Nuclear medicine versus radiology:
general considerations (image characteristics, dosimetry)

Thanks to Emilien MICARD, IADI, Nancy (France)
Nicolas GRENIER, Bordeaux (France)
Note that this talk is focused on functional imaging.

For anatomic imaging, just use radiology!
Radionuclide imaging was the reference for brain imaging up to 1975!
Then, came CT:

...and MRI:
Radionuclide brain imaging was dead!

... for a while!
Imaging improved and new indication occurred

...specific tracers were introduced:

$^{123}$I-CIT

normal  AD  Lewy body dementia
Spatial Resolution
Temporal resolution
Noise
Physics behind image
Tracers/CM
Radiation burden
Available physiological parameters
Conclusion
SPATIAL RESOLUTION

NM – MAG3  MRI

...so, are we dead again?
SPATIAL RESOLUTION

Is spatial resolution an issue in renal functional imaging?

1- No, not at all

2- Yes but no need for a high resolution

3- Yes, a very good resolution should be sought
## SPATIAL RESOLUTION

<table>
<thead>
<tr>
<th>Modality</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>NM</td>
<td>2D projections - 10 mm</td>
</tr>
<tr>
<td>PET</td>
<td>3D – (5 mm)^3</td>
</tr>
<tr>
<td>MRI</td>
<td>multiple 2D – (2 mm)^2 10 mm</td>
</tr>
<tr>
<td>CT</td>
<td>~ 3D – (1 mm)^2 × 5 mm</td>
</tr>
<tr>
<td>US</td>
<td>2D slices – (1 mm)^2</td>
</tr>
</tbody>
</table>
### SPATIAL RESOLUTION

<table>
<thead>
<tr>
<th>NM</th>
<th>MRI</th>
<th>Which structures should be separated?</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓</td>
<td>✓</td>
<td>right kidney vs. left kidney!</td>
</tr>
<tr>
<td>±</td>
<td>✓</td>
<td>upper part vs. lower part when duplicated</td>
</tr>
<tr>
<td>±</td>
<td>✓</td>
<td>kidneys vs. other organs</td>
</tr>
<tr>
<td>±</td>
<td>✓</td>
<td>parenchyma vs. cavities</td>
</tr>
<tr>
<td>×</td>
<td>✓</td>
<td>cortex vs. medulla</td>
</tr>
<tr>
<td>×</td>
<td>×</td>
<td>nephrons, intrarenal vessels</td>
</tr>
<tr>
<td>±</td>
<td>✓</td>
<td>arterial input function (aorta, LV, …)</td>
</tr>
</tbody>
</table>
SPATIAL RESOLUTION

NM has a poor spatial resolution
...but is it a drawback? (probably for arterial input function)

1- do we need a good resolution for function?
   (most of the time: separate LK from RK...)

2- Projection images show the whole kidney in a single image

3- How long is it to draw ROIs? (segmentation tools are not ready)

× N slices
Need for registration in MRI
NM does even not realise the motion (so no need for correction!!!)
but it strongly compromises attempts to differentiate cortex and medulla in NM!
Spatial Resolution
Temporal resolution
Noise
Physics behind image
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Conclusion
What temporal resolution do we need for renal functional imaging?

1- better that 1 s
2- 1 s – 10 s
3- 10 – 60 s
4- no better than 1 min
## TEMPORAL RESOLUTION

<table>
<thead>
<tr>
<th>Modality</th>
<th>Temporal Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>NM</td>
<td>~ 1-10 s</td>
</tr>
<tr>
<td>PET</td>
<td>10 s (list mode)</td>
</tr>
<tr>
<td>MRI</td>
<td>2-3 s</td>
</tr>
<tr>
<td>CT</td>
<td>better than 1 s (radiation !)</td>
</tr>
<tr>
<td>US</td>
<td>&lt; 1 s</td>
</tr>
</tbody>
</table>

Compromise with spatial resolution and noise.
TEMPORAL RESOLUTION

<table>
<thead>
<tr>
<th>NM</th>
<th>MRI</th>
<th>What changes must we be able to see?</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓</td>
<td>✓</td>
<td>renal perfusion (~ 1 s / VMTT ~ 5 s)</td>
</tr>
<tr>
<td>✓</td>
<td>✓</td>
<td>renal uptake (10 – 20 s are OK)</td>
</tr>
<tr>
<td>✓</td>
<td>✓</td>
<td>drainage (10 – 20 s are OK)</td>
</tr>
<tr>
<td>?</td>
<td>✓</td>
<td>lung motion (1 s)</td>
</tr>
<tr>
<td>✗</td>
<td>✓</td>
<td>cardiac motion (much better than 1 s)</td>
</tr>
</tbody>
</table>

Temporal resolution is not much an issue except if we want to differentiate cortex from medulla.
Spatial Resolution
Temporal resolution
Noise
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Conclusion
Clearly more noise on the NM images
But renal imaging relies mostly on curves

Small and comparable amount of noise
More a problem for neonates (in both techniques)
Spatial Resolution
Temporal resolution
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PHYSICS BEHIND IMAGES

NM: direct signal (\(\gamma\) rays) from the injected molecule it makes it simple and robust to quantify though corrections should be made (attenuation, scattering...)

