Dual energy computed tomography for non-invasive differentiation of renal stone composition

Poster No.: C-0079
Congress: ECR 2012
Type: Scientific Exhibit
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Keywords: Calcifications / Calculi, Comparative studies, CT, Urinary Tract / Bladder, Abdomen
DOI: 10.1594/ecr2012/C-0079
Renal stones are frequently diagnosed in the United Arab Emirates (UAE). The incidence of renal stones, especially of pure uric acid (UA) stones, is far higher than in the West. In Western countries, pure uric acid stones are diagnosed in around 10%, whereas UA stones are observed in around 30% in the UAE and in the entire Middle East, respectively (1).

The primary diagnosis, localization, and identification of associated complications of renal stones by computed tomography (CT) have become common standard; CT has widely replaced conventional radiographic procedures (2-7). Several publications proposing dual-energy computed tomography (DECT) for determination of urinary stone composition have been published to date (7-12).

The purpose of the study was to non-invasively assess the composition of renal stones by DECT in our UAE patient population, especially to assess if differentiation can be achieved between uric acid stones and mixed stones with different amounts of calcium content. Therefore patients with suspected renal stones were examined with dual-energy computed tomography. If our assumption of reliable non-invasive determination of urinary tract stone composition by DECT can be confirmed, unnecessary invasive procedures, such as surgical stone extraction or extra-corporal shockwave lithotripsy (ESWL) can be avoided. Furthermore stones with very high calcium content are not suited for ESWL due to potential major post-interventional complications. Consequently patients with pure uric acid stones may rather receive pharmacological therapy for stone dissolution.
Methods and Materials

The prospective clinical trial was approval by the Institutional Review Board - IRB (AAMDHREC # 10/26). All DECT examinations were conducted at the Al Ain - VAMED Hospital (AAH), a SEHA facility and teaching hospital of the Faculty of Medicine and Health Sciences (FMHS) / UAE University (UAEU). In total 31 in- and out-patients from the AAH Urology- and Emergency Departments with suspected renal stones were referred to DECT after informed consent, and prospectively examined at 80 kV and 140 kV without intravenous contrast medium injection. Body weight was limited to 95 kilograms as DECT images of extra-large patients at 80 kV are too noisy, and CT attenuation numbers at 80 kV can be altered by hardening artifacts, which may subsequently result in registration of incorrect CT data. All DECT were conducted at the AAH Siemens DECT Somatom Definition Dual Source 64 Slices, using Syngo MMWP, version VE 1A as evaluation software: (Siemens Comp. Erlangen/ Germany). The following DECT protocol was carried out: slice thickness of 0.6 mm, 0.7 pitch, and reconstructions at 1.5 mm slice thickness.

Regions of interest (ROI) were hand drawn and defined at unenhanced 80 kV and 140 kV DECT images, as described by Matlaga (7); attenuation values were measured and compared with published data (7-12).

In addition 10 excreted renal stones were in vitro examined in a water phantom at 80 kV and 140 kV using the same protocol. Subsequently these 10 calculi were analyzed by in vitro Fourier-Transform Infra-Red Spectroscopy (IRS) at the Biomnis Laboratoires (Lyon/ France).

For further stone determination, dual-energy indices, \( DEI = \frac{[HU (80 kV) - HU (140 kV)]}{[HU (80 kV) + HU (140 kV) + 2000]} \) were calculated in accordance with published data by Graser (9) and subsequently by Eiber (12).
Results

Our patient population consists of 31 patients, all males. The age ranged from 24 to 52 years; mean age was 36 years.

In 29 out of 31 patients renal stones were detected; in total 39 renal calculi were identified. The diameter of all renal stones varied from 2 mm to 14 mm. In nine patients attenuation values were -in accordance with published data- characteristic for uric acid stones: 160.80 HU to 749.50 HU at 80 kV, and 107.90 HU to 651.20 HU at 140 kV (7-10). DEI were calculated from 0.0071 to 0.0269.

Higher attenuation values, > 1300 HU at 80 kV, and > 1000 HU at 140 kV, suggestive of stones with calcium content were determined in 30 calculi, including 17 mixed stones, with DEI from 0.0413 to 0.0863 (fig. 1-3) and 13 high-level calcium containing stones with DEI from 0.0862 to 0.1186 (fig. 4-6) (Table 1).

<table>
<thead>
<tr>
<th>Stone composition</th>
<th>n / %</th>
<th>Size (range/cm)</th>
<th>Density at 80kV (range/HU)</th>
<th>Density at 140kV (range/HU)</th>
<th>DEI (range)</th>
<th>DEI (average +/-SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Ca++</td>
<td>13/ 33.33</td>
<td>0.11-1.38</td>
<td>335.20-1462</td>
<td>335.20-1011</td>
<td>0.0862-0.11</td>
<td>0.0995 (+/-0.0094)</td>
</tr>
<tr>
<td>Mixed</td>
<td>17/ 43.59</td>
<td>0.08-0.55</td>
<td>225.60-1273</td>
<td>128.90-1055</td>
<td>0.0413-0.083</td>
<td>0.0621 (+/-0.0140)</td>
</tr>
<tr>
<td>Uric Acid</td>
<td>9/ 23.08</td>
<td>0.08-0.69</td>
<td>160.80-749</td>
<td>107.90-651</td>
<td>0.0862-0.021</td>
<td>0.09190 (+/-0.0060)</td>
</tr>
</tbody>
</table>

