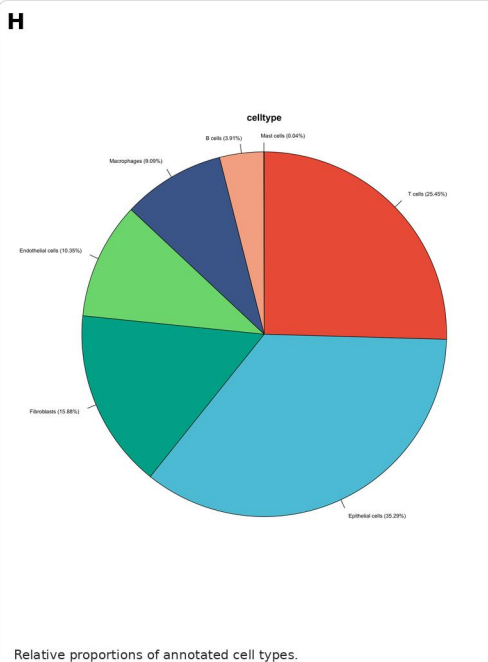
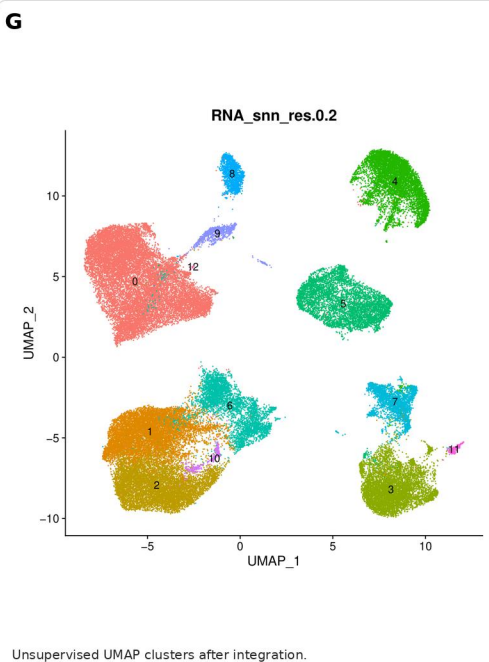
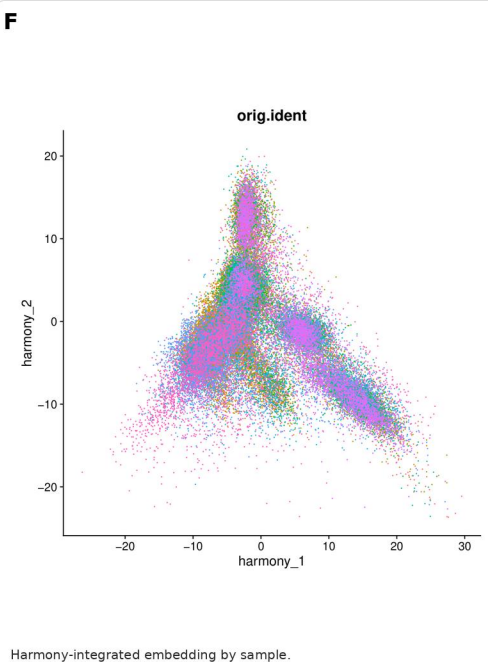
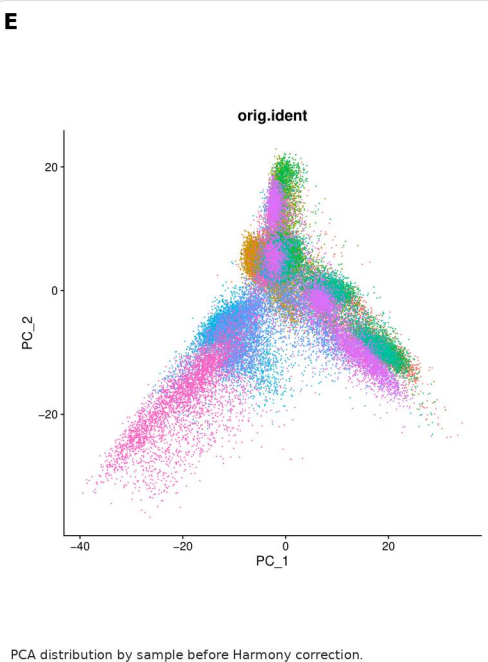
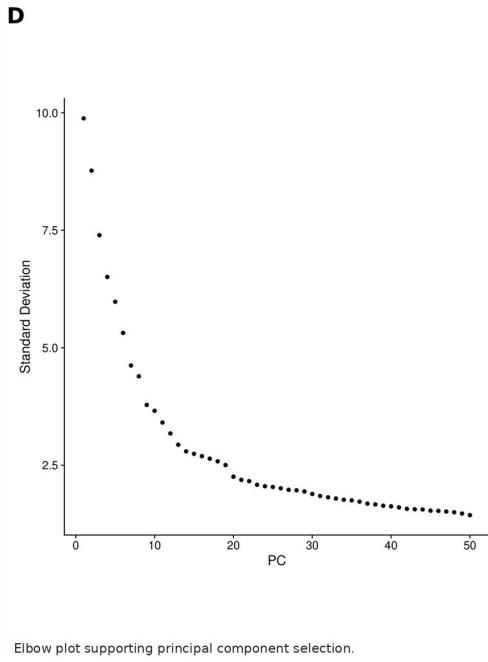
