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When Giants Take the Next Step: Short Commentary on Sauropod Foot Biomechanics

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Abstract

A recent study by Jannel et al. (2019) has been published on the biomechanics and foot posture of the gigantic sauropod non-avian dinosaurs in a preliminary attempt to understand how these giants could support their massive weight on land. As the leading author, I have been invited to present a short review of this study. Here, I sum up succinctly the importance of this work prior to discussing some of the caveats and avenues for future researches in this unusual field of science.

Keywords: Dinosaurs • Sauropods • Foot • Biomechanics

About the Study

Sauropod dinosaurs are unique in the history of life for the simple reason that they include the largest animals to have ever walked on the Earth. The ability of sauropods to withstand the mechanical forces induced by their immense size therefore represents one of the most striking adaptations in evolution. Although many studies have theorized the potential biomechanical and locomotory constraints imposed by the unparalleled dimensions of these animals (e.g., restriction in limb movements, increase in bones robusticity, etc.), research on sauropod feet (forefoot and hind foot) has been minimal in comparison with the rest of the body [1-4]. Indeed, perhaps due to the scarceness of the fossil record, little is known about the exact carrying capacity of sauropod feet [5]. Yet, as the only body parts directly interacting with the substrate, the morphofunctional abilities of sauropod feet provide critical insights into the evolution of gigantism within the clade [6, 7].

The recently published study by Jannel et al. is important in the context of functional, comparative, and evolutionary morphological work in Paleontology because it quantifies the movement, posture and biomechanics of a sauropod dinosaur hind foot for the first time [8]. Using a combination of physical and innovative computational approaches, this study firstly evaluated the range of motion between the joints of a sauropod hind foot and found them to be capable of much larger movements than previously thought. These movements, although likely to have been restricted in life by soft tissue, are proposed to have played a crucial role in the stability, stress accommodation and possible kinematics of the foot during locomotion [8]. Secondly, by combining these biomechanical analyses with comparisons with modern taxa, analysis of fossilized sauropod tracks, and accepted mechanical principles, this study virtually reconstructed the most plausible in life foot posture(s) of the animal. The results indicate that sauropods most likely exhibited a hind foot posture with the heel elevated above the substrate, as if in " high-heels " (i.e., in scientific terms, a foot posture ranging from skeletally digitigrade-to-subunguligrade continuum). Importantly, this finding implies the presence of a soft tissue pad positioned beneath the elevated bones, similar to what is seen in extant elephants [9]. Fundamentally, this soft tissue pad is inferred to have helped reduce the pressure exerted on the foot during support and locomotion and is thought to represent one of the key adaptations enabling the clade Sauropoda to achieve their emblematic gigantism.

This study highlights the complexity behind the biomechanical abilities of sauropod feet. However, due to the scarcity of the fossil record, only one specimen could be used, the Australian Middle Jurassic Rhoetosaurus brownei. Caution should therefore be taken when inferring large-scale macroevolutionary patterns from this research. Consequently, many inferences presented in this study still rest largely on qualitative interpretations and require further biomechanical investigations.

The emergence of novel computational approaches, such as those employed in this study, provides a means to address previously unanswerable questions. For instance, the use of three-dimensional musculoskeletal modelling method is now being developed to evaluate the effect of soft tissues on sauropod biomechanics, such as muscles [2,3]. This approach could therefore be adopted to better understand the morphofunctional abilities of sauropod feet. Similarly, finite element analysis is a commonplace method used in engineering and medical science that predict how a virtual structure reacts to real-world forces [10]. This method is now getting more attention in the zoological and paleontological sciences to address questions regarding the form and function in living and extinct organisms [10].

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Research is currently ongoing using this method to investigate the long-standing hypothesis that sauropod hind foot featured a soft tissue pad to reduce bone stresses and locomotor pressures. In this forthcoming research, finite element analysis is used to quantify the biomechanical effects of various possible skeletal postures with and without the presence of a soft tissue pad [11]. Lastly, novel morphometric and statistical analyses are being performed on sauropod ichnology (i.e., the branch of paleontology dealing with the study of fossilized footprints) to evaluate more quantitatively the relationships between sauropod track patterns and the biomechanics of sauropod feet [12-14]. Indeed, it has been shown that inferring foot anatomy based solely on tracks might be problematic because distinct foot skeletal and functional postures (i.e., based on the bones only or with inferences of soft tissues, respectively) can result in comparatively similar track shapes [8]. Ultimately, these new techniques offer an opportunity to assess large-scale macroevolutionary patterns that may have occurred throughout the evolutionary history of the clade with more certainty.

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