

On Unsupervised Methods for Medical Image Segmentation: Investigating Classic Approaches in Breast Cancer DCE-MRI

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Supplementary Materials

Table S1. Dice Index (DI) values obtained by the four investigated unsupervised methods on each of the 50 segmented breast masses on DCE-MRI. In the last row the mean value \pm the standard deviation is reported.

SMRG	k-means	FCM	sFCM
74.5523	77.6812	80.8156	71.913
81.6112	80.2641	83.7927	85.2817
81.1125	72.9021	80.0002	79.8785
73.0397	73.863	77.4577	77.6678
63.0009	76.6988	80.6518	82.4025
65.2639	62.9885	66.0448	72.2373
62.9308	69.6813	71.0732	68.8191
50.209	55.9366	65.6076	65.1683
75.6513	72.2494	77.5294	73.087
67.3168	76.5848	75.8113	81.7189
73.4676	82.7592	79.5216	84.4293
73.2868	81.7125	85.5915	85.2811
77.9424	80.1806	84.2868	77.8859
66.0536	68.4374	70.7215	76.978
72.8335	78.249	82.4652	83.2476
84.4709	77.8979	84.1694	84.8938
69.9567	76.3991	79.8308	75.397
86.0078	85.2594	88.4341	87.0016
78.0735	72.6007	80.9927	81.9666
75.6768	70.5007	72.4215	76.8183
32.2509	58.6519	60.0544	80.7549
79.3964	74.5433	78.7098	73.4655
68.0249	80.926	73.2655	77.4908
80.1226	81.4591	85.7467	86.7711
72.2755	58.1532	71.4013	70.3541
73.8336	64.8001	76.4963	80.2893
73.6567	69.472	78.8079	81.8905
72.3401	64.7638	71.2173	71.8456
64.4008	68.1352	69.4733	78.4099
84.2713	79.3189	84.6474	82.0866
70.1655	58.4357	66.8468	61.1731
81.1409	79.891	79.124	83.2774
66.2517	48.5027	61.523	62.5525
82.7052	80.9903	89.1957	82.5343
43.6629	69.1079	76.2275	75.6799
48.6677	74.9018	81.2143	80.487

75.3722	62.146	75.586	67.973
80.8265	77.1659	82.8026	82.4028
64.7864	76.1511	73.1782	78.4462
74.121	74.1967	82.0072	83.7251
69.2429	60.477	73.3592	68.8143
74.5201	72.4912	77.7498	78.1192
74.298	67.5387	77.2461	76.8669
62.1666	72.8685	72.0753	73.5022
81.5965	80.3457	84.7614	86.4683
85.1588	86.7977	89.9521	90.7555
62.7593	66.7588	76.0502	77.5403
79.396	76.0186	78.4622	80.1921
85.0602	78.2216	82.9549	83.3343
76.2208	76.5857	76.5456	82.1267
71.82 ± 10.83	72.65 ± 8.26	77.48 ± 6.77	78.23 ± 6.50

Table S2. Jaccard Index (JI) values obtained by the four investigated unsupervised methods on each of the 50 segmented breast masses on DCE-MRI. In the last row the mean value ± the standard deviation is reported.

SMRG	k-means	FCM	sFCM
59.7551	65.8785	69.0161	59.8221
69.5155	67.7386	72.3444	74.4492
69.705	60.9891	68.1589	67.3352
58.0614	59.3308	63.9939	63.8456
48.6593	63.0525	68.2861	70.5284
49.5289	47.767	50.8667	57.1047
46.1441	53.5997	55.56	52.6024
35.7038	41.3242	50.1328	49.6028
63.7253	57.8354	64.1959	58.8935
54.0001	63.348	62.6493	69.6497
59.2379	71.0073	66.9512	73.6498
61.7904	70.447	75.5571	75.8576
64.9828	68.2473	73.5825	66.1521
51.3999	54.3713	57.1189	63.1192
59.3332	65.2004	71.1231	72.0338
73.3648	65.2977	73.0495	73.9661
55.7992	64.1896	68.361	63.6537
77.7367	77.2267	81.8341	79.5469
65.4022	60.892	69.2114	70.567
64.98	59.304	61.8383	65.7032
26.0031	49.5461	51.3724	69.3537
67.783	62.7568	66.8139	61.2636
53.8504	69.3618	61.2079	65.303
68.5	71.1325	75.9039	77.1196
60.1603	44.9049	59.4556	56.3269
59.7704	49.9684	63.01	67.3894
58.7884	56.6725	65.3441	69.752