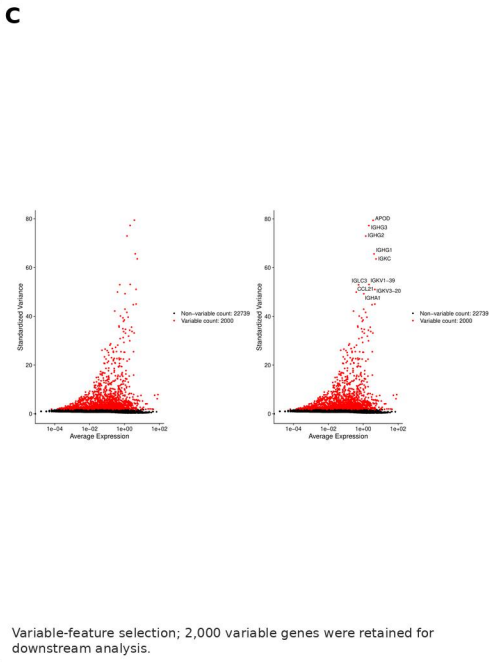
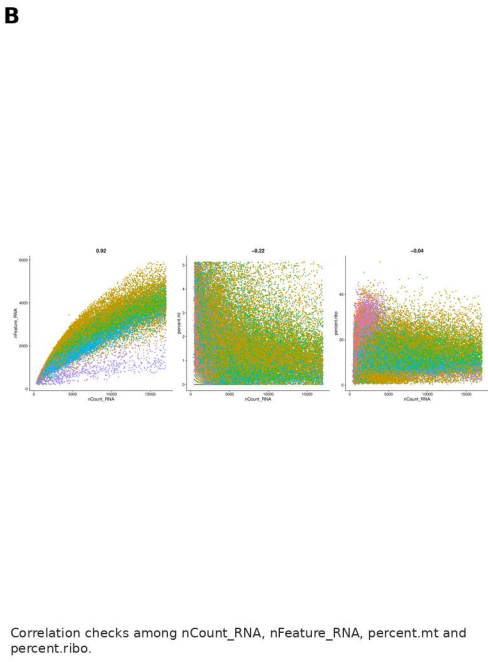
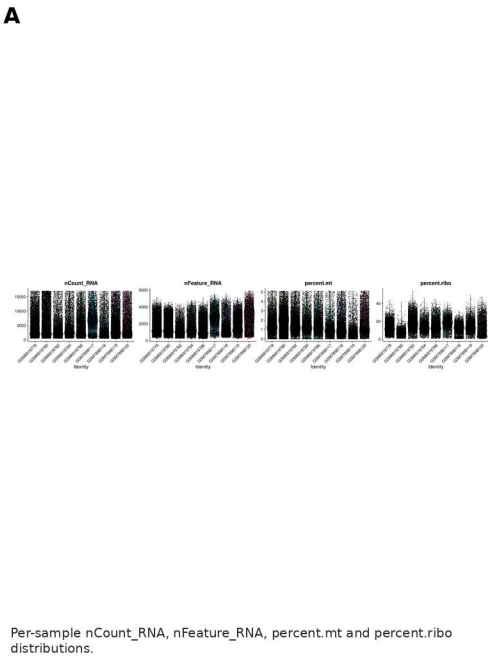
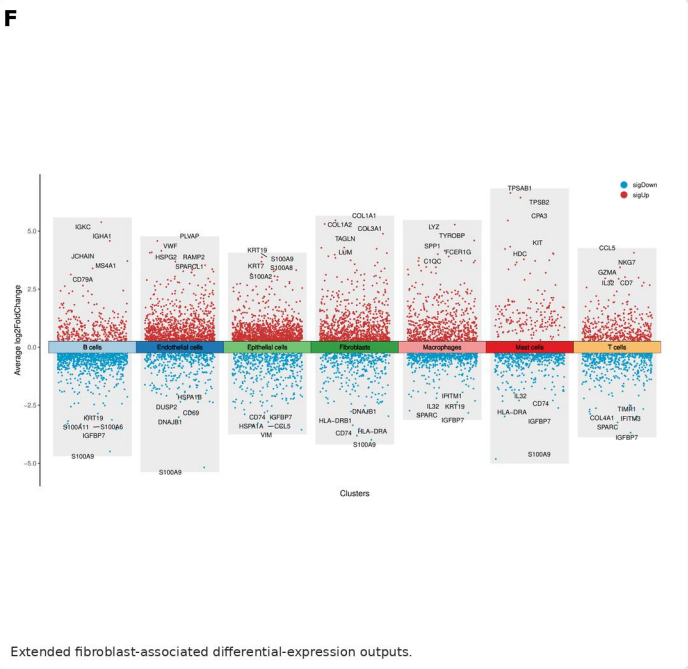
