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CASE REPORT

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Patient-specific 3D-printed scaffold for pediatric superior sternal cleft repair

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Abstract

Rationale Sternal cleft is a rare congenital chest wall defect resulting from failed fusion of the sternal bars during embryogenesis. Primary closure is often feasible in the neonatal period due to thoracic wall compliance, but delayed presentations require complex reconstruction using autologous tissues, muscle flaps, and/or biomaterials.

Patient concerns A two-year-old male presented with a visible anterior chest wall defect and progressive respiratory distress.

Diagnoses Physical examination revealed an isolated superior sternal cleft with visible cardiac pulsations beneath the skin. Three-dimensional computed tomography (3D-CT) confirmed the defect dimensions and sternal configuration.

Interventions A patient-specific biodegradable scaffold composed of polycaprolactone (PCL) + hyaluronic acid + β-tricalcium phosphate (β-TCP) was designed using CAD-CAM workflows and produced with 3D printing. The scaffold was fixed to the sternal periosteum with non-absorbable sutures and reinforced with bilateral pectoralis major muscle flaps.

Outcomes No intraoperative complications occurred. The patient was extubated at 12 h, monitored in the intensive care unit for 2 days, and discharged on postoperative day 7. At the 1- and 3-month follow-ups, respiratory symptoms had resolved; chest wall stability and cosmetic appearance were satisfactory; and imaging confirmed implant stability.

Lessons Patient-specific 3D-printed biodegradable implants can provide a safe and anatomically conforming option for pediatric sternal cleft repair when primary closure is not feasible.

Keywords Sternal cleft, 3D-printed implant, Polycaprolactone (PCL), Congenital chest wall anomaly, Biomaterial-based reconstruction

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Introduction

Sternal cleft (SC) is a rare congenital anomaly caused by failure of midline fusion of the sternal bars during embryogenesis, accounting for only a small fraction of chest wall defects [1]. It can be classified as complete or partial, with the superior partial type being the most common and the inferior partial type the rarest [2]. After birth, paradoxical respiratory motion and mediastinal exposure covered only by thin skin pose significant cardiopulmonary risks [1].

While primary closure is feasible in the neonatal period due to chest wall compliance, reconstruction becomes more complex in older infants and children due to increasing rigidity and defect width [3, 4]. In such cases, autologous costal/cartilaginous grafts, muscle flaps, and synthetic or biomaterial-based prostheses may be required [2–5]. Systematic reviews and institutional experiences emphasize that surgical strategy should be individualized based on age, morphology of the defect, and associated anomalies [3–7].

In recent years, 3D imaging, CAD-CAM design, and patient-specific implant technology have been increasingly applied in large or irregular defects, with potential advantages of improving anatomical conformity, reducing operative time, and enhancing cosmetic outcomes. Composites such as polycaprolactone (PCL) + hyaluronic acid + β-TCP have gained attention for their biocompatibility, fibro-osseous integration potential, and gradual biodegradation, which may support adaptation to growth in pediatric patients [8, 9].

Case report

A two-year-old male presented with a midline anterior chest wall defect present since birth and progressive respiratory distress exacerbated during exertion. Perinatal history was unremarkable, with no reported prenatal abnormalities. The family reported visible chest wall retractions and cardiac pulsations during crying episode (Fig. 1).

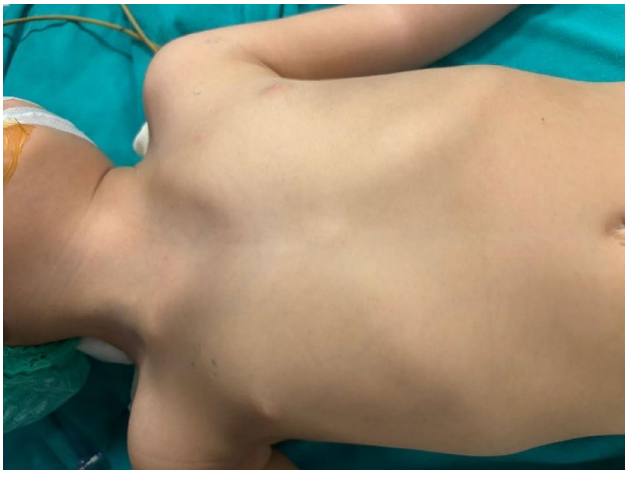

Fig. 1 Preoperative clinical appearance of the patient showing a visible superior sternal cleft with intact overlying skin and visible cardiac pulsations

On examination, an isolated superior sternal cleft measuring approximately 3 cm was identified, with intact overlying skin and visible cardiac pulsations. There were no additional cutaneous lesions. Transthoracic echocardiography demonstrated normal intracardiac anatomy, and abdominal ultrasonography revealed no anomalies. No syndromic features or systemic malformations were noted.

