CT to Ultrasound Registration: A Porcine Phantom Study

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Motivation

Intro

Methods

Results

Discussion

Conclusion

Thanks

- Ultrasound to CT registration can improve many minimally invasive procedures including partial nephrectomy.
- Many new registration techniques are being developed.
- Phantoms are a method of providing a gold standard for registration.
- We provide a recipe for producing a realistic kidney phantoms to validate registration.

Clinical Context

Intro

Methods

Results

Discussion

Conclusion

Thanks

- Amongst Canadians, kidney cancer is the 6th most common cancer in women and 10th most common cancer in men (Canadian Urological Association).
- For diagnosis, patients receive CT angiography (CTA).
- Intraoperatively, the surgeon currently uses ultrasound only to check the margins of the tumour.
- Fusion of CTA and intraoperative US would enable accurate navigation and tumour resection at several stages of the surgery.

Clinical Context

Related Work: Validation Methods

Intro

Methods

Results

Discussion

Conclusion

Thanks

Ground Truth from Anatomical Landmarks

- US to MR on cardiac images. (Zhang *et al*., 2006).
- US to CT via simulated US of kidney and liver. (Wein *et al*., 2008).

Surface Matching

- US to CT of the kidney. (Leroy *et al*., 2007).

Fiducial Markers in Cadavers

- US to CT of femur and pelvis. (Penney *et al.,* 2006)

Fiducial Markers in Phantoms

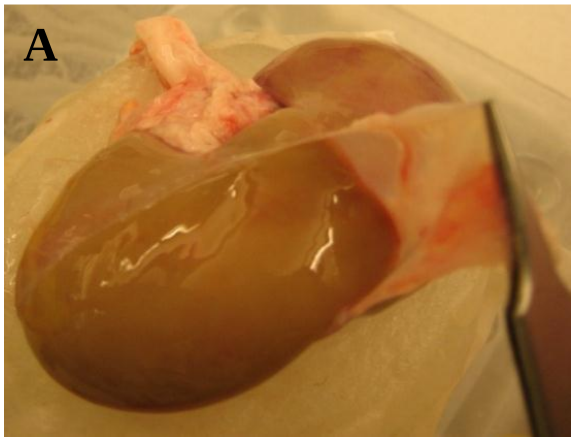
- US to CT via simulated US on phantom of the spine (Gill *et al*., 2009).
- US to CT and elastography to CT on gelatin phantom with excised porcine kidneys (Keil *et al*., 2009).
- What is needed is a phantom with clearly identifiable fiducials that can provide a gold standard for registration of soft tissue.

Goals of Phantom Construction

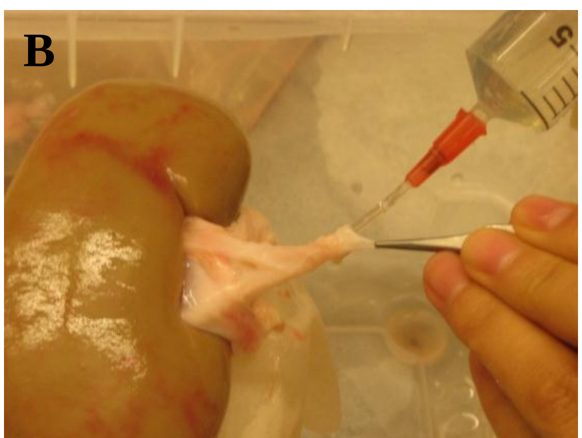
- High quality images in CTA and US.
- Depict the surface boundaries of the kidney.
- Define the vascular and pyramid anatomy of the kidney in both modalities.

Phantom Construction

Intro
Methods
Results
Discussion
Conclusion
Thanks



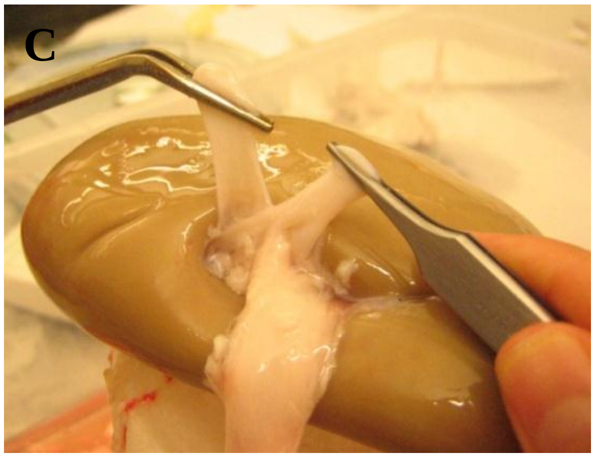
A) Remove the renal capsule so that it does not trap air.