58.1063	49.2088	56.0857	56.9751
49.3982	55.3988	54.9618	64.7393
74.3551	67.9175	73.9309	70.3521
55.7369	43.5485	52.0852	45.7842
70.5614	68.7892	68.1862	72.4061
53.6404	37.6068	48.0681	49.3626
71.0718	71.8954	80.6701	73.2182
31.4953	55.122	61.7782	61.4188
36.0084	60.7833	69.2695	67.6616
62.7262	49.3463	63.9771	54.4086
67.8929	63.5448	70.7093	70.2247
52.4445	63.8756	60.5653	66.7496
59.3128	60.7358	70.0519	72.7911
54.5723	44.6453	58.566	53.8322
59.8545	58.3288	64.2435	64.8991
60.2075	52.9889	63.4346	63.0661
47.1598	57.496	57.5404	58.6067
73.2684	68.4762	74.2091	76.5505
74.2482	77.0614	81.7808	83.0985
49.5568	52.9181	63.0398	64.2608
66.644	62.5138	65.544	67.9595
74.849	66.0083	72.1739	72.0575
62.4125	64.0736	63.4412	70.3248
58.98 ± 11.32	59.87 ± 9.20	65.22 ± 8.13	65.90 ± 8.14

Table S3. Sensitivity values obtained by the four investigated unsupervised methods on each of the 50 segmented breast masses on DCE-MRI. In the last row the mean value \pm the standard deviation is reported.

SMRG	k-means	FCM	sFCM
69.4787	71.3402	76.184	64.8145
83.927	73.0353	83.1099	81.4954
76.5191	62.7034	71.5939	70.882
71.4385	69.1424	75.7859	76.6177
71.6803	78.6729	87.5228	85.5953
73.3642	61.7249	73.6068	71.6696
95.5914	91.7926	95.1876	92.6259
59.4077	52.7039	76.9385	70.0671
78.624	65.6546	76.1374	66.283
70.7872	69.717	80.6877	78.8699
92.7951	81.6848	89.3267	91.3836
68.2334	73.3548	79.9468	79.729
86.682	80.5657	91.3693	78.4704
67.0258	60.145	76.4227	73.9376
67.6775	70.9704	77.7405	78.4162
82.7365	67.9017	76.8326	76.6637
63.3978	71.3347	74.6391	67.0671
82.7338	80.6452	86.5579	84.0008

83.9418	67.1935	88.5257	84.3724
75.2235	62.9094	67.2799	70.4125
39.3074	52.1327	66.261	72.5692
94.6445	72.2817	79.2325	67.3064
86.4276	78.3643	89.0258	71.4348
79.6713	75.885	84.5923	84.6585
67.0922	46.2503	63.6774	58.3471
77.8584	52.5799	71.3632	73.124
78.6089	60.8682	80.8627	78.7742
78.0119	55.6879	74.071	68.1414
81.5818	71.6723	76.9407	79.0362
90.864	71.6388	80.0422	74.0071
75.8755	44.225	54.8458	48.3267
82.9412	74.6911	77.5521	80.7848
69.5292	44.573	58.6972	58.3866
79.518	75.1149	84.6913	75.9966
70.5655	59.478	68.3639	67.5285
40.0118	63.3993	72.9538	70.0873
71.5563	51.1879	68.965	56.3139
90.3557	75.3552	84.168	84.3859
74.548	74.5315	90.9629	84.4747
93.7793	70.7444	86.4132	86.5147
65.2106	50.8363	66.6942	60.5347
80.3049	66.9541	77.2643	74.5879
63.4719	54.001	65.0842	65.0126
65.4998	63.812	73.2973	64.5277
92.5931	69.7096	75.5766	79.9448
91.1406	83.8657	92.0799	90.4339
58.2417	65.1495	79.2895	78.8222
85.384	72.7252	78.5814	79.563
85.6788	69.1775	78.2192	77.1536
92.0715	81.5776	86.6077	80.4825
76.47 ± 12.41	67.23 ± 10.78	77.84 ± 8.72	74.69 ± 9.39

Table S4. Specificity values obtained by the four investigated unsupervised methods on each of the 50 segmented breast masses on DCE-MRI. In the last row the mean value ± the standard deviation is reported.

