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# The First Alveolar Bone Graft Simulator

Jerry Shen, BASc, MASc*†
David M. Fisher, FRCSC, FACS‡
Branavan Yasabala, BEng†
Karen W.Y. Wong Riff, MD, PhD, FRCSC‡
Dale J. Podolsky, MD, PhD, FRCSC*†‡

**Summary:** Alveolar bone graft (ABG) surgery in cleft patients is technically challenging. The procedure requires design, dissection and release of soft tissue flaps to create a seal around the bone graft. In addition, visualization during the procedure is challenging within the confines of the cleft. These features make ABG surgery difficult to learn and teach, and it is, therefore, a suitable procedure for the use of a simulator. A high-fidelity cleft ABG simulator was developed using three-dimensional printing, polymer, and adhesive techniques. Simulated ABG surgery was performed by two expert cleft surgeons for a total of five simulation sessions to test the simulator's features and the ability to perform the critical steps of an ABG. ABG surgery was successfully performed on the simulator. The simulations involved interacting with realistic dissection planes as well as multi-layered synthetic soft (periosteum, mucosa, gingiva, adipose tissue) and hard (teeth, bone) tissue. The simulator allowed performance of cleft marginal incisions, dissection, and elevation of a muco-gingival-periosteal flap, creation of nasal upturned and palatal downturned flaps, nasal and palatal side closure, insertion of simulated bone graft material, and advancement of the muco-gingival-periosteal flap for closure of the anterior wall of the cleft. The ABG simulator allowed performance of the critical steps of ABG surgery. This is the first ABG simulator developed, which incorporates the features necessary to practice the procedure from start to finish.
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## INTRODUCTION

Performance of an alveolar bone graft (ABG) in cleft patients is technically challenging. The procedure requires an understanding of three-dimensional (3D) anatomy and the design of mucosal flaps in relation to the bony cleft to create a watertight seal around the graft.[1] Inadequate design of the flaps may result in communication of the graft with the nasal and/or oral cavity, placing the graft at risk of failure. In addition, the confined space of the alveolar cleft is difficult to access and visualize, in particular, during nasal side closure near the posterior apex of the cleft.[1] This makes the procedure both challenging to execute and difficult to learn and teach. Furthermore, studies have suggested improved results with more experienced surgeons.[2,3] Surgical simulators provide a valuable means to practice surgical procedures to augment real operating experience.[4] Thus, ABG surgery is an ideal procedure for the implementation of a simulator to practice the procedure outside the operating room.

Currently, no ABG simulator exists. This study describes the development, features, and capabilities of a high-fidelity ABG simulator.

## SIMULATOR DEVELOPMENT AND FEATURES

A computed tomography scan image of a patient with an alveolar cleft was used as a template and modified to create a model of bony and soft tissue anatomy. The computed tomography image used has a left unilateral cleft of the primary palate, with a bony apex at the level of the incisive foramen. The simulator (Simulare Medical, a Division of Smile Train, USA) was developed using 3D printing of bony structures and polymer techniques to develop multi-layered synthetic soft tissue. Adhesive

*From the *Posluns Center for Image Guided Innovation and Therapeutic Intervention (PCIGITI), Toronto, Ontario, Canada; †Simulare Medical, Division of Smile Train, Toronto, Ontario, Canada; and ‡Division of Plastic & Reconstructive Surgery, The Hospital for Sick Children, Toronto, Ontario, Canada.*

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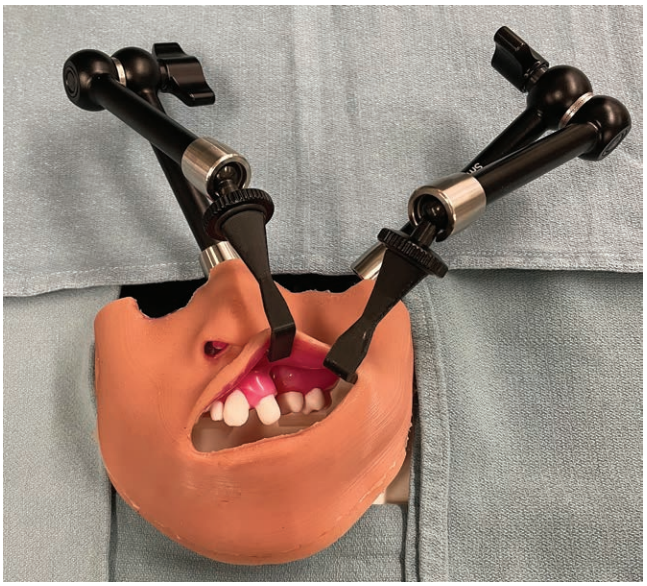

