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Abstract

Purpose

The Agatston scoring method fails to identify all the calcium in cardiac computed tomography (CT) scans, especially for calcifications within the low-density regime. A new approach that eliminates the need for thresholding and provides more accurate and reproducible quantification of calcium mass is necessary.

Materials and Methods

The accuracy of integrated intensity and volume fraction techniques in measuring calcium mass was assessed. Integrated intensity calcium mass, volume fraction calcium mass, Agatston scoring, and spatially weighted calcium scoring were compared to the known calcium mass in both simulated and physical phantoms. The simulation was designed to resemble a 320-slice CT scanner. Fat rings were incorporated into the simulated phantoms, resulting in small (30x20 cm2), medium (35x25

cm2), and large (40x30 cm2) phantoms. Three calcification inserts of varying diameters and hydroxyapatite densities were placed within the phantoms. Calcium mass measurements were repeated across different beam energies, patient sizes, insert sizes, and densities.

Results

In the phantoms, integrated intensity calcium mass and volume fraction calcium mass demonstrated lower root mean squared error (RMSE) and deviation (RMSD) values than Agatston scoring for all measurements. Specifically, integrated calcium mass (RMSE: 0.49 mg, RMSD: 0.49 mg) and volume fraction calcium mass (RMSE: 0.58 mg, RMSD: 0.57 mg) were more precise for low-density (25-100 mgHAcm-3) calcium measurements than Agatston scoring (RMSE: 3.70 mg, RMSD: 2.30 mg). Likewise, integrated calcium mass (7.87%) and volume fraction calcium mass (10.19%) had fewer false-negative (CAC=0) measurements than Agatston scoring (40.74%) and spatially weighted calcium scoring (13.43%). The percentage of false-negative (CAC=0) calcium measurements was even more pronounced in the low-density regime: integrated calcium mass (15.74%), volume fraction calcium mass (20.37%), Agatston scoring (75.00%), and spatially weighted calcium scoring (26.85%).

Conclusion

The integrated calcium mass and volume fraction calcium mass techniques offer better accuracy, reproducibility, and sensitivity than Agatston and spatially weighted calcium scoring methods. These techniques are particularly effective for low-density calcifications (25-100 mgHAcm-3), where the Agatston scoring approach suffers.

Clinical Significance

The integrated calcium mass and volume fraction calcium mass techniques have the potential to enhance risk stratification for patients undergoing calcium scoring and improve risk assessment compared to the traditional Agatston scoring method.

