**Supplementary Tables**

**Table S1.** R packages with corresponding versions utilized in the analytical workflow

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **ID** | **Package** | **Version** | **ID** | **Package** | **Version** |
| 1 | cluster | 2.1.6 | 32 | BiocGenerics | 0.50.0 |
| 2 | DoubletFinder | 2.0.4 | 33 | Matrix | 1.7-1 |
| 3 | scplotter | 0.1.1 | 34 | lessR | 4.3.7 |
| 4 | GseaVis | 0.1.0 | 35 | ggtricks | 0.1.0 |
| 5 | pathview | 1.44.0 | 36 | hrbrthemes | 0.8.7 |
| 6 | Rgraphviz | 2.48.0 | 37 | viridis | 0.6.5 |
| 7 | topGO | 2.56.0 | 38 | viridisLite | 0.4.2 |
| 8 | SparseM | 1.84-2 | 39 | paletteer | 1.6.0 |
| 9 | GO.db | 3.19.1 | 40 | reshape2 | 1.4.4 |
| 10 | graph | 1.82.0 | 41 | scales | 1.3.0 |
| 11 | org.Mm.eg.db | 3.19.1 | 42 | RColorBrewer | 1.1-3 |
| 12 | AnnotationDbi | 1.66.0 | 43 | clipr | 0.8.0 |
| 13 | IRanges | 2.38.1 | 44 | xlsx | 0.6.5 |
| 14 | S4Vectors | 0.42.1 | 45 | readxl | 1.4.3 |
| 15 | clusterProfiler | 4.12.6 | 46 | harmony | 1.2.3 |
| 16 | rvcheck | 0.2.1 | 47 | Rcpp | 1.0.13-1 |
| 17 | eulerr | 7.0.2 | 48 | ggpubr | 0.6.0 |
| 18 | annosc | 0.1.0 | 49 | patchwork | 1.3.0 |
| 19 | circlize | 0.4.16 | 50 | lubridate | 1.9.3 |
| 20 | colorBlindness | 0.1.9 | 51 | forcats | 1.0.0 |
| 21 | ggthemr | 1.1.0 | 52 | stringr | 1.5.1 |
| 22 | ggsci | 3.2.0 | 53 | dplyr | 1.1.4 |
| 23 | ggthemes | 5.1.0 | 54 | purrr | 1.0.2 |
| 24 | ggSCvis | 0.0.2 | 55 | readr | 2.1.5 |
| 25 | scRNAtoolVis | 0.1.0 | 56 | tidyr | 1.3.1 |
| 26 | ClusterGVis | 0.1.1 | 57 | tibble | 3.2.1 |
| 27 | monocle | 2.32.0 | 58 | ggplot2 | 3.5.1 |
| 28 | DDRTree | 0.1.5 | 59 | tidyverse | 2.0.0 |
| 29 | irlba | 2.3.5.1 | 60 | Seurat | 5.1.0 |
| 30 | VGAM | 1.1-12 | 61 | SeuratObject | 5.0.2 |
| 31 | Biobase | 2.64.0 | 62 | sp | 2.1-4 |

