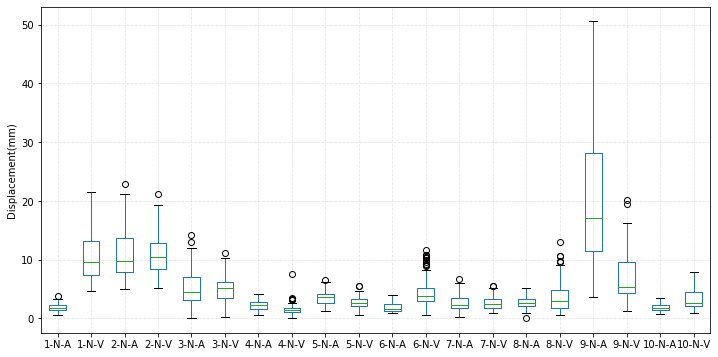
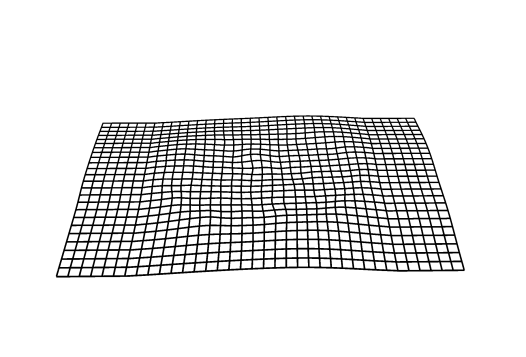
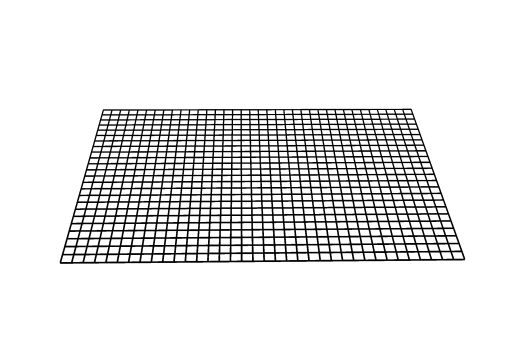
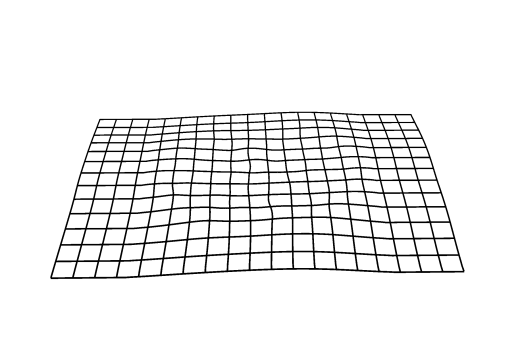
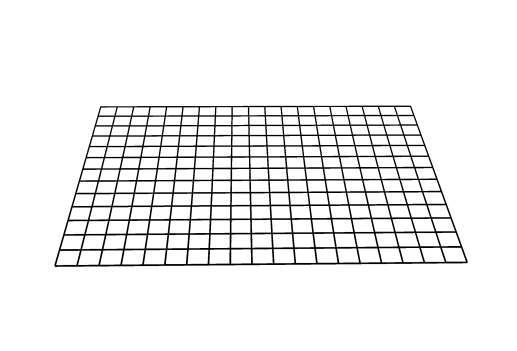
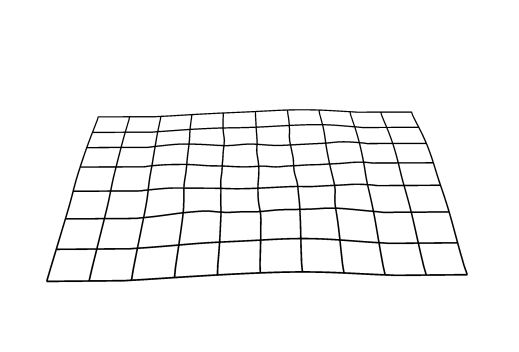
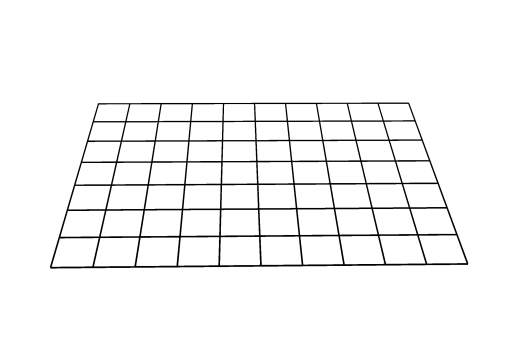
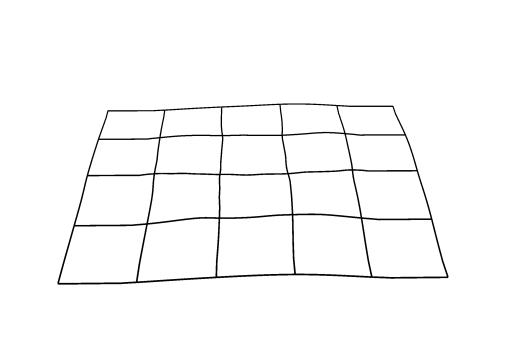
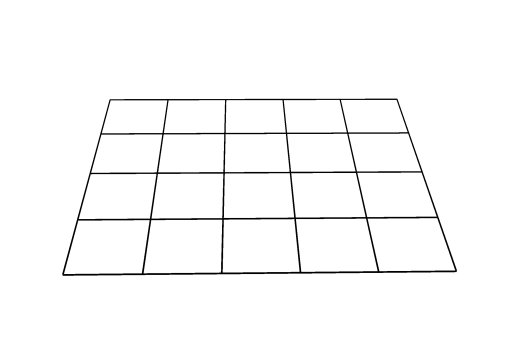
Pulmonary Contrast- and Non-contrast- Enhanced Computed Tomography Image Registration Based on Multi-resolution B-spline Transformation