Figures

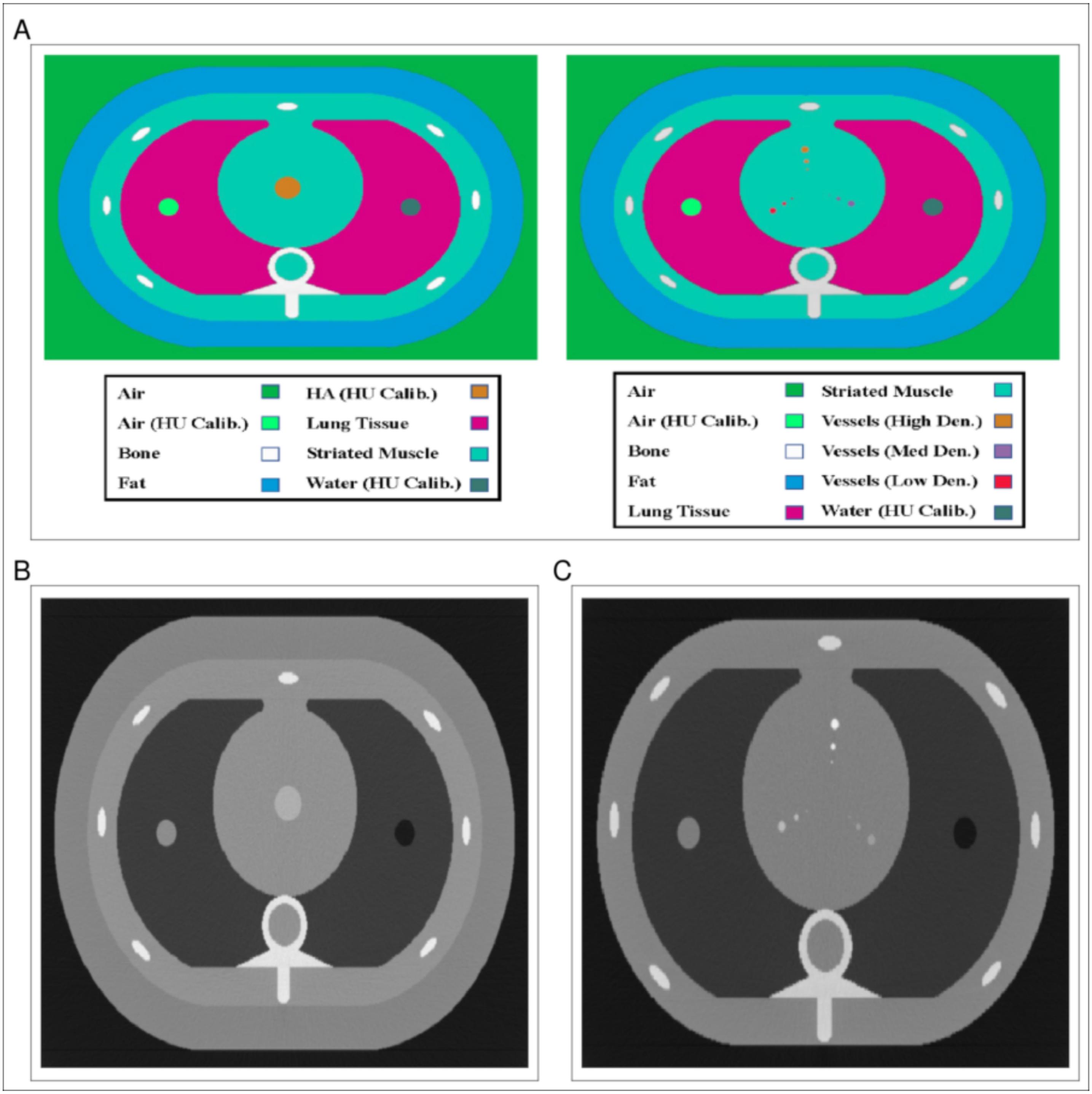

Fig. 1 Shows a sketch (A) of the simulated phantom with the colors highlighting the different materials in the simulated phantoms, (B) a medium-sized phantom at 120 kV with a cross-section of the calibration rod, (C) a small-sized phantom at 120 kV with a cross-section of the normal-density (200, 400, 800 mgHAcm-3) inserts.