B) Inject contrast agent (Omnipaque iohexol):

- 1 to 40 dilution in water to highlight parenchyma.
- 1 to 5 dilution in gelatin solution to highlight the arteries.

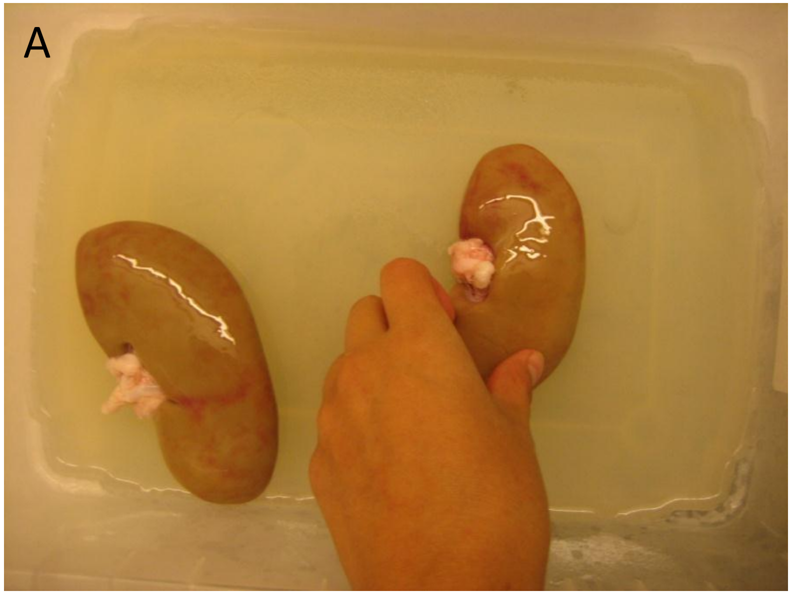
Phantom Construction Cont’d



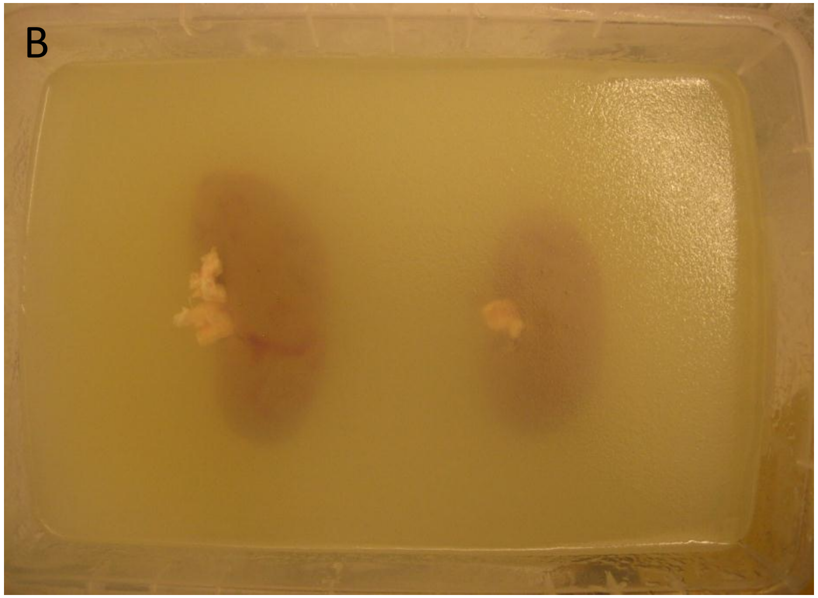
C) Artery and vein are separated.

D) Artery and vein are tied off to prevent leaking of contrast agent into the agar.

Phantom Construction Cont'd



A) Placement of excised kidneys on an agar layer.



