

Supplementary Information

Geometric, acquisition and image-formation limits of two-dimensional ultrasound volumetry across simulated fluid-filled structures

Online Resource 1

Physical and Engineering Sciences in Medicine

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Supplementary Table S1. Frozen geometry design spaces

Family	Volume (mL)	Principal shape ranges	Additional morphology
Bladder-like	10-500	L/W 1.10-2.40; W/H 1.00-1.60; longitudinal and transverse exponents 1.70-3.00	Pearness -0.15 to 0.35; neck taper 0-0.30; mild LR/DV asymmetry
Simple cyst-like	1-300	Exact triaxial ellipsoid; major/intermediate 1.00-1.50; intermediate/minor 1.00-1.30	No taper, lobulation, or asymmetry
Gallbladder-like	5-120	L/W 1.60-3.20; W/D 0.85-1.20; longitudinal exponent 1.60-2.40	Pearness 0.15-0.45; neck taper 0.15-0.45; mild centerline asymmetry
Dilated renal collecting-system-like	1-65	Longitudinal/AP 1.20-3.20; transverse/AP 1.20-2.80	Pelvis-dominant or 2-4 communicating lobes; funnel taper 0.10-0.35

Supplementary Table S2. Definitive synthetic-ultrasound parameters

Parameter	Frozen value
Engine	PyMUST 0.1.9 / SIMUS
Probe	C5-2v convex
Native center frequency	3.57 MHz
Elements / pitch / radius	128 / 0.508 mm / 49.57 mm
Bandwidth	79%
Transmission	Single zero-delay
B-mode grid	256×256 polar
Dynamic range	30 dB
Scatterer density	5.882/mm ²
Explicit wall	No
Localization	Target-aware positive outward gradient centroid
Search window / smoothing	±4 mm / 0.7 mm Gaussian
Wall-localization QC	≤2.0 mm
Median / max dimension QC	≤1.5 mm / ≤3.0 mm
Center QC	≤2.0 mm
Fan-support QC	≤2.0 mm

Supplementary Table S3. Acquisition perturbation effect in the primary bladder-like design

Formula	Mean Δ APE A-G (pp)	Median Δ APE (pp)	APE worsened (%)	APE improved (%)	$ \Delta$ APE >5 pp (%)
0.52	+2.27	+1.27	60.7	39.3	38.2
0.2 π	-1.08	-0.49	45.6	54.4	40.2
0.625	-1.80	-0.87	41.8	58.2	36.9

Supplementary Table S4. Effective coefficient distributions

Geometry family	Stage	Mean k_true	Median k_true	5th-95th percentile
Bladder-like	G	0.591	0.593	0.493-0.684
Bladder-like	A	0.611	0.608	0.510-0.724
Bladder-like	U	0.625	0.620	0.511-0.760
Simple cyst-like	G	0.524	0.524	0.524-0.524
Simple cyst-like	A	0.536	0.534	0.523-0.555
Simple cyst-like	U	0.551	0.555	0.511-0.599
Gallbladder-like	G	0.545	0.548	0.470-0.614
Gallbladder-like	A	0.622	0.604	0.483-0.819
Gallbladder-like	U	0.685	0.706	0.474-0.934
Dilated renal collecting-system-like	G	0.531	0.515	0.421-0.689
Dilated renal collecting-system-like	A	0.549	0.533	0.487-0.678
Dilated renal collecting-system-like	U	0.546	0.554	0.444-0.651

Supplementary Table S5. Primary morphology associations with k_true in exact geometry

Factor	Spearman ρ with k_true
longitudinal shape exponent	0.825
transverse shape exponent	0.502
pearness	0.151
caudal neck taper	-0.046
length to width ratio	-0.001
width to height ratio	0.001
target volume ml	0.000
dorsoventral asymmetry	0.000
left right asymmetry	-0.000

Supplementary Table S6. Primary agreement and heteroscedasticity diagnostics

Stage	Formula	Geometric bias (%)	Ratio LoA as %	ρ volume vs error	ρ volume vs APE	Log-log slope
G	0.52	-11.6	-27.5 to +7.8	0.798	-0.000	0.997
G	0.2π	+6.8	-12.4 to +30.3	0.732	-0.002	1.001
G	0.625	+8.1	-10.2 to +30.1	0.736	0.002	1.023
A	0.52	-14.4	-30.6 to +5.5	0.825	0.001	1.000
A	0.2π	+3.4	-16.1 to +27.5	0.745	0.004	1.001
A	0.625	+4.5	-13.4 to +26.0	0.743	0.004	1.005
U	0.52	-16.2	-34.2 to +6.8	0.793	-0.117	0.924
U	0.2π	+1.3	-20.5 to +29.1	0.722	-0.089	0.923
U	0.625	+2.4	-17.3 to +26.7	0.713	-0.085	0.918

Supplementary Table S7. Sensitivity analysis for the three preserved wall-localization QC exceptions

Formula	Primary median APE	Exclude QC exceptions	Change (pp)	Primary fail >15%	Exclude fail >15%	Force QC cases fail
0.52	16.29	16.10	-0.19	54.3	53.8	54.3
0.2π	8.23	8.46	+0.23	24.7	24.9	25.8
0.625	7.75	7.85	+0.10	20.6	20.9	21.7