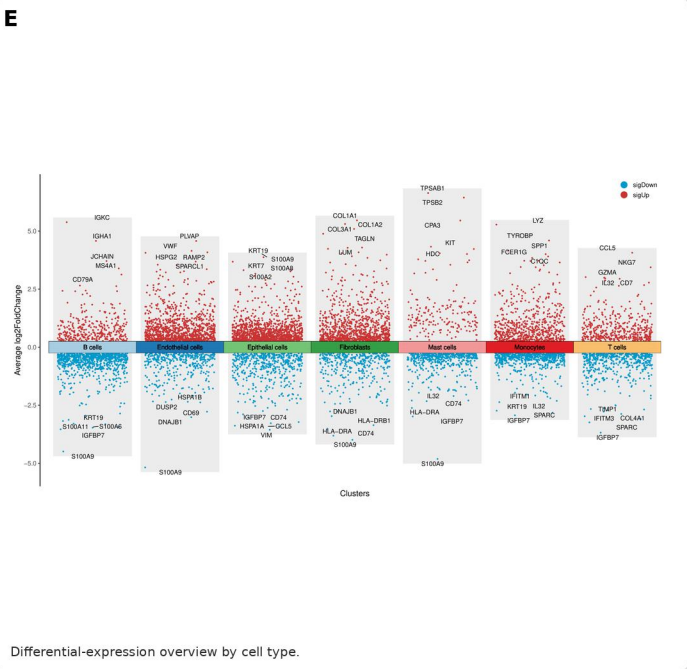
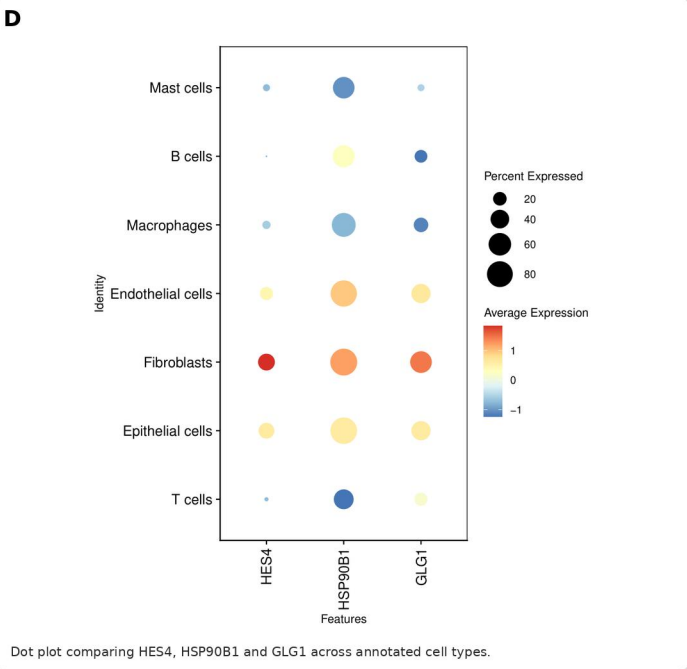
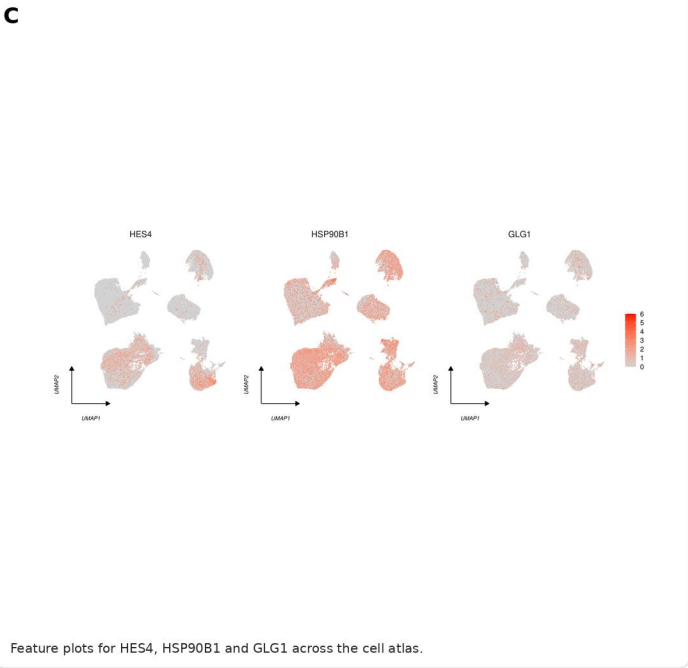
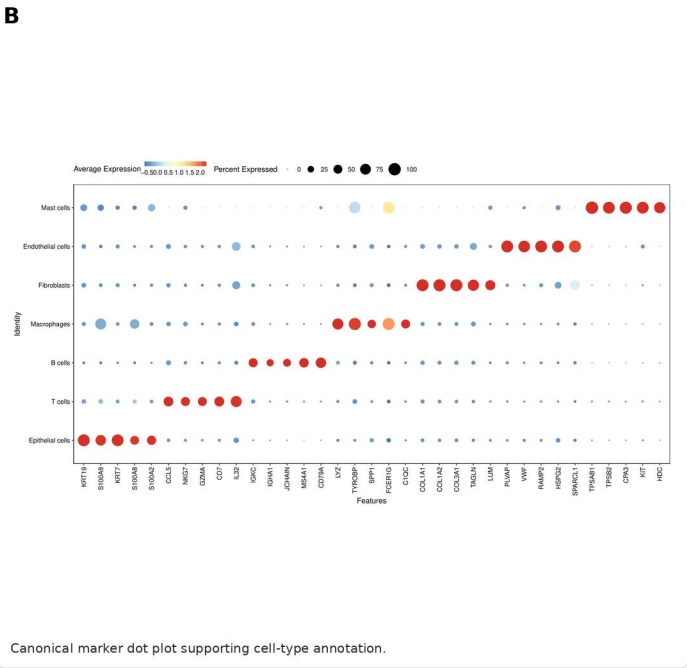
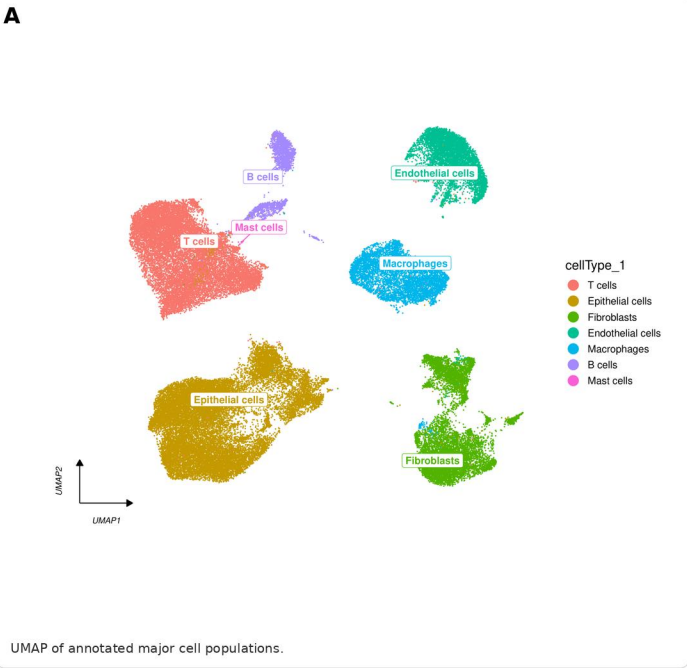