Three-dimensional CT, performed under sedoanalgesia using a standard-dose protocol, provided detailed evaluation of the defect length, width, and sternal configuration. Based on these data, a patient-specific scaffold was designed using CAD-CAM technology and fabricated by three-dimensional printing from a PCL + hyaluronic acid + β-TCP composite under hygienic clean-room conditions at the Kandilli Deep Technology Base of Boğaziçi University by BlooCell® Health Technologies. The scaffold was sterilized with ethylene oxide prior to surgery. The material was selected for its biocompatibility and capacity to support fibro-osseous integration (Fig. 2). The implant was manufactured within 7 days following CT acquisition and implanted 3 days after production.

Under general anesthesia in the supine position, an upper midline incision was performed. The sternal periosteum along the defect margins was carefully exposed. The custom scaffold was seated within the defect and secured with non-absorbable sutures to the periosteum, restoring chest wall contour and rigidity. Bilateral pectoralis major flaps were mobilized and advanced over the implant, providing additional soft tissue coverage and reinforcement (Figs. 3, 4 and 5).

Operative time was 120 min. No intraoperative complications occurred. The patient was extubated 12 h postoperatively and monitored in the intensive care unit for 2 days with stable hemodynamics. No re-intervention was required. During ward follow-up, no wound infection, seroma, or implant-related complications occurred. Oral intake began on postoperative day 2, respiratory distress resolved, and mobilization was achieved. The patient was discharged on postoperative day 7.

At the 1-month follow-up, the patient was asymptomatic, with a well-healed incision and stable chest wall; the implant was not palpable, and imaging confirmed stable positioning. At 3 months, pulmonary function was age-appropriate, exertional retractions had resolved, and the family reported high cosmetic satisfaction. Radiological assessment demonstrated perifocal fibrosis and progressive tissue integration (Fig. 6).

