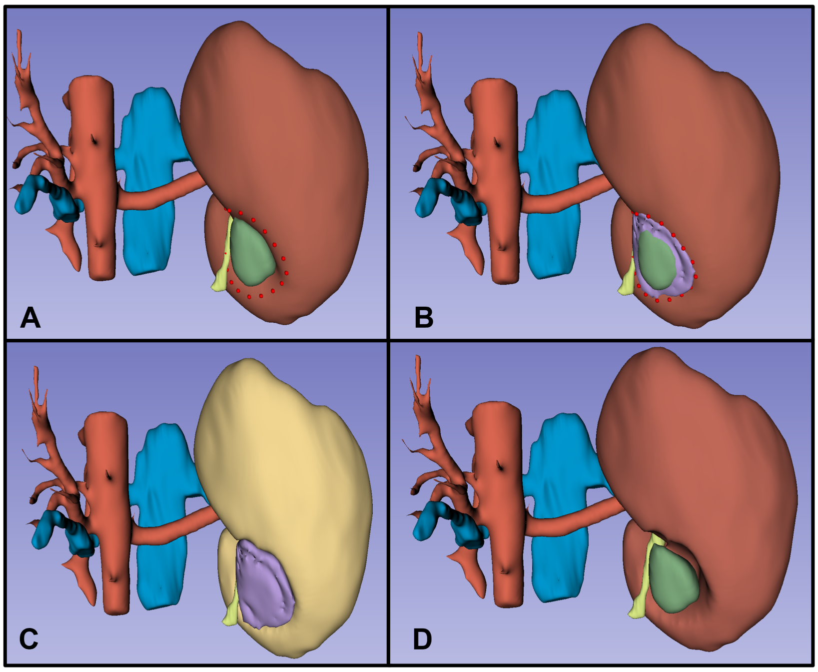
Virtual Resection to Estimate Postoperative Kidney Volume in Nephron-Sparing Surgery for Wilms Tumour Patients: Standardized Protocol



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1 Introduction

Wilms tumors (WT), also known as nephroblastoma, are the most frequently occurring renal tumor in children with a five years survival rate of $\sim$90% [2]. Approximately 35 children are affected with WT in The Netherlands annually and the majority of cases presents itself with a unilateral tumor. In 5-10 % of WT patients the disease presents itself bilateral with an increased likelihood for end-stage renal disease and secondary morbidity [5]. Treatment of WT is in accordance to the Umbrella treatment protocol prescribed by the Renal tumor Study Group of the International Society of Peadiatric Oncology (SIOP-RTSG) [6]. This treatment protocol describes neoadjuvant chemotherapy, followed by open radical or partial nephrectomy, also known as nephron sparing surgery (NSS), and adjuvant chemotherapy. Open NSS is the preferred surgical treatment in bilateral and syndromic unilateral patients to preserve as much functional remaining renal volume (RRV).

In nonsyndromic patients, radical nephrectomy is the standard of care due to the inherent risk for irradical resection in NSS. This upstages the patient, therewith requiring radiotherapy and possibly chemotherapy. However, NSS may reduce the risk of end-stage renal failure and allows for more surgical treatment options in secondary tumors in the contralateral kidney [1]. Such cases requires extensive preoperative planning to ensure a safe oncological outcome and the preservation of functional RRV.

For the preoperative planning of NSS, three-dimensional (3D) visualization are routinely used. The introduction of these techniques improved the anatomical orientation of surgeons performing oncologic renal surgery [7]. In addition, Isotani et al. showed that 3D visualizations could be used for virtual resection of adolescence renal tumors [3]. This technique allows surgeons to virtually performing NSS and estimate the RRV preoperatively.

