Quantitative Assessment of Bone-Selective MRI Techniques for Craniofacial Imaging

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BACKGROUND & PURPOSE

- CT is the clinical standard for evaluation and surgical planning of craniofacial skeletal pathologies. However, there are concerns of ionizing radiation exposure for pediatric patients. **Bone-selective MRI can serve as an ionizing-radiation-free alternative to CT**.
- Bone has relatively low proton density (~20% by volume) and short T_2 relaxation time (~0.5 ms), and thus both bone and air appear black in standard MRI. "Black-bone" MRI has been espoused as a technique for craniofacial imaging using conventional 3D gradient-echo (GRE).
- Unlike GRE, **ultrashort/zero echo time (UTE/ZTE)** sequences are "solid-state" MRI techniques that capture the short T_2 signal of bone tissues before it decays, and hence, can differentiate bone from air.

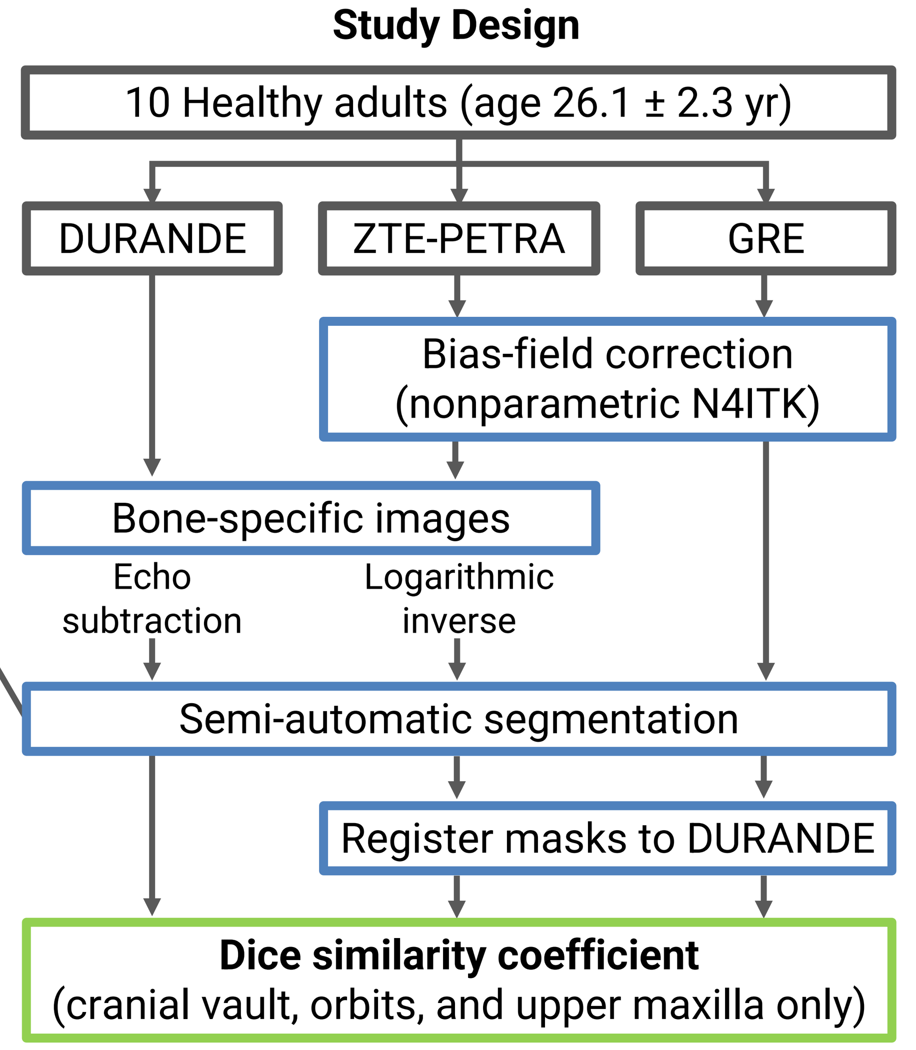
Purpose: to assess the efficacy of the solid-state MRI methods for skull imaging (UTE/ZTE) compared to each other and to "black-bone"-MRI. This was achieved by examining the mutual bias of their binary images and the relative agreement in standard craniometric measurements derived from 3D skull reconstructions.