**Fig. 1.** The ABG simulator with self retractors providing retraction of the oral cavity.

techniques were used to incorporate dissection planes and soft tissue–bone interfaces. The simulator comprises an interchangeable one-time use cartridge that inserts into a base. Self retractors that lock into place were developed and integrated into the base to allow performing the procedure without assistance (Fig. 1). **(See figure, Supplemental Digital Content 1,** which displays visualization of the alveolar cleft anatomy. **http://links.lww.com/PRSGO/C832**.) The simulator was developed in consultation with three expert cleft surgeons (D.M.F., K.W.R., D.J.P.) who have extensive experience developing cleft simulation tools.[5,6]

## PERFORMANCE OF AN ABG USING THE SIMULATOR

Five ABGs were performed on the simulator, by authors D.M.F. and D.J.P., and highlights of the procedure are described and illustrated. A scalpel is used to incise through the mucosa along the anterior aspect of the residual alveolar cleft. This incision joins incisions made along the greater and lesser segment cleft margins. Anteriorly these marginal incisions are superficial within a mucosal-submucosal layer and progress to a subperiosteal layer inferiorly near the teeth. The mucosa is then elevated off the bone along the greater segment incision. A papillary incision is then performed over the lesser segment. This involves first using a scalpel along the teeth-gingival margin followed by elevation in the subperiosteal layer to raise a gingival-mucosal-periosteal flap from lateral to medial. A back cut is performed at the distal aspect of the last molar using either a scalpel or dissection scissors. The gingival-mucosal-periosteal flap is retracted superiorly, and the periosteum is scored transversely 2 mm above the bone–periosteal interface to allow for mobilization of the flap medially. This periosteal

### Takeaways

**Question:** Performance of an alveolar bone graft (ABG) in cleft patients is challenging. A surgical simulator that allows performance of the critical steps of the procedure provides a valuable learning experience.

**Findings:** The features and utilization of the first ABG simulator were demonstrated and included the ability to create mucosal flaps; dissect and incise gingiva, mucosa and periosteum; create nasal upturned and palatal downturned flaps; and close around the alveolar cleft.

**Meaning:** The ABG simulator allows performing an end-to-end ABG in a realistic environment that allows practicing the procedure to gain competence before operating on real patients.

incision is carried anteriorly, joining the periosteum previously incised during the lesser segment marginal incisions. (**See Video 1 [online],** which displays the incising along the alveolar cleft mucosa, elevation of a gingiva-mucosal-periosteal flap, and scoring the periosteum.) An elevator is then used to separate the gingiva-mucosa-periosteum from the bone within the cleft on both the lesser and greater segments toward the apex of the alveolar cleft. (**See figure, Supplemental Digital Content 2,** which displays visualization of the posterior bony apex. **http://links.lww.com/PRSGO/C833**.) Scissors are then used to cut the lesser and greater segment marginal mucosa, gingiva, and periosteum transversely toward the cleft apex, creating separate nasal and palatal side flaps. The nasal flaps are continuous with the residual alveolar cleft anteriorly. The upturned nasal flaps and the residual alveolar cleft are closed using sutures, completing the nasal side closure. Downturned palatal flaps are sutured together, completing the palatal side closure (Fig. 2). (**See Video 2 [online],** which displays the creation of nasal upturned and palatal downturned flaps and nasal and palatal side closure.) Simulated bone graft material (playdough) is then inserted into the cleft (Fig. 3). The gingival-mucosal-periosteal flap from the lesser segment is then advanced one tooth width medially and is sutured to the greater segment mucosa and palatal side mucosa to close the anterior wall of the cleft (Fig. 4). Vertical mattress sutures are then passed between the teeth to secure the flap inferiorly. (**See Video 3 [online],** which displays the insertion of simulated bone graft material and closure of the anterior wall of the cleft.)

## DISCUSSION

The following study presents the first ABG simulator developed that successfully allows performing a cleft ABG from start to finish within a highly realistic environment. The simulator incorporates multi-layered tissue, dissection planes, and synthetic tissue interfaces, which allows the user to create soft tissue flaps that are critical to understand to successfully execute the procedure. The simulator allows performing one of the most difficult steps of the procedure: creation and suturing of

