“Show Me The Unseeable” Dossier

Flow of Urine from the Renal Medulla to the Ureter
Anterolateral cross-sectional view of the right kidney

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1. PROJECT OVERVIEW

Goal
The goal of this project was to create an anatomically accurate and realistically illuminated illustration of a human kidney without a directly observable specimen. The figure was staged from a non-standard viewpoint, with a cross-sectional cut that provided a view of how urine travels from the renal medulla into the ureter.

Audience
Scientific

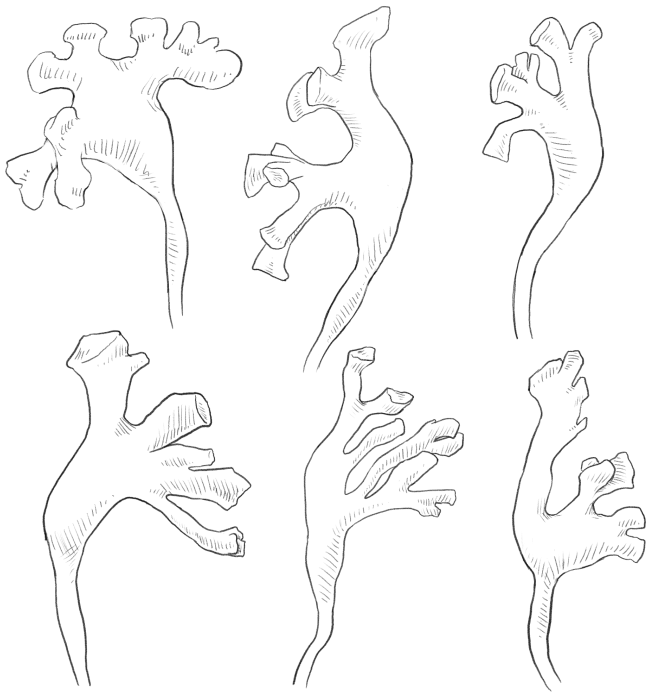
Basic workflow
- Research and collection of radiological data
- Maquette-building from data
    - **Software**: radiological data to model in 3DSlicer, cross-sectional cut and details sculpted in ZBrush, staging and lighting in Cinema 4D
- Greyscale rendering with maquette as lighting reference and static images of fresh kidneys as texture references
    - **Software**: basic layout in Adobe Illustrator, linear sketch in Procreate, detailed rendering in Adobe Photoshop
- Colourization with surgical videos as colour reference in Adobe Photoshop

2. RESEARCH & MAQUETTE BUILDING

After settling on the topic of "a cross sectional view of a human kidney that shows how urine travels from the renal medulla into the ureter", I teamed up with my classmates, Cathy Zhou and Raymond Zhang, to research kidney anatomy and develop a maquette. We took an exploratory approach by dissecting the kidneys of five cadavers in our anatomy laboratory. Despite the great deal of intra- and interindividual variation, this investigation gave us some familiarity with the patterns in kidney tissue texture, renal pyramid shape, arrangement, and number, and differences in overall size.

I visited Grant's museum and sketched the variability of renal calyx size, number, and arrangement. This approach helped me visualize the three dimensional aspects of the calyces, especially those that project anteriorly and posteriorly.

Fig 1. Sketches of renal pelvis variation from Grant's museum



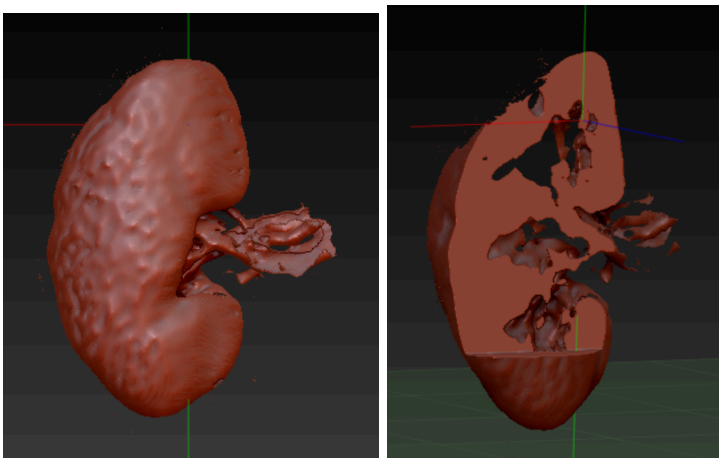
Following this exploration, we sought radiological data to use as the basis of a digital three-dimensional model of the kidney. Making a model would give us a convenient way to view the effects of light on 3D forms and make custom cut-aways, both of which are not possible when working from two-dimensional images in anatomical atlases.

I downloaded a sample dataset of contrast-enhanced renal MRA scans from the OsiriX library of DICOM datasets (titled "BEAUFIX"), and used 3DSlicer to assemble the cross-sectional images into a 3D model. The .obj file was imported into ZBrush to clean and sculpt it.

Fig 2. Kidney model from renal MRA scan, unedited (DICOM Image Library, n.d.)