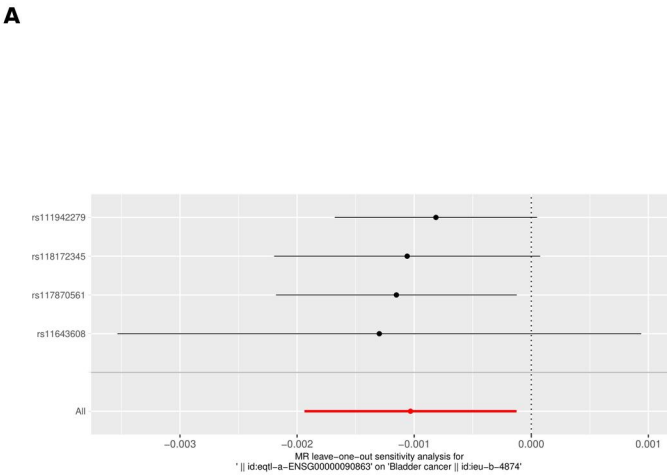
Supplementary Fig. S1. scRNA-seq quality control and integration diagnostics



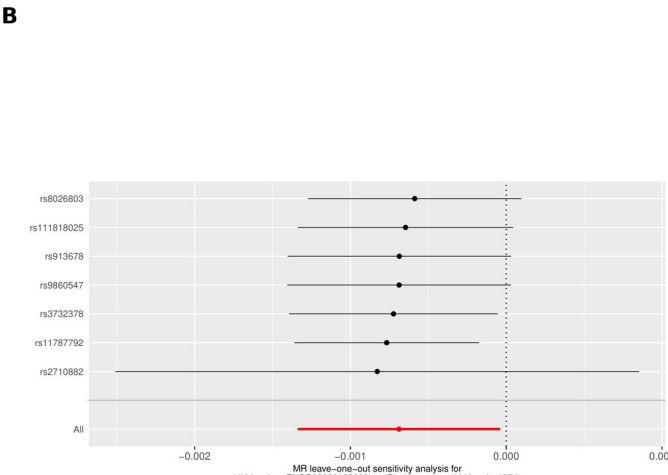
Supplementary Fig. S2. Extended cell annotation and GLG1 localization