A novel virtual resection tool was developed and validated as a NSS planning tool for the treatment of WT patients by Van der Zee et al. [8]. The virtual resection tool describes the steps that have to be followed for virtual resection that result in a predicted RRV and resection volume. The developed tool was able to estimate the postoperative kidney volume, as a fraction of the preoperative kidney volume, with a median volume fraction of 0.94 (IQR = 0.16). More information about instalation and required software can be found in the installation section. The protocol requires 3D anatomical models of the kidney, tumour and in some cases nephroblastomatosis. The following steps have to be followed are visualised as a workflow shown in figure 2. The workflow section describes the workflow step by step.

2 Installation

Download the supplementary files and make sure the following open-source software programs are installed:

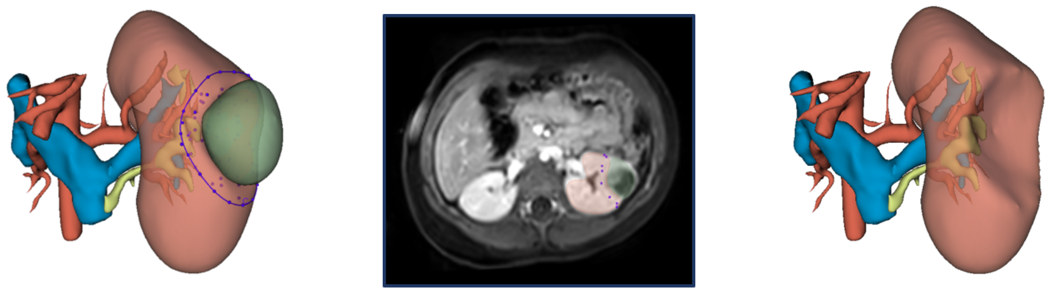
- 3D Slicer (latest stable version)
- Resectionplanner extension in 3D Slicer

Follow the installation instructions of the open-source 3D Slicer software. The ResectionPlanner can be downloaded in the Extension Wizzard. Go to the Github (https://github.com/JaspervanderZee/Virtual-Resection) to download the VirtualResection.py file. An example 3D Slicer file can be found in the Github as well for comparison. The python script must be added into the extension folder of the software that can be found using the dictionary example below:

Directionary: 'C:/Users/NAME/AppData/Local/NA-MIC/Slicer 5.0.3/lib/Python/Lib/site-packages'

3 Virtual Resection Workflow

The surgical protocol for NSS consist of the circumscription of the resection border with diathermy and subsequent tumor removal [4]. The virtual resection was designed to mimic this surgical technique. The surgeon is able to orientate the patients anatomy by inspecting the 3D visualization and the available imaging data. The methodology for virtual resection is visualized in figure 2. After inspection, the surgeon pinpoints several markups on the surface of the kidney and the software, in 3D Slicer, computes a closed curve between these markups. This closed curve, visualized as the purple line in figure 2-I, represents the circumscription of the resection border with diathermy. Secondly, the surgeon pinpoints several intraparenchymal markups in the available imaging data. Both closed circle and intraparenchymal markups are combined and used as input to the ResectionPlanner. This results in a 3D model of the virtual remaining kidney used for the determination of the virtual RRV. Finally, the surgeon is able to make small final corrections on the 3D model with tools in 3D Slicer.



(a) (b) (c)

Figure 2: Workflow for virtual resection: (a) 3D visualization that contains the closed curve that was pinpointed by the surgeon, indicated in purple. (b) Preoperative MRI imaging (post-contrast fat-suppressed T1-weighted sequence) of the abdomen with the kidney and WT segmented in red and green respectively. The surgeon is asked to pinpoint intraparenchymal markups which are visualized as purple dots. (c) Virtual RRV after virtual resection in 3D Slicer.

Step 1:
Please make sure the kidney model is a segmentation called 'Kidney' with a segmentation node of the kidney that is called 'Kidney'. Make sure the kidney is available as segmentation node. If you only have the kidney model, please right click on the model and click *convert model to segmentation node*. Make sure that the names are consistent. The output for this step and all the following steps are visualized in Figure 2.