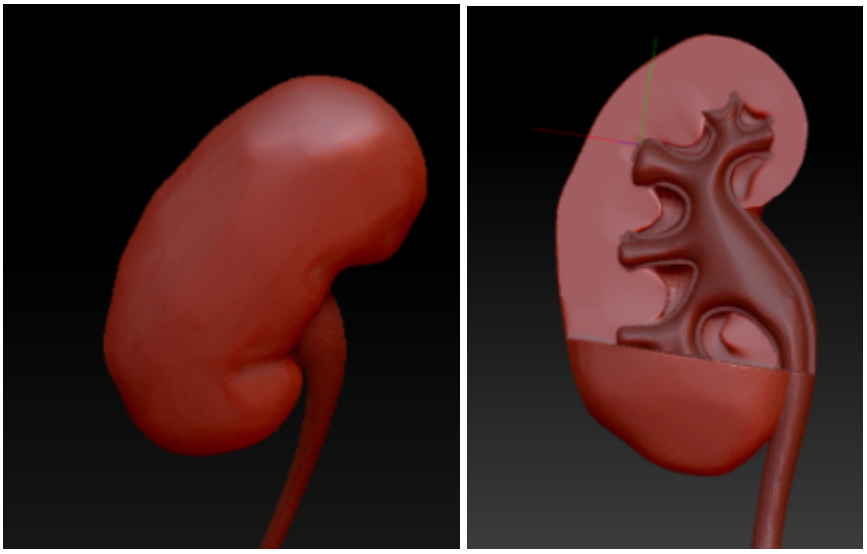
The model was, evidently, quite messy. I attempted to clean it, then create a cross-sectional cut-away. Despite my best efforts, the model was lacking in clarity both internally and externally (in professional terms, a bust).

Fig 3. Cleaned kidney and cross-sectional cut



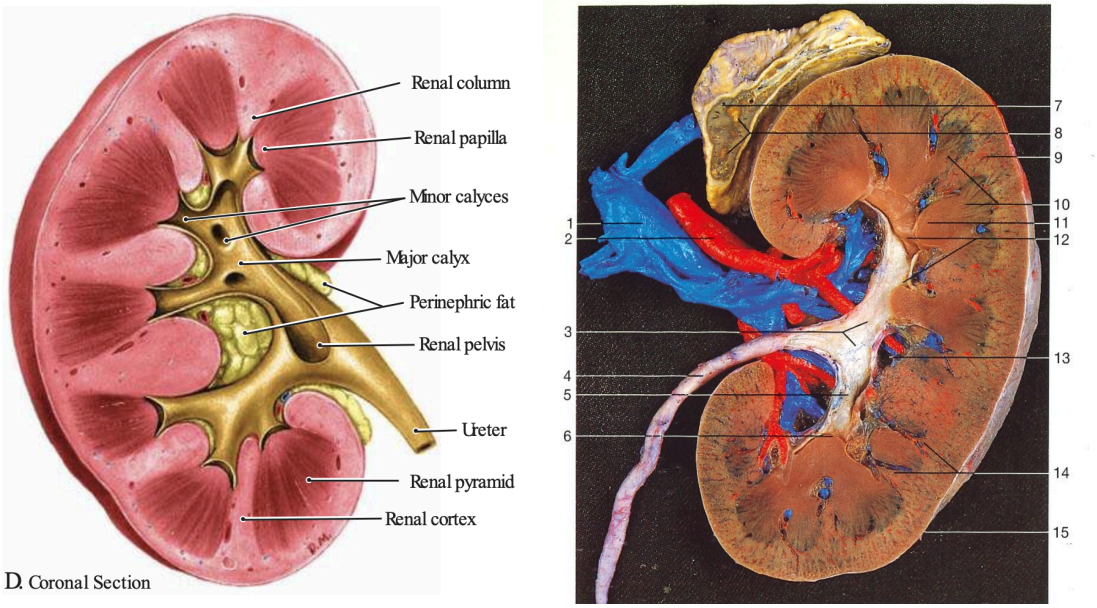
Our team landed on the Japanese Body Parts Data set and used the pre-formed model of a right kidney and ureter. Since the model was pre-made, we skipped 3DSlicer and went straight into ZBrush. The model was cut using a live boolean cube, placed in such a way that the superior ¾ of the anterior half of the right kidney and renal pelvis were hidden. This cut exposed a coronal plane and a transverse plane, in such a way that one could visualize the urine flowing from the renal medulla, through the renal pelvis and into the ureter.

Fig 4. Imported model and custom cut (Body Parts 3D, n.d.)