SMRG	k-means	FCM	sFCM
84.965	92.2979	91.1718	92.9095
81.3086	92.3766	86.0671	90.7752
88.9859	93.2203	93.188	93.401
77.8302	83.7796	81.3668	82.2969
62.1119	79.0139	75.8304	80.7297
59.8741	72.0316	61.3916	75.9033
47.0159	56.2009	57.015	54.8193
45.902	66.1982	61.4892	64.6862
78.4439	88.397	84.8585	88.8974

66.9744	90.2895	75.7427	87.5167
63.0228	87.5133	74.7144	80.8514
87.7922	95.5499	93.4522	94.4677
70.9006	83.6785	78.8086	83.6785
76.0396	89.5646	73.7485	84.1984
88.5144	92.1912	91.136	91.4586
86.684	94.8502	93.5316	95.4133
86.4766	89.7697	91.3582	94.4598
90.5434	92.1444	91.0408	91.3151
73.258	83.7568	76.0613	82.7524
81.9048	92.4681	88.3819	91.393
27.8767	69.8959	57.185	93.9613
70.5914	87.071	81.4537	88.6163
58.9067	88.4024	65.9201	90.9084
85.068	92.6898	89.7537	91.016
80.7529	90.8582	84.5167	95.6713
71.2831	91.5644	83.5581	90.6867
70.058	92.2938	79.2896	86.2415
70.2647	87.6337	71.7932	78.5256
58.5367	66.8622	71.7953	80.2046
81.8876	95.1179	92.6626	95.2248
74.5379	94.973	91.6469	91.7702
81.7691	88.9856	85.9071	89.3307
68.6594	72.6461	72.6882	74.0319
88.2191	95.6806	94.9266	96.1891
38.9249	92.3695	89.9131	90.0601
81.878	93.5285	92.6915	95.8612
81.5067	91.467	86.6601	91.9544
73.5159	81.587	81.837	81.3258
73.2641	87.6205	68.8057	79.7038
62.2777	88.5493	80.0114	83.6007
81.9069	88.8855	87.9912	87.8963
71.5287	86.6635	81.8272	84.7749
94.3704	97.8986	96.8248	96.3526
74.8777	88.7763	81.3526	92.9465
77.9703	97.9437	98.022	95.6576
80.8666	92.0684	88.7759	91.578
74.8711	77.6633	75.8944	79.5084
74.6405	82.2088	78.7255	81.0622
86.4782	94.1848	91.7965	92.9207
66.4171	77.1754	72.4106	85.4094
73.65 ± 13.50	86.97 ± 8.93	81.94 ± 10.41	87.10 ± 8.24

Table S5. False Positive Ratio (FPR) values obtained by the four investigated unsupervised methods on each of the 50 segmented breast masses on DCE-MRI. In the last row the mean value ± the standard deviation is reported.

SMRG	k-means	FCM	sFCM
0.1658	0.1046	0.0743	0.0799
0.2157	0.154	0.0961	0.075
0.1154	0.0561	0.0603	0.0298
0.2352	0.1899	0.1977	0.1629
0.5003	0.3095	0.228	0.2478
0.5264	0.5011	0.2707	0.3143
1.0939	0.7491	0.7668	0.7168
0.759	0.667	0.5186	0.2989
0.3665	0.2557	0.155	0.1605
0.404	0.3615	0.1462	0.1084
0.6776	0.3948	0.2734	0.1669
0.0911	0.0619	0.0504	0.0395
0.3633	0.2637	0.1862	0.1862
0.5383	0.5802	0.2104	0.1082
0.1677	0.1242	0.1218	0.1146
0.1285	0.0549	0.0372	0.039
0.1327	0.0903	0.0481	0.1066
0.1525	0.1768	0.1391	0.0958
0.2999	0.3289	0.2337	0.1095
0.1527	0.0875	0.0703	0.0565
0.7503	0.555	0.0458	0.0577
0.5315	0.2632	0.1444	0.1874
0.8124	0.6913	0.0993	0.1542
0.1853	0.1298	0.1125	0.0687
0.1235	0.0793	0.0316	0.0299
0.334	0.1523	0.085	0.0641
0.3505	0.2478	0.1309	0.06
0.4436	0.3676	0.2478	0.1109
0.9181	0.4852	0.2372	0.2868
0.3364	0.108	0.0584	0.0592
0.5644	0.0596	0.0575	0.0203
0.2595	0.2174	0.1484	0.0953
0.3542	0.2522	0.2166	0.1936
0.1143	0.0497	0.0343	0.0393
2.2879	0.1005	0.0986	0.0658
0.0943	0.0569	0.0337	0.0461
0.1491	0.0823	0.0364	0.0359
0.3304	0.1917	0.2102	0.1932
7.3719	0.7713	0.4025	0.2463
0.6197	0.256	0.2284	0.163
0.2595	0.1772	0.1664	0.1586
0.3482	0.2072	0.1457	0.1302
0.05	0.0247	0.0291	0.0155
0.5246	0.4423	0.0963	0.1116
0.7718	0.0176	0.0489	0.018
0.2288	0.1283	0.089	0.0842