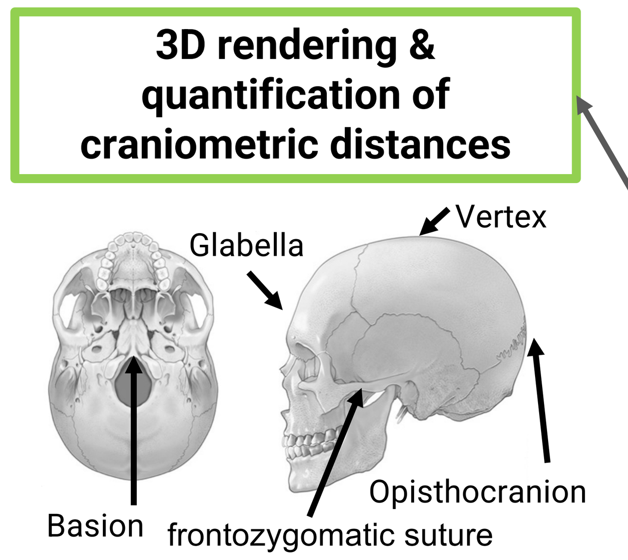
METHODS

Three MRI sequences:

1. **DURANDE** (3D dual-radiofrequency and dual-echo UTE).[1]
2. **ZTE-PETRA** (pointwise-encoding, time reduction with radial acquisition).[2]
3. **GRE** (or black-bone MRI).[3]

