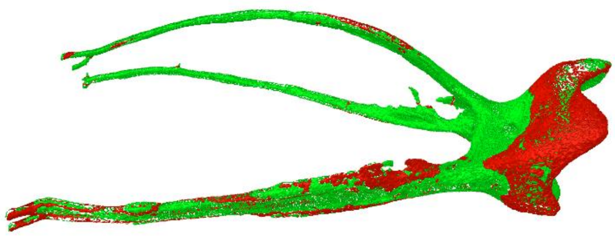
Bruker microCT

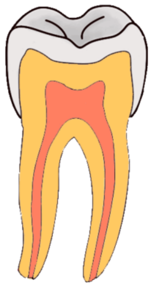
MicroCT 3D registration after tooth root canal procedures: removed volume, drill debris and touched/untouched surfaces



Method note MN110

April 2017

Introduction: the root canal before and after a procedure



MicroCT imaging is useful in endodontic research into root canal obturation, for assessing root canal procedures such as drilling the canals and addition or removal of filler material. A frequent scenario is the before-and-after scan; a tooth is images by microCT, then a procedure is carried out on the root canal, after which a second scan is performed with the same settings. Here we will go through the steps in DataViewer and CTAn for first registering scans of a tooth before and after a root canal drilling procedure, and then analyzing the outcome. We will look at measuring two things, (a) material removed by drilling and added – such as drilling debris; and (b) surfaces of the root canal touched (i.e. eroded) and untouched after the drilling. Drilling debris can prevent bonding of resin cementation to the root canal wall (Serafino *et al.* 2004). Untouched surface is an important parameter of the effectiveness of files for root canal drilling. Both of these analyses give the endodontist important information about the outcome of experimental root canal procedures.

Method

Scan and reconstruction advice prior to bone morphometric analysis

Scan settings

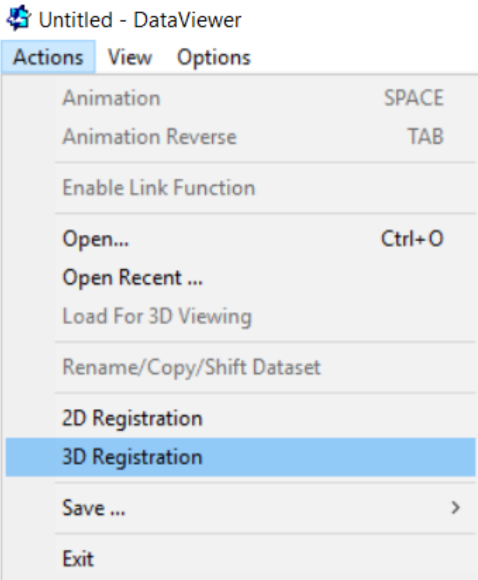
MicroCT scan settings for a human tooth should include a minimum of 1mm Al filter. The “Cu+Al” filter present in the SkyScan1172 and 1272 (40 microns of copper and 500 microns of aluminum) which is equivalent to about 2mm aluminum filtration, is preferable especially if the tooth is a molar. Higher filter is possible with scanners such as the SkyScan1275, up to 1mm copper (or brass) and this will reduce beam hardening. The applied voltage should be 60-100 kV. A scan with 360 degrees rotation is preferable to 180 degrees only.

Reconstruction settings

Apply visually appropriate smoothing and check post-alignment correction. When selecting beam hardening correction be careful not to misinterpret the two mineralized tissue layers around the root canal – the dentin immediately bordering the canal and the cementum at the outer edge of the root. Dentin is slightly more X-ray-dense than cementum, and the resulting gradient in attenuation to higher values near the center of the tooth roots can be misinterpreted as excessive beam hardening with overcorrection.

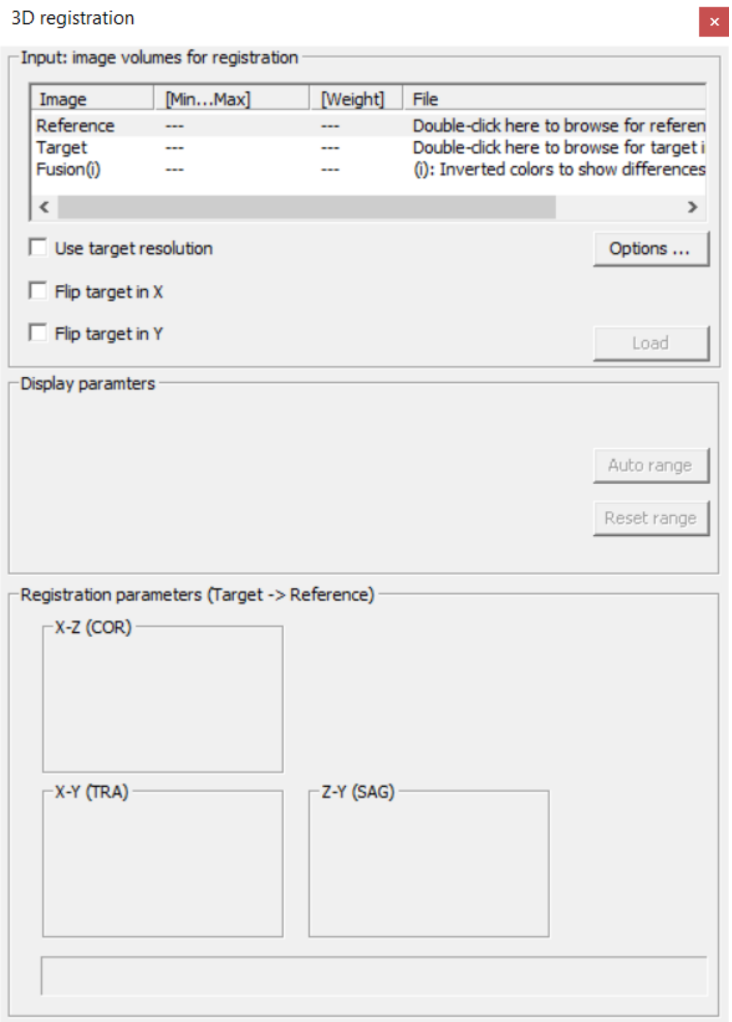
3D registration of the before and after scans of a molar tooth