Supplementary Figure S1

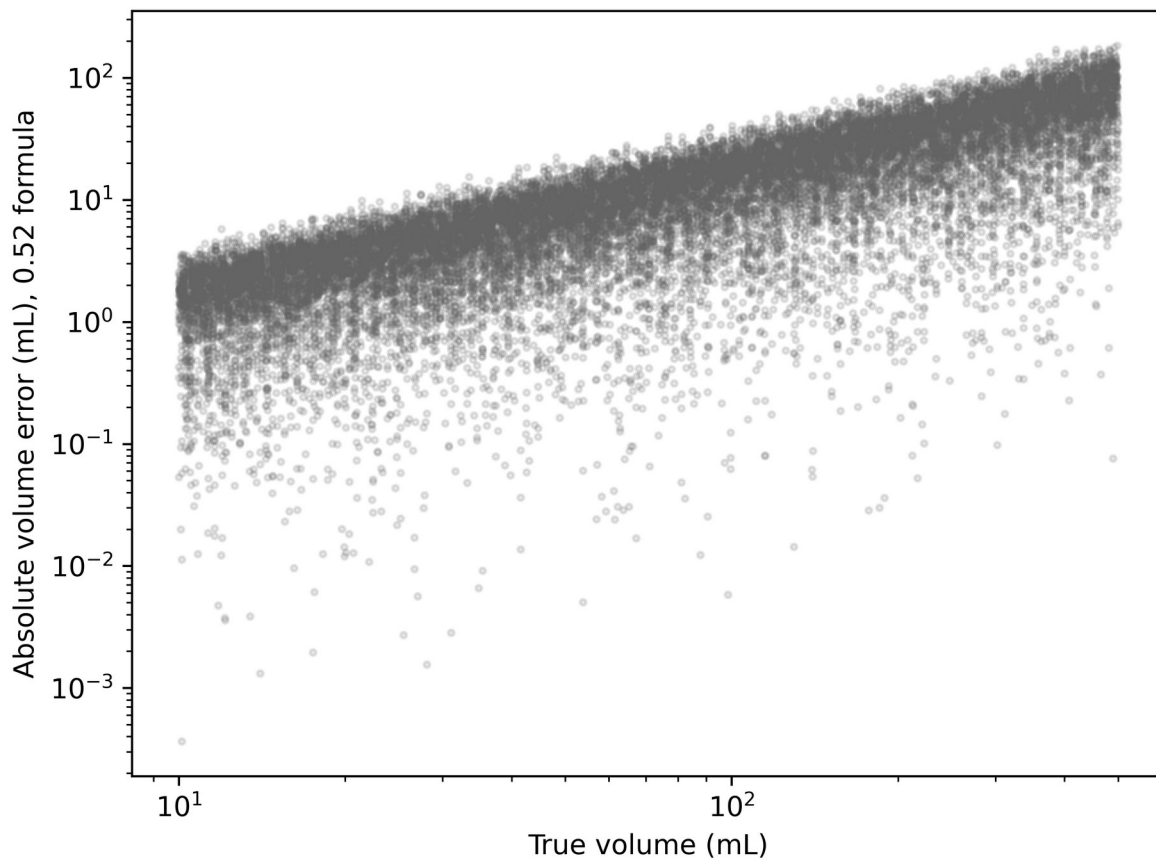


Fig. S1 Absolute volumetric error for the 0.52 formula versus true volume in acquisition-perturbed geometry. Logarithmic axes show the approximately multiplicative error structure: absolute error scales strongly with volume whereas percentage error is essentially volume-independent

Supplementary Figure S2

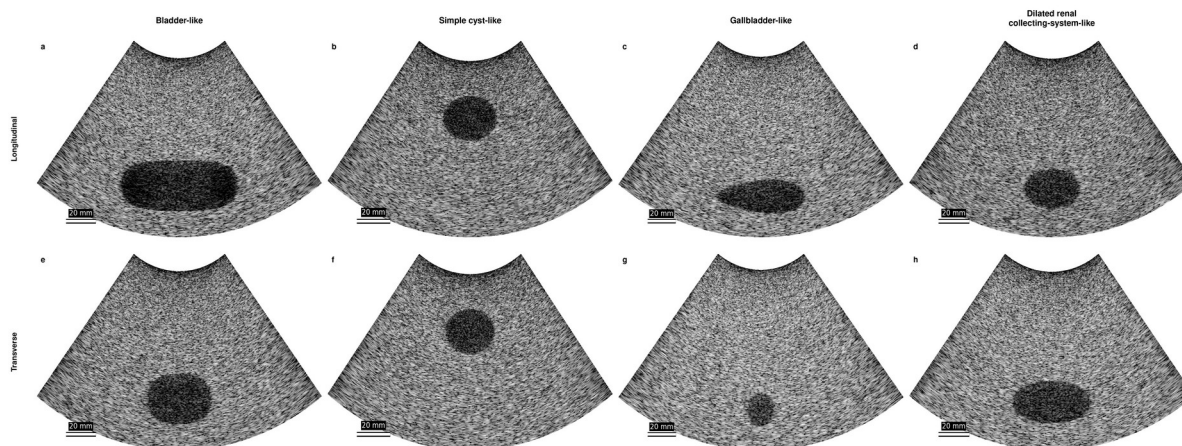


Fig. S2 The same prospectively selected acquisitions shown as unannotated synthetic B-mode images. Columns and rows correspond to Fig. 7. Scale bars indicate 20 mm