Study Design





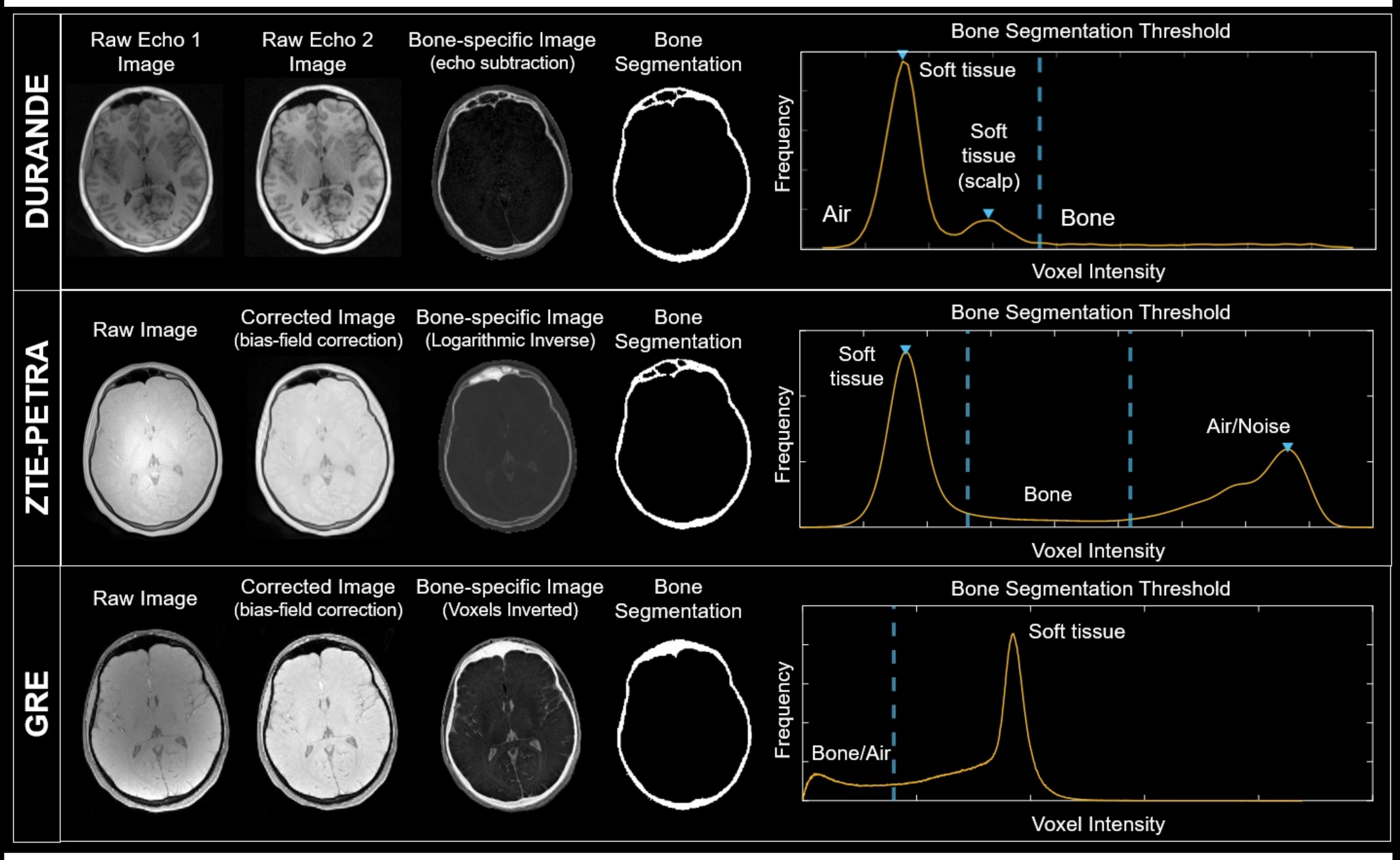


Fig 1. Raw and processed images from the three MRI sequences

RESULTS

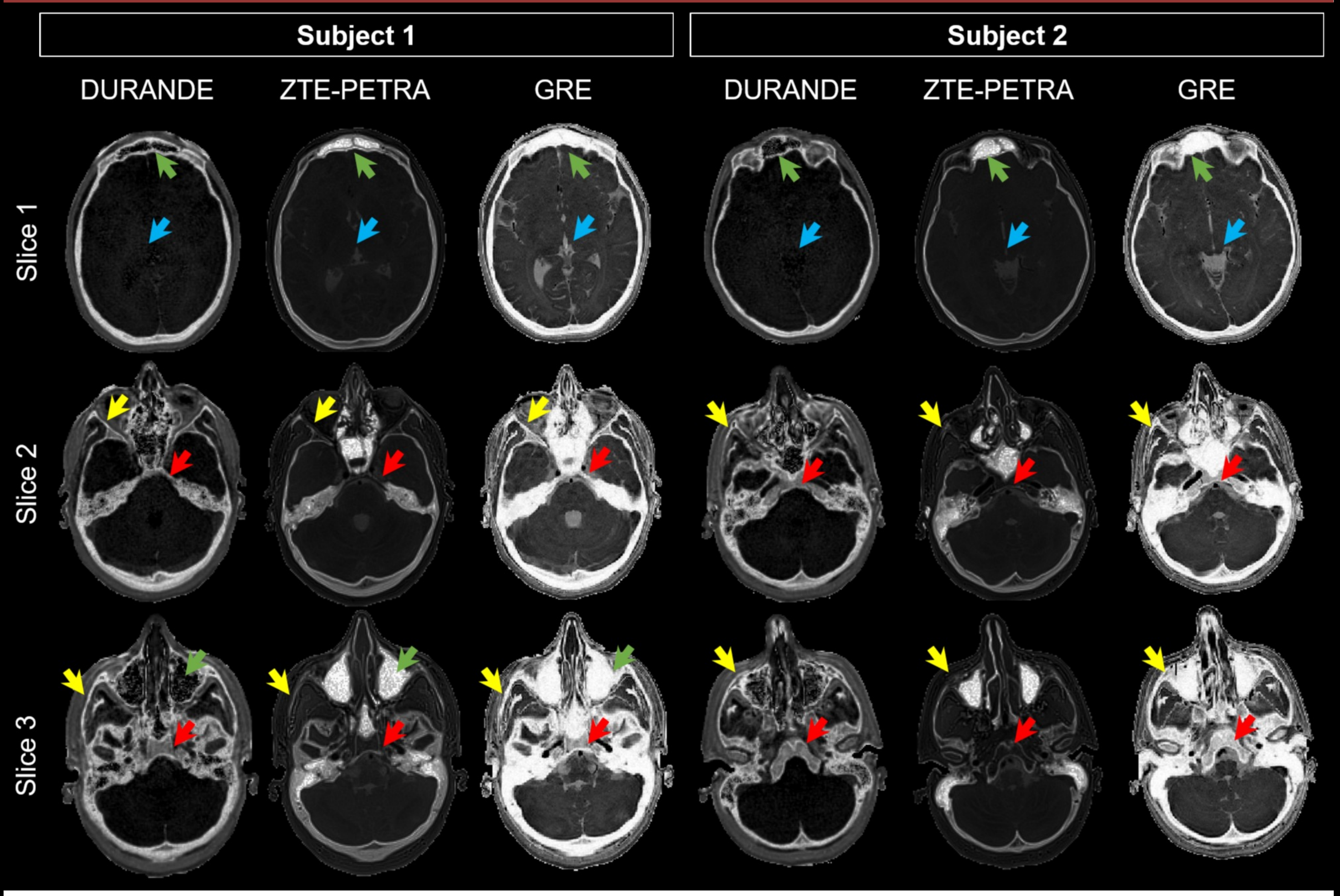


Fig. 2: Axial images acquired with three MRI sequences. Air appears black in DURANDE and white in ZTE-PETRA (green arrows), while both air and bone have the same voxel intensity in GRE. DURANDE and ZTE-PETRA have superior soft-tissue suppression (blue arrows), and DURANDE has higher contrast in thinner facial bones (yellow arrows). Bone marrow is fully attenuated after logarithmic inversion (red arrows) in the proton-density weighted ZTE-PETRA images.

