Quantifying Dual Energy Signal Hidden Within Single Energy Noise

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SUMMARY

BACKGROUND
Several AI algorithms have been proposed to transform single-energy CT into dual-energy images. It is generally believed that such algorithms must work on textural features alone (e.g., bright vessels are probably iodinated).

OBJECTIVE
To demonstrate that some dual-energy information is available within noise itself.

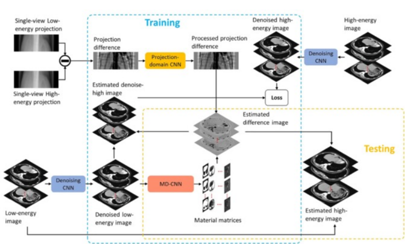
METHODS
We used numerical simulations of an idealized classification task of a uric acid vs. calcium kidney stone of equal attenuation. Noise is estimated assuming that the signal and background are known exactly.

RESULTS
For a 1 cm stone, we can achieve an area under ROC curve of 0.97.

CONCLUSIONS
AI algorithms that transform single-energy into dual-energy images might be able to harvest some information from noise.

PRIOR WORK

T Lyu [1] provides an example of an AI algorithm (MD-CNN) that predicts dual energy from single energy reconstructions and tested this on scanners from two different vendors. This can be understood as a specific case of cross-modality transformation; another example of this is synthetic CT from MRI for radiotherapy treatment planning [2].



Example dual-energy prediction network [1].

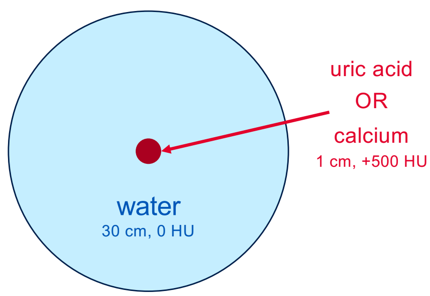
Other groups have worked on this problem in various ways, for example, by adding a "quality check" network to ensure explainability [3]. However, as in many AI methods, the fundamental mechanism through which the algorithm performs material decomposition is not clear.

GEDANKEN EXPERIMENT

Our project is motivated by the following thought experiment:

Suppose a single-energy CT image consists only of a cylinder of unknown material at the center of a cylindrical water phantom. Could any AI algorithm determine the atomic number of the unknown material?

As a clinically motivating example, consider the classification of a kidney stone into uric acid or calcium-based [4]. Noninvasive classification using dual energy CT can guide treatment. If the two options have the same mean attenuation, would an AI algorithm be able to differentiate them? Many expect this task to be impossible.

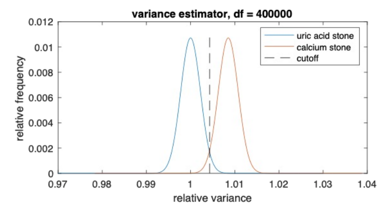


METHODS

- We assume a 2-alternative forced choice (2AFC) problem, with signal and background known exactly (SKE/BKE).
- Among the two alternatives, the *mean* signal of calcium and uric acid are identical, so they cannot be used in differentiation. The *variance* of these two alternatives is different, however.
- Why is the variance different? Calcium presents more photoelectric effect and more attenuation of low-energy X-rays. The *number* of X-rays is decreased even when (by assumption) the *total energy* of the X-rays is the same as in the uric acid option. This implies fewer quanta and therefore more Poisson noise.
- We numerically modeled a 100 kV spectrum filtered by either 30.5 cm of water (i.e., a water-like stone of 1 cm at +500 HU) or 30 cm water & 3.5 mm of cortical bone (chosen to generate the same mean signal). We measure the sample variance across many such equivalent pixels and use this as a test statistic.

RESULTS

- Under our simplifying assumptions, our test statistic follows a χ^2 distribution with many degrees of freedom. We assumed 400,000 df (e.g., 1000 views, 20 pixels in the x-direction, 20 pixels in the z-direction)
- The uric acid and calcium alternatives separate the test statistic by 0.8%.



- This separation is sufficient to achieve a classification accuracy (area under the receiver operating characteristic curve) of 0.97.

CONCLUSIONS

- Noise provides some indication of dual-energy signal. While weak, it is enough to classify large objects (500 HU, 1 cm), some of which have clinical relevance.
- While AI algorithms probably rely primarily on textural features (e.g., bright vessels are iodinated), they could potentially incorporate noise of the signal too to help classify ambiguous, bright lesions.

REFERENCES

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2. M Boulanger et al, "Deep learning methods to generate synthetic CT from MRI in radiotherapy: A literature review." *Physica Medica* (2021).
3. Y Li et al, "A quality-checked and physics-constrained deep learning method to estimate material basis images from single-kV contrast-enhanced chest CT scans." *Med Phys* (2023).
4. AN Primak et al, "Noninvasive differentiation of uric acid versus non–uric acid kidney stones using dual-energy CT." *Acad Rad* (2007)