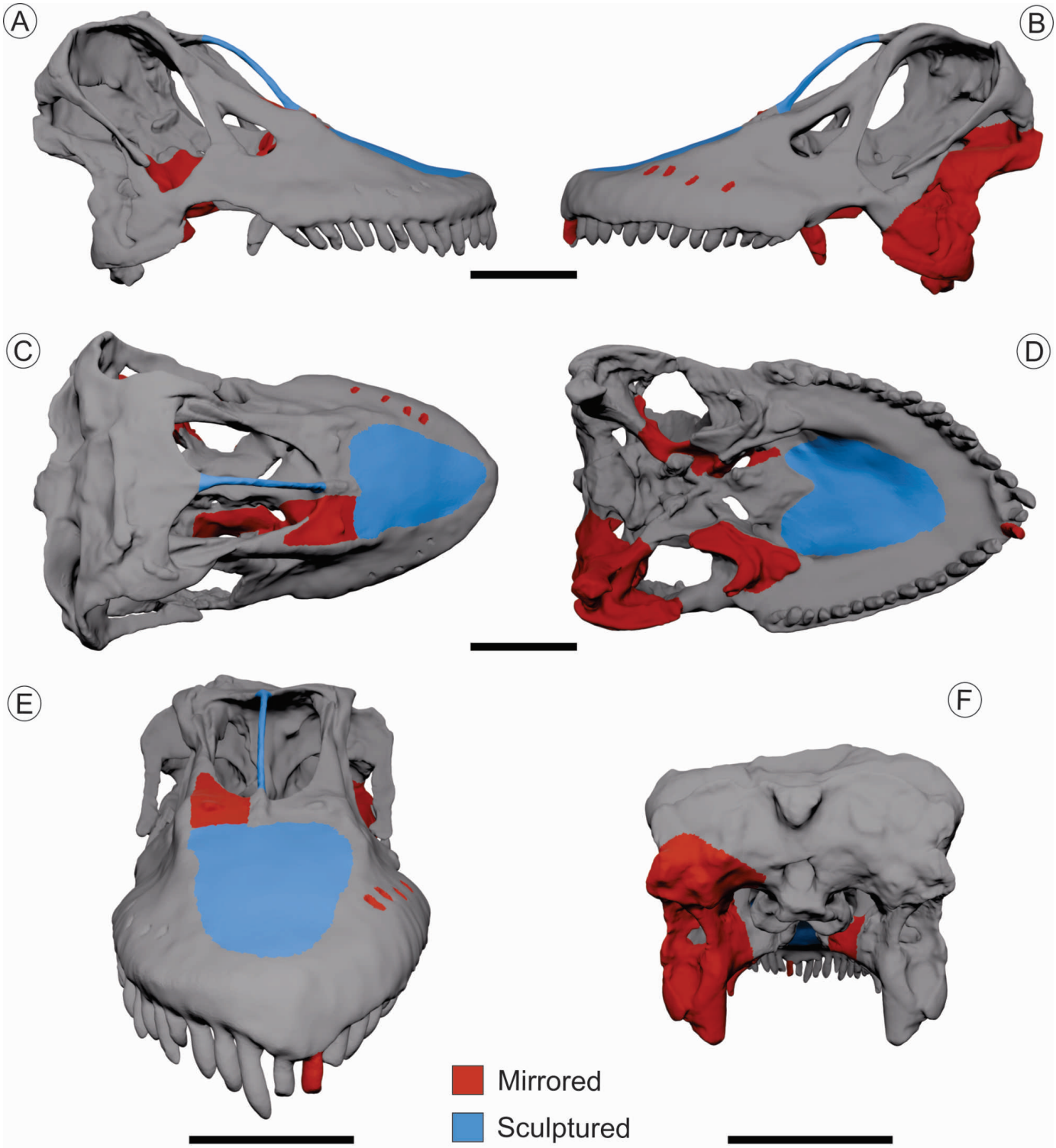

Figure 2. Original skull of *Sarmientosaurus mussacchioi* MDT-PV 2 reconstructed. In right lateral (a), left lateral (b), dorsal (c), ventral (d), anterior (e), posterior (f) and supratemporal fossa in focus (g) views. Scale bar = 10 cm.