MRI: complex radio signal (usually) coming from hydrogen nuclei complex mechanisms for contrast signal is modified by contrast agents

US: echoes coming from interfaces mechanical wave injected bubbles add more interfaces

CT: attenuation of X-rays by heavy nuclei injected iodine attenuates more
Spatial Resolution
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Is linearity an issue for MR functional renal imaging?

1- yes it is, but it can be easily corrected

2- yes it is, and it cannot be easily corrected

3- no, it is not

4- what do you mean by linearity?
for NM, diagnostic agents are tracers
  no injection, no image!
signal is proportional to the amount of agent

linearity!

for radiology, diagnostic agents are contrast agents
image even without injection
(very few exceptions for MRI)

so signal is NOT proportional to the amount of agent
NO LINEARITY
DIAGNOSTIC AGENTS

signal

NM

concentration
Why does linearity matters?
Calibration curves
or linearisation formulae may be used! (may be OK for CT and US)

\[ y = x^2 \quad \text{not linear} \quad 2y \neq (2x)^2 \]

but can be made linear:

\[ \sqrt{y} = \sqrt{x^2} = x \]

\[ 2\sqrt{y} = 2x \]
DIAGNOSTIC AGENTS

concentration = 2          concentration = 3

signal = 4                signal = 9

take square root
(linearisation)
and infer concentration

concentration: concentration:
\[ \sqrt{4} = 2 \]  \[ \sqrt{9} = 3 \]
DIAGNOSTIC AGENTS

concentration = 2
concentration = 3

signal = 4
signal = 9

average signal: $13/2 = 6.5$

taking square root to infer concentration

$\sqrt{6.5} = 2.55$

average concentration: 2.5

not the same
Assuming linearity to average different values within one voxel results in an error when the response is not linear. 
But: the error was small!

Yes, but concentration factors in kidney are about one hundredfold. 
This happened in a single nephron between glomerulus and distal tubule: these structures are very close one to the other! 
This probably results in big errors!
Also: non monotonic curves cannot be linearised: you need to remain in the first, ascending part (less contrast)
Sensitivity to diagnostic agents:

~ mmol for MRI
~ pmol for NM

factor of $10^9$

Explains lack of toxicity of NM agents
(huge concern for NSF in patients with renal diseases)
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Conclusion
<table>
<thead>
<tr>
<th>Modality</th>
<th>Radiation Burden</th>
</tr>
</thead>
<tbody>
<tr>
<td>NM</td>
<td>~ 1 mSv</td>
</tr>
<tr>
<td>PET</td>
<td>?</td>
</tr>
<tr>
<td>MRI</td>
<td>ø</td>
</tr>
<tr>
<td>CT</td>
<td>~ 8 mSv – may be less (low dose)</td>
</tr>
<tr>
<td></td>
<td>may be much more (dynamic CT)</td>
</tr>
<tr>
<td>US</td>
<td>ø</td>
</tr>
</tbody>
</table>

*NM brings irradiation but not much (“negligible” to “minimal”)*

*CT may not be acceptable*
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AVAILABLE PARAMETERS

relative GFR: validated for NM

probably feasible for MRI
dynamic contrast enhanced: deconvolution analysis
(so-called “compartmental analysis”)
but hampered by lack of linearity
needs further validation

*multicentric study by Claudon (Nancy): results to come soon!*

absolute GFR: many methods in NM, very poor precision

attempts in MRI: no convincing validation yet

AVAILABLE PARAMETERS

perfusion: indices for NM: Peters...
(validation ???)

MRI: dynamic contrast enhanced (DCE)
MRI: arterial spin labeling (ASL)
MRI: phase contrast flow measurements (PC-MRA)

US: μ-bubbles
AVAILABLE PARAMETERS

drainage: many indices for NM
a few of them only partially validated

MRI: probably similar indices
better resolution between cortex and medulla
may improve indices
usually: “transit time” = time for contrast in pelvis
AVAILABLE PARAMETERS

MRI: $^{23}\text{Na}$ imaging

High Na concentration in the medulla corticopapillary osmotic gradient

*Maril, Magnetic Resonance in Medicine 56:1229–1234 (2006)*
MRI: Imaging renal hypoxia with BOLD (see also Dr PRASAD’s talk)

R2* maps

normal  lower GFR: less O₂ consumption?

Wang, ISMRM’2010

see also  Prasad, Circulation 1996; 94:3271-3275
MRI: Diffusion imaging (DWI) - (see also Dr PRASAD’s talk)

brings information on microstructure (vessels, tubules, swelling)
isoropic / anisotropic

fibrosis
“obstruction”
renal masses

no clear relation with a physiological parameter
rather “micro-anatomy”


AVAILABLE PARAMETERS

MRI: Elastography?
  fibrosis
AVAILABLE PARAMETERS

PET: not much used potential!
CONCLUSION

NM has:
noise and poor spatial resolution (acceptable temporal resolution)

BUT it has linearity (which comes very useful for quantifying)
  it has sensitivity

US may be helpful for perfusion

CT is much limited by the radiation burden

Lack of linearity for MRI may be especially difficult to overcome for
kidney because of urine concentration
Validation studies still lack for MRI (nice potential still)
In the meanwhile, NM is still living.