

From Chisels To Cyberspace: Technological Transitions In Craniosynostosis Surgical Management

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INTRODUCTION

Total Cranial Vault Remodeling (CVR) technique, which is used to treat Craniosynostosis is potentially:

- Long
- Technique-sensitive
- Highly variable in outcomes
- Surgeon’s experience dependent

The surgical technique has undergone only minor refinements over the past 60 years, heavily relying on manual handheld tools to remodel a patient’s calvarial anatomy.



This study proposes a novel technique leveraging 200 years of advancements in woodworking and engineering technologies to improve the speed, accuracy, and precision of the procedure.

METHODS

A systematic review using PRISMA methodology identified 12 studies showing quantifiable improvements from integrating technologies like CAD/CAM, virtual reality (VR), 3D printing, and computer numerical control (CNC) machining.

The steps of the workflow were as follows:

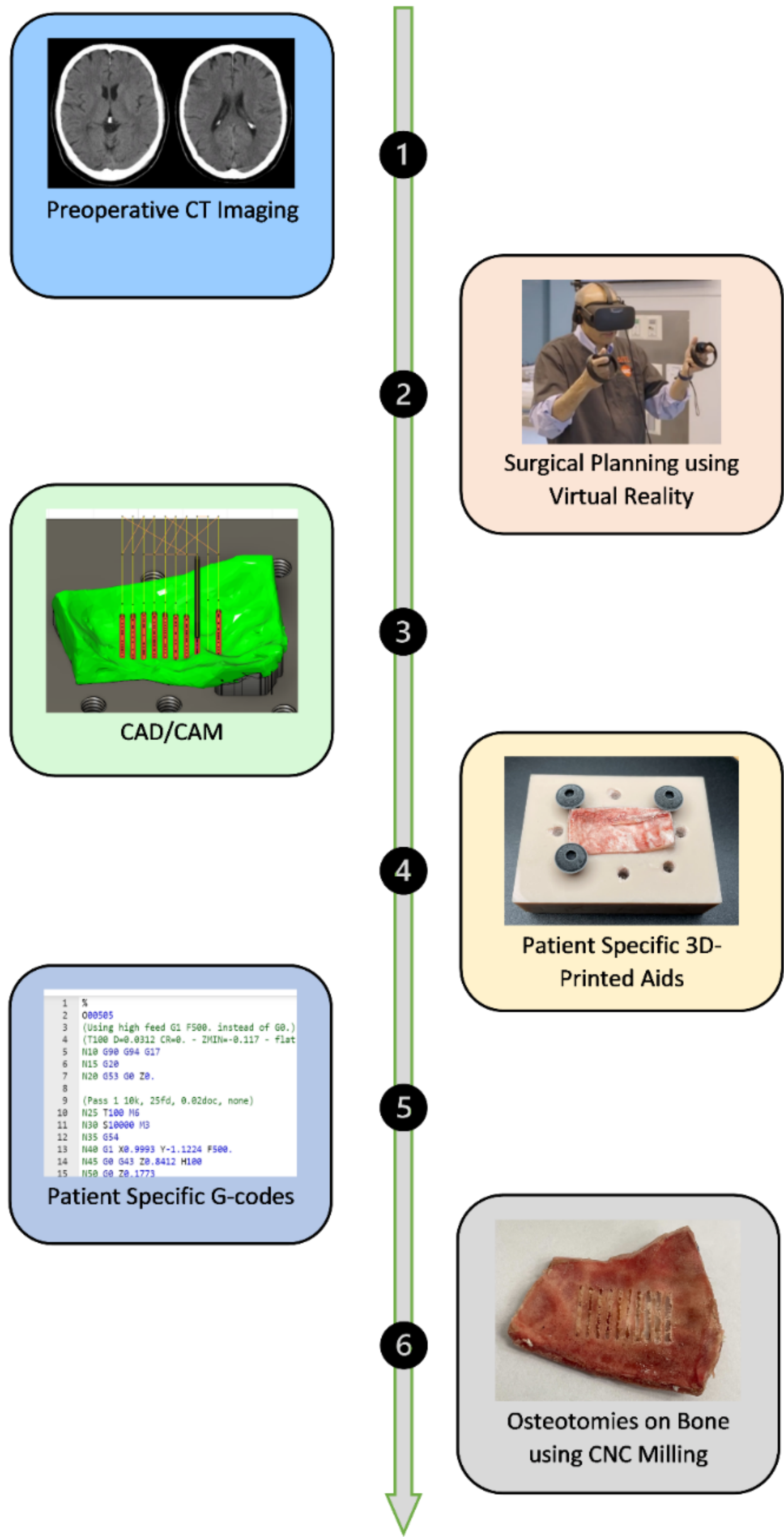
- 1) 3D Reconstruction of Bony CT anatomy
- 2) Surgical planning in virtual reality (VR)
- 3) Precise pattern micro-osteotomy (kerfing pattern) planning in CAD/CAM
- 4) Design and 3D printed manufacture of custom guides/aids
- 5) Execution of the exact pattern osteotomy with a computer numerical control (CNC) milling machine

The workflow was subsequently tested on a 12-day-old porcine calvarium, which was our choice of animal model reported to have properties closest to human infant calvarium.