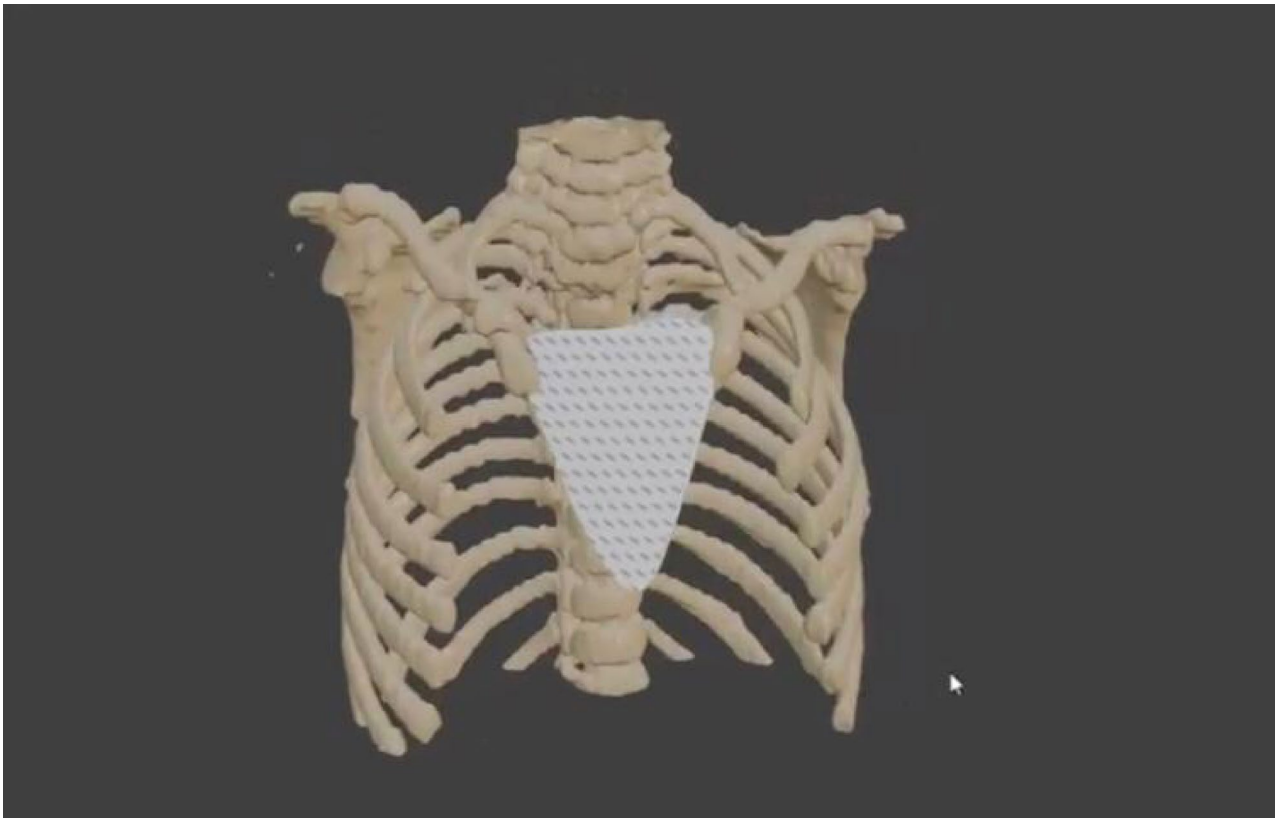

Fig. 2 Three-dimensional reconstruction of the thoracic cage demonstrating the patient-specific 3D-printed biodegradable scaffold designed to restore continuity of the superior sternal cleft and conform anatomically to the defect

Discussion

Primary closure in the neonatal period is considered ideal for SC due to reduced tissue tension and thoracic wall pliability [3]. In older infants and children, increasing rigidity and wider defects necessitate more complex reconstruction strategies, including autologous costal or cartilaginous grafts, muscle flaps, and supportive prostheses [2–5]. Meta-analyses and reviews emphasize individualized strategies according to patient age, defect morphology, and associated anomalies [3, 4]. Institutional series similarly report that small defects may be closed primarily, while larger gaps benefit from chondrotomies and supportive materials [5].

In this case, the patient-specific 3D-printed biodegradable scaffold provided excellent conformity to the defect, reduced dead space, and offered secure fixation points. The PCL + hyaluronic acid + β-TCP composite demonstrated favorable biocompatibility, gradual degradation, and potential compatibility with chest wall growth [8, 9]. Coverage with vascularized pectoralis major flaps further enhanced stability and reduced infection risk.

Reports in the literature describe successful reconstructions using patient-specific implants (e.g., PEEK or biodegradable composites) when primary closure was not feasible [8]. Clinical applications of PCL/β-TCP implants in cranio-maxillofacial and orthopedic reconstructions also support their safe use and potential translatability to pediatric chest wall reconstruction [8, 9]. Nevertheless, long-term outcomes in growing children remain limited, and ongoing surveillance for remodeling dynamics and rare complications such as infection, displacement, or mismatch between degradation and tissue formation is warranted.

In conclusion, the combination of patient-specific 3D-printed biodegradable scaffolds and muscle flaps may provide a safe and effective solution for pediatric SC repair when primary closure is not feasible. Long-term follow-up will clarify the adaptation of these implants to chest wall growth and their durability.

Patient perspective

The family expressed satisfaction with the resolution of respiratory symptoms and the cosmetic appearance following surgery.

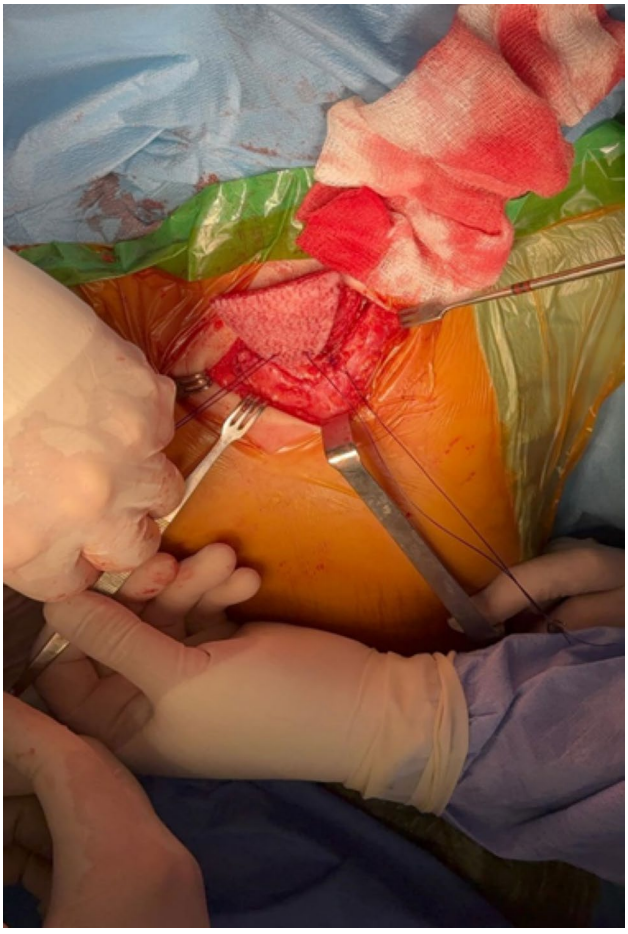

Fig. 3 Intraoperative exposure of the sternal cleft margins following midline incision; the defect edges and periosteum are prepared for scaffold placement