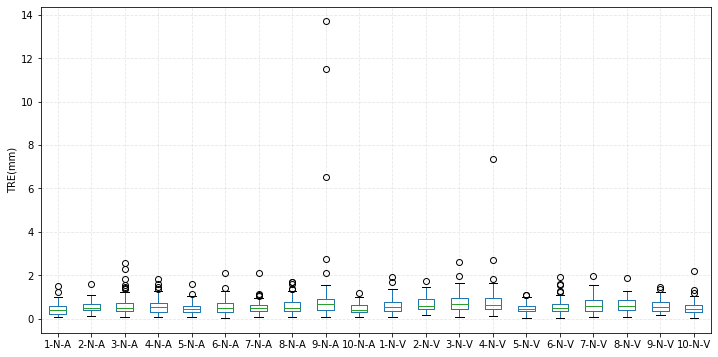
**Supplementary Figures**



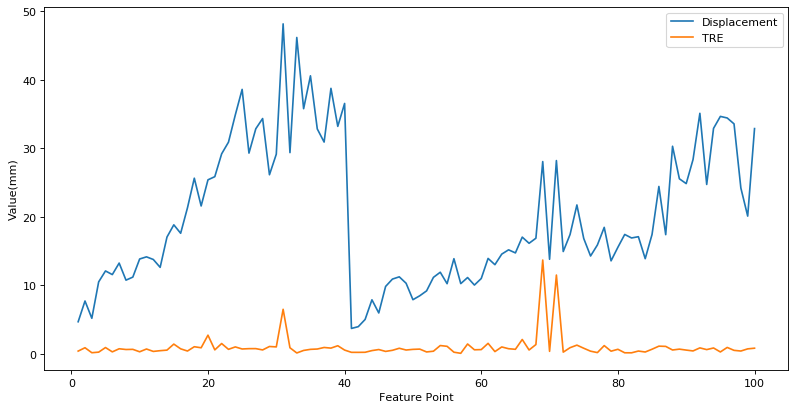
**Supplementary Fig. 1** Box diagram of the lung feature point displacements for all 10 cases



**Supplementary Fig. 2** Coarse-to-fine registration for multi-resolution B-spline transformation with resolutions 64, 32, 16, and 8. The first column shows the control grids, while the second column shows the control grids after B-spline transformation.



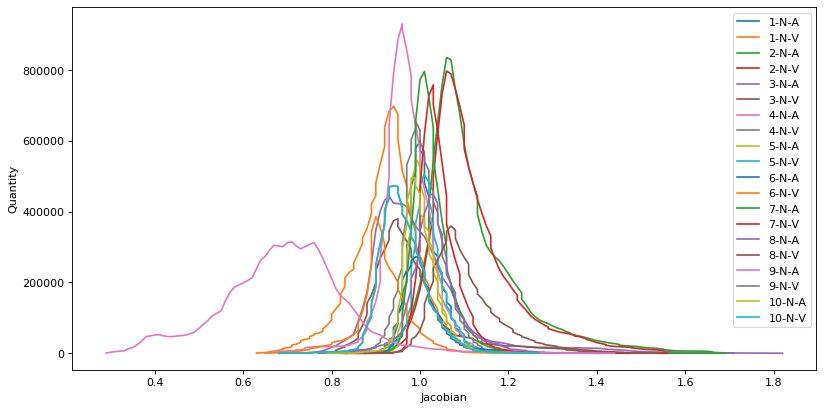
**Supplementary Fig. 3** Box diagram of the target registration error (TRE) for each case.