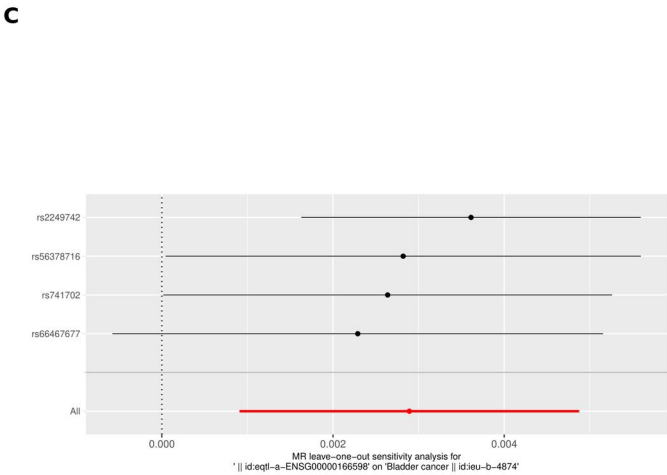
Supplementary Fig. S3. MR association and colocalization diagnostics



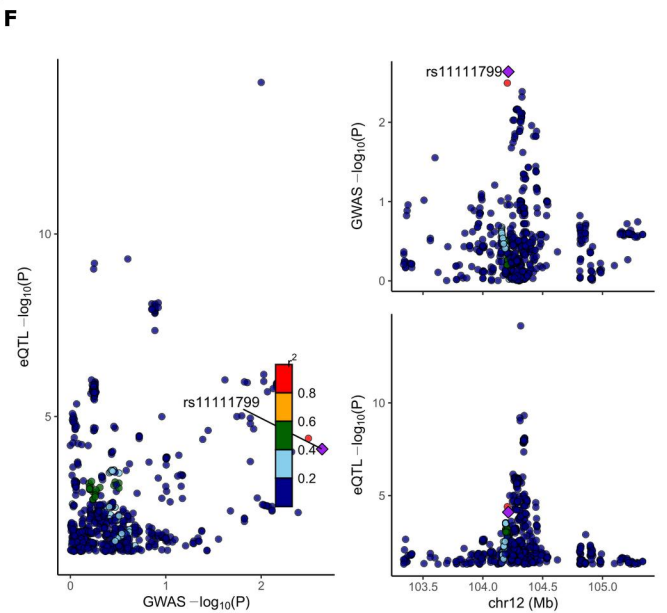
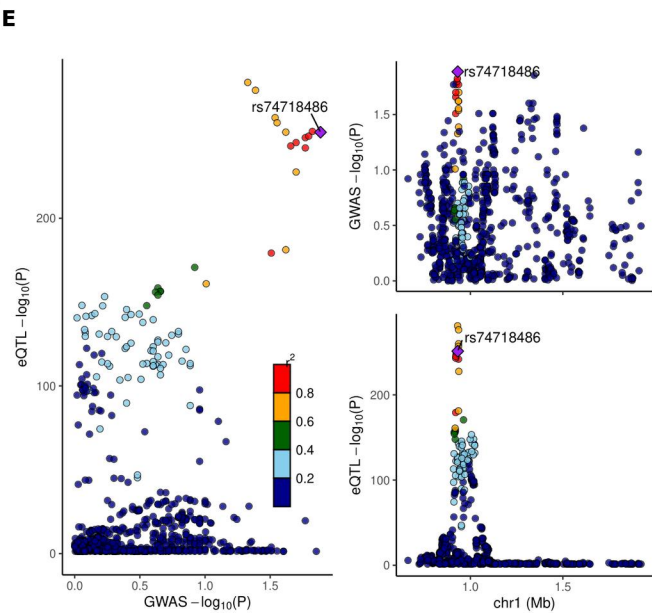
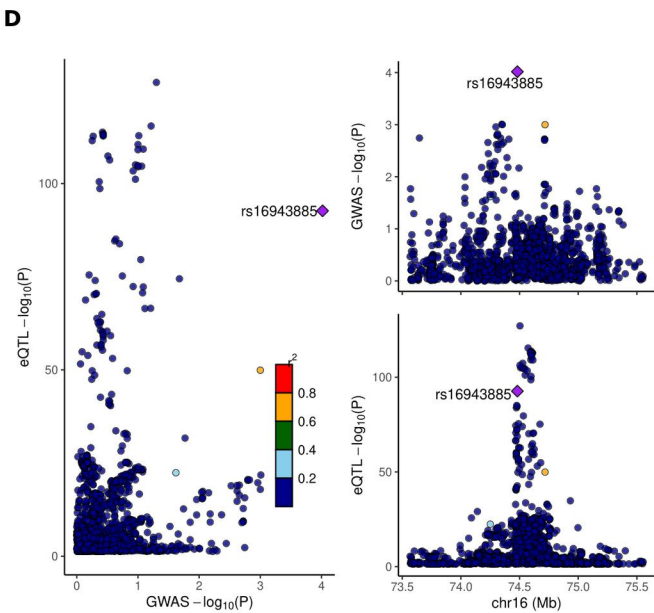
Leave-one-out sensitivity analysis for GLG1.



