# Automated CT renal parenchymal volume assessment with Total Segmentator/3D Slicer in kidney disease

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## Introduction:

Renal parenchymal volume (RPV) assessment has a long history of clinical value since the advent of radioisotope renography in the late 1950s. CT has always been technically capable of measuring renal parenchymal volume however this was only possible manually – a very laborious task that was clinically impractical. Total Segmentator/3D Slicer [2](3DS) : Recently there have been significant strides in software capable of carrying out automated renal segmentation from CT & MRI . Total Segmentator (TS)[1] is a free to use software from Wasserth et al (Basel) that can Segment over 104 organs/structures. It has been shown to be highly accurate in assessing RPV in normal kidneys[3]. We utilised 3D Slicer to display and analyse the results from TS.

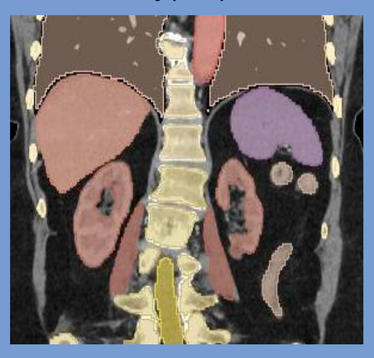
## Aims:

To assess the accuracy of TS RPV output in a number of disease processes. The accuracy was assessed against MAG3. A simple visual correlation scale was devised to assess the quality/accuracy of the renal segmentation and subsequently the segmented renal volume was used to calculate split renal function and compared with the MAG3 result.

## Method and Technical Setup

- Technical setup was challenging requiring knowledge of Python and reasonably capable Hardware: NVidia RTX 3080 12GB, CPU Ryzen 7 5800x, 16 GB RAM
- Average Segmentation Time, 130 seconds – 300 slice (1mm) CT approx. 144Mb.
- Output: Nifti file format. Viewed with 3DS the segmentation is seen as a coloured overlay on the original CT. TS also provided the segmentation volume and voxel density(HU).

| Segment | Voxel Count | Vol (mm3) | Min HU | Max HU |
|---|---|---|---|---|
| Rt Kidney | 534,408 | 465,789 | -236 | 942 |
| Lt Kidney | 29,057 | 25,326 | -178 | 199 |

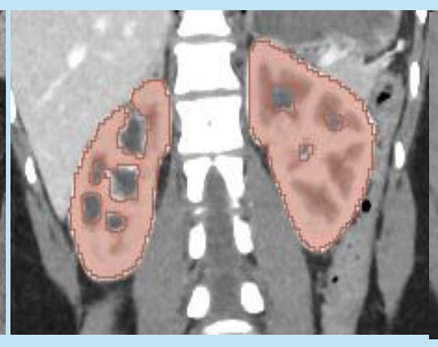


- TS segments out the renal cortex only without including the renal pelvis, perinephric fat, or calcification/stones. It also tries to highlight cysts and tumours separately.
- Initially several cases with different pathologies were assessed to gauge accuracy; selected cases are shown in the right column. Impact of contrast phase/non contrast also assessed.
- 10 consecutive patients with a MAG3 scan from 1 year ago and timely/comparable CT were assessed with TS/3DS and their results tabulated. All cases were anonymized.
- A soft tissue filter (20 to 50 HU for non con and 60 to 200 for post con) was also applied to the segmentation to see if it would improve results.

## Visual assessment of the segmentation accuracy was carried out and ranked:

Good correlation: Estimated 90+% correlation between the segmentation carried out by TS and the actual kidney volume. Results potentially safe to use for clinical decision making.
OK correlation: Estimated 75+% correlation between TS and actual kidney volume.
Suboptimal correlation: Sub 75% correlation – not safe to use for clinical decision making.

Good correlation



OK correlation: Some of the central cortex is missing

Suboptimal: Much of the upper pole is missing (Lt>Rt)

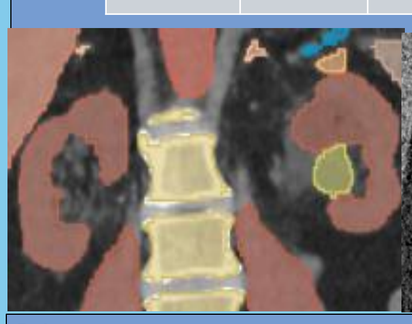
## Comparison with MAG3

The table below shows a comparison of the segmented CT split renal function (SRF) and corresponding MAG3 result. Of the 9 cases with good or OK segmentation all demonstrated good matches with the MAG3 result.
Case 10 had suboptimal segmentation and is discussed below.