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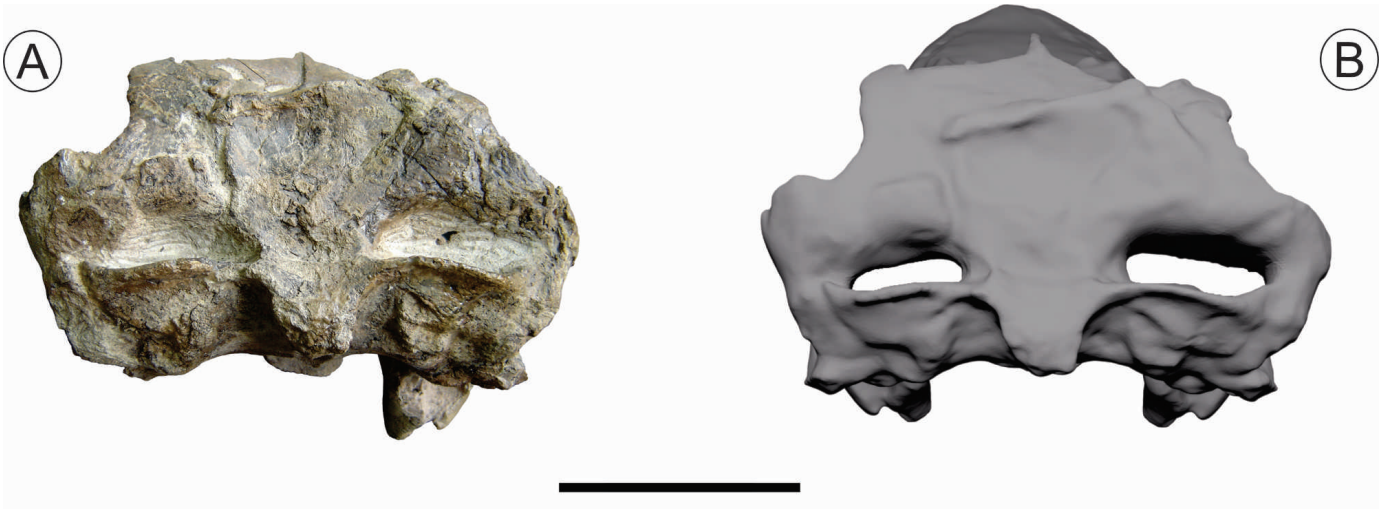

Figure 3. Supratemporal fenestra of *Sarmientosaurus mussacchioi* MDT-PV 2. In original fossil dorsal view (a) and reconstructed dorsal view (b). Scale bar = 10 cm.

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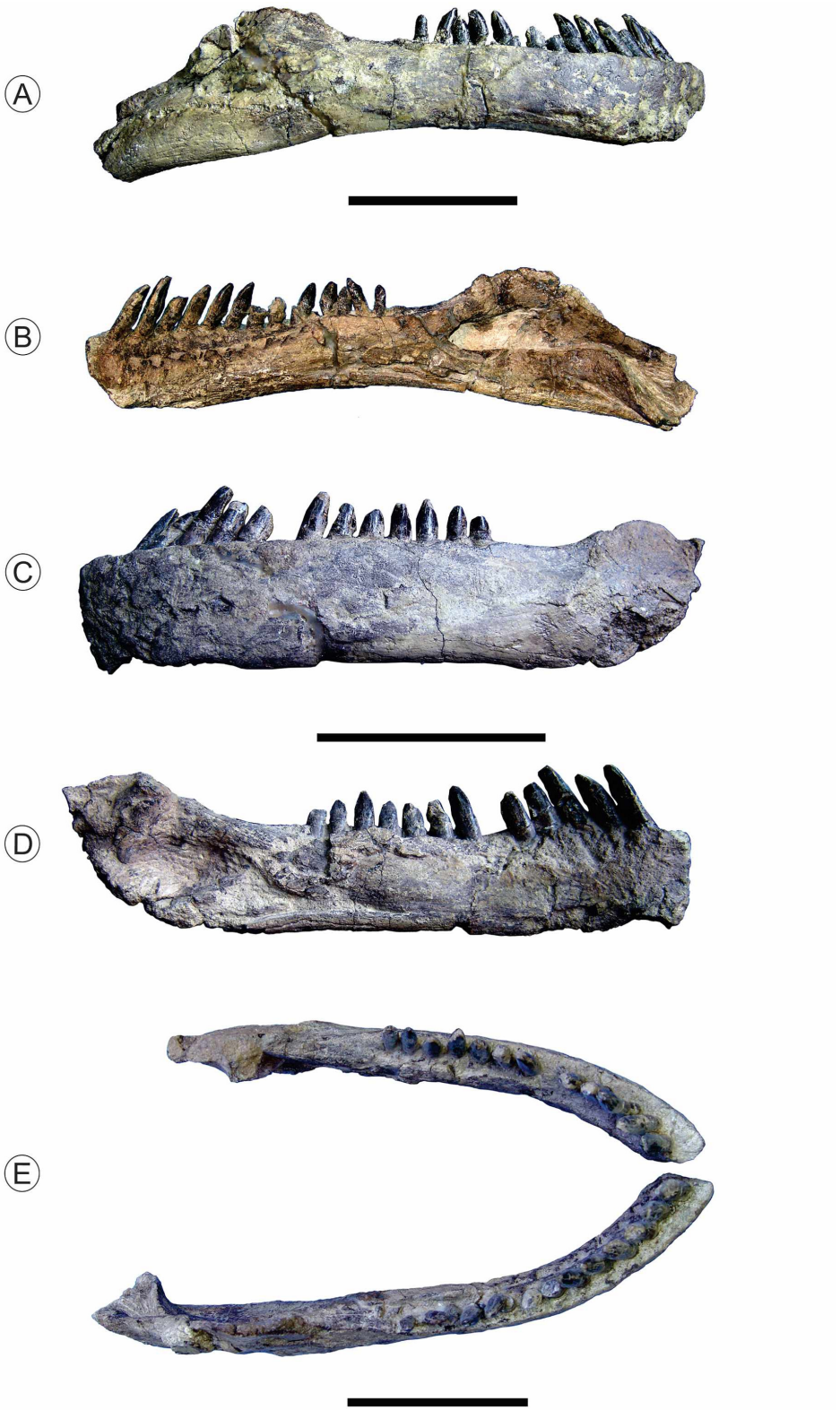