Leave-one-out sensitivity analysis for HES4.



Leave-one-out sensitivity analysis for HSP90B1.



A



PI3K-Akt signaling pathway

Chemokine signaling pathway

JAK-STAT signaling pathway

Communication role analysis based on incoming and outgoing interaction strength.

Outgoing communication patterns of secreting cells.

D

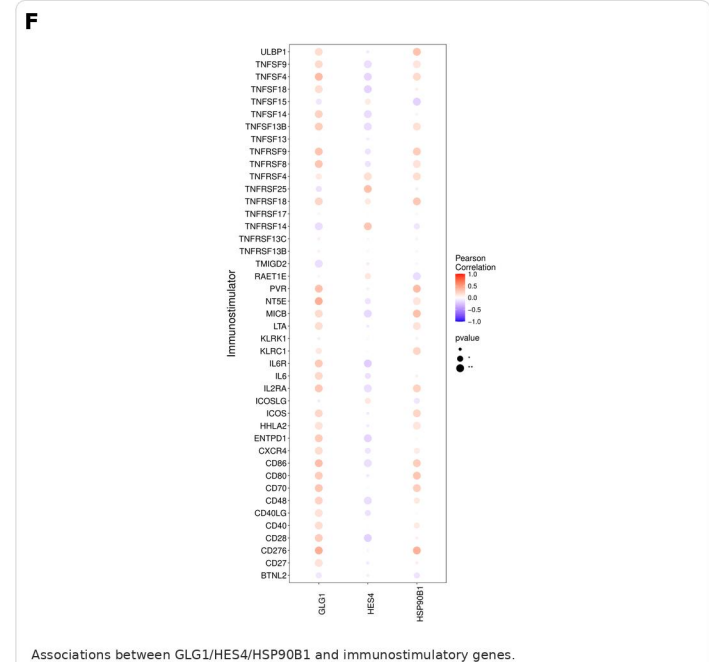
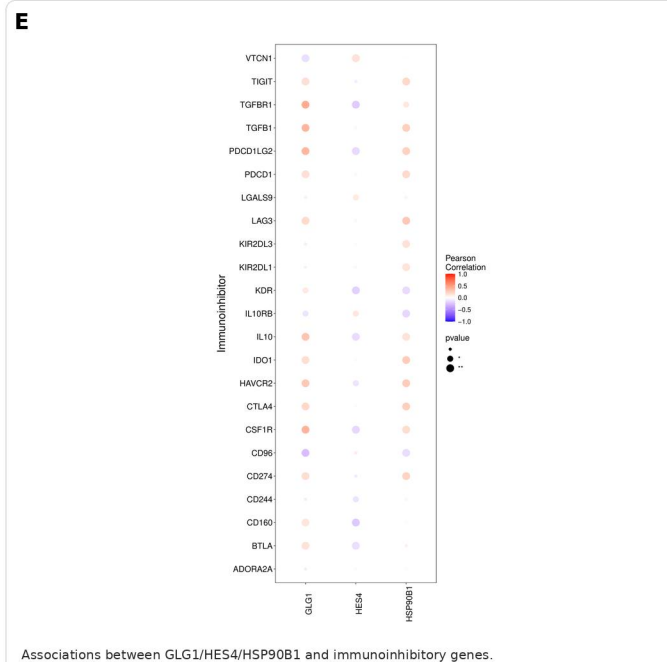
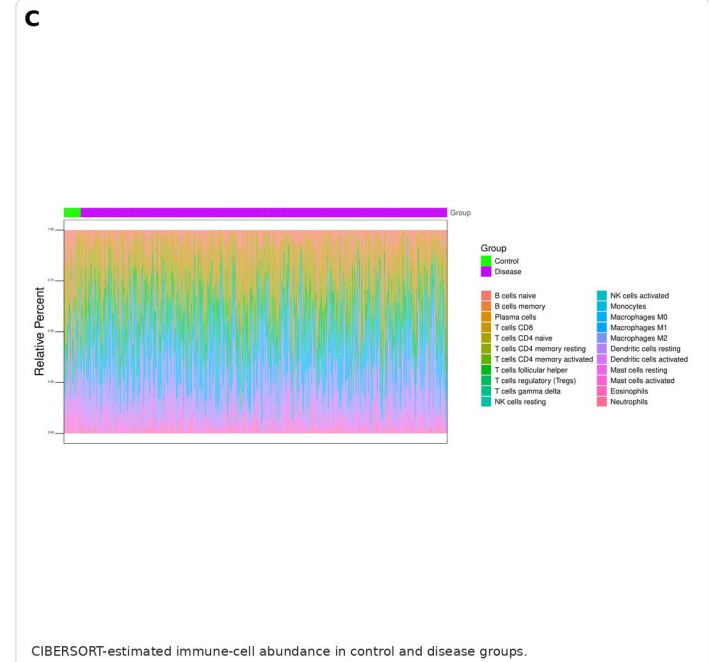


Cell-type chord plot for selected signaling communication.