We will take the example of a human molar tooth with two roots, which was scanned twice in the SkyScan1172 desktop scanner, using the "Cu+Al" filter (2mm Al equivalent) – before and after a root drilling procedure in which both roots were drilled from the crown downwards. Both roots and the central root cavity are therefore expanded to larger size and volume in the scanned molar after the procedure than before.



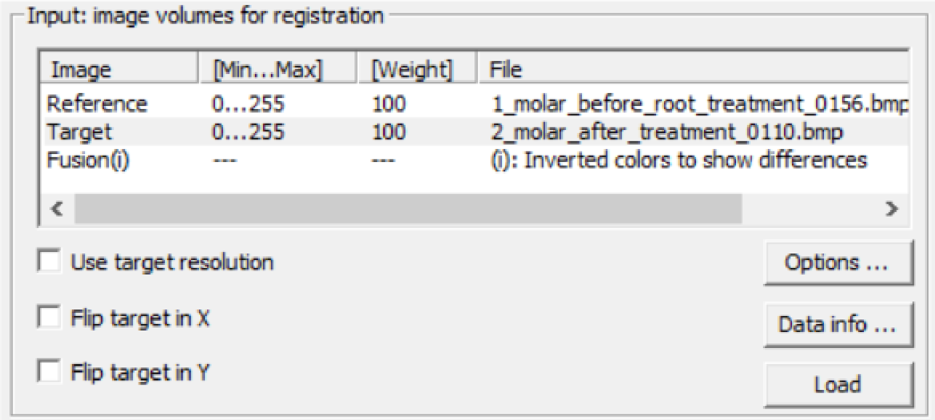
First – open DataViewer, version 1.5.0.1 or higher, preferably a more recent version. In the *Actions* menu select the item *3D Registration*.

A window will open looking like this:



Loading the "before" and "after" scan datasets for 3D registration

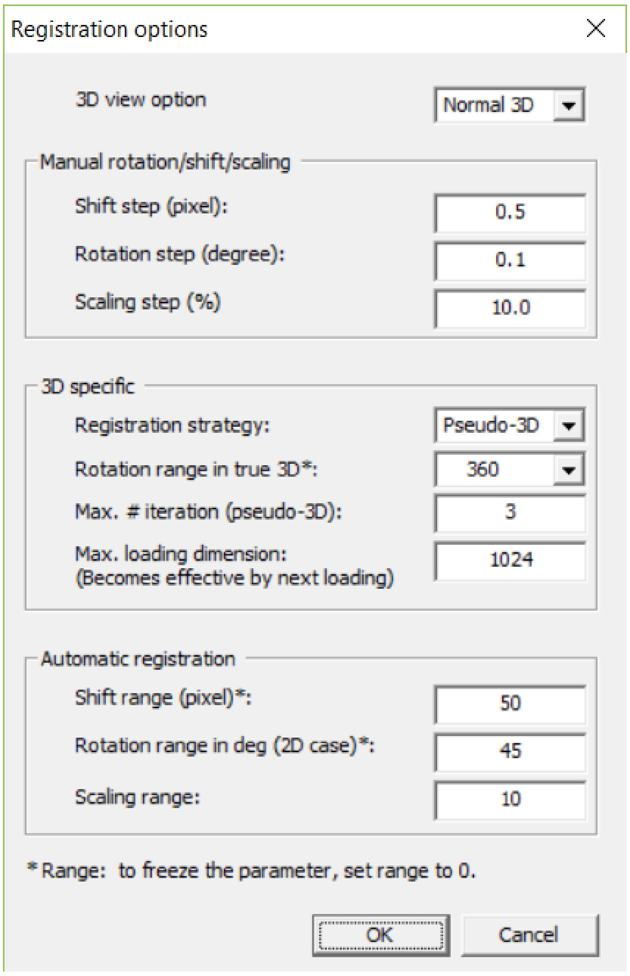
In the upper pane of this window is a table listing the two input datasets. These are the datasets that are going to be registered together in 3D. They are called the "reference" and the "target". The reference dataset will not be moved or adjusted. The target dataset will be moved and adjusted to fit onto the reference dataset. When comparing before and after scans, as in this case, typically the scan before the procedure is loaded as the reference dataset, and the scan after the procedure is loaded as the target dataset (although you can do it the other way around if you prefer).



In our case we load as reference the dataset "1_molar_before_root_treatment" and as the target dataset we load "2_molar_after_treatment".

Before clicking on "Load" – which will load the two datasets and start the 3D registration procedure – it is useful to check the registration settings by clicking on the "Options" button. This will open the window shown here on the right.