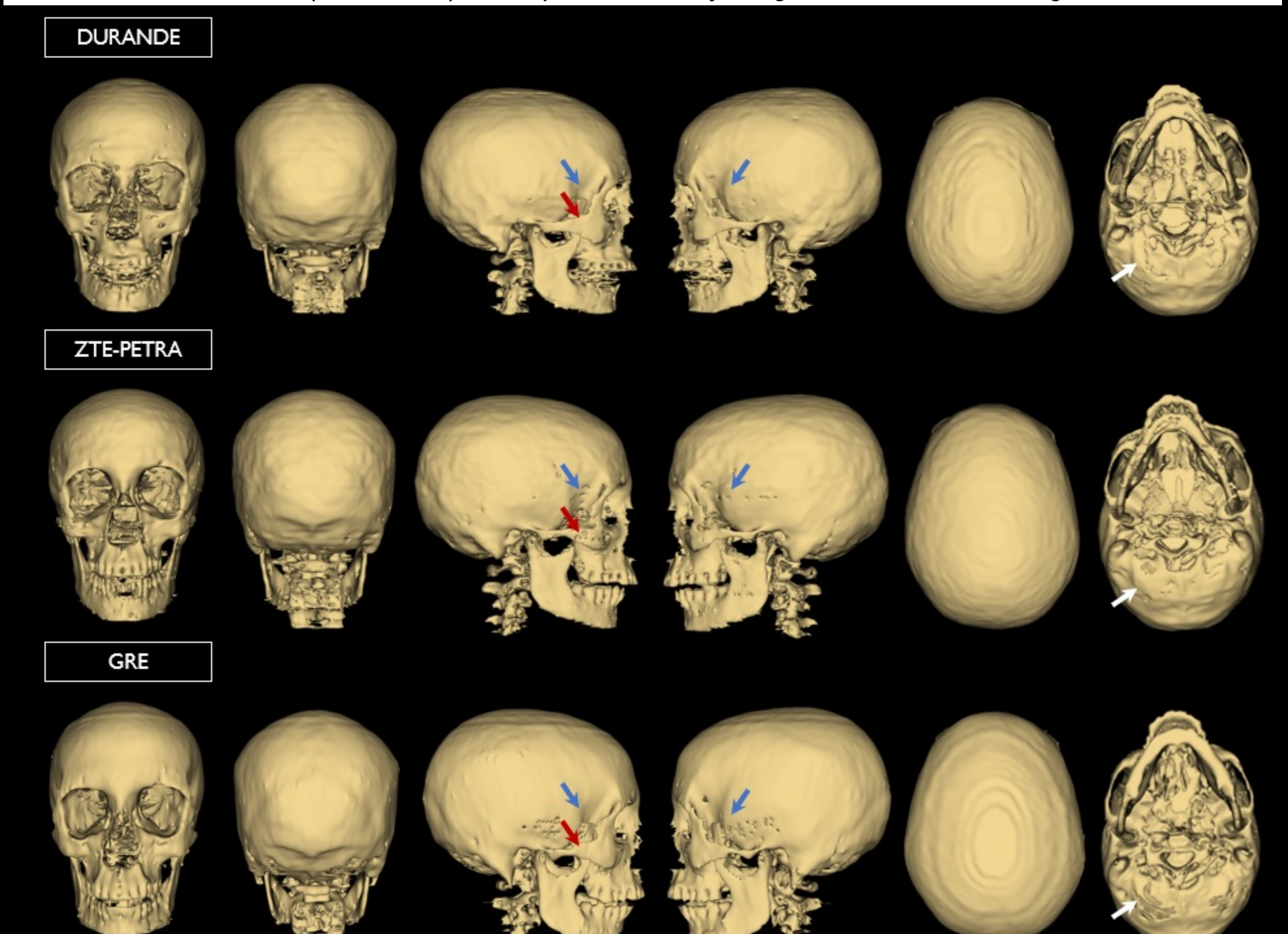


Fig. 3: Skull 3D renderings of one participant (24 yo female). Note slight differences in regions of thin bone (blue arrows), zygomatic bone (red arrows), and occipital bone (white