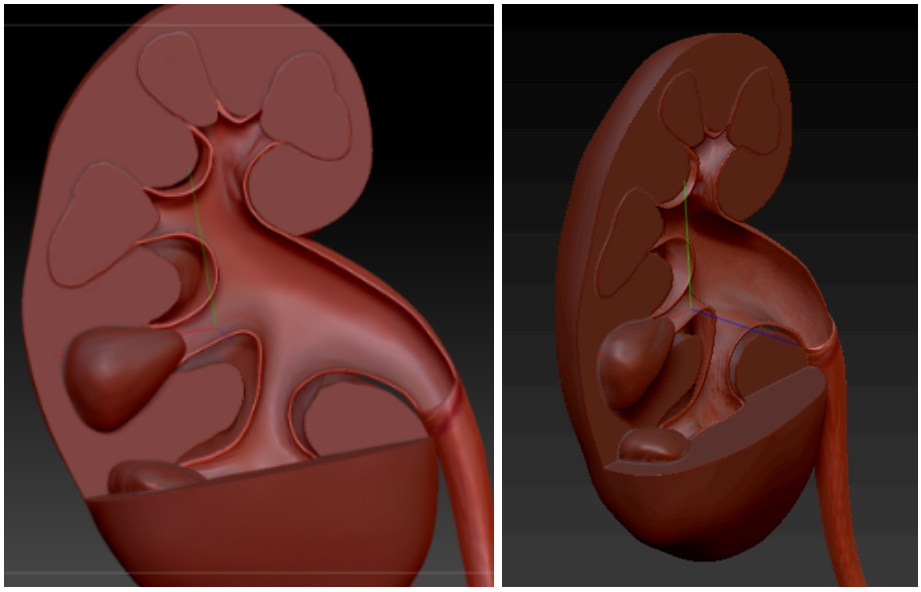
Internal structures were sketched into the kidney's surface which was otherwise solid (no internal structure was preserved in the pre-made model). This sculpt was based on anatomical atlases, photographs of kidneys, and our experience dissecting kidneys in the anatomy lab.

Fig 5. Anatomical atlas references for sculpt (Agur & Dalley, 2017; Rohen et al., 2011).



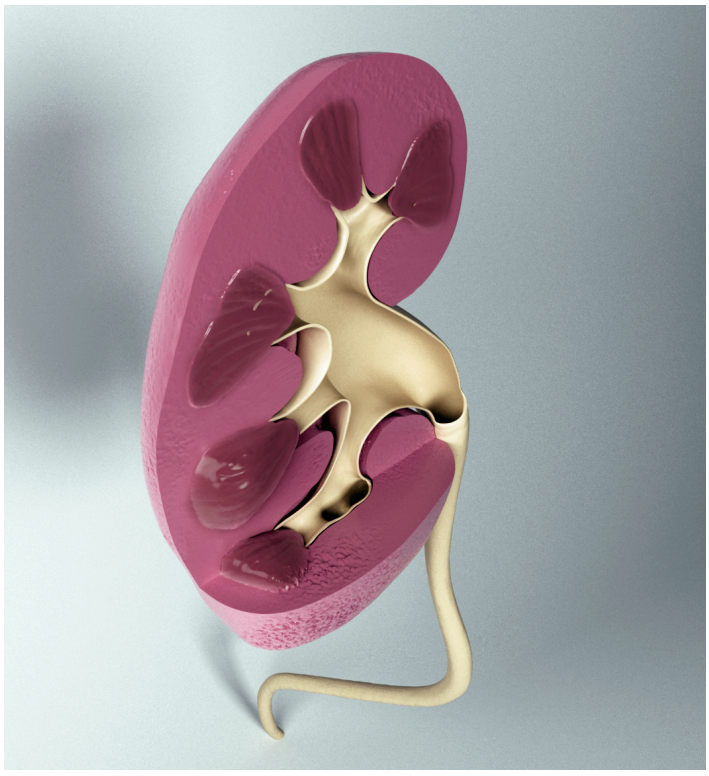
Empty spaces were left between the renal columns and the calyces, which would normally be occupied with fat and blood vessels (these were rendered later during the painting process). Two of the inferior pyramids were inflated to better convey the three-dimensional nature of the renal pyramids.

Fig 6. Final maquette in Zbrush



In Cinema 4D, materials were created for the ureter, renal cortex, and renal pyramids by adjusting pre-existing sample materials. Upper left lighting was added, as is convention, as well as a softer front-facing illumination to soften the shadows on the coronal plane. Several iterations of the maquette were rendered before landing on a final angle and lighting setup:

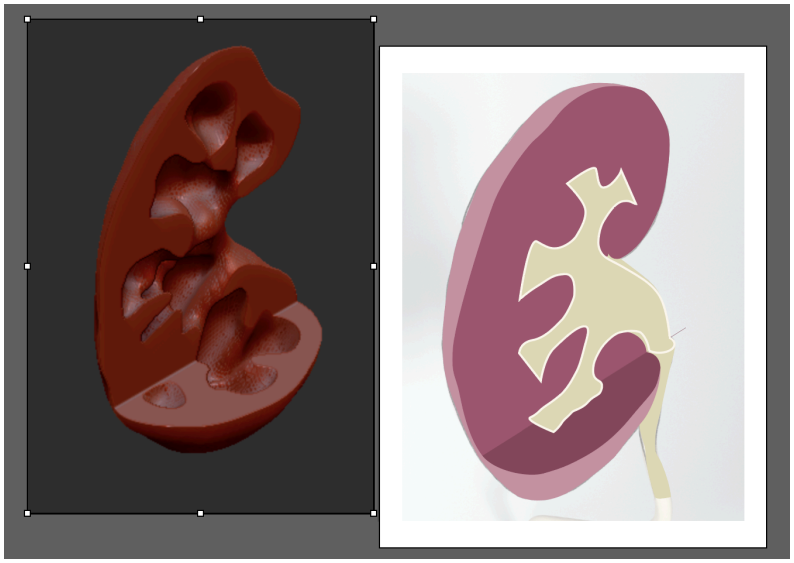
Fig 7. Final maquette in Cinema 4D



3. INITIAL DRAFTS

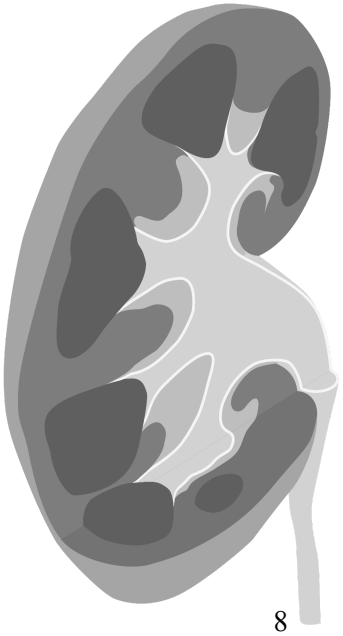
Initial layout of the sketch was done in Adobe Illustrator, by tracing over the maquette. After consulting the anatomical atlases further, I found that the shape of the renal pyramids in our maquette was inaccurate; they generally occupy more of the parenchyma than was modelled. I consulted yet another CT database, the IRCAD Respiratory Cycle dataset, and used their pre-masked kidney model to better understand the dimensionality of the internal kidney structure. I started my layout in colour, before switching to greyscale.

Fig 8. IRCAD maquette and Illustrator layout (*Respiratory cycle 3D-IRCADb-02.*, n.d)



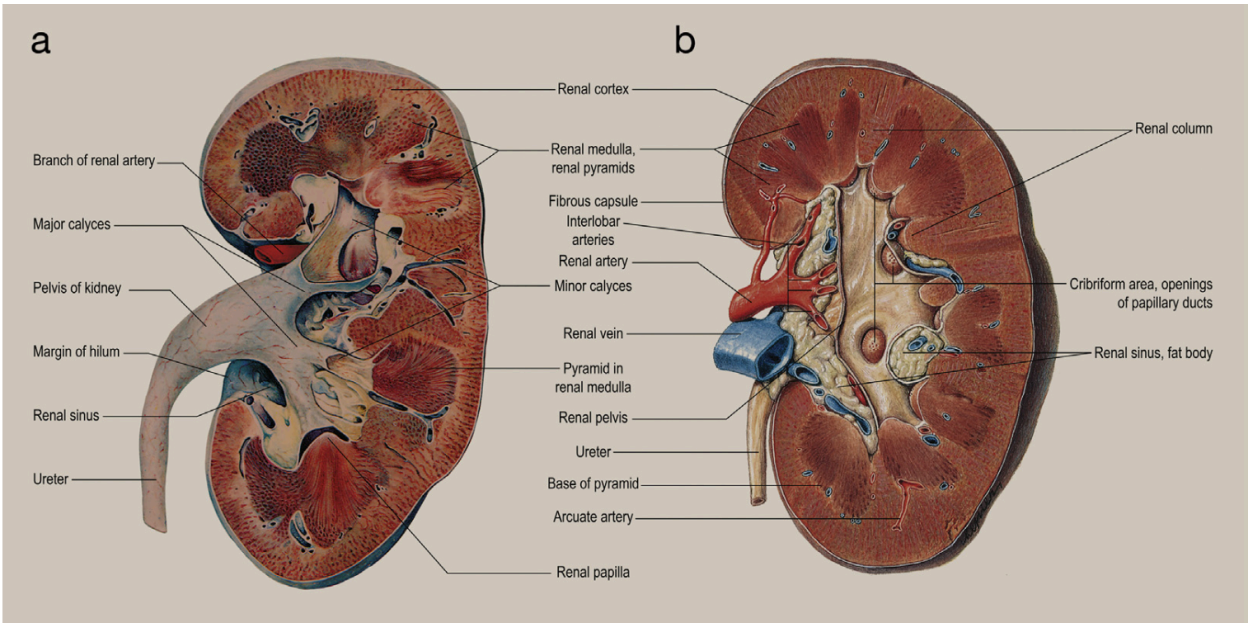
I made some modifications to the general shape of the flat and 3D pyramids, and developed a clear, flat greyscale of the kidney. I colour picked from a greyscale version of the maquette render in order to (roughly) mimic its tones.

Fig 9. Greyscale maquette and illustrator layout of elements.