B) Kidneys encased in agar.

Phantom Construction

Intro

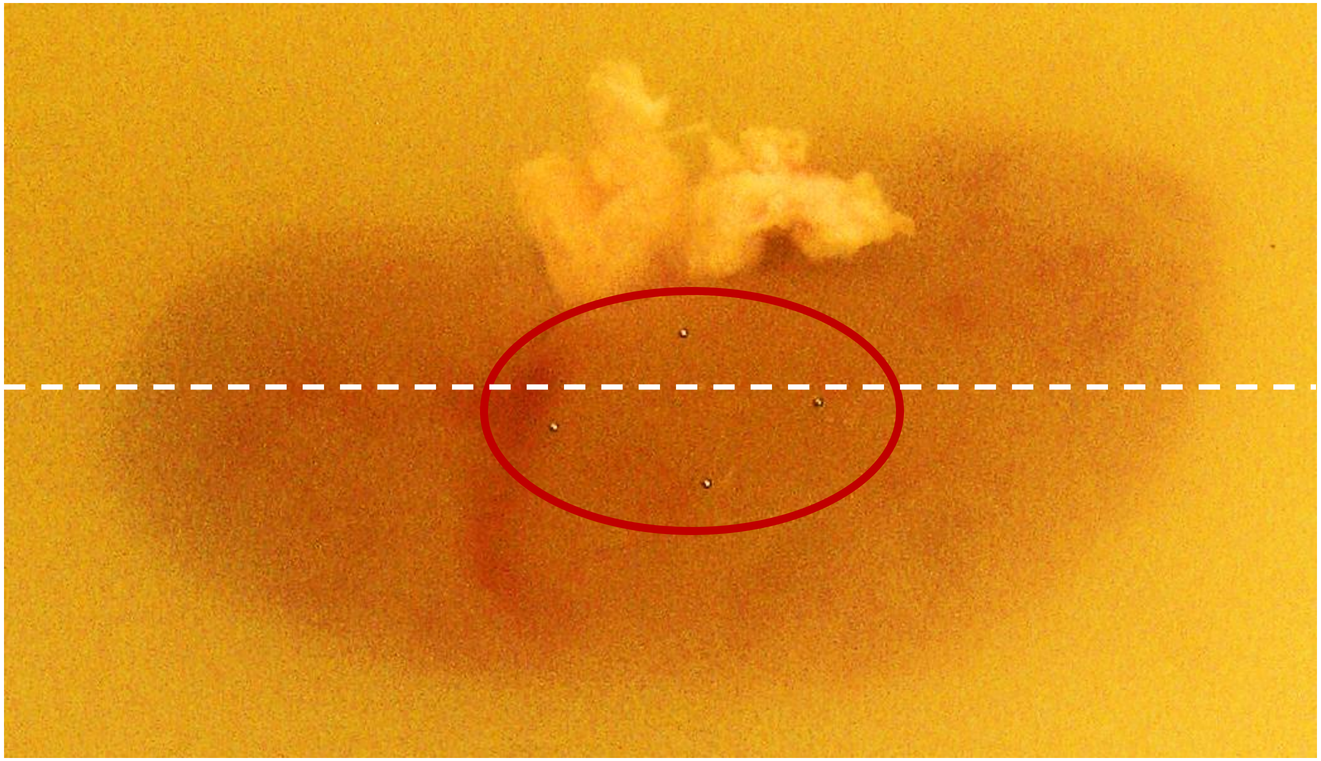
Methods

Results

Discussion

Conclusion

Thanks

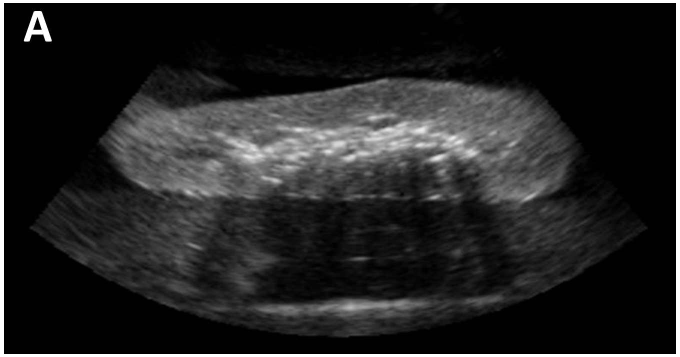


Ultrasound and CT Acquisition

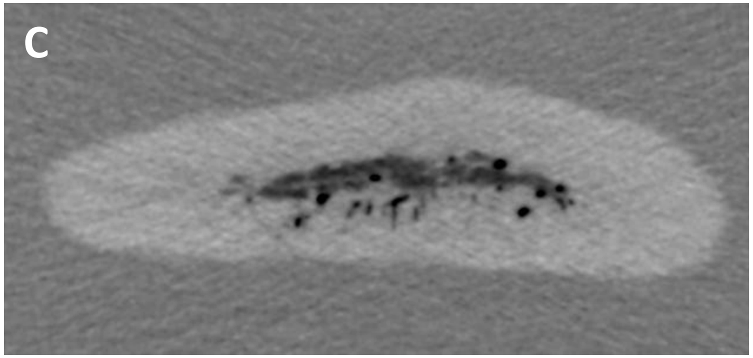
- US acquired using the Ultrasonix Sonix RP machine (Ultrasonix Medical Corporation with the convex curvilinear abdominal probe (4DC7-340) .