**Table S2.** Top20 cell type-specific marker genes used for cluster annotation

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **ID** | **log2FC** | **cluster** | **gene** | **ID** | **log2FC** | **cluster** | **gene** |
| 1 | 5.49  | Fibr | Mfap4 | 91 | 8.53  | NK | Ms4a4b |
| 2 | 4.36  | Fibr | Sfrp2 | 92 | 9.51  | NK | Trdc |
| 3 | 4.80  | Fibr | Pdgfra | 93 | 8.60  | NK | Gimap7 |
| 4 | 5.13  | Fibr | Mfap5 | 94 | 8.45  | NK | Podnl1 |
| 5 | 4.77  | Fibr | Steap3 | 95 | 8.39  | NK | Cd226 |
| 6 | 4.44  | Fibr | Dpt | 96 | 9.17  | NK | Sh2d2a |
| 7 | 4.51  | Fibr | Islr | 97 | 8.97  | NK | Icos |
| 8 | 5.89  | Fibr | Aox3 | 98 | 9.00  | NK | Tcrg-C1 |
| 9 | 4.91  | Fibr | Lsamp | 99 | 9.52  | NK | Tcrg-C4 |
| 10 | 5.98  | Fibr | Wnt16 | 100 | 9.11  | NK | Trdv4 |
| 11 | 4.97  | Fibr | A2m | 101 | 7.26  | Meso | Msln |
| 12 | 4.29  | Fibr | Gdf10 | 102 | 7.20  | Meso | Upk3b |
| 13 | 5.81  | Fibr | Scara5 | 103 | 7.44  | Meso | Nkain4 |
| 14 | 4.28  | Fibr | Rasd2 | 104 | 7.74  | Meso | Lgals2 |
| 15 | 4.25  | Fibr | Tex15 | 105 | 6.81  | Meso | Prr15 |
| 16 | 4.86  | Fibr | Pappa | 106 | 6.91  | Meso | Xpnpep2 |
| 17 | 4.22  | Fibr | Gm48898 | 107 | 7.75  | Meso | Tm4sf5 |
| 18 | 5.57  | Fibr | D630033O11Rik | 108 | 8.88  | Meso | Lrrn4 |
| 19 | 5.05  | Fibr | Hsd11b2 | 109 | 6.46  | Meso | Fgf1 |
| 20 | 4.53  | Fibr | Wnt6 | 110 | 6.36  | Meso | Fam180a |
| 21 | 7.31  | Gran | Il1b | 111 | 6.32  | Meso | Cybrd1 |
| 22 | 7.92  | Gran | S100a8 | 112 | 6.89  | Meso | Myrf |
| 23 | 7.55  | Gran | Csf3r | 113 | 6.55  | Meso | Rab6b |
| 24 | 8.05  | Gran | S100a9 | 114 | 6.47  | Meso | Folr1 |
| 25 | 7.67  | Gran | Hcar2 | 115 | 6.86  | Meso | Rpp25 |
| 26 | 7.41  | Gran | G0s2 | 116 | 7.37  | Meso | Muc16 |
| 27 | 8.23  | Gran | Cxcr2 | 117 | 6.28  | Meso | Ildr2 |
| 28 | 7.40  | Gran | Acod1 | 118 | 7.82  | Meso | Bnc1 |
| 29 | 7.59  | Gran | Gm13822 | 119 | 6.56  | Meso | Pcnx2 |
| 30 | 7.50  | Gran | Clec4e | 120 | 6.80  | Meso | Rprml |
| 31 | 7.31  | Gran | Mirt1 | 121 | 7.91  | Endo | Egfl7 |
| 32 | 7.27  | Gran | Hp | 122 | 8.11  | Endo | C130074G19Rik |
| 33 | 7.99  | Gran | Il1f9 | 123 | 9.54  | Endo | Ptprb |
| 34 | 7.90  | Gran | Trem1 | 124 | 7.97  | Endo | Emcn |
| 35 | 7.02  | Gran | Cd33 | 125 | 7.89  | Endo | Abcb1a |
| 36 | 8.00  | Gran | Gm39321 | 126 | 9.06  | Endo | Adgrl4 |
| 37 | 7.52  | Gran | Asprv1 | 127 | 8.70  | Endo | Tie1 |
| 38 | 7.49  | Gran | Mirt2 | 128 | 8.75  | Endo | Mmrn2 |
| 39 | 8.80  | Gran | Stfa2l1 | 129 | 8.85  | Endo | Ushbp1 |
| 40 | 7.42  | Gran | Wfdc21 | 130 | 10.23  | Endo | Cyyr1 |
| 41 | 6.08  | Epit | Cldn7 | 131 | 8.87  | Endo | Myct1 |
| 42 | 5.94  | Epit | Wfdc2 | 132 | 8.31  | Endo | Fam167b |
| 43 | 5.90  | Epit | Msx1 | 133 | 9.36  | Endo | Sox18 |
| 44 | 6.09  | Epit | BC048679 | 134 | 9.69  | Endo | Robo4 |