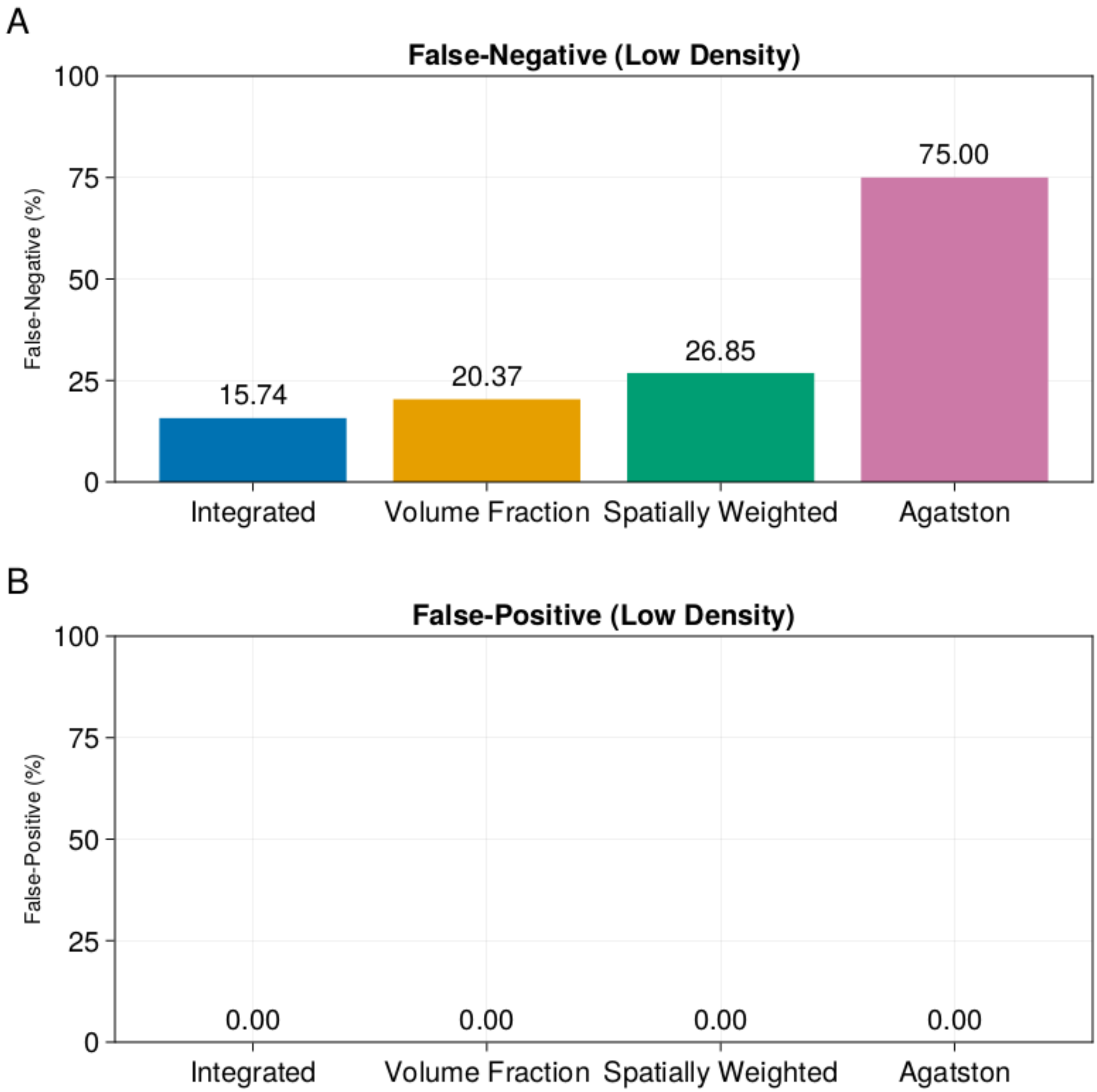

Fig 2. Shows the percentage of false-negative (CAC=0) and false-positive (CAC>0) scores for the low-density (25, 50, 100 mgHAcm-3) inserts. Every tube voltage (80, 100, 120, 135 kV) and size (small, medium, large) is included in the analysis.