- CT scans were acquired using the Aquilion 64-slice CT scanner (Toshiba Medical Systems)

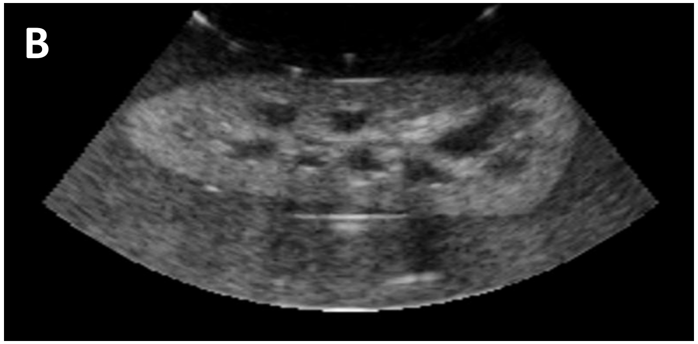
Comparison



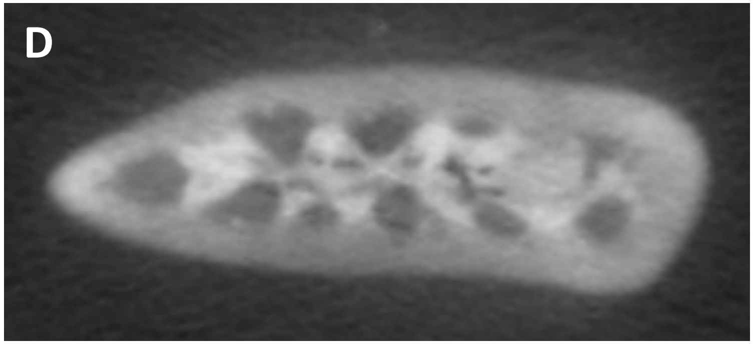
A) US of non-freshly excised kidney with no contrast.



C) CT of non-freshly excised kidney with no contrast.