| 45 | 6.27  | Epit | Cldn3 | 135 | 9.76  | Endo | Syt15 |
| 46 | 5.90  | Epit | Elf3 | 136 | 10.96  | Endo | Aplnr |
| 47 | 6.76  | Epit | Fermt1 | 137 | 8.49  | Endo | Tmem252 |
| 48 | 6.41  | Epit | Dlx5 | 138 | 9.12  | Endo | Erg |
| 49 | 6.44  | Epit | 4833423E24Rik | 139 | 9.77  | Endo | Gpihbp1 |
| 50 | 5.94  | Epit | Cldn4 | 140 | 8.30  | Endo | Gm32688 |
| 51 | 5.91  | Epit | Fcgbp | 141 | 9.26  | Peri | Rgs5 |
| 52 | 5.93  | Epit | Sftpd | 142 | 7.62  | Peri | Ndufa4l2 |
| 53 | 6.23  | Epit | S100g | 143 | 8.59  | Peri | Higd1b |
| 54 | 6.34  | Epit | Prap1 | 144 | 6.53  | Peri | Mustn1 |
| 55 | 6.25  | Epit | Pax8 | 145 | 7.72  | Peri | Notch3 |
| 56 | 6.36  | Epit | Clca1 | 146 | 6.46  | Peri | Kcnj8 |
| 57 | 6.07  | Epit | St14 | 147 | 7.25  | Peri | Gucy1b1 |
| 58 | 6.04  | Epit | Urah | 148 | 5.90  | Peri | Cspg4 |
| 59 | 6.97  | Epit | Tmem45b | 149 | 7.51  | Peri | Abcc9 |
| 60 | 6.36  | Epit | Tspan1 | 150 | 8.06  | Peri | Rgs4 |
| 61 | 6.93  | Macr | Cd74 | 151 | 6.92  | Peri | Kcnk3 |
| 62 | 6.75  | Macr | Aif1 | 152 | 8.74  | Peri | Olfr558 |
| 63 | 7.53  | Macr | Ms4a7 | 153 | 5.80  | Peri | Ednrb |
| 64 | 7.55  | Macr | Pld4 | 154 | 5.88  | Peri | Gja4 |
| 65 | 7.48  | Macr | Trem2 | 155 | 6.38  | Peri | Slc7a2 |
| 66 | 7.03  | Macr | H2-Aa | 156 | 7.65  | Peri | Foxs1 |
| 67 | 7.34  | Macr | Ms4a6c | 157 | 8.98  | Peri | Vtn |
| 68 | 7.60  | Macr | C1qc | 158 | 5.72  | Peri | Olfml2b |
| 69 | 7.54  | Macr | C1qb | 159 | 6.67  | Peri | Heyl |
| 70 | 6.59  | Macr | Ifi207 | 160 | 6.47  | Peri | Rasl12 |
| 71 | 7.80  | Macr | C1qa | 161 | 6.61  | SMC | Tagln |
| 72 | 6.86  | Macr | H2-Eb1 | 162 | 5.84  | SMC | Acta2 |
| 73 | 7.61  | Macr | Ly86 | 163 | 7.31  | SMC | Myh11 |
| 74 | 7.22  | Macr | H2-Ea-ps | 164 | 8.86  | SMC | Pcp4 |
| 75 | 7.22  | Macr | Ms4a6d | 165 | 5.28  | SMC | Smtn |
| 76 | 7.43  | Macr | C3ar1 | 166 | 7.74  | SMC | Cnn1 |
| 77 | 6.46  | Macr | Pf4 | 167 | 9.23  | SMC | Actg2 |
| 78 | 8.47  | Macr | Cx3cr1 | 168 | 7.28  | SMC | Lmod1 |
| 79 | 6.86  | Macr | Adgre1 | 169 | 6.08  | SMC | Fbxl22 |
| 80 | 6.43  | Macr | Ms4a4c | 170 | 6.69  | SMC | Sh3bgr |
| 81 | 8.67  | NK | Cd3g | 171 | 5.63  | SMC | Aspn |
| 82 | 8.46  | NK | Trbc2 | 172 | 6.84  | SMC | Hmcn2 |
| 83 | 8.93  | NK | Lat | 173 | 6.06  | SMC | Jph2 |
| 84 | 9.76  | NK | Cxcr6 | 174 | 7.15  | SMC | Syndig1 |
| 85 | 9.20  | NK | Trbc1 | 175 | 6.25  | SMC | Kcnh2 |
| 86 | 8.49  | NK | Gimap3 | 176 | 7.45  | SMC | Aard |
| 87 | 11.51  | NK | Nkg7 | 177 | 7.41  | SMC | Tnnt2 |
| 88 | 9.32  | NK | Il2rb | 178 | 5.30  | SMC | Aoc3 |
| 89 | 8.58  | NK | Ctsw | 179 | 5.25  | SMC | Rspo3 |
| 90 | 8.65  | NK | Skap1 | 180 | 5.41  | SMC | Cacnb2 |

**Supplementary Figures**



**Figure S1.** Batch effect evaluation and correction for scRNA-seq data