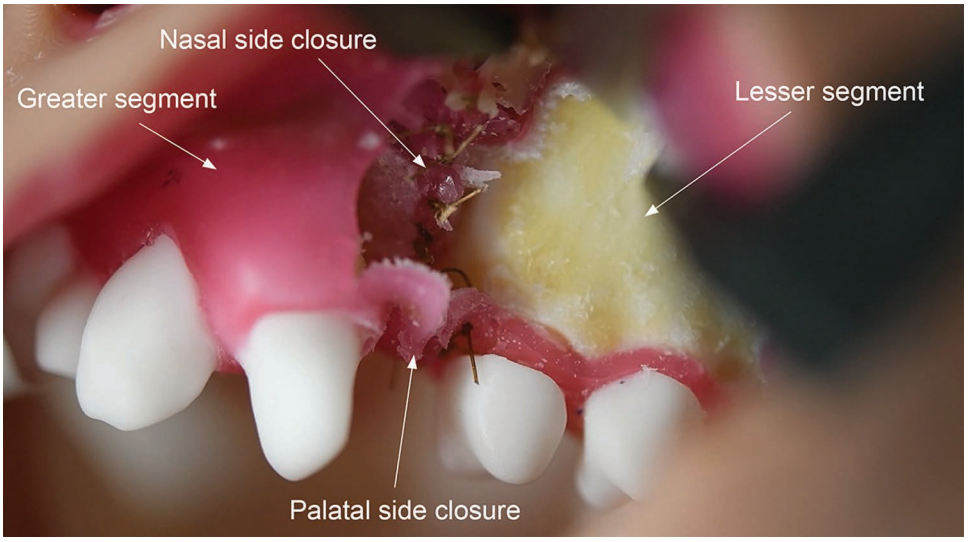


**Fig. 2.** Illustration of closure of the upturned nasal side flaps and downturned palatal side flaps as well as the alveolar cleft recipient site with elevation of the gingiva-mucosal-periosteal flap.

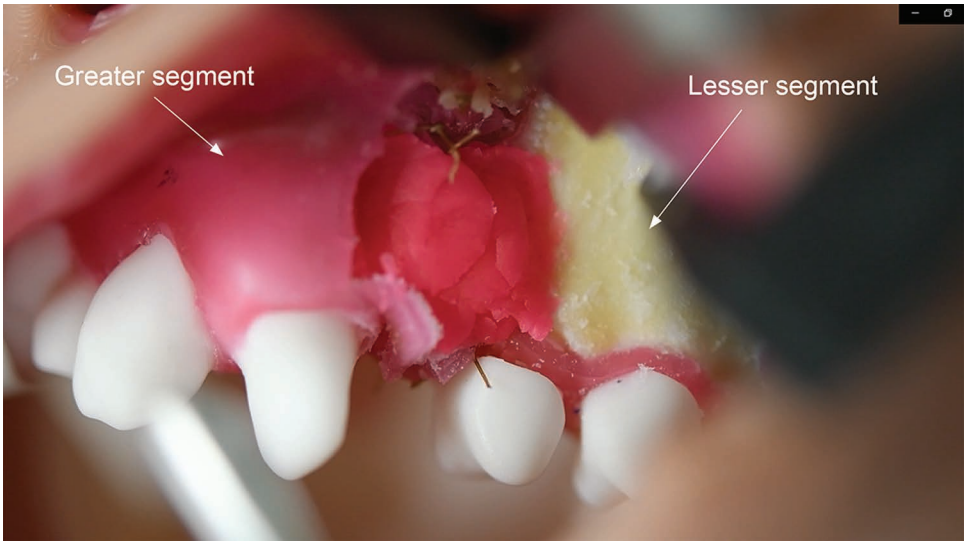


**Fig. 3.** Insertion of simulated graft material (playdough) into the alveolar cleft recipient site.

the nasal upturned and palatal downturned flaps within a constrained workspace environment. The simulator provides feedback to the user, requiring adequate tissue release of the muco-gingivo-periosteal flap to successfully advance and inset the flap for anterior wall closure of the cleft site.

Alternative incisions can be performed on the simulator, and one such incision described by Abyholm et al leaves a gingival cuff attached to the teeth.[7] Although we believe it is necessary to pair the labial and palatal gingiva at the level of the teeth immediately adjacent to the cleft to provide gingiva for subsequent tooth eruption within the cleft, alternative techniques do not disrupt gingiva from permanent dentition beyond the cleft site to preserve the periodontal ligaments that maintain gingival adherence to the erupted teeth.

A limitation of the simulator is its cost at US $250 per unit. The simulator will be distributed free of charge to the Smile Train global partner network and will be available for purchase for non-Smile Train partners. Further investigation is necessary to build evidence to support using the simulator, including an evaluation of the simulator by a larger group of experts and trainees. Furthermore, development of a virtual simulator would augment the physical simulator to enhance the training experience.

Future modifications to the simulator will include implementation of a Veau 3 cleft with a soft tissue posterior apex and variable morphology of the cleft. Despite these considerations, this study presents the first platform to practice ABG surgery outside the operating room, providing a valuable training environment to augment real operating experience.

**Fig. 4.** Closure of the cleft after advancing the gingiva-mucosal-periosteal flap medially for closure of the anterior wall of the cleft.

***Dale J. Podolsky, MD, PhD, FRCSC***
Division of Plastic and Reconstructive Surgery
The Hospital for Sick Children
5428-555 University Avenue
Toronto, ON M5G 1X8
E-mail: dale.podolsky@sickkids.ca

## DISCLOSURES

*Simulare Medical is a division of Smile Train, a not-for-profit entity that disseminates and distributes cleft surgical simulators that will include the ABG simulator presented in this study. Jerry Shen is supported financially by Smile Train, Branavan Yasabala is currently employed by Simulare Medical, and Dr. Dale Podolsky is on the Board of Directors of Simulare Medical. Smile Train generously provided financial support for the development of the ABG simulator presented in this study. Drs. David Fisher and Karen Wong Riff have no financial interest to declare in relation to the content of this article.*

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