**Supplementary Fig.4** Line chart of the displacement and target registration error (TRE) for case 9-N-A.

|  |
| --- |
|  |
| (a) |
|  |
| (b) |
|  |
| (c) |
|  |
| (d) |

**Supplementary Fig. 5** Three-dimensional lung vessel reconstruction of case 9. (a) The green vessel represents the plain scan (C); the red vessel represents the arterial-phase scan (A) before registration. (b) The green vessel represents the plain scan (C); the blue vessel represents the venous-phase scan (V) before registration. (c) The green vessel represents the plain scan (C); the red vessel represents the arterial-phase scan (A) after registration. (d) The green vessel represents the plain scan (C); the blue vessel represents the venous-phase scan (V) after registration.



**Supplementary Fig. 6** Line chart of the Jacobian determinants for each case

**Supplementary Tables**

**Supplementary Table 1.** Comparison results (mm) of sampling strategies.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sampling strategy** | | **Before reg** | **Without mask** | **With mask** |
| **Case 1** | N–A | 1.85±0.60 | 0.51±0.26 | 0.43±0.27 |
| N–V | 10.29±3.75 | 0.85±0.91 | 0.58±0.34 |
| **Case 2** | N–A | 10.87±3.99 | 1.05±0.98 | 0.53±0.25 |
| N–V | 10.77±3.10 | 0.99±0.85 | 0.66±0.34 |
| **Case 3** | N–A | 5.29±3.04 | 1.24±1.47 | 0.62±0.43 |
| N–V | 5.08±2.46 | 1.15±1.08 | 0.75±0.41 |
| **Case 4** | N–A | 2.30±0.82 | 0.64±0.39 | 0.57±0.35 |
| N–V | 1.54±0.89 | 0.82±0.77 | 0.80±0.78 |
| **Case 5** | N–A | 3.69±1.16 | 0.67±0.40 | 0.48±0.25 |
| N–V | 2.63±0.96 | 0.61±0.35 | 0.47±0.22 |
| **Case 6** | N–A | 1.96±0.81 | 0.59±0.30 | 0.54±0.32 |
| N–V | 4.48±2.50 | 0.94±0.86 | 0.55±0.32 |
| **Case 7** | N–A | 2.73±1.32 | 0.69±0.51 | 0.52±0.27 |
| N–V | 2.59±1.10 | 0.89±0.81 | 0.64±0.36 |
| **Case 8** | N–A | 2.69±0.97 | 0.64±0.35 | 0.59±0.33 |
| N–V | 3.75±2.80 | 1.01±0.91 | 0.62±0.32 |
| **Case 9** | N–A | **19.79±10.36** | **8.86±7.28** | **1.00±1.82** |
| N–V | 6.97±3.96 | 1.00±0.94 | 0.58±0.27 |
| **Case 10** | N–A | 1.85±0.52 | 0.50±0.21 | 0.46±0.24 |
| N–V | 3.17±1.61 | 0.69±0.51 | 0.49±0.31 |
| **All 10 cases** | | 5.52±5.46 | 1.22±2.51 | 0.59±0.55 |