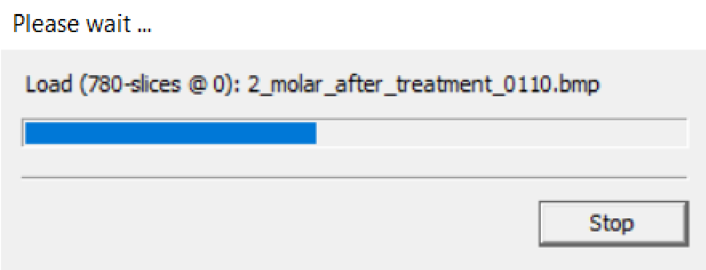
In the middle pane with the heading "3D specific", there is a choice of "Registration strategy". "Pseudo 3D" means iterative registration in 2D in the three orthogonal planes (coronal, transaxial and sagittal) which, when repeated in several cycles, approximates closely to a 3D registration. It is several times faster than the other option, "True



3D", which applies a least-squares 3D fitting algorithm which is much more time-consuming.

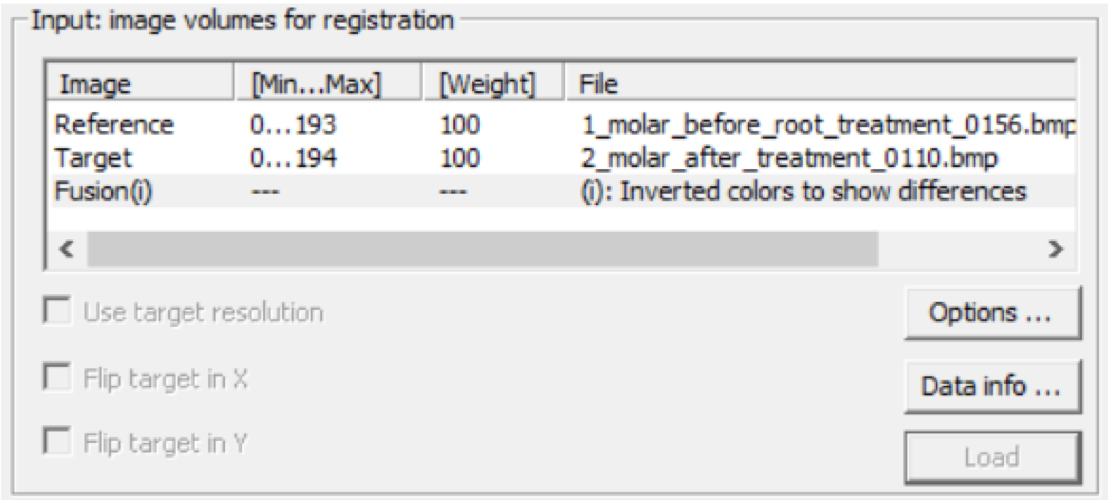
In the same pane, after "Max loading dimension", you can set the maximum size to be loaded without downsizing. If any of the dimensions of your datasets, X, Y or Z, exceed this value, then the reference and target datasets will be downsized by 2x2x2 binning on loading for 3D registration. Note however that if the datasets are downsized on loading, when saving the results of registration the option will exist for saving the output datasets at full resolution without binning.

When you click "Load", the progress of the import of the reference and target datasets will be shown:



When loading is complete, the fused image will be displayed in the main image window to the right.

This "fusion" image is the third image to be listed in the pane at the top right under the heading "Input: image volumes for registration".