0.187	0.3237	0.2846	0.275
0.305	0.2185	0.1886	0.1731
0.1886	0.1023	0.0912	0.0513
0.5437	0.4605	0.1529	0.3965
0.55 ± 1.05	0.25 ± 0.20	0.16 ± 0.13	0.14 ± 0.12

Table S6. False Negative Ratio (FNR) values obtained by the four investigated unsupervised methods on each of the 50 segmented breast masses on DCE-MRI. In the last row the mean value \pm the standard deviation is reported.

SMRG	k-means	FCM	sFCM
0.2866	0.3519	0.3052	0.2382
0.2696	0.185	0.1607	0.1689
0.373	0.2912	0.2348	0.2841
0.3086	0.2338	0.2856	0.2421
0.2133	0.144	0.2832	0.1248
0.3828	0.2833	0.2664	0.2639
0.0821	0.0737	0.0441	0.0481
0.473	0.2993	0.4059	0.2306
0.3435	0.3372	0.2138	0.2386
0.3028	0.2113	0.2921	0.1931
0.1832	0.0862	0.072	0.1067
0.2665	0.2027	0.3177	0.2005
0.1943	0.2153	0.1332	0.0863
0.3985	0.2606	0.3297	0.2358
0.2903	0.2158	0.3232	0.2226
0.321	0.2334	0.1726	0.2317
0.2867	0.3293	0.366	0.2536
0.1935	0.16	0.1727	0.1344
0.3281	0.1563	0.1606	0.1147
0.3709	0.2959	0.2478	0.3272
0.4787	0.2743	0.6069	0.3374
0.2772	0.3269	0.0536	0.2077
0.2164	0.2857	0.1357	0.1097
0.2412	0.1534	0.2033	0.1541
0.5375	0.4165	0.3291	0.3632
0.4742	0.2688	0.2214	0.2864
0.3913	0.2123	0.2139	0.1914
0.4431	0.3186	0.2199	0.2593
0.2833	0.2096	0.1842	0.2306
0.2836	0.2599	0.0914	0.1996
0.5577	0.5167	0.2412	0.4515
0.2531	0.1922	0.1706	0.2245
0.5543	0.4161	0.3047	0.413
0.2489	0.24	0.2048	0.1531
0.4052	0.3247	0.2943	0.3164
0.366	0.2991	0.5999	0.2705

0.4881	0.4369	0.2844	0.3103
0.2464	0.1561	0.0964	0.1583
0.2547	0.1553	0.2545	0.0904
0.2926	0.1349	0.0622	0.1359
0.4916	0.3947	0.3479	0.3331
0.3305	0.2541	0.197	0.2274
0.46	0.3499	0.3653	0.3492
0.3619	0.3547	0.345	0.267
0.3029	0.2006	0.0741	0.2442
0.1613	0.0957	0.0886	0.0792
0.3485	0.2118	0.4176	0.2071
0.2727	0.2044	0.1462	0.2142
0.3082	0.2285	0.1432	0.2178
0.1842	0.1952	0.0793	0.1339
0.33 ± 0.11	0.25 ± 0.09	0.23 ± 0.12	0.22 ± 0.09

Table S7. Mean Absolute Distance (MAD) values obtained by the four investigated unsupervised methods on each of the 50 segmented breast masses on DCE-MRI. In the last row the mean value \pm the standard deviation is reported.