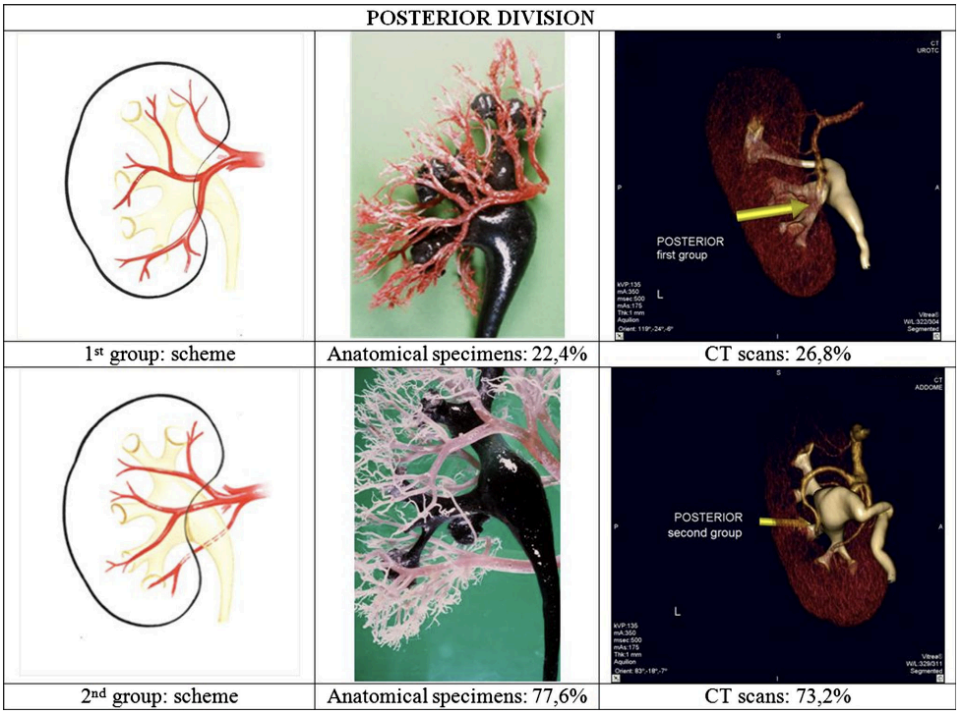
I found a very helpful illustration in a basic kidney anatomy journal article, wherein the renal capsule was shown to continue into the hilum and over the surface of the renal columns. This helped me determine how the sides of the renal column intersect with the renal pyramids.

Fig 10. Coronal sections through the left kidney (Mahadevan, 2019).



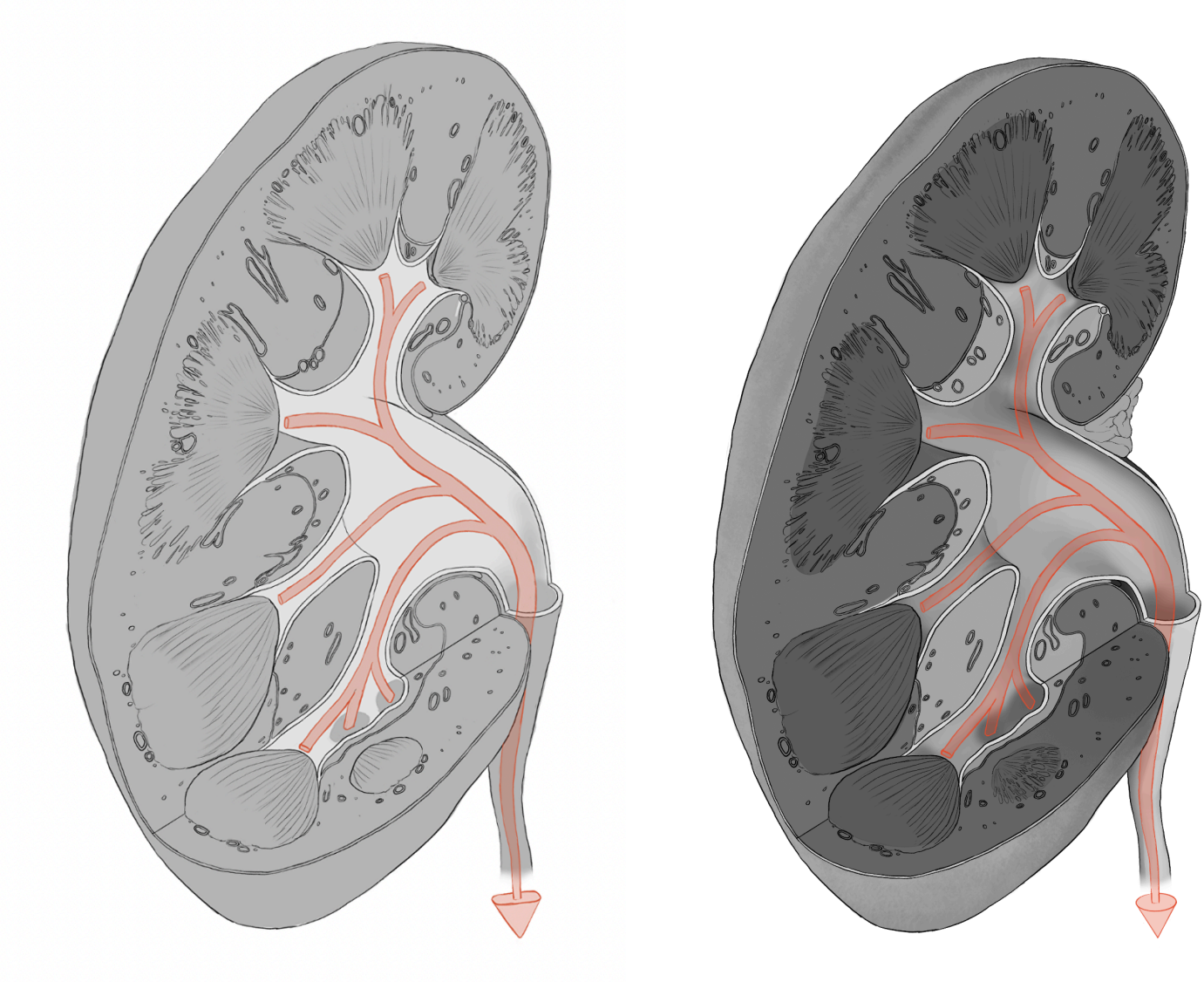
Determining where to place the cut vessels was a challenge. I consulted a paper on renal segmental artery anatomy to get a better idea of the variation in vessel distribution within the renal sinus. This strategy helped me visualize where the highest densities of cut vessels might be.

