

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 our [Editorial Policies](#) 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
Only common tests should be described solely by name; describe more complex techniques in the Methods section.
- ☒ ☐ 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
Give P values as exact values whenever suitable.
- ☒ ☐ 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

All data were collected by commercial software (MRI, MR Solutions Preclinical Scan version 1.2, Bruker ParaVision version 5.1, and GE Healthcare DV25.0_version R02; TEM, Gatan DigitalMicrograph version 3.22.1461.0; XRD, Rigaku PDXL version 2.6.1.2; VSM, Lake Shore VSM Software version 4.9.0; DLS, Zetasizer Software version 7.12; XPS, Thermo Scientific Avantage Software version 5.980; FT-IR, OPUS version 6.5; ICP-MS, MassHunter 4.1 Workstation Software G7201C Ver C.01.01; Optical microscope, Leica LAS X version 3.5.2, NIS-Elements version 4.60.0.11710; Size exclusion chromatography, UNICORN version 7.0.).

Data analysis

All data were analysed by commercial or open-source software (MRI, ImageJ 1.51 j8 and Horos 3.3.5; TEM, Gatan DigitalMicrograph version 3.22.1461.0; XRD, Rigaku PDXL version 2.6.1.2; VSM, Lake Shore VSM Software version 4.9.0; DLS, Zetasizer Software version 7.12; XPS, Thermo Scientific Avantage Software version 5.980; FT-IR, OPUS version 6.5; ICP-MS, MassHunter 4.1 Workstation Software G7201C Ver C.01.01; Optical microscope, Leica LAS X version 3.5.2, NIS-Elements version 4.60.0.11710; Size exclusion chromatography, UNICORN version 7.0.; data and statistical analyses, Graphpad Prism version 8.0.0, Origin version 9.5., Microsoft Excel version 16.41, Phoenix WinNonlin Software version 6.2.).

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 and 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 main data supporting the results in this study are available within the paper and its Supplementary Information. The raw and analysed datasets generated during the study are too large to be publicly shared, yet they are available for research purposes from the corresponding authors on reasonable request

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

Life sciences study design

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

Sample size	Sample sizes were determined according to previous experimental experience. Sample sizes were sufficient to show the same trends across replicates performed for each experiment.
Data exclusions	No data were excluded from the experiments.
Replication	Each experiment was repeated five or more times, unless specified. All experimental findings were reliably reproduced.
Randomization	The animals were randomly assigned to all experiments.
Blinding	Data collection and analysis were not performed blindly.

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 and archaeology
☐	☒ Animals and other organisms
☒	☐ Human research participants
☒	☐ Clinical data
☒	☐ Dual use research of concern

Methods

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

Animals and other organisms

Policy information about [studies involving animals](#); [ARRIVE guidelines](#) recommended for reporting animal research

Laboratory animals	Adult male Balb/c mice (6–8 weeks, 20–25 g), adult male Sprague-Dawley rats (8–10 weeks, 250–350 g), and adult male New Zealand rabbits (16–18 weeks 2.6–3.4 kg) were used in the MRI imaging experiments. Adult female Sprague-Dawley rats (6 weeks, 150–170 g) were used in the toxicity tests. Adult male Sprague-Dawley rats (9 weeks, 250–310 g) were used in the pharmacokinetics, biodistribution, excretion and histology studies. The mice and rats were purchased from OrientBio Inc., and the rabbits were obtained from DooYeol Biotech.
Wild animals	The study did not involve wild animals.
Field-collected samples	The study did not involve samples collected from the field.

All animal experiments were conducted under protocols approved by the Institutional Animal Care and Use Committee of Yonsei University College of Medicine (approval numbers: 2014-0298, 2017-0242) and the Animal Care Committee of Biototech, Inc. (approval numbers: 150627, 150634, 150700, and 170503).

Note that full information on the approval of the study protocol must also be provided in the manuscript.