Figure 4. Original mandibles of *Sarmientosaurus mussacchioi* MDT-PV 2. Right mandible in right lateral (a) and left lateral (b) views. Left mandible in left lateral (c) and right lateral (d) views. Both mandibles in dorsal (e) view. Scale bar = 10 cm.

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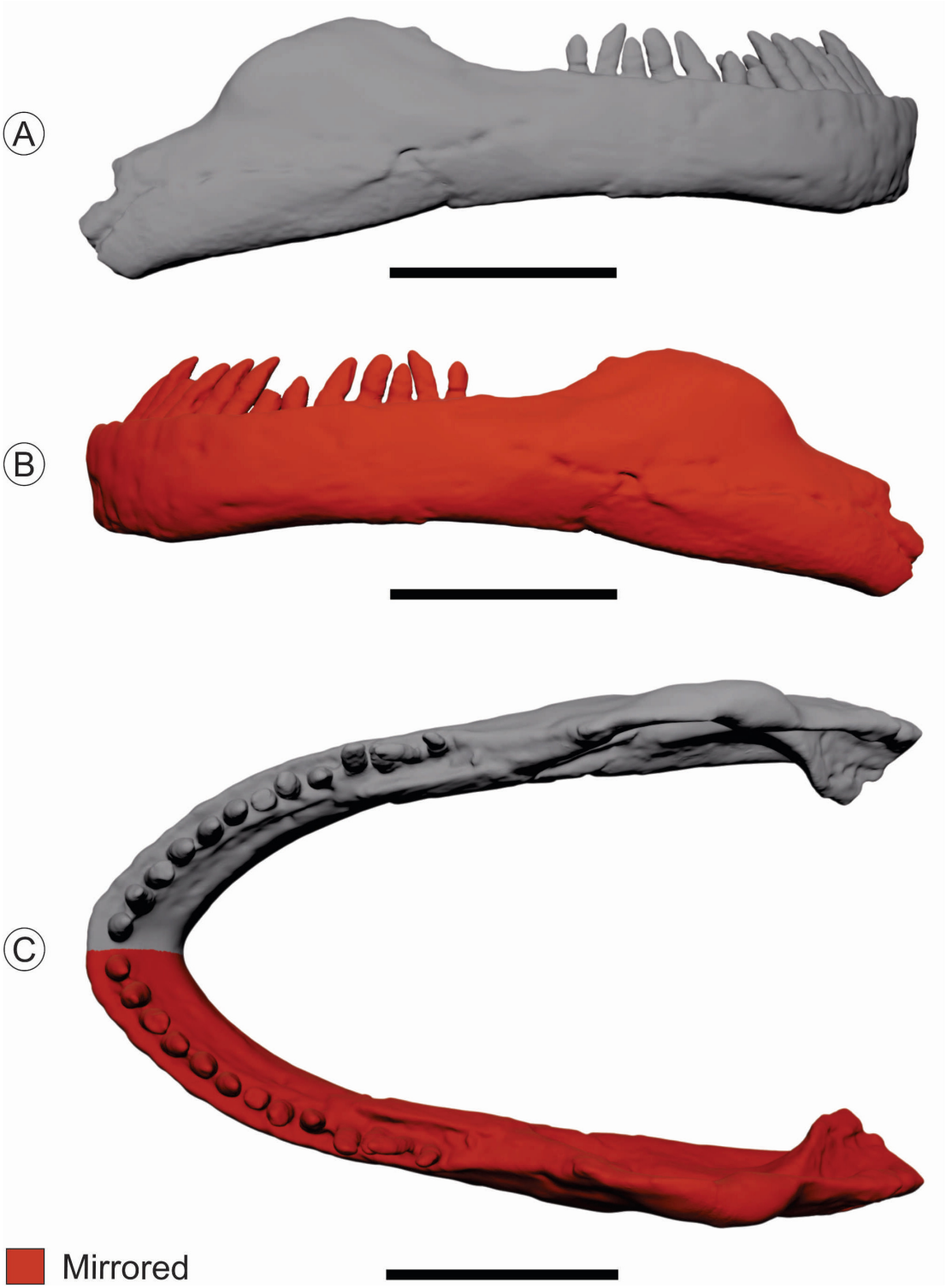

Figure 5. Mandible of *Sarmientosaurus mussacchioi* MDT-PV 2 reconstructed. In right lateral (a), left lateral (b) and dorsal (c). Scale bar = 10 cm.