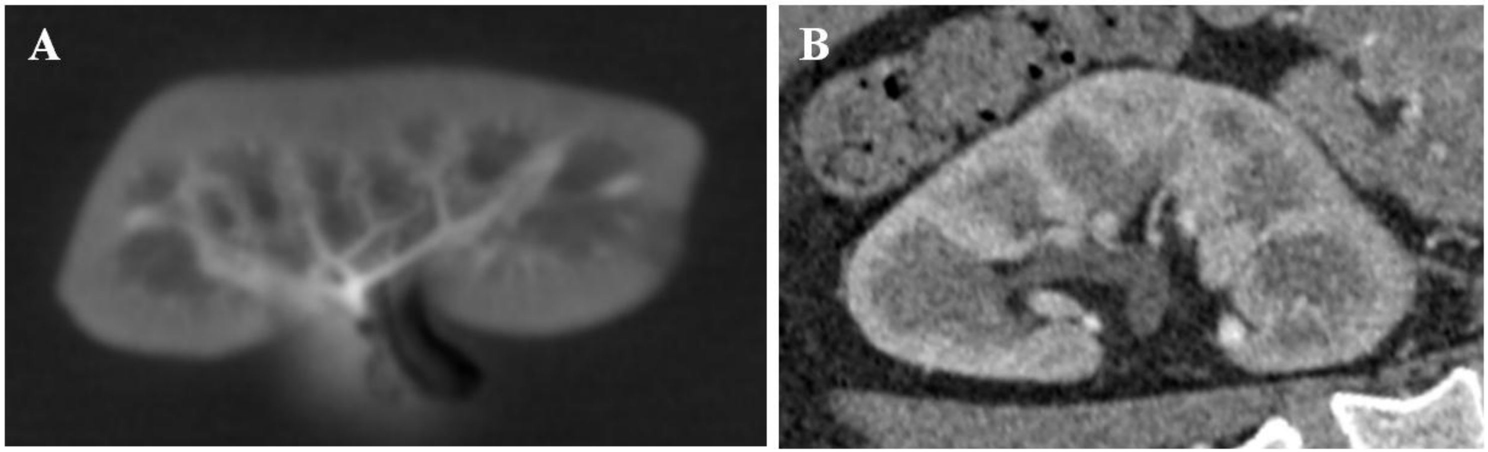
B) US of freshly excised kidney with contrast.



D) CTA of freshly excised kidney.