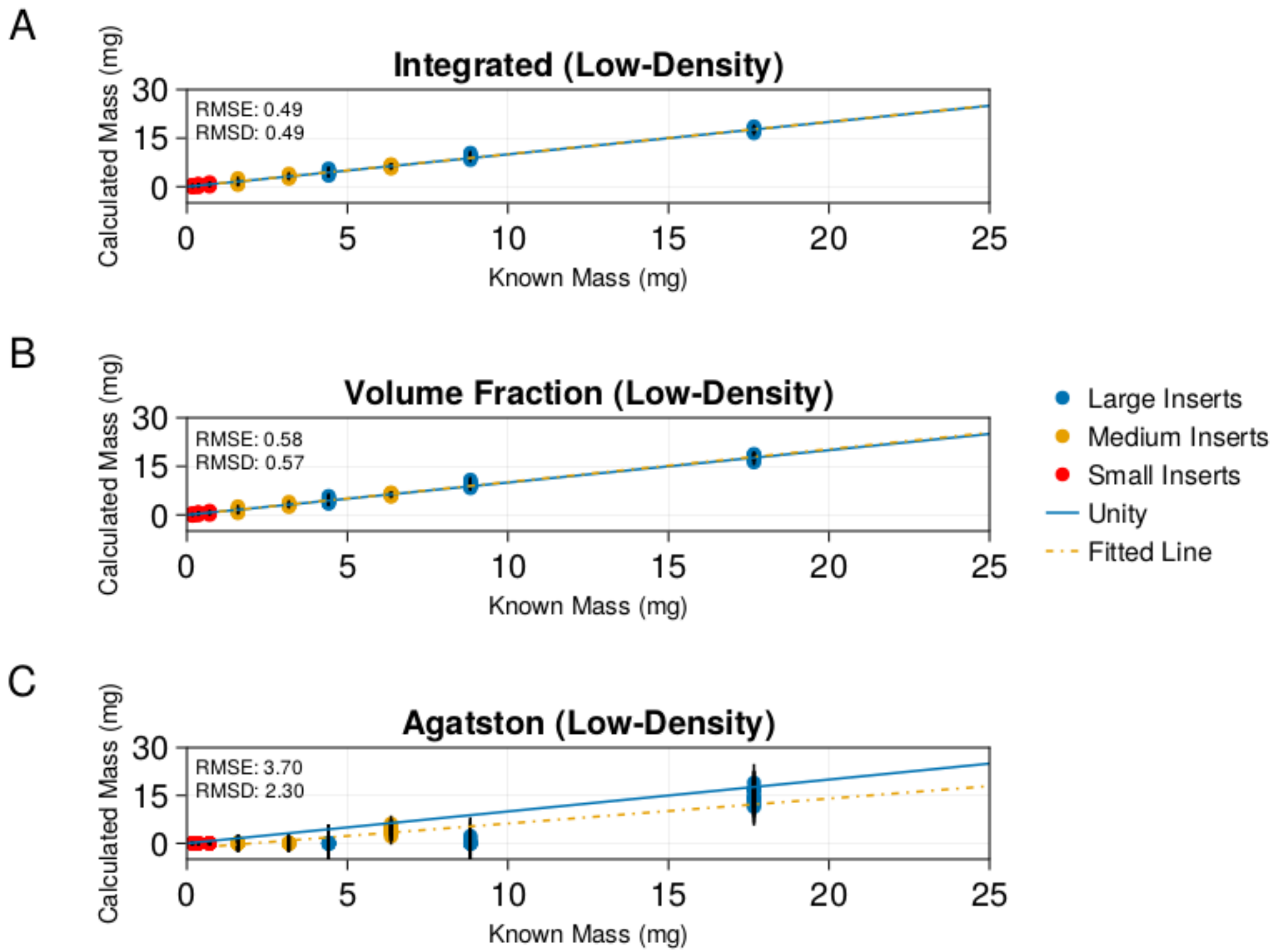

Fig. 3 Shows the linear regression analysis comparing measured calcium to the known calcium for the low-density (25, 50, 100 mgHAcm-3) phantoms. Every tube voltage (80, 100, 120, 135 kV) and size (small, medium, large) is included in the analysis. (A) shows the results of integrated calcium mass. (B) shows the results of the volume fraction method. (C) shows the results of Agatston mass scoring. The best-fit line, along with the root mean squared error (RMSE) and root mean squared deviation (RMSD) values are shown in each plot. The small, medium, and large inserts label corresponds to the insert diameter (1, 3, and 5 mm, respectively).

Appendix

This is for preparing the abstract only. Will not be shown in the actual abstract

```
using Images, CairoMakie, PlutoUI
```

```
const FIG_DIR = joinpath(dirname(dirname(pwd())), "figures");
```

```
stationary_dir = joinpath(FIG_DIR, "stationary");
```

```
medphys_theme = Theme(
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    )
);
```

```julia
function combined_img()
    img1 = load(joinpath(FIG_DIR, "phantom materials.png"))
    img2 = load(joinpath(FIG_DIR, "slice_rod_120_medium_normal.png"))
    img3 = load(joinpath(FIG_DIR, "slice_inserts_120_small_normal.png"))

    f = Figure(resolution = (1800, 1800))

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    heatmap!(rotr90(img1))
    hidedecorations!(ax)

    ax = CairoMakie.Axis(f[2, 1])
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    hidedecorations!(ax)

    ax = CairoMakie.Axis(f[2, 2])
    heatmap!(rotl90(img3))
    hidedecorations!(ax)

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            label;
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            padding=(0, 0, 0, 0),
            halign=:right,
        )
    end

    save(joinpath(dirname(dirname(pwd())),"figures", "combined.png"), f)
    f
end;
```

```julia
combined_img();
```