**Supplementary Table 2.** Comparison results (mm) of final control point spacing in multi-resolution strategies.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Final control point spacing** | | **Before reg** | **64** | **32** | **16** | **8** |
| **Case 1** | N–A | 1.85±0.60 | 0.49±0.26 | 0.46±0.27 | 0.43±0.27 | 0.44±0.26 |
| N–V | 10.29±3.75 | 0.92±0.53 | 0.69±0.41 | 0.58±0.34 | 0.58±0.35 |
| **Case 2** | N–A | 10.87±3.99 | 1.12±0.73 | 0.68±0.39 | 0.53±0.25 | 0.50±0.35 |
| N–V | 10.77±3.10 | 1.21±0.67 | 0.79±0.37 | 0.66±0.34 | 0.64±0.31 |
| **Case 3** | N–A | 5.29±3.04 | 1.06±0.77 | 0.68±0.48 | 0.62±0.43 | 0.63±0.43 |
| N–V | 5.08±2.46 | 1.09±0.76 | 0.82±0.45 | 0.75±0.41 | 0.74±0.44 |
| **Case 4** | N–A | 2.30±0.82 | 0.70±0.36 | 0.63±0.35 | 0.57±0.35 | 0.57±0.35 |
| N–V | 1.54±0.89 | 0.96±0.75 | 0.82±0.77 | 0.80±0.78 | 0.80±0.79 |
| **Case 5** | N–A | 3.69±1.16 | 0.62±0.29 | 0.52±0.26 | 0.48±0.25 | 0.46±0.27 |
| N–V | 2.63±0.96 | 0.62±0.28 | 0.50±0.22 | 0.47±0.22 | 0.46±0.23 |
| **Case 6** | N–A | 1.96±0.81 | 0.64±0.33 | 0.56±0.33 | 0.54±0.32 | 0.51±0.36 |
| N–V | 4.48±2.50 | 0.72±0.37 | 0.62±0.30 | 0.55±0.32 | 0.50±0.30 |
| **Case 7** | N–A | 2.73±1.32 | 0.73±0.35 | 0.62±0.30 | 0.52±0.27 | 0.49±0.30 |
| N–V | 2.59±1.10 | 0.74±0.34 | 0.68±0.33 | 0.64±0.36 | 0.62±0.39 |
| **Case 8** | N–A | 2.69±0.97 | 0.74±0.35 | 0.65±0.35 | 0.59±0.33 | 0.57±0.35 |
| N–V | 3.75±2.80 | 0.80±0.49 | 0.69±0.40 | 0.62±0.32 | 0.57±0.30 |
| **Case 9** | N–A | **19.79±10.36** | **2.27±2.40** | **1.41±1.79** | **1.00±1.82** | **1.09±2.13** |
| N–V | 6.97±3.96 | 1.00±0.79 | 0.71±0.51 | 0.58±0.27 | 0.60±0.28 |
| **Case 10** | N–A | 1.85±0.52 | 0.53±0.25 | 0.50±0.23 | 0.46±0.24 | 0.47±0.25 |
| N–V | 3.17±1.61 | 0.67±0.40 | 0.55±0.32 | 0.49±0.31 | 0.49±0.28 |
| **All 10 cases** | | 5.52±5.46 | 0.88±0.82 | 0.68±0.59 | 0.59±0.55 | 0.59±0.61 |

**Supplementary Table 3.** Comparison results (mm) of final control point resolution in multi-resolution strategies.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Number Of Resolutions** | | **Before reg** | **3** | **4** | **5** | **6** |
| **Case 1** | N–A | 1.85±0.60 | 0.43±0.26 | 0.44±0.26 | 0.43±0.26 | 0.43±0.27 |
| N–V | 10.29±3.75 | 0.58±0.33 | 0.59±0.34 | 0.59±0.34 | 0.58±0.34 |
| **Case 2** | N–A | 10.87±3.99 | 0.54±0.26 | 0.53±0.25 | 0.53±0.25 | 0.53±0.25 |
| N–V | 10.77±3.10 | 0.66±0.34 | 0.65±0.34 | 0.65±0.34 | 0.66±0.34 |
| **Case 3** | N–A | 5.29±3.04 | 0.62±0.42 | 0.63±0.43 | 0.61±0.43 | 0.62±0.43 |
| N–V | 5.08±2.46 | 0.74±0.41 | 0.74±0.41 | 0.75±0.41 | 0.75±0.41 |
| **Case 4** | N–A | 2.30±0.82 | 0.57±0.34 | 0.57±0.34 | 0.55±0.34 | 0.57±0.35 |
| N–V | 1.54±0.89 | 0.80±0.78 | 0.79±0.78 | 0.79±0.78 | 0.80±0.78 |
| **Case 5** | N–A | 3.69±1.16 | 0.47±0.25 | 0.47±0.25 | 0.47±0.25 | 0.48±0.25 |
| N–V | 2.63±0.96 | 0.48±0.22 | 0.47±0.22 | 0.47±0.22 | 0.47±0.22 |
| **Case 6** | N–A | 1.96±0.81 | 0.54±0.33 | 0.53±0.33 | 0.54±0.33 | 0.54±0.32 |
| N–V | 4.48±2.50 | 0.55±0.32 | 0.55±0.32 | 0.56±0.32 | 0.55±0.32 |
| **Case 7** | N–A | 2.73±1.32 | 0.53±0.26 | 0.52±0.26 | 0.52±0.26 | 0.52±0.27 |
| N–V | 2.59±1.10 | 0.65±0.37 | 0.64±0.36 | 0.64±0.36 | 0.64±0.36 |
| **Case 8** | N–A | 2.69±0.97 | 0.59±0.33 | 0.59±0.34 | 0.59±0.34 | 0.59±0.33 |
| N–V | 3.75±2.80 | 0.62±0.32 | 0.63±0.32 | 0.62±0.31 | 0.62±0.32 |
| **Case 9** | N–A | **19.79±10.36** | **4.95±8.58** | **0.96±1.60** | **0.92±1.54** | **1.00±1.82** |
| N–V | 6.97±3.96 | 0.58±0.26 | 0.58±0.26 | 0.59±0.29 | 0.58±0.27 |
| **Case 10** | N–A | 1.85±0.52 | 0.46±0.24 | 0.46±0.24 | 0.46±0.24 | 0.46±0.24 |
| N–V | 3.17±1.61 | 0.49±0.32 | 0.48±0.29 | 0.49±0.31 | 0.49±0.31 |