SMRG	k-means	FCM	sFCM
1.2956	1.1454	1.0009	1.0367
0.8757	0.8687	0.7444	0.6874
2.5873	2.9727	2.4371	2.6494
2.2854	2.167	1.9995	1.9543
1.6407	1.0775	1.0556	0.7385
1.6132	1.5766	1.9961	1.2792
2.6446	2.1494	1.9384	2.2315
4.2677	2.2376	2.5845	2.4052
3.0087	2.6024	2.4604	2.5289
1.125	0.7207	0.9258	0.6878
1.2988	0.6268	0.9226	0.5662
1.3197	1.2118	1.0447	1.0074
0.99	0.7686	0.6275	0.7847
2.5649	1.7339	2.5404	1.7045
1.7592	1.5297	1.272	1.2676
0.8897	1.116	0.8722	0.8416
2.0465	1.7981	1.4398	1.4842
4.4224	3.9124	7.813	3.937
1.2105	1.1612	1.2639	1.0539
0.9748	1.1474	0.9318	0.9384
5.151	1.8007	2.3604	0.6323
3.7997	2.5767	2.8482	2.5567
2.5567	1.3183	2.5995	1.1139
1.2994	1.1477	1.0147	0.973
1.168	1.3201	1.0701	1.2546
0.896	0.9963	0.7211	0.6109

1.2739	0.9483	0.9567	0.7615
1.2873	1.2363	1.2432	1.2335
1.6239	1.4675	1.2065	0.8026
1.2828	1.216	1.0943	1.1006
3.2605	2.5644	2.1649	2.3789
1.3822	1.3355	1.473	1.2538
4.935	6.3627	5.1601	5.1947
1.2282	1.1698	0.8425	1.133
7.8347	1.9616	1.7345	1.8279
1.2496	1.0603	0.8331	0.8728
0.9743	1.1389	0.8352	1.1429
0.6707	0.7692	0.5823	0.6899
3.5399	0.826	1.2042	0.9009
1.0731	0.7067	0.6207	0.5454
1.1068	1.4777	1.0052	1.1438
1.0398	0.8919	0.8029	0.7346
2.9629	3.501	2.7087	2.7514
1.6246	1.1552	1.3999	1.079
2.2043	1.2241	0.9808	0.8903
0.8481	0.7221	0.6178	0.515
1.4212	1.6102	1.5693	1.4781
1.1551	1.1384	1.1276	0.9862
1.0303	1.3917	1.1379	1.1014
1.4391	1.4795	1.4346	0.8909
2.00 ± 1.41	1.58 ± 0.99	1.58 ± 1.22	1.37 ± 0.90

Table S8. Maximum Distance (MaxD) values obtained by the four investigated unsupervised methods on each of the 50 segmented breast masses on DCE-MRI. In the last row the mean value \pm the standard deviation is reported.

SMRG	k-means	FCM	sFCM
3.2021	2.9945	2.5897	3.0777
2.4472	2.1307	1.8372	1.9715
10.2381	9.6884	9.2446	9.8692
7.3296	6.2083	6.714	6.048
4.5897	2.7602	3.3304	1.8845
5.2153	4.5098	6.5503	4.4682
7.0168	6.047	5.5277	6.3119
10.0841	6.3242	7.0558	6.941
9.193	8.3016	8.3411	7.6906
3.2787	1.713	2.3976	1.7721
3.8457	1.497	2.5492	1.3786
3.6229	3.3655	2.9291	2.7084
3.4286	2.0592	2	2.0028
7.185	4.4476	6.7093	4.8857
4.7428	3.9733	3.1891	3.2154
2.5081	2.5954	2.3179	2.1706