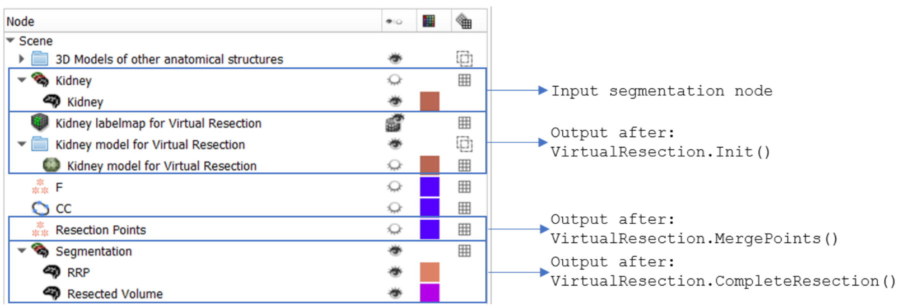


Figure 2: Outputs for all steps.

Step 2:
Import the virtual resection workflow into the dictionary. Go to the 'Python Interactor' and make the command: 'import VirtualResection'.

Step 3:
This step consists of the creation of a kidney model and a kidney labelmap as shown in Figure 2. These two

nodes are needed for the final resection. Therefore, make the command: 'VirtualResection.Init()'. Please check if the two nodes appear in the node list.

Step 4:
Markups have to be pinpointed on the kidney surface that forms the peripheral resection border. Go the the *markups* selection and click on the markups called 'CC'. Pinpoint several markups on the surface of the kidney in a consecutive manner. If the selected markups are sufficient, click *resample* in the *markups* selection and set the following settings:

- **Output node**: overwrite current node
- **Number of resampled points**: approximately 20

Step 3:
Pinpoint intraparenchymal markups in the kidney volume that defines the depth of the resection. Go the the *markups* selection and click on the markups called 'F'. Pinpoint several markups on different anatomical 2D-slices and/or orientations.

Step 4:
The markups have to be combined as one markup file. Therefore, make the command: 'VirtualResection.MergePoints.()'. Check if the visibility of 'F' and 'CC' are switched off and a new markups node is created namely 'Resection Points'.

Step 5:
Go to the *ResectionPlanner* extension and set the following settings listed below. Figure 3 visualize an example the settings that have to be filled in.

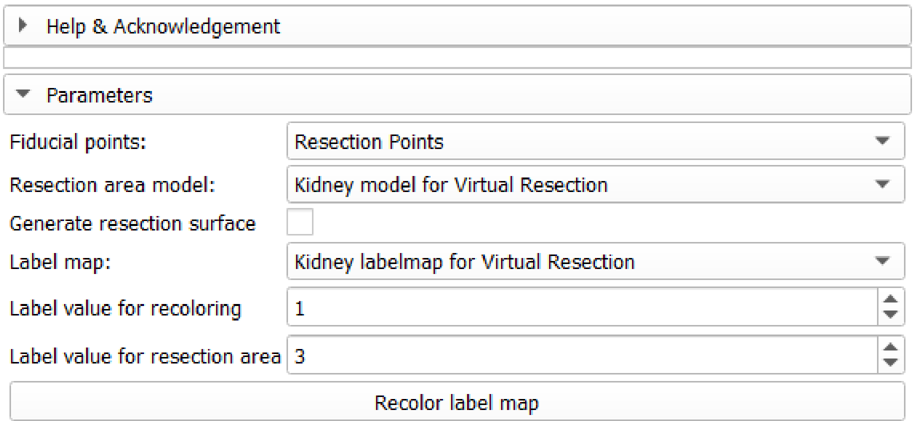


Figure 3: Preview of the *ResectionPlanner* extension with the different settings that have to be set to.