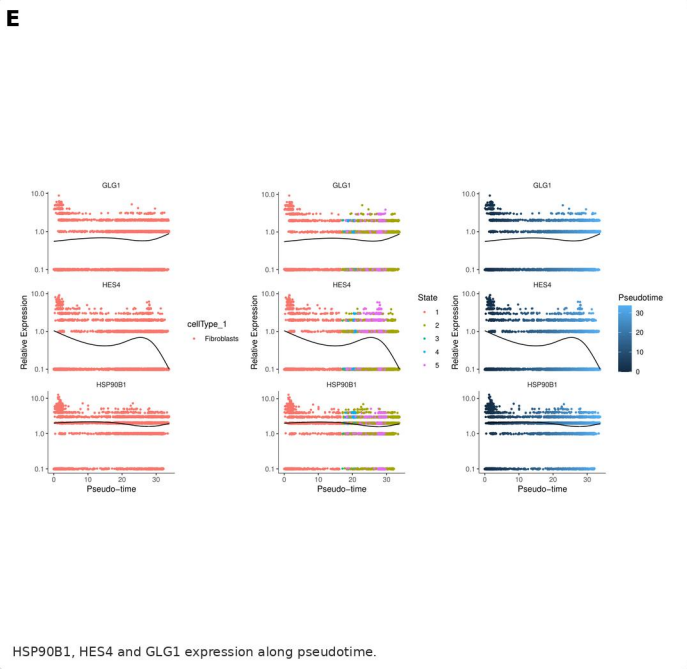
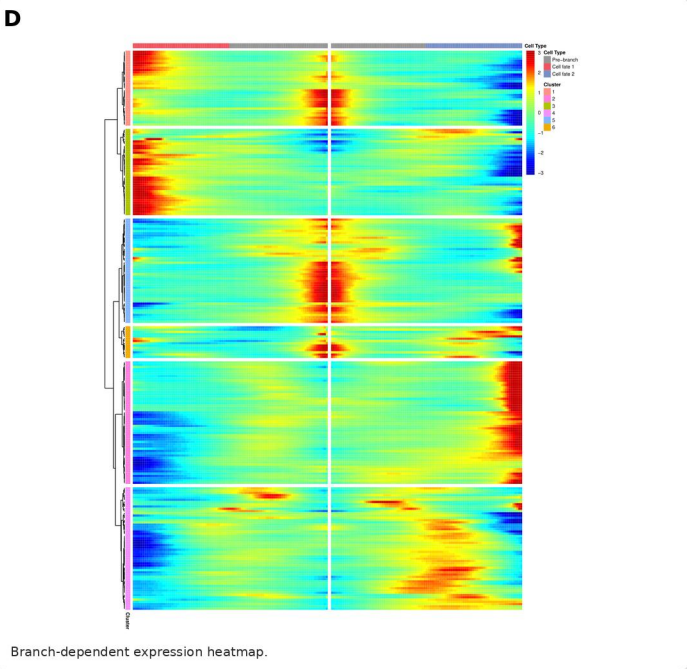
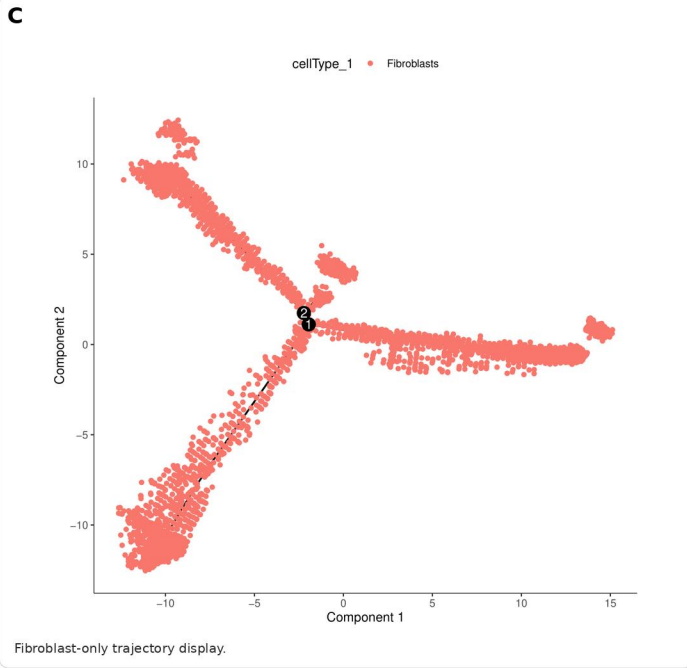
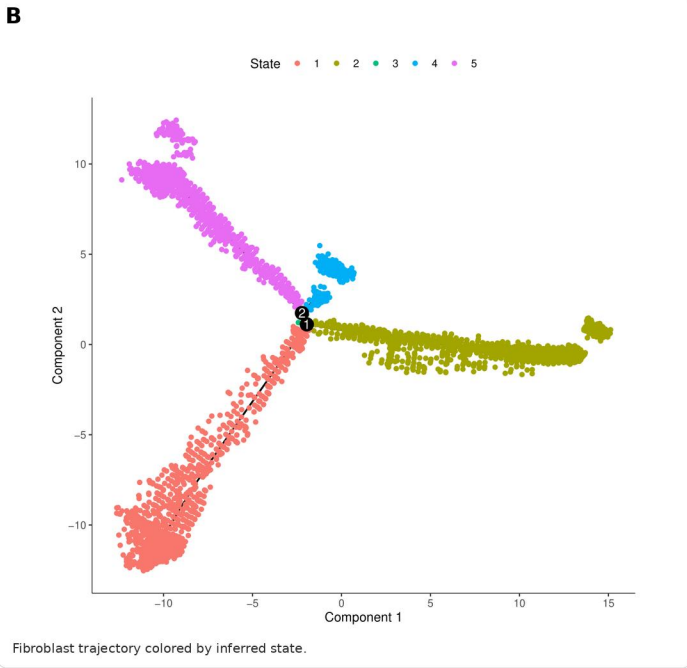
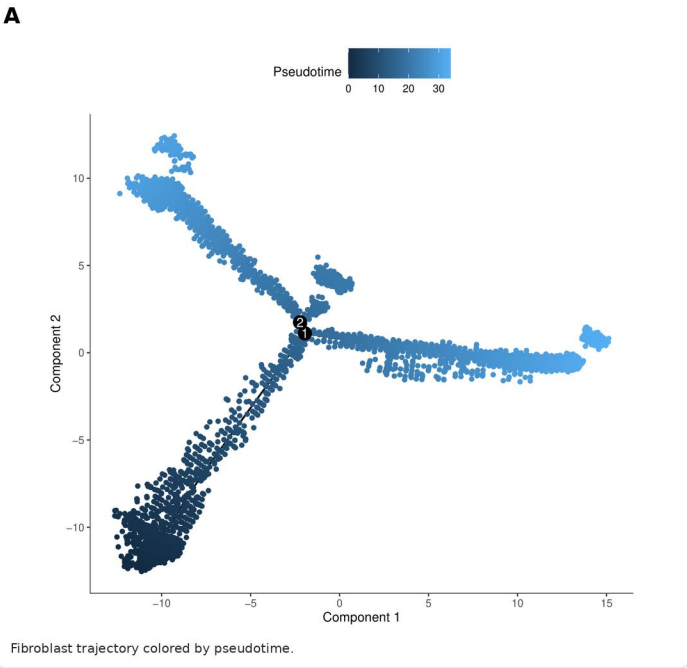
Heatmap showing the enrichment of various biological processes across different cell types. The y-axis lists biological processes, and the x-axis lists cell types. A color scale indicates the p-value, ranging from blue (low) to red (high). A legend on the right shows the color scale and a p-value threshold of 0.05.

