

Reporting Summary

Nature Research wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Research policies, see [Authors & Referees](#) and the [Editorial Policy Checklist](#).

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

- | | |
|-------------------------------------|--|
| n/a | Confirmed |
| ☐ | ☒ The exact sample size (n) for each experimental group/condition, given as a discrete number and unit of measurement |
| ☐ | ☒ A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly |
| ☒ | ☐ The statistical test(s) used AND whether they are one- or two-sided
<i>Only common tests should be described solely by name; describe more complex techniques in the Methods section.</i> |
| ☒ | ☐ A description of all covariates tested |
| ☒ | ☐ A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons |
| ☐ | ☒ A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals) |
| ☒ | ☐ For null hypothesis testing, the test statistic (e.g. F , t , r) with confidence intervals, effect sizes, degrees of freedom and P value noted
<i>Give P values as exact values whenever suitable.</i> |
| ☒ | ☐ For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings |
| ☒ | ☐ For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes |
| ☒ | ☐ Estimates of effect sizes (e.g. Cohen's d , Pearson's r), indicating how they were calculated |

Our web collection on [statistics for biologists](#) contains articles on many of the points above.

Software and code

Policy information about [availability of computer code](#)

Data collection	Custom LabVIEW programs (National Instruments Corp., Austin, TX, USA) for experimental testing of swimming performance.
Data analysis	Blender 2.79, ZBrush 4r7, and ClayTools 3D 2.0 for model rendering and sculpting; FlashPrint 3.26.0 to cut 3D model; Meshlab 2016.12 and Python 3.7 (through platform Anaconda) for calculation of the Centre of Mass; Meshroom 2019.1.0 for photogrammetry; custom LabVIEW 2013 programs (National Instruments Corp., Austin, TX, USA) for experimental testing of swimming performance; ImageJ 1.51w for retrocalculation of missing Lines of arrested Growth (histology).

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors/reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Research [guidelines for submitting code & software](#) for further information.

Data

Policy information about [availability of data](#)

All manuscripts must include a [data availability statement](#). This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A list of figures that have associated raw data
- A description of any restrictions on data availability

The authors declare that all data supporting the findings of this study are available within the paper and its Supplementary Information files (Source data).

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☐ Behavioural & social sciences ☒ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	We present the first unambiguous evidence for an aquatic propulsive structure in a dinosaur, the giant theropod <i>Spinosaurus aegyptiacus</i> . This dinosaur has a tail with an unexpected and unique shape consisting of extremely tall neural spines, and elongate chevrons forming a large, flexible, fin-like organ capable of extensive lateral excursion. Using a mechanical flapping apparatus to measure undulatory forces in physical tail models, we show that the tail shape of <i>Spinosaurus</i> produces far greater thrust and efficiency than the tail shapes of terrestrial dinosaurs, comparable to that of extant aquatic vertebrates that use vertically expanded tails to generate forward propulsion while swimming. This conclusion is consistent with a suite of adaptations for an aquatic lifestyle and a piscivorous diet in <i>Spinosaurus</i> , and with a persistent and significant invasion of aquatic environments by spinosaurid dinosaurs.
Research sample	A nearly complete, partially articulated fossil tail of a subadult individual of <i>Spinosaurus aegyptiacus</i> (FSAC-KK 11888), from the Cretaceous Kem Kem beds of south-eastern Morocco. Plastic tail shapes from the following species: <i>Spinosaurus aegyptiacus</i> , <i>Coelophysis bauri</i> , <i>Allosaurus fragilis</i> , <i>Crocodylus niloticus</i> , <i>Triturus dobrogicus</i> , and a rectangular control tail scaled to the same surface area as the <i>Spinosaurus</i> tail.
Sampling strategy	Systematic collection of a partial dinosaur skeleton (one individual). Tail shape experiments: <i>Coelophysis</i> and <i>Allosaurus</i> are well known taxa and reflect a basal theropod and large-bodied theropod respectively. The two extant aquatic tetrapods (salamander and crocodile) were chosen as they are known for utilizing tail-propelled swimming.
Data collection	N.I. led the expeditions and the project. N.I., S.M., C.D.S., M.F., M.A., D.M.M., G.B., S.Z. D.M. and A.A. collected the specimens in the field. N.I., S.M., C.D.S., M.F., J.W., G.V.L. and S.E.P. designed the research. N.I., S.M., C.D.S., M.F., J.W., G.V.L. and S.E.P. designed and performed the experiments. N.I., S.M., C.D.S., M.F., M.A., D.M.M., J.W., G.B., S.Z. D.M., D.M.U., U.J., J.J., A.A., G.V.L., and S.E.P. analysed the data.
Timing and spatial scale	2018-2019; the specimen was collected from the Kem Kem beds, which crop out along the Moroccan-Algerian border for over 250 km. The fossil was collected from a well-defined field site (site map included in our submission) located near the town of Zrigat.
Data exclusions	No data were excluded
Reproducibility	The experiments were repeated over multiple days to ensure consistent measures. All repeats were successful.
Randomization	We did not use quantitative approaches that would require randomization.
Blinding	Our study (field: palaeontology) does not include experiments that would require blinding.
Did the study involve field work?	☒ Yes ☐ No

Field work, collection and transport

Field conditions	Desert escarpment close to Moroccan Algerian border
Location	In- and ex-situ on the slopes of a south-east facing escarpment fringing the Aferdou Zrigat plateau (Tafilalt basin, Akrabou Formation, Kem Kem beds). See Supplemental Information.
Access and import/export	Permits for fieldwork were obtained from Ministère de l'Energie, des Mines, et de l'Environnement. Permits: 4581/DE/2019 (issued on 17/07/2019) and 4118/DE/2018/DG (issued on 06.06.2018). The work was performed in close collaboration with researchers in Morocco (FSAC, Casablanca). The specimens collected are deposited at the Département de Géologie/Laboratoire de Biodiversité et Santé, Faculté des Sciences Ain Chock, Hassan II University, Casablanca, Morocco.
Disturbance	No disturbance

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☐	☒ Palaeontology
☒	☐ Animals and other organisms
☒	☐ Human research participants
☒	☐ Clinical data

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Palaeontology

Specimen provenance	Permits for fieldwork were obtained from Ministère de l'Energie, des Mines, et de l'Environnement. Permits: 4581/DE/2019 (issued on 17/07/2019) and 4118/DE/2018/DG (issued on 06.06.2018). The work was performed in close collaboration with researchers in Morocco (FSAC, Casablanca). The specimens collected are deposited at the Departement de Géologie/Laboratoire de Biodiversité et Santé, Faculté des Sciences Ain Chock, Hassan II University, Casablanca, Morocco.
Specimen deposition	Laboratoire de Biodiversité et Santé, Faculté des Sciences Ain Chock, Hassan II University, Casablanca, Morocco
Dating methods	No new dates are provided
☒ Tick this box to confirm that the raw and calibrated dates are available in the paper or in Supplementary Information.	