**CT phase impact:** In general post contrast sequences were more likely to provide accurate segmentation but surprisingly non contrast scans also frequently provided accurate segmentation. 4 cases in the below table had multiple phases available for comparison: in 3 cases the PV/urographic phase demonstrated significant improvement compared to the NC and in the other case the NC was slightly better than the post contrast sequences.
Renal volumes were significantly higher from the post contrast segmentation compared to NC.

**Soft tissue filter (STF):** the application of the soft tissue filter occasionally improved the results but was largely negligible.

| Case Name | Phase | TS/3DS Split | | Visual Correlation | MAG- 3 | | MAg-3/TS 3DS Match | Change with STF |
|---|---|---|---|---|---|---|---|---|
| | | Right | Left | | Right | Left | | |
| Case 1 | NC | 95% | 5% | Good | 95% | 5% | Match | 0% |
| Case 2 | PV | 56% | 44% | Good | 50% | 50% | Match | 4% |
| Case 3 | PV | 55% | 45% | OK | 50% | 50% | Match | 0% |
| Case 4 | NC | 58% | 42% | Good | 57% | 43% | Match | 1% |
| Case 5 | NC | 12% | 88% | Good | 7% | 93% | Match | 7% |
| Case 6 | NC | 49% | 51% | Good | 50% | 50% | Match | 0% |
| Case 7 | NC | 57% | 43% | OK | 53% | 47% | Match | 1% |
| Case 8 | Uro | 41% | 59% | Good | 43% | 57% | Match | 2% |
| Case 9 | NC | 51% | 49% | Good | 49% | 51% | Match | 0% |
| Case 10 | NC | 50% | 50% | Suboptimal | 88% | 12% | Mismatch 35.3% | 3% |

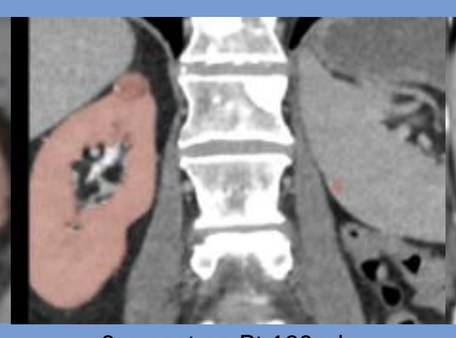


Case 10: Tight Left PUJ stricture following treatment for an impacted stone and subsequent cortical loss. Only non-contrast scan available. TS significantly overestimated left renal cortex with inclusion of parapelvic cysts. Good right segmentation.
Calculated SRF: 50/50; MAG3: 88/12

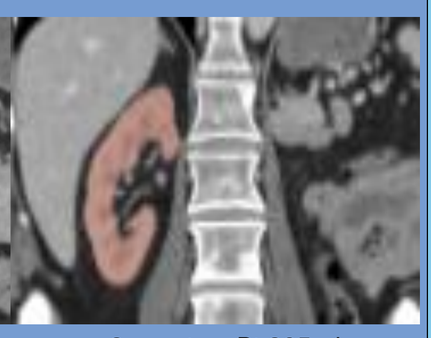
## Selected Cases: Case A

65y old male underwent a left Nephroureterectomy for cancer 2 years ago. (Also, on treatment for metastatic (bone) prostate cancer). Pre-op creatinine of 75 (eGFR 90) rising to 115 (eGFR 55) post operatively and stable.
3 images below from CTs carried out pre -operatively, 6 months and 2 years post op demonstrate good renal volumes bilaterally with equal split function pre-operatively and only mild right renal hypertrophy on the post operative follow up scans. Right renal volume: Pre-op= 180ml (left also 180ml); 6 months: 190ml; 2 years 205ml. There is good segmentation of the right kidney on all CTs but there was small volume mis-registration of the spleen as the left kidney on some of the post operative scans.
(Small nodule at the right upper pole classed as Bosniak 2F, remained stable).