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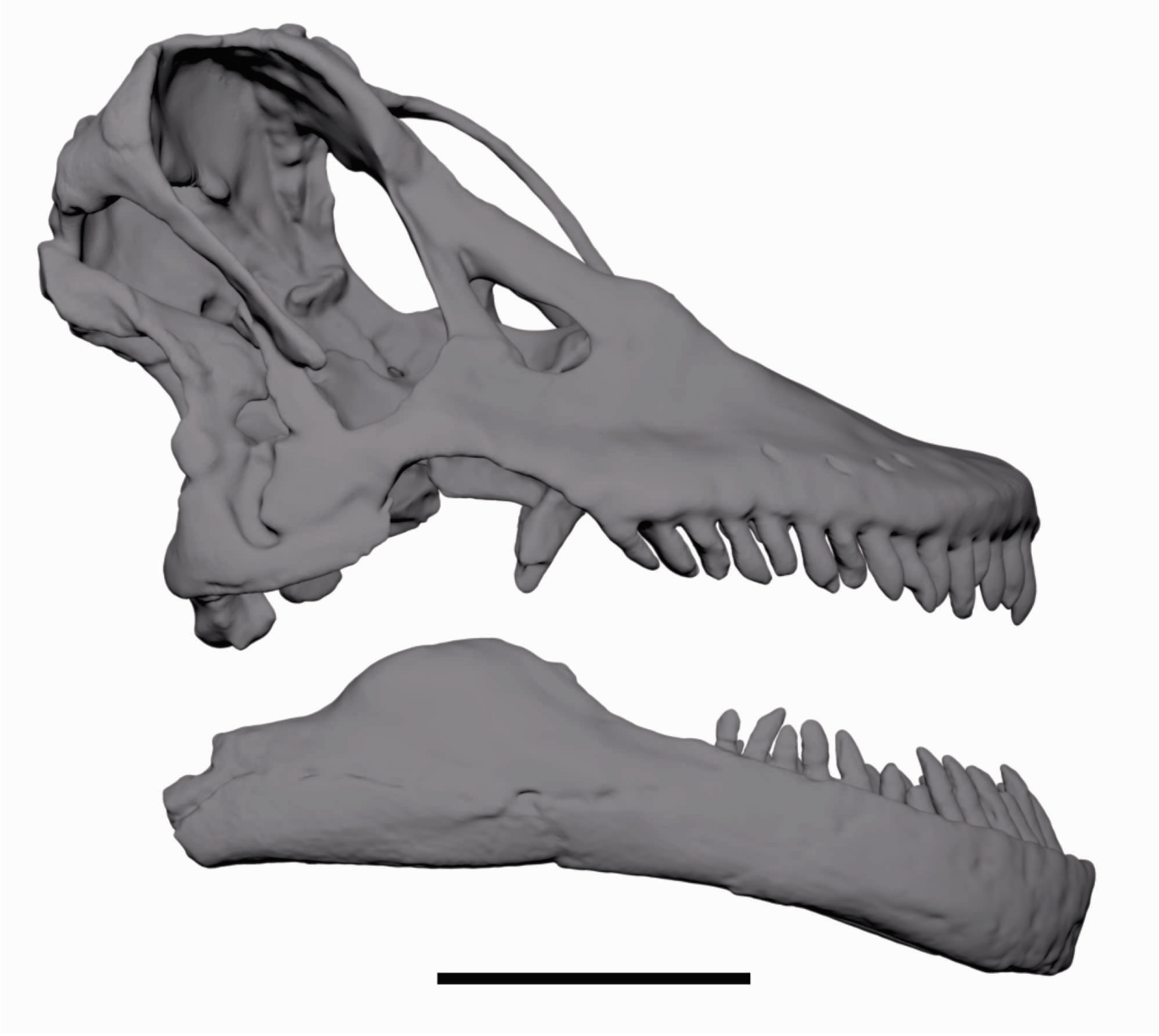

Figure 6. Skull and mandibles of *Sarmientosaurus mussacchioi* MDT-PV 2 reconstructed in .STL format in right lateral view. Scale bar = 10 cm.

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