Biological Process	Fibroblasts - 7 cells	Fibroblasts - Epithelial cells	Fibroblasts - Endothelial cells	Fibroblasts - Macrophages	Fibroblasts - 8 cells	Fibroblasts - Adipocytes
VEGFB - VEGFR1						
PTN - SOC4						
PTN - SOC1						
PTN - NCL						
PCF - VEGFR1						
NADP7 - INCR						
NADP7 - (TSGA+TSG1)						
MF - ACKR5						
MF - CD19-CKOR6						
MF - CD19-CD46						
MDK - SOC4						
MDK - SOC1						
MDK - NCL						
MDK - LRP1						
MDK - (TSGA+TSG1)						
MDK - (TSGA+TSG1)						
GRN - SORT1						
ANXA1 - PPRI						
ANGPT2 - TEX						
ANGPT2 - (TSGA+TSG1)						

Fibroblast outgoing ligand-receptor pairs toward recipient cell types.

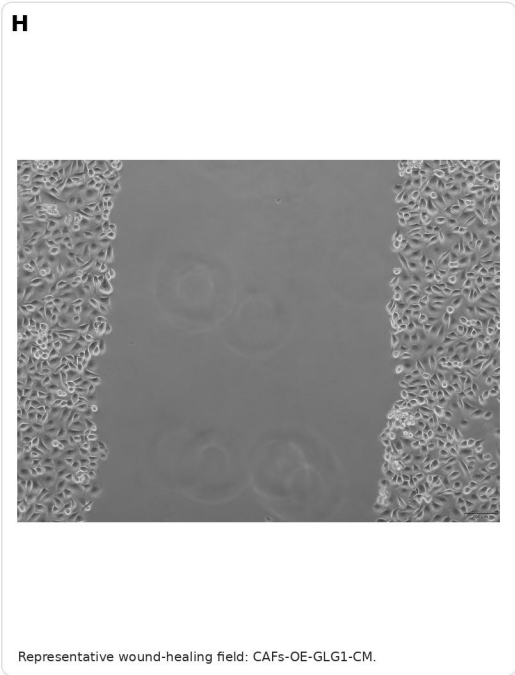
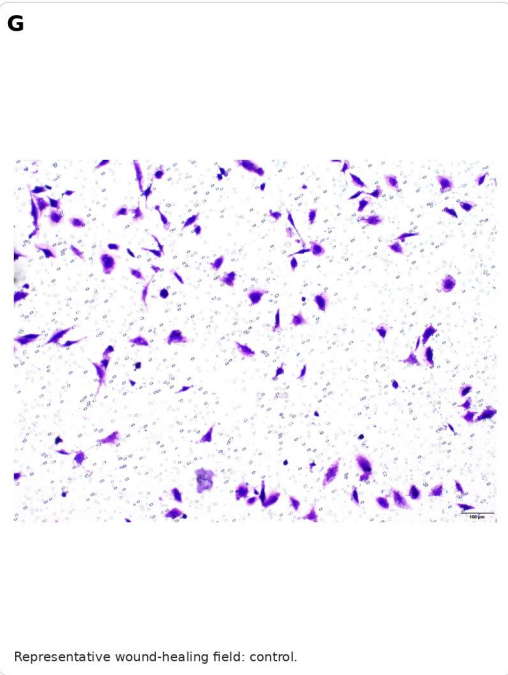
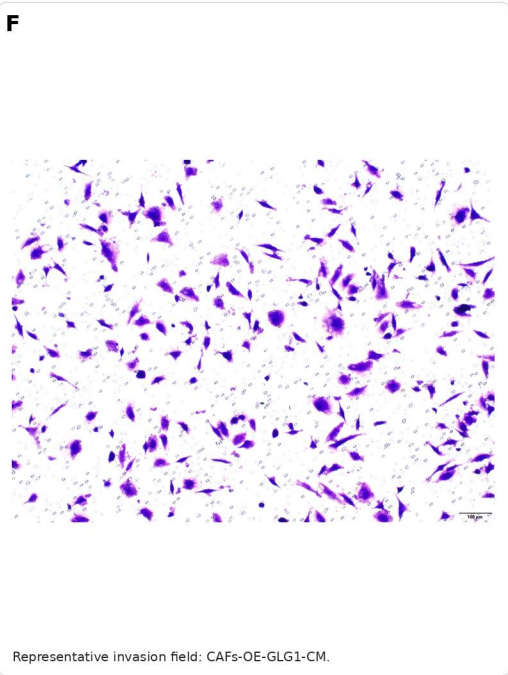
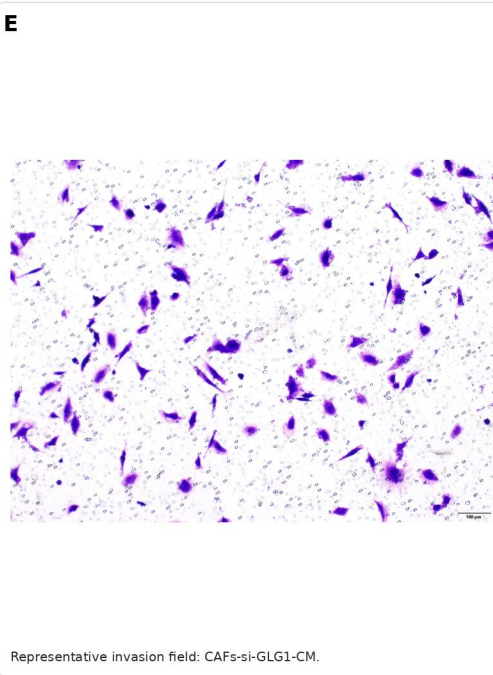
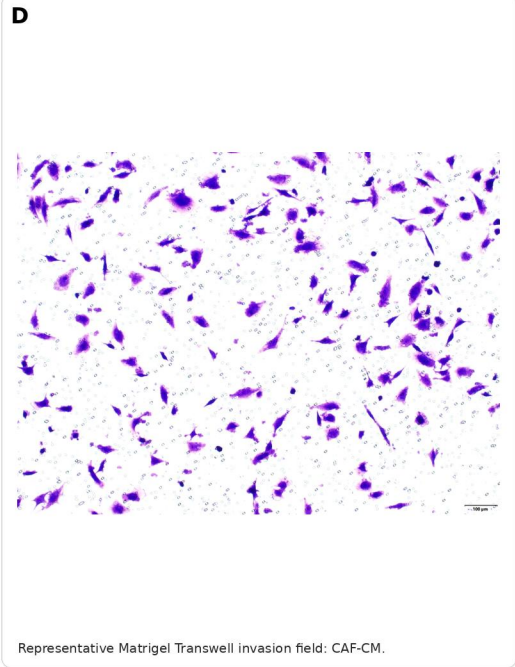
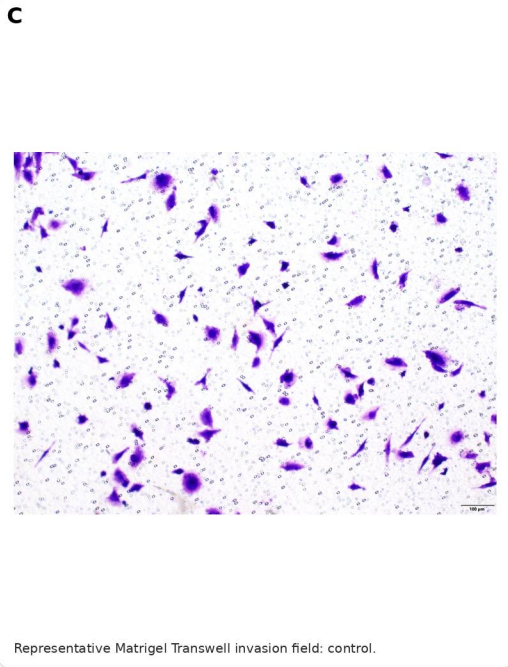
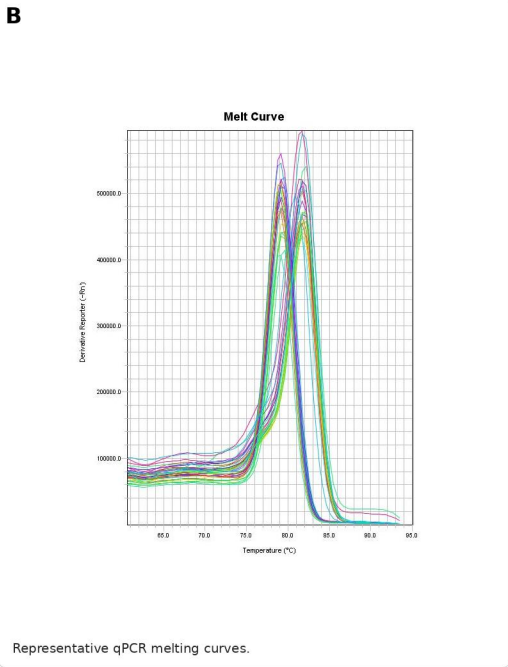
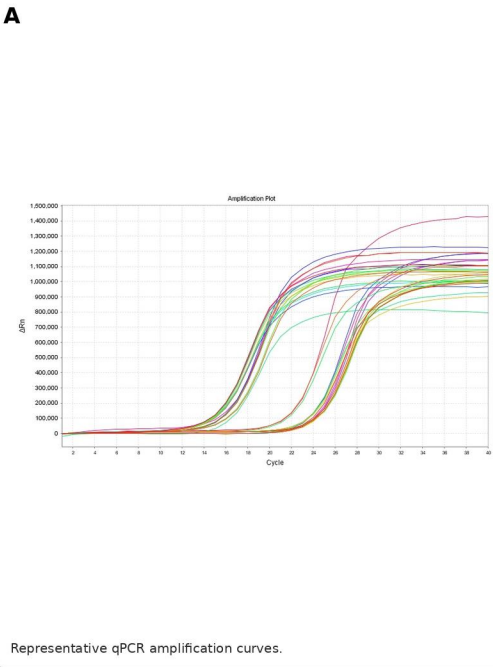


Supplementary Fig. S6. Fibroblast pseudotime and key-gene dynamics



Pseudotime results are interpreted as fibroblast-state associations rather than direct lineage proof.

Supplementary Fig. S7. Supporting in vitro functional assay images



Supplementary Fig. S8. Extended xenograft histology images