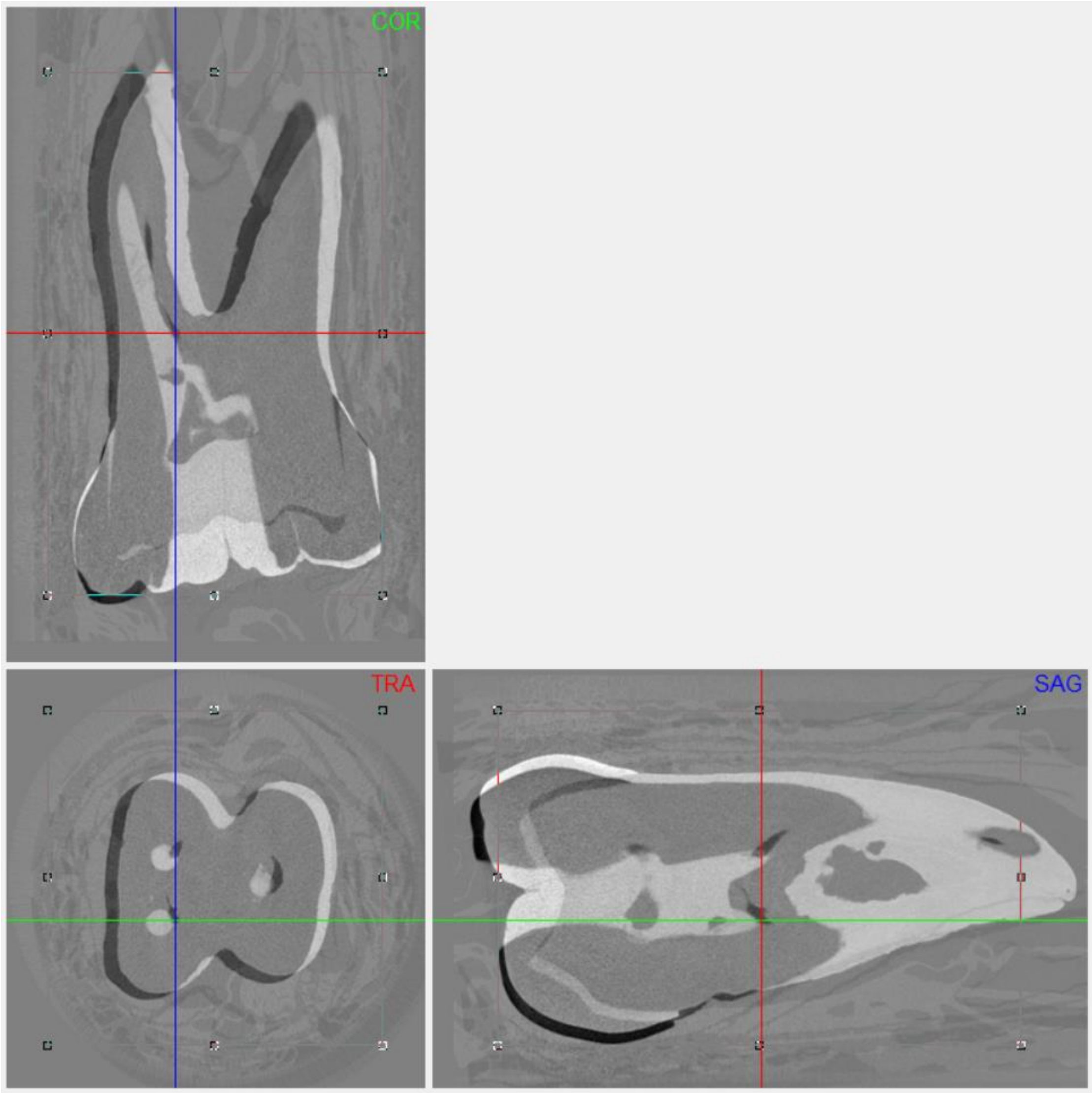
The greyscales in the fusion image look unusual. This is because it is a subtraction image. The greyscales in the target (after) dataset are subtracted from the greyscales in the reference (before) dataset. However to prevent negative greyscales, all greyscales are initially binned and compressed by two. Thus the lowest greyscale (that of air) changes from 0 to 128 (half of 256). So for any voxel in the image:

A greyscale of exactly 128 means that the reference and target are the same

A greyscale less than 128 – lighter – means that the target is less dense than the reference, indicating that something has been removed.

A greyscale more than 128 – darker – means that the target is more dense than the reference, indicating something has been added

Thus in the image below, the large column of lighter color in the center of the crown area represents the drilling through the crown to access the root canals from above.

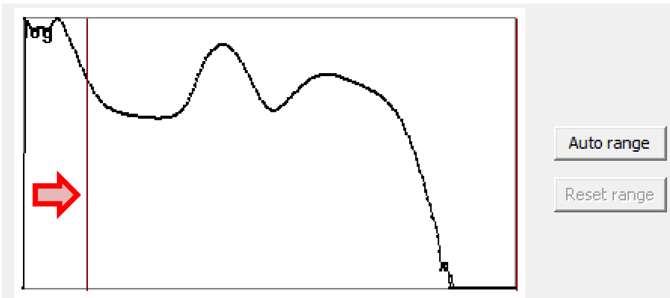


Previous method notes also give details of 3D registration

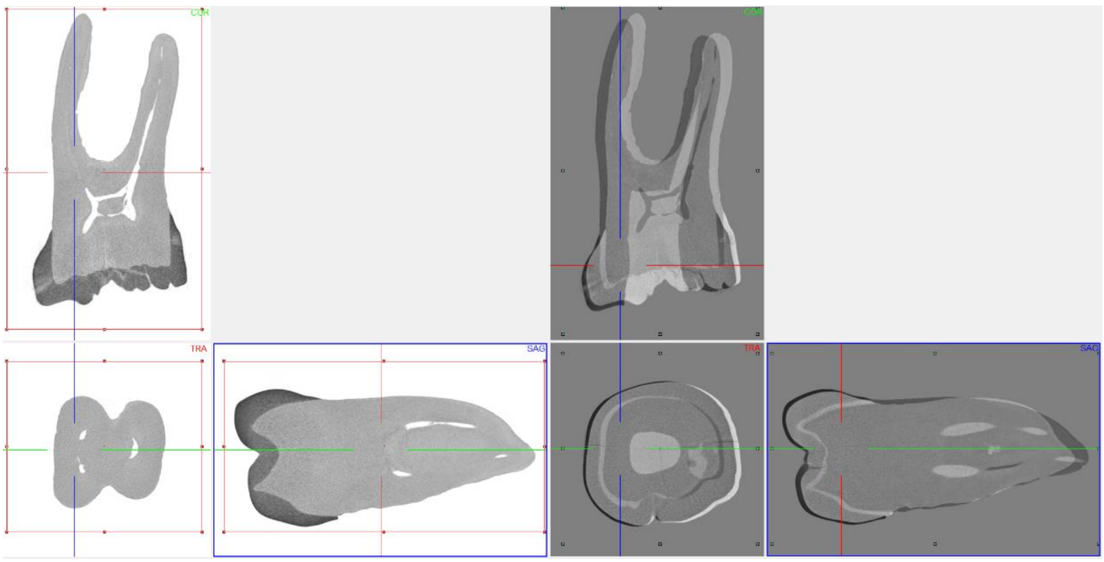
Please note that other previous method notes also describe 3D co-registration in DataViewer. MN44 describes in detail the 3D registration method including the keyboard controls for approximately aligning datasets prior to accurate software registration. MN47 and 48 also describe advanced 3D registration methods.