**Supplementary Table 4.** Comparison results of similarity measures.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Histogram bins** | | **Before reg** | **8** | **16** | **32** | **64** |
| **Case 1** | N–A | 1.85±0.60 | 0.51±0.35 | 0.46±0.29 | 0.44±0.26 | 0.45±0.24 |
| N–V | 10.29±3.75 | 0.74±0.65 | 0.67±0.63 | 0.59±0.34 | 0.57±0.33 |
| **Case 2** | N–A | 10.87±3.99 | 2.80±5.34 | 0.82±1.03 | 0.53±0.25 | 0.51±0.23 |
| N–V | 10.77±3.10 | 2.85±5.35 | 1.40±2.76 | 0.65±0.34 | 0.63±0.32 |
| **Case 3** | N–A | 5.29±3.04 | 1.62±2.37 | 1.00±1.22 | 0.63±0.43 | 0.59±0.41 |
| N–V | 5.08±2.46 | 1.59±2.03 | 0.97±0.86 | 0.74±0.41 | 0.73±0.39 |
| **Case 4** | N–A | 2.30±0.82 | 0.68±0.39 | 0.61±0.36 | 0.57±0.34 | 0.56±0.33 |
| N–V | 1.54±0.89 | 0.89±0.80 | 0.83±0.79 | 0.79±0.78 | 0.78±0.78 |
| **Case 5** | N–A | 3.69±1.16 | 0.68±0.75 | 0.47±0.27 | 0.47±0.25 | 0.48±0.25 |
| N–V | 2.63±0.96 | 0.83±1.01 | 0.50±0.27 | 0.47±0.22 | 0.47±0.20 |
| **Case 6** | N–A | 1.96±0.81 | 0.64±0.42 | 0.54±0.34 | 0.53±0.33 | 0.55±0.31 |
| N–V | 4.48±2.50 | 0.65±0.38 | 0.59±0.35 | 0.55±0.32 | 0.55±0.31 |
| **Case 7** | N–A | 2.73±1.32 | 0.62±0.34 | 0.54±0.29 | 0.52±0.26 | 0.52±0.25 |
| N–V | 2.59±1.10 | 0.74±0.42 | 0.66±0.39 | 0.64±0.36 | 0.63±0.35 |
| **Case 8** | N–A | 2.69±0.97 | 0.86±0.76 | 0.63±0.38 | 0.59±0.34 | 0.58±0.30 |
| N–V | 3.75±2.80 | 1.17±1.38 | 0.73±0.43 | 0.63±0.32 | 0.61±0.31 |
| **Case 9** | N–A | **19.79±10.36** | **1.46±2.29** | **1.30±2.14** | **0.96±1.60** | **4.22±7.85** |
| N–V | 6.97±3.96 | 0.70±0.38 | 0.64±0.35 | 0.58±0.26 | 0.57±0.24 |
| **Case 10** | N–A | 1.85±0.52 | 0.59±0.33 | 0.49±0.28 | 0.46±0.24 | 0.46±0.22 |
| N–V | 3.17±1.61 | 0.58±0.35 | 0.52±0.32 | 0.48±0.29 | 0.48±0.28 |
| **All 10 cases** | | 5.52±5.46 | 1.06±2.08 | 0.72±0.98 | 0.59±0.51 | 0.75±1.95 |