Pre op Rt 180ml Lt 180ml



6m post op Rt 190ml



2y post op Rt 205ml

**Case B:** 66 y old male. Underwent cystectomy and ileal conduit formation 5 years ago for bladder primary. Early left anastomotic stricture causing left hydronephrosis (1 month). Managed with nephrostomy for 1 year then ureter re-implanted when no recurrence confirmed. Pre reimplantation DMSA Rt 84%; Lt 16%. 6 months post reimplantation MAG3 stable with Rt 84%; Lt 16%. Pre cystectomy creatinine 80 (eGFR 90) post reimplantation creatinine 90 (eGFR 75). Though there is significant loss of function on left the eGFR remains relatively stable. The explanation for this is only provided by the CT renal segmentation volumes.

Preo op R t170ml LT 170ml

6m post op Rt 210ml Lt 110ml
Nephrostomy in situ LT Kidney

2 Years post op Rt 225ml Lt 90ml

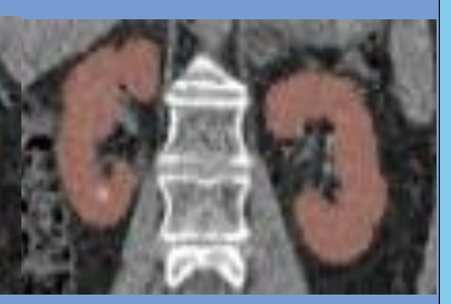
TS/3DS segmentations are classed as good for all scans. Above CT images from initial precystectomy scan -Rt 170ml;Lt also 170ml; 6months post cystectomy Rt 210ml (65%); Lt 110ml(35%); and 2 years post cystectomy (8months post reimplantation) Rt 225ml (71%); Lt 90ml(29%). As the renal volumes demonstrate though there was left renal atrophy there was also right renal hypertrophy making the left atrophy appear worse and yet the eGFR drop is only mild due to the compensatory right renal hypertrophy with a pre cystectomy total renal vol of340 ml and post reimplantation total renal vol of 315ml.

**Case C:** 65 y old female with medullary sponge kidneys (MSK). 10 year follow up scans. Renal function over this time has remained good with a creatinine of 60 (eGFR 95) 10 years ago and current creatinine of 67(eGFR 85). Renal segmentation is classed as good for all scans though the segmentation excluded some of the stones and so its difficult to assess stone volume over time.

First CT from 10 y ago renal volumes; Rt 145ml (47%), Lt 165 (53%); 2nd CT from 5 years ago Rt 130ml 46%), Lt 155ml(54%); 3rd CT from now, Rt 125ml (47%), Lt 145ml (53%). Therefore, despite a diagnosis of MSK the patient's renal volumes are relatively preserved (10 y ago total renal volume 310ml, now 270ml) hence the preserved eGFR and subsequently no need to be as aggressive with stone treatment (treatment for symptomatic relief).

10 Y ago Rt 145ml Lt 165ml eGFR 95

5 Y ago Rt 130 ml Lt 155ml



Current Rt 125ml Lt 145ml eGFR 85

## Conclusion

Though significant limitations remain, the latest renal segmentation AI software has significantly improved and is capable of providing clinically useful information such as absolute renal volume as well as split renal function to a high degree of accuracy where there is limited or no renal parenchymal distortion – which constitutes the majority of cases.
The absolute renal volume assessment is a new capability that isn't easily assessed on MAG3/DMSA. Changes in absolute renal volume has the potential to identify renal disease early on – potentially even before changes in traditional markers of renal disease such as creatinine.

References -
1. Wasserthal J, et al. *TotalSegmentator: Robust segmentation of 104 anatomical structures in CT images*. Radiol Artif Intell. 2023;5(5):e230024. https://doi.org/10.1148/ryai.230024
2. Image segmentation was performed using 3D Slicer (version 5.8, www.slicer.org)
3. Mitsui Y, et al. The assessment of renal cortex and parenchymal volume using automated CT volumetry for predicting renal function after donor nephrectomy. Clin Exp Nephrol. 2018 Apr;22(2):453-458. doi: 10.1007/s10157-017-1454-1. Epub 2017 Jul 24. PMID: 28741049.