arrows) among the three sets of renderings.

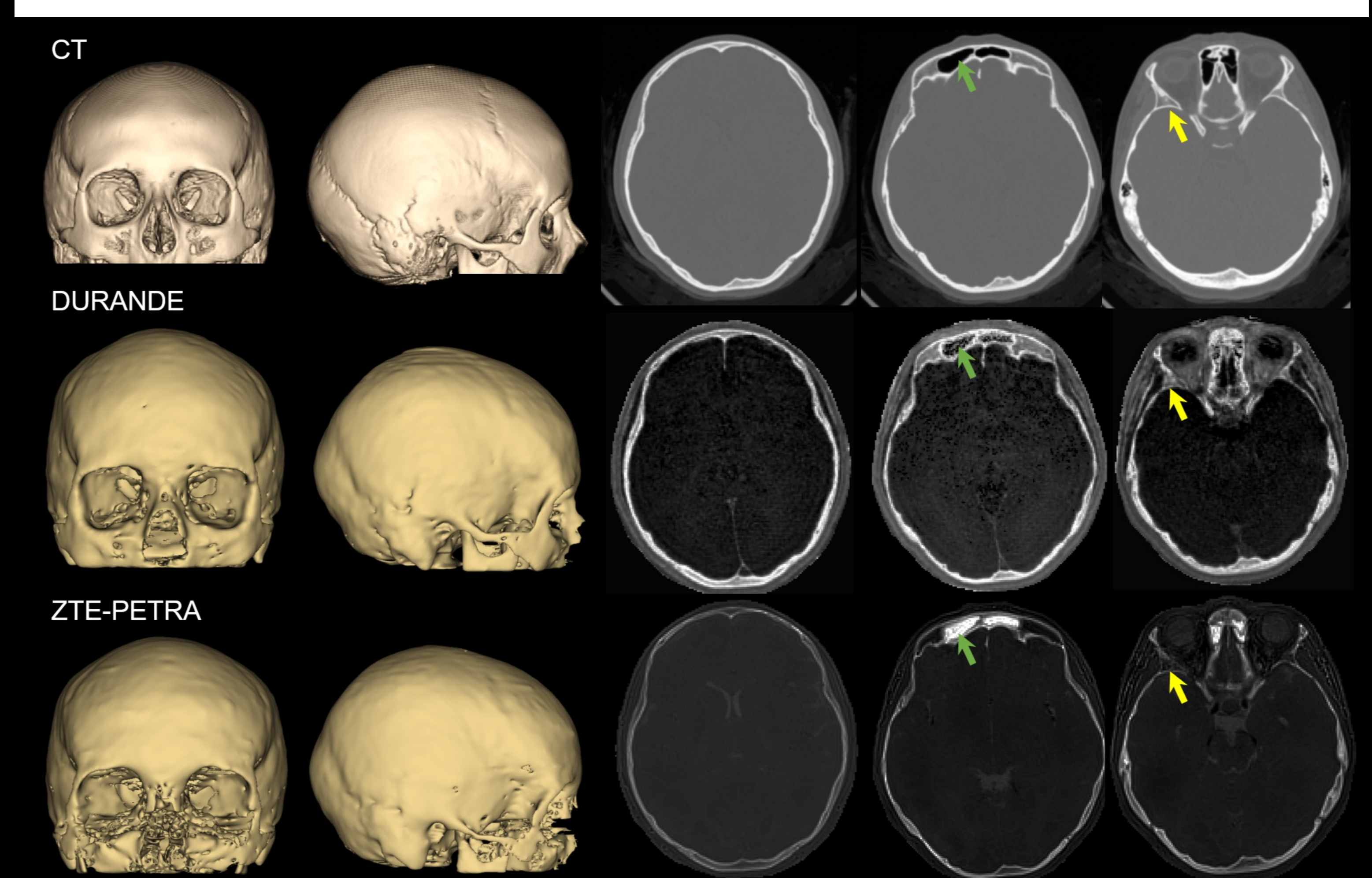
Dice similarity score (mean ± standard deviation):
DURANDE vs ZTE-PETRA 81.2% ± 12.7%
DURANDE vs GRE 78.3% ± 12.8%
ZTE-PETRA vs GRE 76.3% ± 14.2%