Fig 11. Distribution of posterior division renal segmental arteries in 2D and 3D views.



While the strategy of laying out elements in Illustrator was effective for isolating each structure to its own layer, it was lacking in detail. Two iterations of clean, linear sketches were developed in Procreate before moving to a full greyscale rendering. Details such as blood vessels, striations of the renal pyramids, and the arrow indicating the flow of urine were added. Feedback sessions provided the guidance to include fat poking out of the hilum.

Fig 12. Iterations of a linear sketch of the kidney.



After receiving sign-off on the sketch (yippee!), it was time to move onto the full tonal rendering.

4. TONAL RENDERING

As discussed in the previous section, laying out the structures in Illustrator allowed a more organized workflow in which I could build up details on each structure individually, without impacting any others.

Fig 13. Sequential build-up of textures on isolated structures (renal pelvis, addition of blood vessels and fat texture, shading on renal pyramids).

Cathy found some photographs of real kidneys, which provided an excellent reference for tissue texture in the cortex, pyramids, and fat:

Fig 14. Cross-sectional views of a human kidneys (Calvo, n.d.).

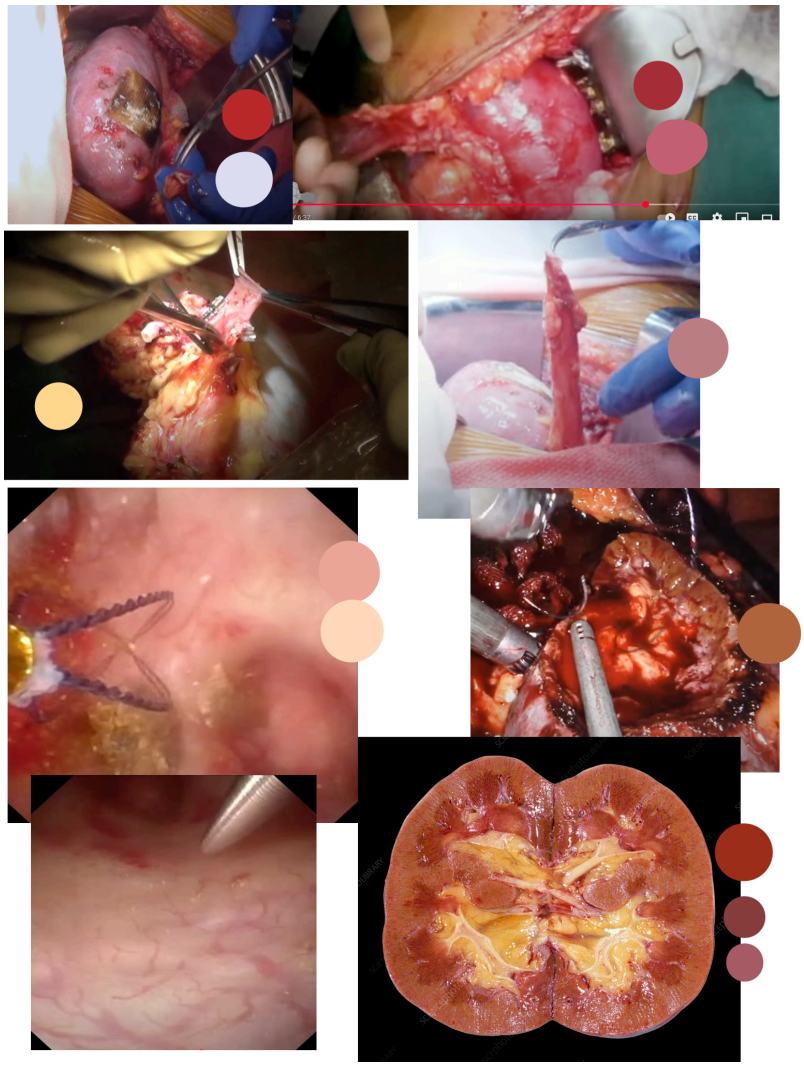
Texture was slowly but surely built up using a variety of brushes. The parenchyma texture was mostly applied with grainy, crunchy-looking brushes that gave it that rough appearance. The renal pelvis and the fat were shaped with a soft airbrush that gentled their edges and gave the impression of gradual curvature. A hard-edged brush was used for most of the specular highlights. Fig 14 was paramount to this step. Finally, the greyscale was complete.