Comparison

Intro
Methods
Results
Discussion
Conclusion
Thanks

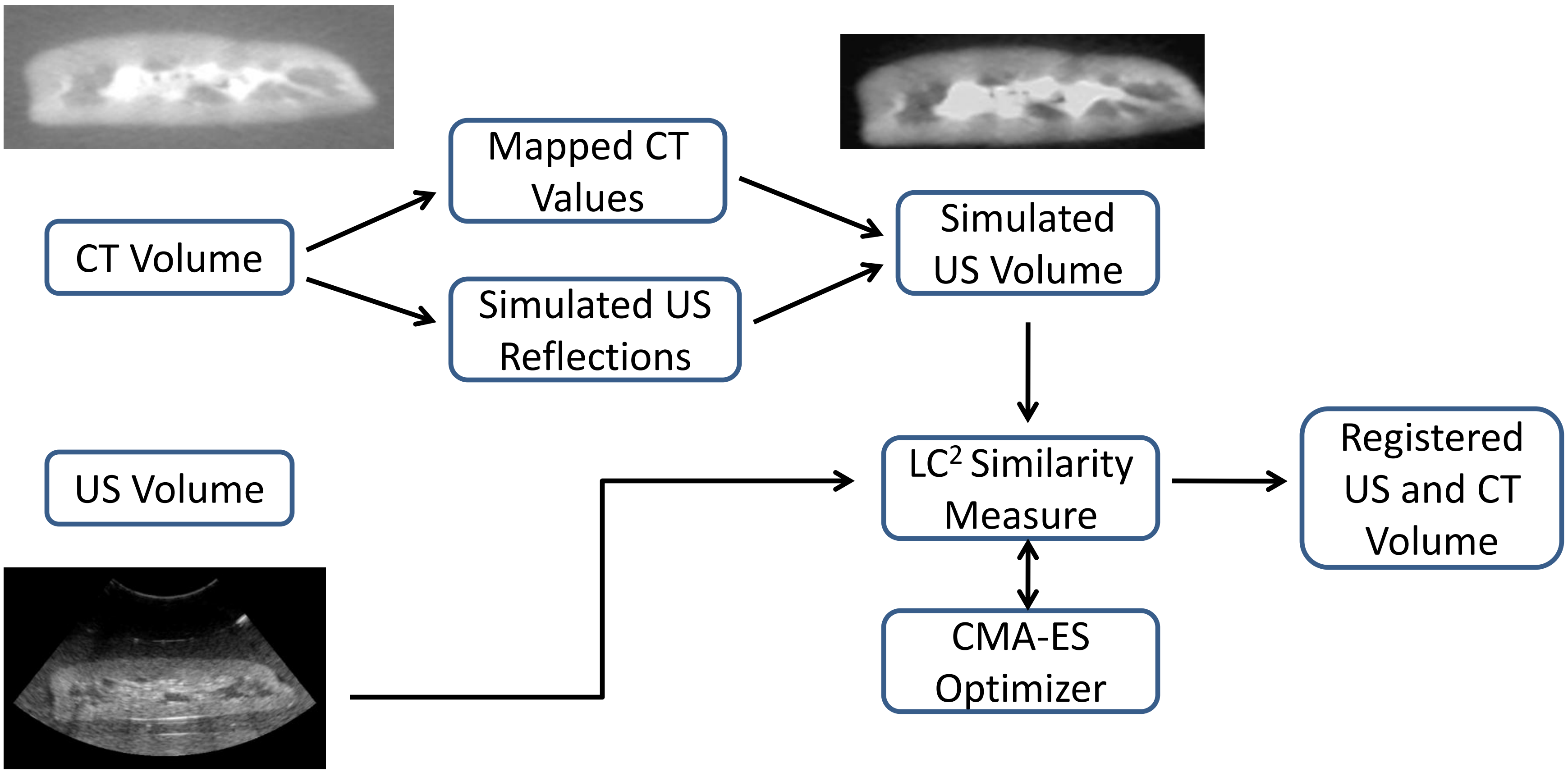


A) CTA of phantom.

B) CTA of human kidney.

- Can identify the vascular system, renal pyramids and the renal cortex.

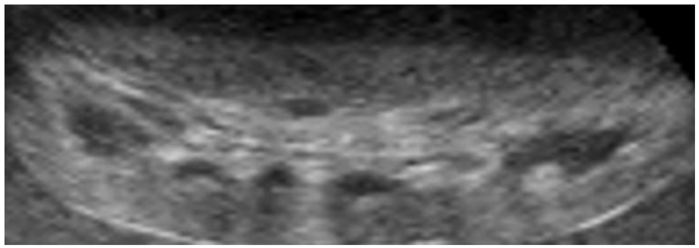
Registration Algorithm



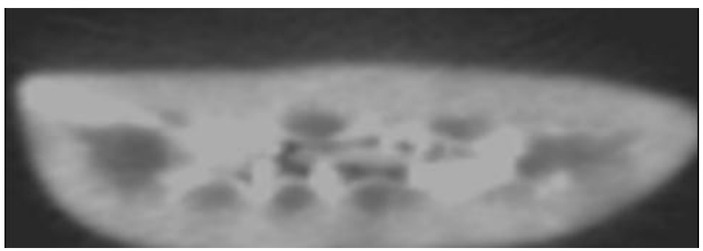
For registration algorithm, see Gill *et al*., 2009 and Wein *et al*., 2008

$$LC^2 = \frac{\sum\left(U(x,y)-f(x,y)\right)^2}{N \times Var(U)}$$

Registration Results



Ultrasound



Simulated Ultrasound

CT

- 30 trials of the registration algorithm
- 7 corresponding CT to US volumes generated a mean TRE of 5.7 ± 2.9 mm.
- Comparable to results from other studies.

Discussion

- Fiducial localization error in US data.
- Inherent distortions in US caused by speed of sound and scan-conversion.
- Can improve registration with more sophisticated simulation such as considering the true shape of the radiating beam (Shams *et al.*, 2008).
- Slight blurring around the boundaries of the organ due to leaking of contrast agent. This can be avoided by injecting contrast agent at the time of the CT.

Conclusions and Future Work

- Our phantom design produces realistic image features in both US and CTA, and provides a gold standard with fiducials.
- Successful registration was performed with accuracy of 5.7 mm.
- Studies conducted *in vivo* will present some differences that are not represented by the phantom such as deformation.
- Having a gold standard by which to test algorithms supports the development of CT to US intensity-based registration.

Thank you!