General tips for 3D registration

- Although registration is possible with datasets of different pixel size, it is simpler and reduces complications to have pixel size the same in reference and target datasets. For most meaningful registration results, scan and reconstruction parameters should be the same in reference and target datasets
- Although dataset XYZ dimensions don't need to be the same for registration to work, it simplifies the process if dimensions are similar.
- It speeds up and simplified registration if the orientation of the datasets is approximately the same prior to loading for registration.
- Generally don't accept the software "auto range" rescaling of the grey scale histogram. Instead, click on "Reset range" to set contrast limits to the original maximum range.
- When registering the tooth scans however it can help to move up the lower threshold (green/red lines) on the displayed histogram. (Double-click on the histogram for log scale.)



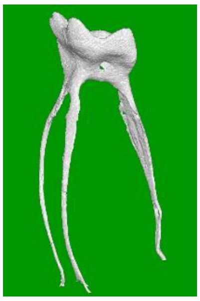
  This removes surrounding low density material like plastic tubes or paper tissue (by saturation), allowing the 3D registration to focus on the mineralized tooth material only. Comparing the images below to the fusion image on the previous page, one can see that saturating away the low density end removes the detail of surrounding plastic tube and paper tissue from the registration calculation and results.
- After 3D registration, click the "keep" button in the lowest pane under the title "Registration parameters (target > reference). This writes the registration transformation parameters to the target scan log file. After you do this, if you subsequently reload the same reference-target scans, they will assume registered positions automatically, so you don't have to repeat the registration.



Saving the registered image results

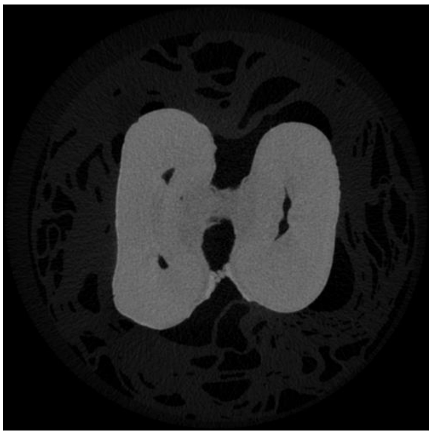
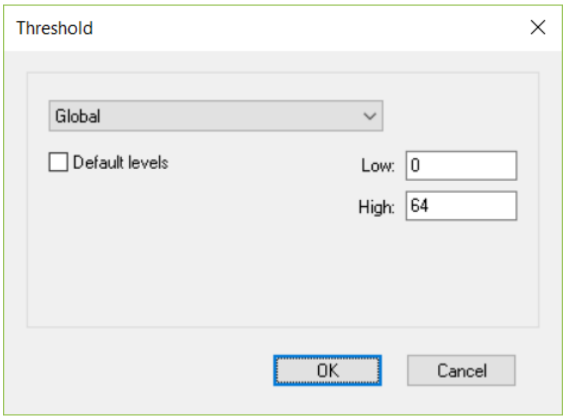
Make sure that the target, reference and difference image are al selected for saving.

Imaging and analyzing removed material and drill debris.

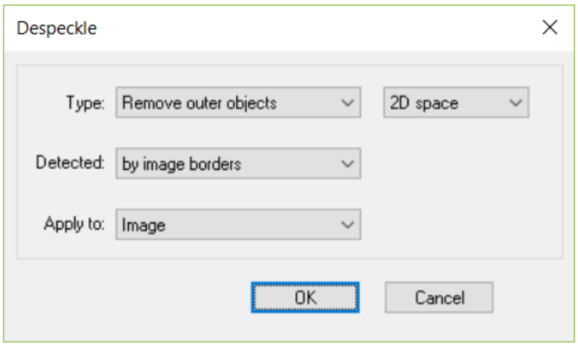


First binarize the root canals in the registered reference and target datasets

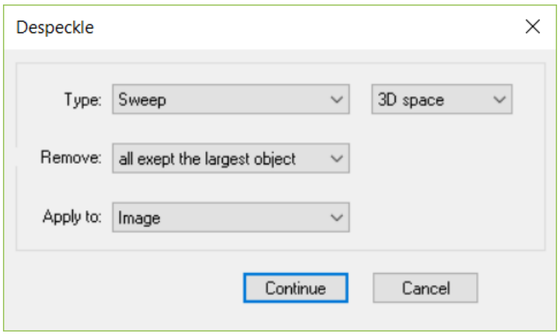
In CTAn open both the reference and target datasets in the “Registration” subfolder. Create a binary dataset of the root canals in both before and after scans by the following steps:

<table>
<tr><td>1. Load the registered molar dataset</td><td></td></tr>
<tr><td>2. Apply an inverse threshold