Fig 15. Full tonal rendering of the kidney.

5. COLOURIZATION & LABELLING

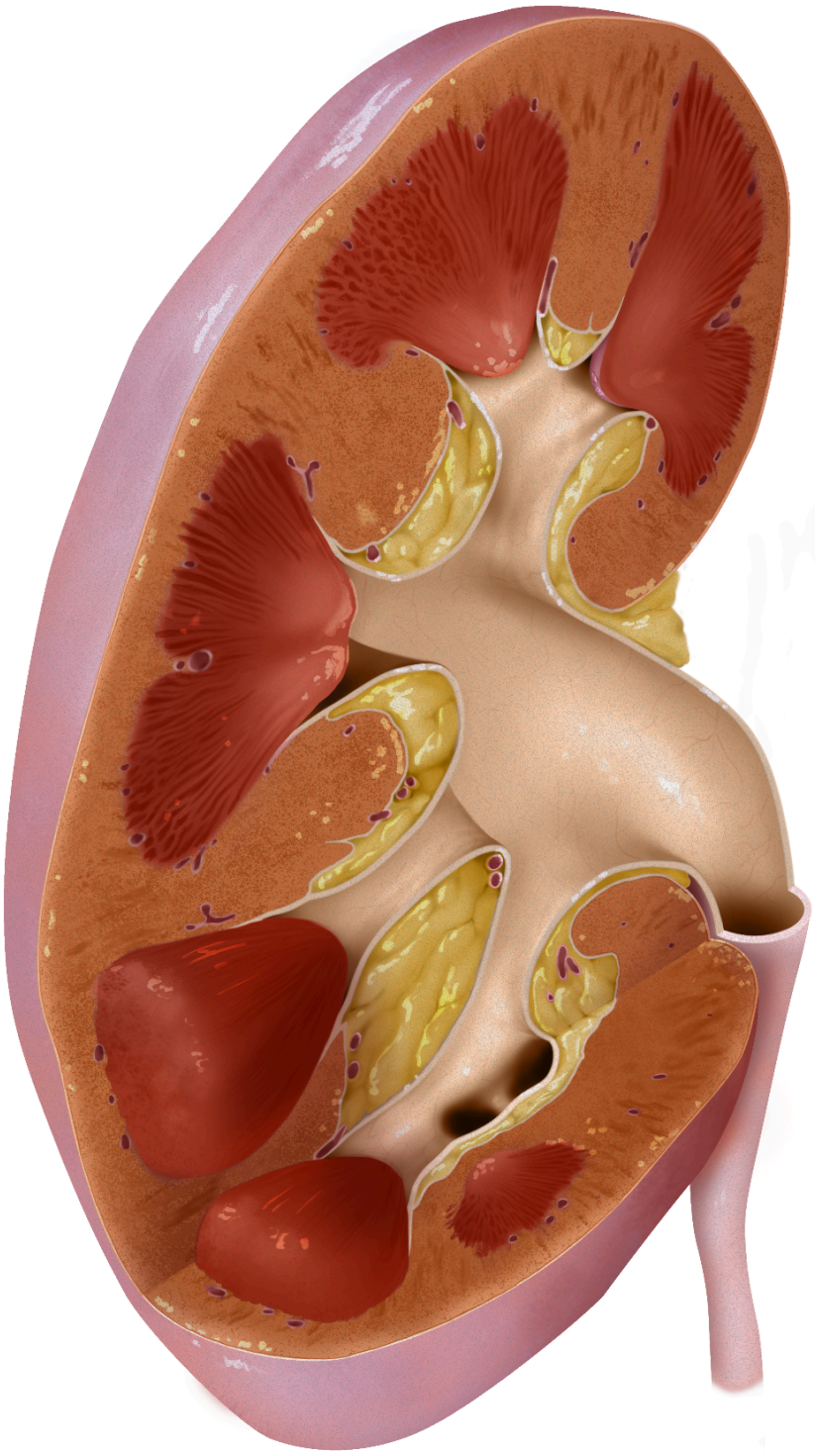
I referenced surgical videos of kidney transplants, partial and radical nephrectomies, and ureteroscopies as colour references for the colourization step. I developed a colour palette from screenshots of said videos.