Intro

Methods

Results

Discussion

Conclusion

Thanks

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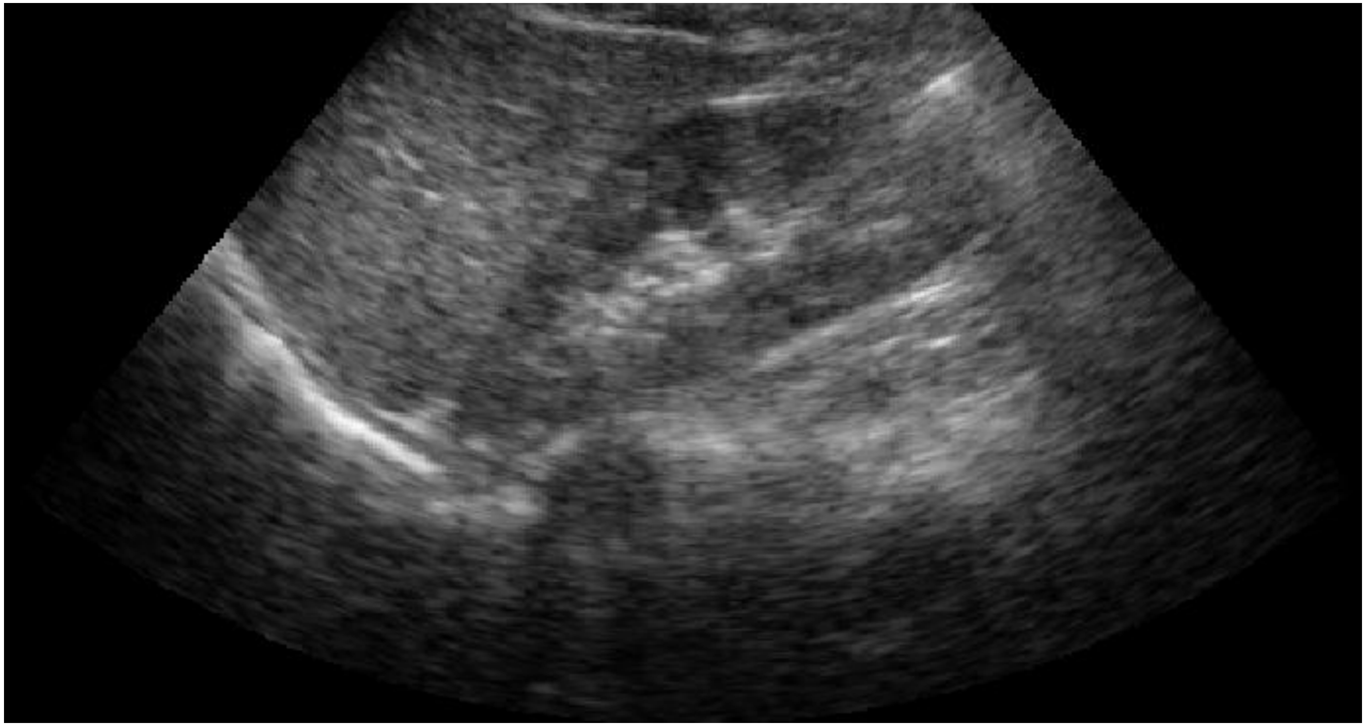
Ultrasound of Patient's Kidney



Equations

$$\Delta r(x,y,d) = \left(d^T \nabla\mu(x,y)\right) \frac{|\nabla\mu(x,y)|}{\left(2\mu(x,y)\right)^2} ,$$

$$\Delta t(x,y) = 1 - \left(\frac{|\nabla\mu(x,y)|}{\left(2\mu(x,y)\right)}\right)^2 ,$$

$$r(x,y) = I(x,y-1)\Delta r(x,y,d) ,$$

$$I(x,y) = \begin{cases} I(x,y-1)\Delta t(x,y) , & |\nabla\mu(x,y)| < \tau \\ 0 , & |\nabla\mu(x,y)| \geq \tau \end{cases} ,$$

Equations Cont'd

$$r(x,y) = \frac{\log(1+ar(x,y))}{\log(1+a)}$$

$$p(x,y) = 1.36\mu(x,y) - 1429$$

$$f(x,y) = \begin{cases} \alpha p(x,y) + \beta r(x,y) + \gamma, & I(x,y) > 0 \\ 0, & I(x,y) = 0 \end{cases}$$

$$LC^2 = \frac{\sum\left(U(x,y) - f(x,y)\right)^2}{N \times Var(U)}$$