RESULTS

The proposed technique was applied successfully in 5 porcine calvarial specimens. Surgical planning, CAD/CAM conversion, and osteotomies execution proceeded smoothly without complication in any of the specimens with the following results:

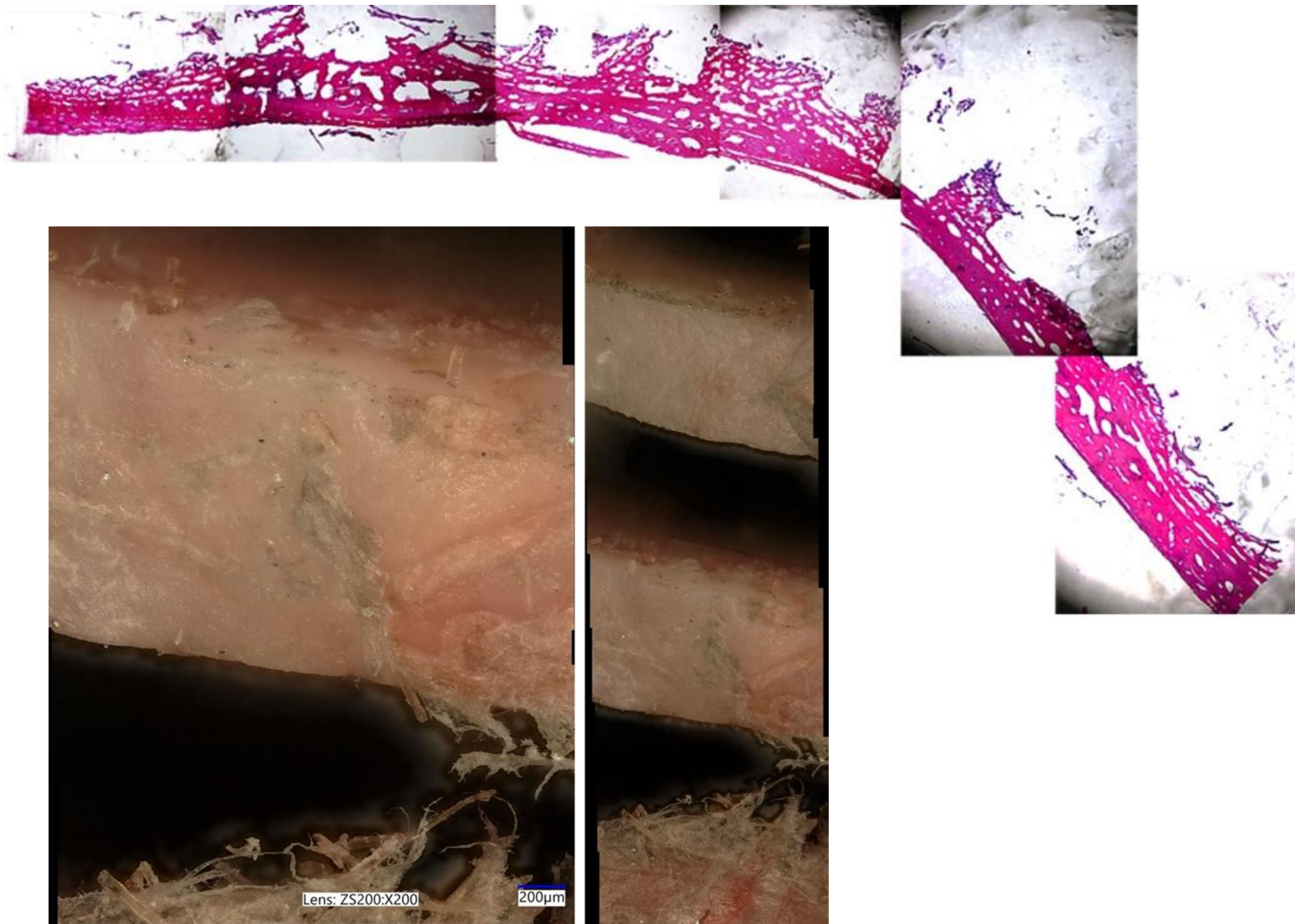
- The mean machining time was 11.25min (±2.98min).
- The CNC cutting tool could create micro-osteotomies with a kerf of 1/32” (0.8mm) and 0.8mm proximity to adjacent osteotomies, enabling micropatterns otherwise impossible by hand.
- This preserved adjacent bone microstructure (confirmed by hematoxylin-eosin-stained sections) and avoided thermal necrosis (mean temperature: 51.08°C ± 28.03°C).
- Maximum CNC osteotomy deviation was 0.010”.
- Micropatterns tested included straight lattice, spiral, and double-reverse spiral, each impacting bone pliability differently.



Combined workflow in the order of its operational execution for the correction of craniosynostosis.

CONCLUSION

This research combines well-established techniques from various fields (kerfing, VR simulation, CAD/CAM, and CNC cutting) to create a digital workflow for calvarial osteotomy. Employing a computer-controlled cutting tool offers the advantages of speed, accuracy, and reduced heat-induced bone injury. It enables precise, closely spaced osteotomies, enhancing bone flexibility and potentially leading to new shape correction and fixation methods. The reliability and repeatability of digital tools ensure accurate presurgical planning execution, potentially allowing a larger portion of this complex procedure to occur in a controlled environment before the patient ever reaches the OR.



(Top) Complete stitched fluorescence microscope images showing minimal distortion of cells around the cuts, and (bottom) digital microscopic imaging confirming no cell necrosis on the inside of the machining passes (Image Courtesy: Keyence).

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