Fig 16. Kidney colour references from surgical videos



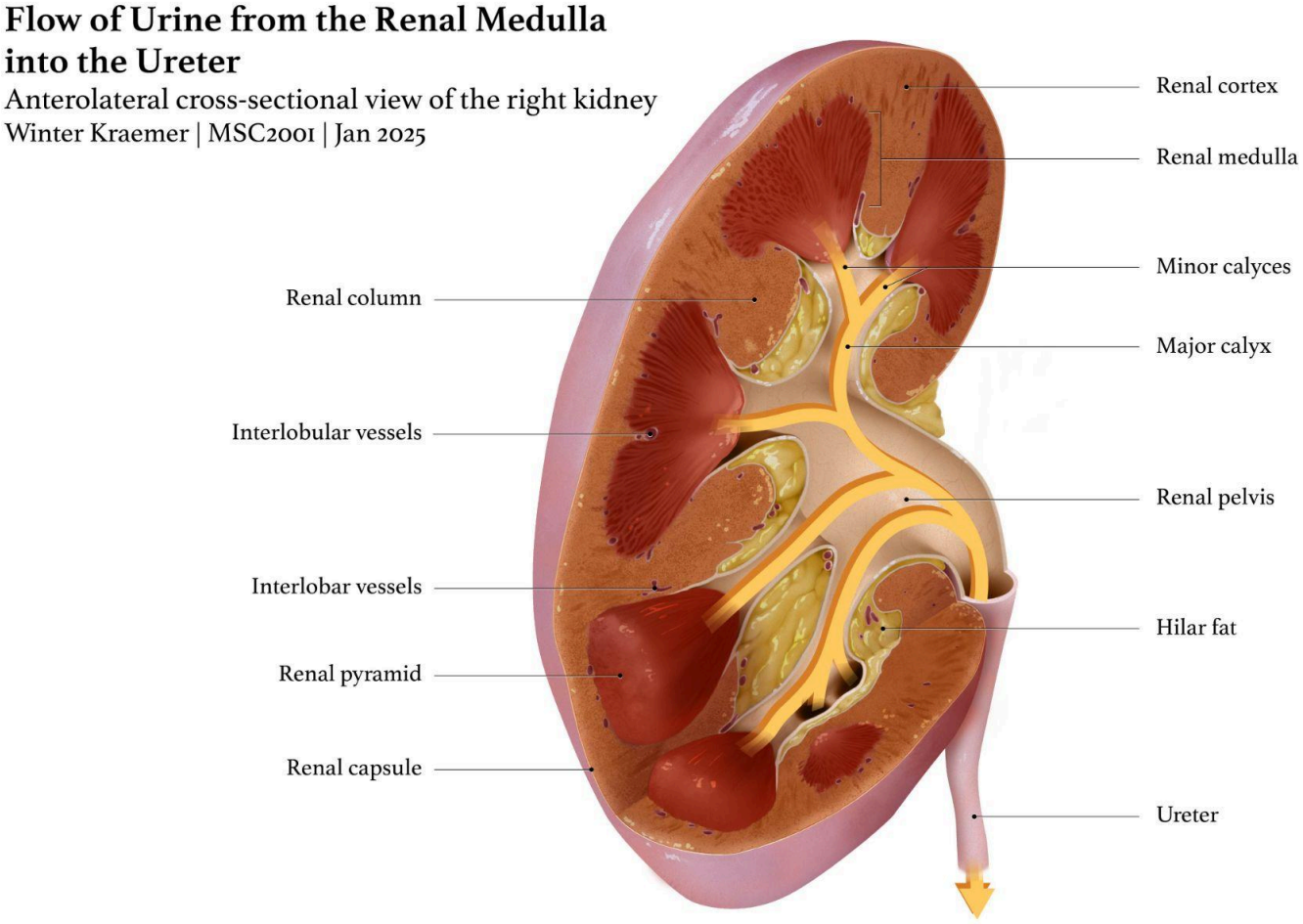
The colourization process was easy. Almost too easy. I chose a modified version of the Michael Corrin™ strategy, wherein I added a layer of flat colour over the structure of choice and set the layer mode to “Color”, which yielded more vivid hues than the “Multiply” mode. The strategy was recommended to me by Molly Wells. Each structure has a discrete colour and textures were already resolved in the greyscale stage, so I did not have to worry about the destructive workflow created by putting multiple colours in one layer. This was the end result:

Fig 17. Colourized rendering of human kidney



Finally, the arrows and labels were added in Illustrator, and were checked against Grant's Atlas to confirm their accuracy. And so, I was released from the clutches of this assignment (mostly).

Fig 18. Labelled, colourized kidney render



6. FUTURE STEPS

In the future, I would like to return to this project and work on the following (based on my own goals and others' feedback):

- Variation in colour to provide more depth, not just depending differences in value for the same hue (makes it look flat)
- Increase the detail and realism of the cut blood vessels
- Rework the shape of the fat so it looks more like a cut plane, and less three-dimensional
- Add blood vessels to the outside of the ureter
- Improve the accuracy of the specular highlights, perhaps by observing from a real kidney purchased at a butcher's shop
- Refine the arrow so that it looks more like it occupies the three dimensional space of the kidney

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