</td><td></td></tr>
</table>

3. Run “despeckle” and “remove outer objects” in 2D, to remove air space.



4. Run “despeckle” and sweep in 3D



5. Save the binarised root canal space

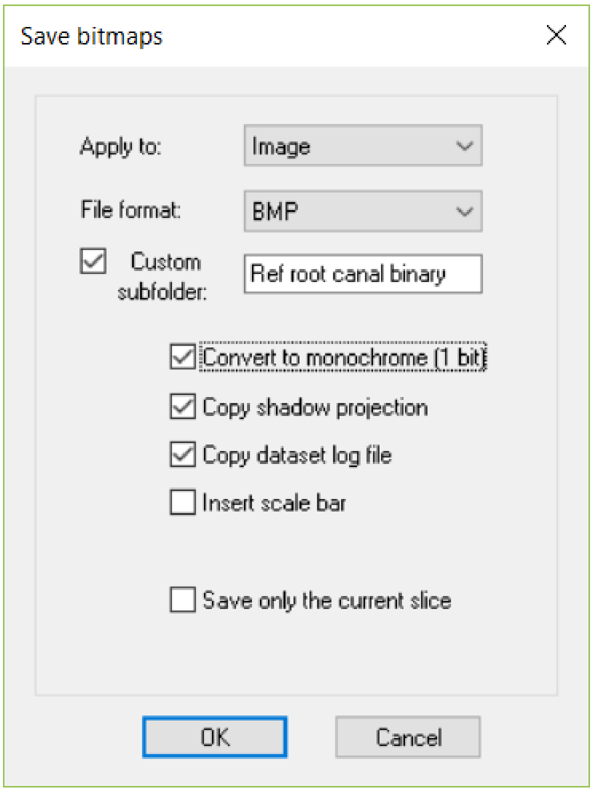
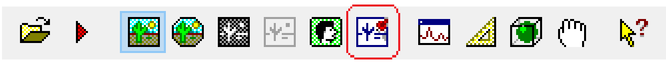
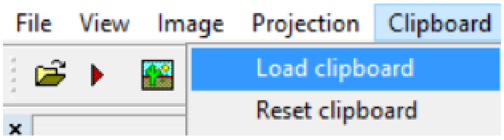


Image arithmetic: reference – target = removed material; target – reference = added debris

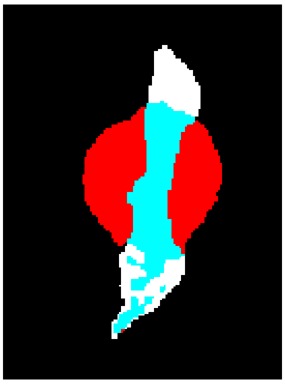
In CTAn open the binarized root canal dataset from the registered reference ("before") scan. Then click on the clipboard button (circled in red)

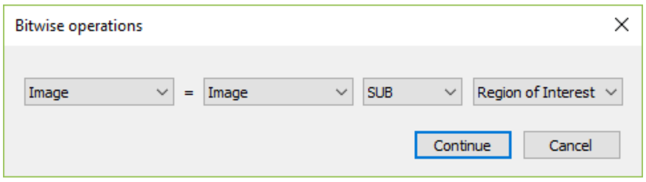


Then load the binarized root canal dataset from the target ("after") scan, into the clipboard by first clicking on the clipboard page button, then the "Clipboard" menu, then select "Load clipboard" (if you have CTAn 1.16; with earlier versions you can instead load the target dataset as an ROI in the BMP format.)

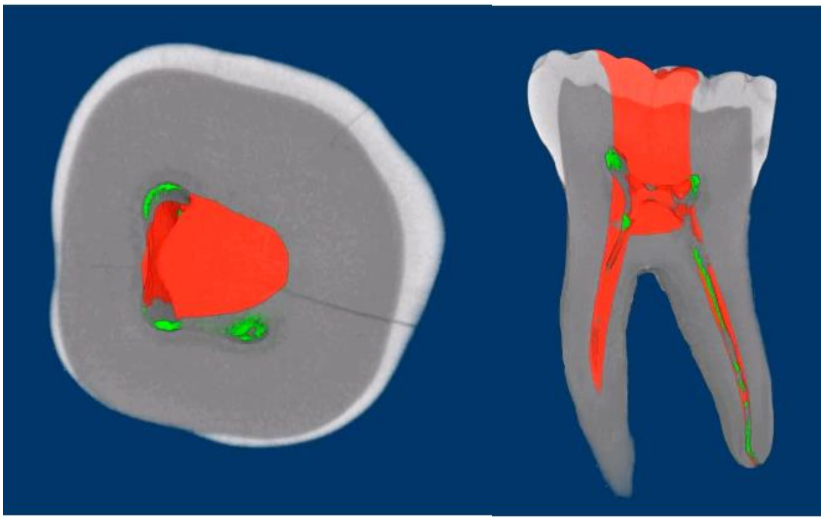


With these two datasets loaded, we now go to custom processing and do some simple "image arithmetic". Just subtracting one root canal binary from the other, before minus after equals what has been removed – the drilled out dental tissue. And after minus before equals what has been added – in practice this means the drilling ***debris***. This is an important outcome for endodontists to be able to both visualise and quantify. The image to the right shows the result of this image arithmetic. The original image from the before scan – the smaller elongated canal cross-section, is in white. The canal in red is larger after the drilling and circular in cross-section. Blue-shaded white region means space present both before and after. However the pure white areas were space before but solid after, and are **debris** from the drilling. Both the removed material (before minus after) and the debris (after minus before) can be saved as binarized image datasets using the "save bitmaps" plugin.





In the CTVox images to the left, the removed material (before-scan minus after-scan) is shown in red while the drilling debris (after-scan minus before-scan) is shown in green.



