nature portfolio

Corresponding author(s): Huaiwu Lu, Bei Wei, Huiling Shang

Last updated by author(s): Oct 13, 2025

Reporting Summary

Nature Portfolio 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 Portfolio 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	For scRNA-seq data, the Cell Ranger pipeline (v7.1.0) was used to preprocess the data; for Xenium data, the Xenium Ranger (v 3.0.0)was used to preprocess the data.
Data analysis	Seurat (5.0.1) was used to analyze the scRNA-seq and Xenium data. For the spatial analysis, custom algorithms has been published in biorxiv paper and cited in our manuscript.

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 Portfolio 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 description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

The datasets generated during this study will be made publicly available upon manuscript acceptance. Until then, the data are available from the corresponding author upon reasonable request. Processed data are available upon request from reviewers during the peer-review process since the data is too large.

Research involving human participants, their data, or biological material

Policy information about studies with human participants or human data. See also policy information about sex, gender (identity/presentation), and sexual orientation and race, ethnicity and racism.

Reporting on sex and gender	This is a study on cervical cancer, thus samples were all from female patients.
Reporting on race, ethnicity, or other socially relevant groupings	The samples were all from Asian patients/participants.
Population characteristics	The participants were well balanced on ages (ranging from 37 to 70) and cancer stages for different groups.
Recruitment	This is a retrospective study, we collected the samples carefully to avoid any biases.
Ethics oversight	Sun Yat-sen Memorial Hospital of Sun Yat-sen University, the First Hospital of Jilin University and the Third Affiliated Hospital of Harbin Medical University.

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

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 size was guided by feasibility and conventions for exploratory single-cell atlases, here to enhance the statistical power, we determined the sample size 16.
Data exclusions	No data were excluded.
Replication	To ensure reproducibility, we performed independent replicates >= 6 to confirm consistency across samples, and also provided raw/filtered counts and full metadata to enable replication.
Randomization	The samples were collected randomly, and we balanced the stages in different groups.
Blinding	Yes during data collection and preliminary analysis, the investigators were blinded to group allocation, but in the downstream analysis, the grouping information was used for comparative analysis, so the investigators were not blinded.

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
☐	☒ Clinical data
☒	☐ Dual use research of concern
☒	☐ Plants

Methods

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

Clinical data

Policy information about clinical studies

All manuscripts should comply with the ICMJE guidelines for publication of clinical research and a completed CONSORT checklist must be included with all submissions.

Clinical trial registration	No clinical trial
Study protocol	NA, there were no clinical trials included in this manuscript, clinical samples were collected by the physicians. The study was approved by the Ethics Committee of Sun Yat-sen Memorial Hospital of Sun Yat-sen University as well as Ethics Committee from other hospitals; all patients provided informed consent.
Data collection	The data were extracted from the individual hospital databases.
Outcomes	This is a retrospective study, there's no outcome in the study.

Plants

Seed stocks	no
Novel plant genotypes	no
Authentication	no