- Fiducial points: select the markups 'Resection Points'
- Resection area model: select the model 'Kidney for Virtual Resection'
- Generate resection surface: click on the checkbox
- Label map: select the labelmap 'Kidney labelmap for Virtual Resection'
- Label value for recoloring: fill in '1'
- Label value for resection area: fill in '3'

Step 6:
This step involves the final segmentation of the remnant renal volume (RRV). Therefore, make the command: 'VirtualResection.CompleteResection()'. The virtual resection is now finalized and the output are two segmentation nodes of the RRV and the resected volume respectively. If the segmentations are not

sufficient, you can make adjustments in the 'segmentation editor'.

Step 7:
The final volume fraction can be calculated with the model volumes. Model nodes can be derived by right click on the segmentation node and click the option 'Export all visible segments to models'. The volumes can been seen in the 'Models' extension in the subfolder 'Information' folder.

Troubleshooting:

- If the final segmentation is not sufficient and the resected area is too little, small adjustments can be made. Firstly, try to reshape the segmentation with the *scissor* tool or other simple segmentation tools. Secondly, if the first solution was not sufficient try to redo the steps 5 and 6. Make sure to delete the copied kidney model, kidney labelmap and the final segmentation node. Recopy the kidney model and recreate a binary labelmap as done in the first step.
- Names of the segmentation node are not consistend. Please make sure the names are consistent.

4 Acknowledgement

I would like to extend my sincere thanks to all the co-authors of the manuscript [8] for the conceptualization of this protocol. Finally, I would also like to extend my deepest gratitude to Myrthe Buser for the help with all the coding issues. Without her this protocol was not as sufficient as it is today.

References

[1] Norman E. Breslow et al. "End stage renal disease in patients with Wilms tumor: Results from the National Wilms Tumor Study Group and the United States Renal Data System". In: *Journal of Urology* 174.5 (2005), pp. 1972–1975. ISSN: 00225347. DOI: 10.1097/01.ju.0000176800.00994.3a.

[2] J. De Kraker et al. "Reduction of postoperative chemotherapy in children with stage I intermediate-risk and anaplastic Wilms' tumour (SIOP 93-01 trial): A randomised controlled trial". In: *Lancet* 364.9441 (2004), pp. 1229–1235. ISSN: 01406736. DOI: 10.1016/S0140-6736(04)17139-0.

[3] Shuji Isotani et al. "Feasibility and accuracy of computational robot-assisted partial nephrectomy planning by virtual partial nephrectomy analysis". In: *International Journal of Urology* 22.5 (May 2015), pp. 439–446. ISSN: 0919-8172. DOI: https://doi.org/10.1111/iju.12714. URL: https://doi.org/10.1111/iju.12714.

[4] T Klatte and Vincenzo Ficarra. "A Literature Review of Renal Surgical Anatomy and Surgical Strategies for Partial Nepherectomy". In: *Eur Urol.* 68.6 (2015), pp. 980–992. DOI: 10.1016/j.eururo.2015.04.010..

[5] Monika L. Metzger and Jeffrey S. Dome. "Current Therapy for Wilms' Tumor". In: *The Oncologist* 10.10 (2005), pp. 815–826. ISSN: 1083-7159. DOI: 10.1634/theoncologist.10-10-815.

[6] Marry M. Van Den Heuvel-Eibrink et al. "Position Paper: Rationale for the treatment of Wilms tumour in the UMBRELLA SIOP-RTSG 2016 protocol". In: *Nature Reviews Urology* 14.12 (2017), pp. 743–752. ISSN: 17594820. DOI: 10.1038/nrurol.2017.163.

[7] Nicole Wake et al. ""Pin the Tumor on the Kidney:" An Evaluation of How Surgeons Translate CT and MRI Data to 3D Models". In: *Urology* 131.718 (2019), pp. 255–261. ISSN: 15279995. DOI: 10.1016/j.urology.2019.06.016.

[8] Jasper M. van der Zee et al. "Virtual Resection: A New Tool for Preparing for Nephron-Sparing Surgery in Wilms Tumor Patients". In: *Current Oncology* 29.2 (Feb. 2022), pp. 777–784. ISSN: 17187729. DOI: 10.3390/curroncol29020066.