Table 1: In vivo DECT results - density (HU) at 80 kV and 140 kV and DEI (n=29)

10 renal stones, examined in vitro in a water bath, showed density measurements, typical for UA stones in one case (fig. 7, 8), for mixed stones in five cases (fig. 9, 10) and for high-level calcium-content calculi in four cases (fig. 11, 12). In vitro DECT measurements were confirmed by Fourier-Transform Infra-Red Spectroscopy (IRS) analysis for those 10 renal stones (Table 2).
Table 2: In vitro (water bath) DECT results - density (HU) at 80 kV and 140 kV and DEI (n=10)

<table>
<thead>
<tr>
<th></th>
<th>Density (HU) at 80 kV</th>
<th>Density (HU) at 140 kV</th>
<th>DEI (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Ca++</td>
<td>0.20-0.70</td>
<td>557.8-1012</td>
<td>0.0910-0.1183 (+/-0.0112)</td>
</tr>
<tr>
<td>Mixed</td>
<td>0.10-0.30</td>
<td>304.7-579.2</td>
<td>0.0477-0.074 (+/-0.0095)</td>
</tr>
<tr>
<td>Uric Acid</td>
<td>0.40-0.50</td>
<td>548.3</td>
<td>0.0312 (NA)</td>
</tr>
</tbody>
</table>

Laboratory IRS results correspondingly showed in one case a pure uric acid stone, in four cases mixed calculi and in five cases high-level calcium-containing stones. The results were matching with the in vivo DECT examinations, and in vitro results measured in the water phantom at 80 kV and 140 kV. In one stone IRS analysis revealed a different stone composition from the in vitro (water bath) study.
Fig. 1: Axial DECT of a 27-year-old male patient at 80 kV and 140 kV with a mixed renal tract stone in the right distal ureter; attenuation values (axial plane): 524.2 +/- 128.3 HU at 80 kV and 357.5 +/- 79.8 HU at 140 kV.

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**Fig. 2:** Corresponding coronal DECT, same patient as in fig 1.

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Fig. 3: Corresponding stone, same patient as in fig. 1; in vivo density measurements at 80 and 140 kV (matching image), axial plane.

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**Fig. 4:** Axial DECT of a 26-year-old male patient at 80 kV and 140 kV with a high-level calcium containing stone in the left distal ureter; attenuation values (axial plane): 1430.9 +/- 74.8 HU at 80 kV and 911.0 +/- 61.6 HU at 140 kV.

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**Fig. 5:** Corresponding coronal DECT of the same patients as shown in fig. 4.

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**Fig. 6:** Corresponding stone, same patient as in fig. 4; in vivo density measurements at 80 and 140 kV (matching image), axial plane.

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Fig. 7: Uric Acid (UA) stone; in vitro DECT examination in the water phantom at 80 kV and 140 kV with density measurements, axial plane.

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Fig. 8: Photo of the UA stone, measured in the water phantom (corresponding to fig. 7).

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Fig. 9: Mixed stone, in vitro DECT examination in the water phantom at 80 kV and 140 kV with density measurements, axial plane.

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**Fig. 10:** Photo of the mixed stone, measured in the water phantom (corresponding to fig. 9).

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**Fig. 11:** High-level calcium-containing stone, in vitro DECT examination in the water phantom at 80 kV and 140 kV with density measurements, axial plane.

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Fig. 12: Photo of the high-level calcium-containing stone, measured in the water phantom (corresponding to fig. 11).

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Conclusion

Our results clearly demonstrate that unenhanced DECT at 80 kV and 140 kV is a reliable tool for differentiation of renal stone composition between pure uric acid stones, mixed stones, and high-level calcium containing calculi. The DEI as introduced by Graser and Eibner (9, 12) is especially helpful for further differentiation. Determination of renal stone composition by DECT is much more consistent than on conventional radiographs or by using single-energy CT.

For differentiation between pure UA stones, mixed stones and those with high calcium content, DEI calculation appears consistent. DEI of UA stones in our patient population was 0.0071 to 0.0269, DEI of mixed stones was 0.0413 to 0.0863, and DEI of high-level calcium stones was 0.0862 to 0.1186, respectively. All registered DECT attenuation values at 80 kV and 140 kV, and calculated DEI for these three sub-groups are in accordance with published DECT results to date (7-12).

Further differentiation between calcium oxalate calculi and calcium phosphate urinary stones, as proposed by Matlaga (7), was not carried out in the present study, due to the small total number of in vitro examinations in the water phantom.

Pure uric acid renal stones occurred in 23% in our UAE patient population which is also in accordance with the current literature (1).

As a result of our in vivo and in vitro studies, our patients with pure uric acid stones will be treated conservatively after DECT stone differentiation. Invasive procedures for such patients may be replaced by medical treatment. Thus in > 20 % of patients with renal stones in the UAE non-invasive pharmacological treatment may be suitable.
References

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Fig. 13: RD Langer

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