Once the removed (red) and added (green) material is binarized, it is then straightforward to measure it by 3D analysis to assess volume, surface area, thickness and other parameters.

Imaging and analyzing touched and untouched surfaces.

The analysis of touched and untouched surface starts in just the same way as the analysis above of the drilled out and debris material. First the before-and-after scans are registered in 3D. After that, we again make the binary datasets of the root canal spaces in the registered before-and-after datasets. (We can just load the binarized root canal datasets that we already created for the above analysis of removed material and debris.) Then however we introduce a new step – making binary images of a thin boundary around the root canal only, not the whole root canal volume. We start this with the before, reference dataset, already binarized. First threshold the image dataset in custom processing (necessary even for binary images), then following steps will create a one-pixel thick boundary just one pixel external to the original binary of the root canal:

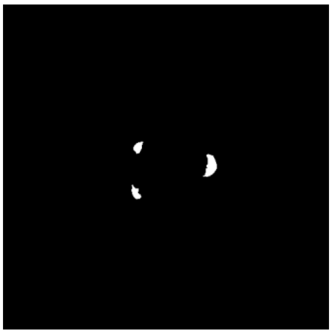
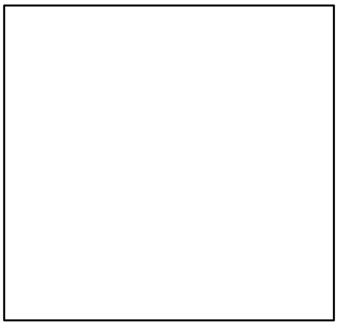
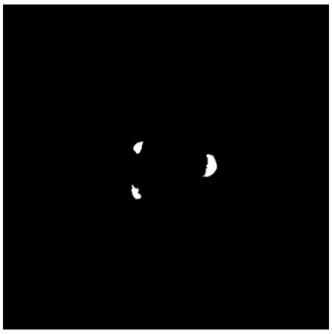
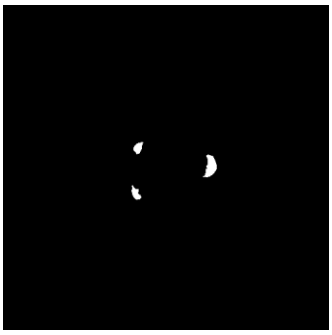
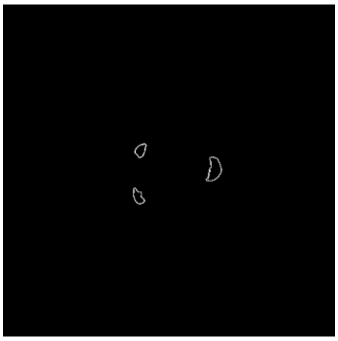
	IMAGE	ROI
1. Load root canal binary of reference dataset		
2. Bitwise: ROI = COPY IMAGE		
3. Morphological operations: Dilate 1 pixel, 3D, apply to ROI		

	IMAGE	ROI
4. Bitwise: IMAGE = ROI SUB IMAGE		
Save Bitmaps / Image, BMP, monochrome (1-bit), save SPR, save log file.		

After this, load into CTAn the binarized dataset (already created from Analysis 2) of the after-scan root canal. Follow a similar procedure but modified to create a 3 pixel thick boundary layer, not just one pixel.

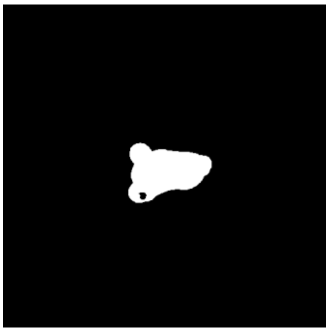
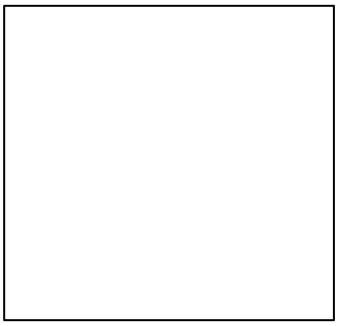
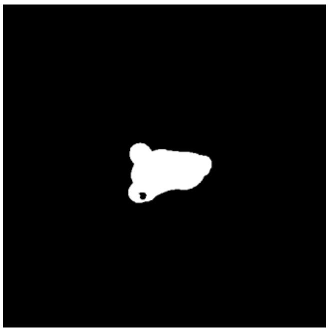
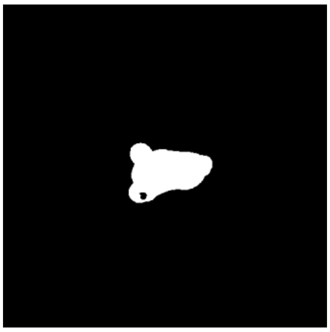
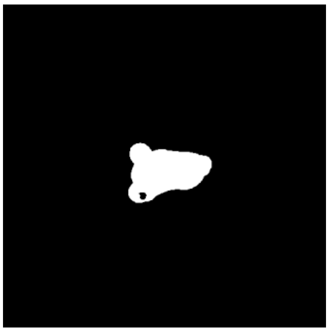
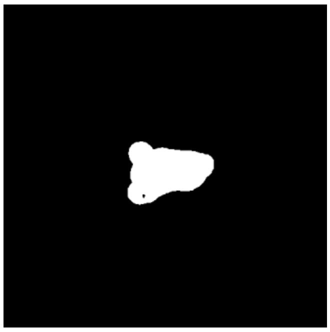
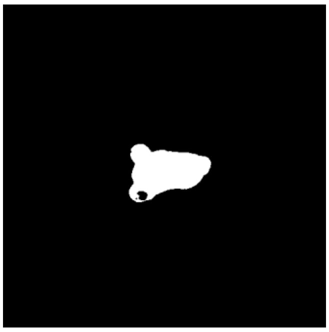
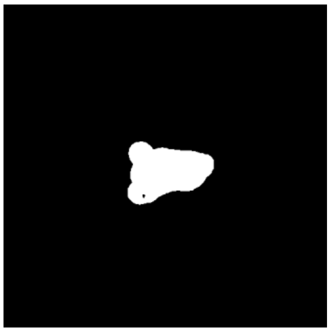
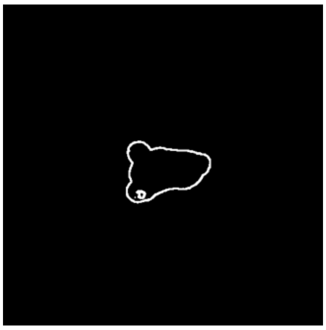
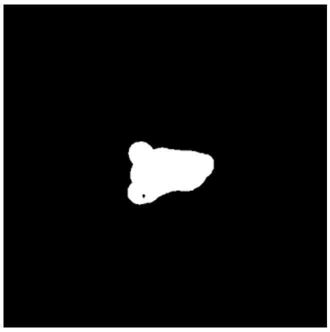
	IMAGE	ROI
1. Load root canal binary of target dataset		
2. Bitwise: ROI = COPY IMAGE		