6.9187	6.0825	5.3856	4.9707
14.6395	11.1933	15.1056	11.5394
3.1552	2.9555	3.6305	3.0448
2.9434	3.003	2.6873	2.708
9.3118	3.6167	6.0016	2.1675
14.182	8.645	10.0555	8.3577
6.8542	3.645	6.885	2.8895
4.088	3.1683	2.8931	3.095
3.7488	4.1802	3.6971	4.2198
1.9799	1.8381	1.5635	1.4523
4.0141	2.1212	2.2949	2.0578
3.1767	2.6778	3.2075	3.2939
3.888	2.9709	2.9126	2.1262
3.5024	3.2534	3.2151	3.1981
9.8003	6.09	5.7575	6.4123
3.5648	3.7131	3.9902	3.5279
15.2682	14.8121	15.3369	15.5206
4.1546	3.4942	2.5819	3.5516
18.6177	5.1254	5.2303	5.2426
2.9738	2.8905	2.3305	2.5816
2.5839	3.0448	2.3916	3.3823
1.6828	1.9625	1.4485	1.8454
6.2831	2.1805	3.2591	2.697
3.6187	1.7153	1.8485	1.5211
2.3301	2.7314	2.2129	2.3657
2.8373	1.8918	1.8664	1.6898
9.4417	9.8105	9.2873	9.2691
3.8352	2.8594	3.2949	2.7411
6.7449	3.0471	2.3914	2.4767
2.6166	1.9888	1.5897	1.5174
4.1166	5.0194	5.2575	5.2835
3.6067	3.218	3.3786	3.0194
3.2646	3.6197	3.2376	3.2318
3.9297	3.8372	3.4987	2.3748
5.63 ± 3.81	4.22 ± 2.73	4.46 ± 3.12	4.04 ± 2.87

Table S9. Hausdorff Distance (HD) values obtained by the four investigated unsupervised methods on each of the 50 segmented breast masses on DCE-MRI. In the last row the mean value ± the standard deviation is reported.

SMRG	k-means	FCM	sFCM
2.3304	2.4239	2.2067	2.443
1.8864	1.8683	1.8846	1.8765
2.975	2.9505	2.9026	2.9933
2.7219	2.5167	2.5227	2.5271
2.063	1.8607	1.7767	1.7767
2.8406	2.8419	2.8513	2.7813

2.2492	2.3607	2.2172	2.4426
2.2458	2.3857	2.3508	2.5095
2.7297	2.6662	2.6306	2.6586
1.6153	1.4913	1.5504	1.5504
1.854	1.5958	1.6724	1.5504
2.4963	2.2504	2.2064	2.1071
2.0292	1.8423	1.7515	1.8806
2.8382	2.6291	2.7709	2.6134
2.3317	2.2612	2.1457	2.1654
1.8325	1.9585	1.8995	1.8558
3.1306	3.0822	2.9756	2.9768
3.3795	3.211	3.2902	3.1954
2.0372	2.0372	2.0111	1.9111
2.331	2.2541	2.333	2.1794
2.5431	2.3819	2.1864	2.2795
2.8167	2.7053	2.7613	2.713
2.1646	2.0202	2.1444	1.9334
2.1563	2.1374	2.0804	2.0879
2.8928	2.9084	2.9232	2.8625
1.7563	1.7472	1.721	1.7825
2.0755	1.9189	1.8086	2.0214
1.5949	1.7856	1.7693	1.7693
1.9596	1.9182	1.9036	1.8032
2.4134	2.2887	2.2303	2.2873
3.0625	2.5597	2.626	2.6008
2.2585	2.2282	2.3094	2.2289
2.9283	2.8314	2.8001	2.8592
2.5908	2.475	2.3713	2.4164
2.7784	2.1933	2.1367	2.2355
2.2117	2.0597	2.048	1.9877
2.1527	2.3303	2.1516	2.3418
1.5949	1.8864	1.6685	1.7856
2.3326	1.5707	1.7071	1.6547
1.8392	1.8392	1.8392	1.6585
2.1798	1.9827	2.0408	2.0835
1.8423	1.7969	1.7178	1.6203
3.0391	3.1606	3.056	3.1574
2.1856	2.1474	2.1551	2.0551
2.0369	1.884	1.7813	1.8389
2.0368	2.1339	1.9929	1.9824
2.4448	2.4631	2.4592	2.5547
1.8325	1.7655	1.7655	1.7655
2.3103	2.2701	2.23	2.1665
2.0168	2.0035	2.1231	1.8223
2.32 ± 0.44	2.24 ± 0.42	2.21 ± 0.43	2.21 ± 0.44