Table 1: Mean difference in craniometric measurements and Lin's concordance correlation coefficient (CCC) between scan pairs across all participants (n=10).

Scan pair	Mean difference in craniometrics (mm, mean ± STD)		
	Glabella to opisthocranion	Left to right frontozygomatic suture	Vertex to basion
DURANDE vs ZTE-PETRA	0.25 ± 1.16	0.38 ± 1.25	1.73 ± 1.21
DURANDE vs GRE	0.21 ± 1.13	0.01 ± 1.26	0.90 ± 1.06
ZTE-PETRA vs GRE	0.04 ± 1.14	0.37 ± 0.83	0.83 ± 1.55
	Lin's CCC (r, [95% confidence interval])		
DURANDE vs ZTE-PETRA	0.99 [0.96, 1.00]	0.95 [0.81, 0.99]	0.96 [0.88, 0.99]
DURANDE vs GRE	0.99 [0.97, 0.99]	0.95 [0.83, 0.99]	0.98 [0.94, 1.00]
ZTE-PETRA vs GRE	0.99 [0.95, 1.00]	0.97 [0.89, 0.99]	0.97 [0.91, 0.99]

Ongoing Work - Preliminary Pediatric Data

Fig 4. Preliminary MRI data of one pediatric patient (15 yo, female) using DURANDE and ZTE-PETRA, compared with clinical CT. Pediatric patients with craniofacial abnormalities are at risk of early exposure to an ionizing radiation. High-resolution MRI can serve as a radiation-free alternative to CT.



SUMMARY & CONCLUSION

- The three MRI techniques yielded good agreement in the skull images and comparable craniometric measurements.
- However, DURANDE and ZTE-PETRA yielded superior air-bone contrast and soft-tissue suppression compared to GRE.
- The main benefit of ZTE-PETRA is its potential short scan time and the low level of acoustic noise it generates. The strength of DURANDE is its straightforward implementation; it is self-normalized and has superior bone-contrast for facial bones with thinner cortical shells.

REFERENCES

[1] Lee H, Zhao X, Song HK, Zhang R, Bartlett SP, Wehrli FW. Rapid dual-RF, dual-echo, 3D ultrashort echo time craniofacial imaging: A feasibility study. Magnetic resonance in medicine. 2019;81(5):3007-16. **[2]** Wiesinger F, Sacolick LI, Menini A, Kaushik SS, Ahn S, Veit-Haibach P, et al. Zero TE MR bone imaging in the head. Magnetic resonance in medicine. 2016;75(1):107-14. **[3]** Eley KA, Watt-Smith SR, Sheerin F, Golding SJ. "Black Bone" MRI: a potential alternative to CT with three-dimensional reconstruction of the craniofacial skeleton in the diagnosis of craniosynostosis. Eur Radiol. 2014;24(10):2417-26.