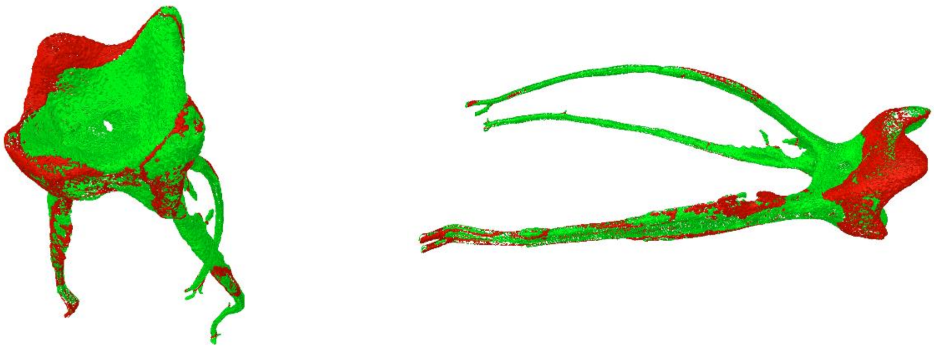
	IMAGE	ROI
3. Morphological operations: Dilate 2 pixel, 3D, apply to ROI		
4. Morphological operations: Erode 1 pixel, 3D, apply to IMAGE		
5. Bitwise: IMAGE = ROI SUB IMAGE		
6. Save Bitmaps / Image, BMP, monochrome (1-bit), copy SPR, copy log file.		

Finally, load the binarized dataset of the 1-pixel boundary around the reference (before-scan), as the image. Then load the binarized dataset of the 3-pixel boundary around the target (after-scan), as the ROI.

The reason for the 3 pixel thickness of the binarized boundary around the target (after-scan) root boundary is to allow for registration error of ± 1 pixel.

The part of the 1-pixel-thick root canal boundary from the before-scan which coincides in space with the 3-pixel-thick root canal boundary from the after-scan, will be considered to be untouched surface, not changed by the experimental procedure. This is now simply the image inside ROI.

The other part of the 1-pixel-thick root canal boundary from the before-scan which is not inside the 3-pixel-thick root canal boundary from the after-scan, will be considered to be untouched surface, not changed by the experimental procedure. This is now simply the image inside (NOT) ROI.



In the above image, generated by CTVol as surface rendered models, green means touched surface (eroded by drilling) and red means untouched surface (not changed between scans before and after drilling).

Quantitative assessment of untouched surface: with 1-pixel thickness, volume (cubic voxels) equals surface area (square pixels)

As with the removed and added material (debris) in the first analysis above, the binary datasets created of the touched and untouched surfaces allow quantitative analysis in CTAn, for instance by 3D analysis for volume, surface area and all other morphometric parameters. Note that in the case of the boundary binary image of untouched surface, since it is 1-pixel thick, it means that the measured volume in units of voxels cubed also equals the surface area in voxels squared, simplifying the assessment of untouched surface.

Touched and untouched surfaces are otherwise referred to as "instrumented" and "non-instrumented" surfaces (Versiani *et al.* 2011). These surfaces can be visualised and quantified as described here using image processing and boolean operations in CTAn custom processing.

References

- Serafino C, Gallina G, Cumbo E, Ferrari, M (2004) Surface debris of canal walls after post space preparation in endodontically treated teeth: a scanning electron microscopic study. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology 97(3): 381-387.
- Versiani MA, Pécora JD, de Sousa-Neto MD (2011) Flat-oval root canal preparation with self-adjusting file instrument: a micro–computed tomography study. Journal of Endodontics 37(7):1002-1007.