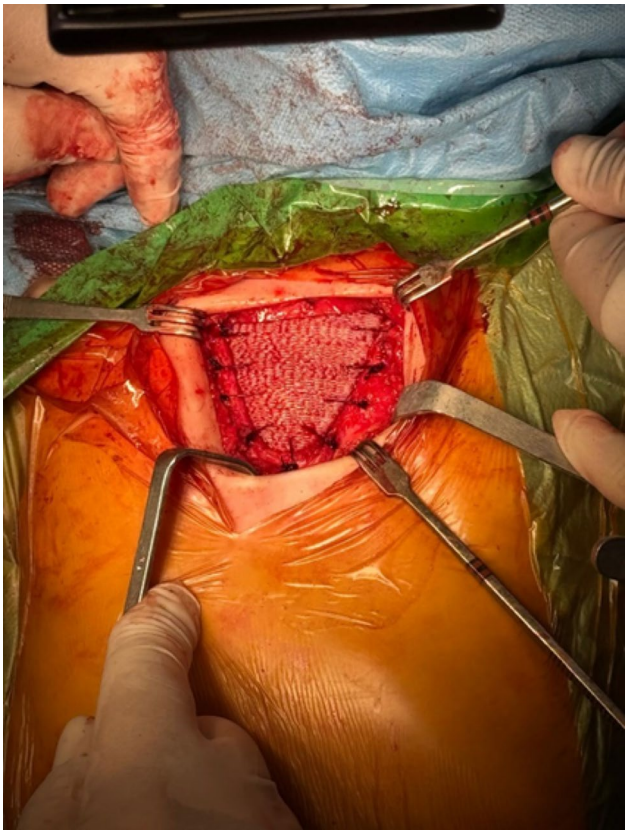

Fig. 4 Fixation of the patient-specific 3D-printed polycaprolactone (PCL) + hyaluronic acid + β-tricalcium phosphate (β-TCP) scaffold to the sternal periosteum with non-absorbable sutures

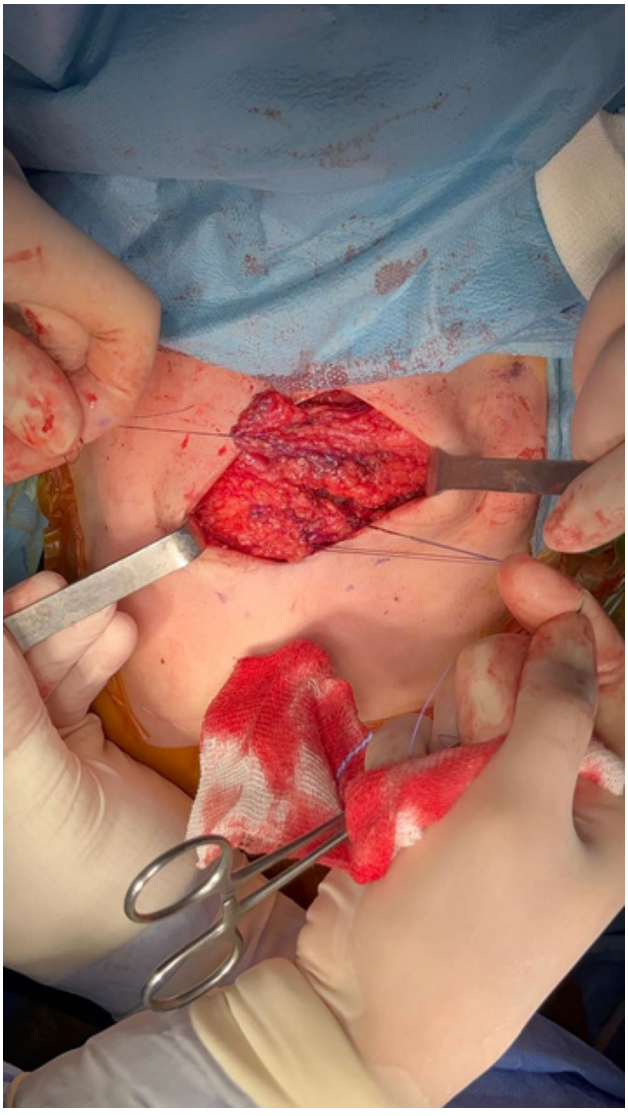

Fig. 5 Bilateral pectoralis major muscle flaps are mobilized and advanced over the scaffold to provide vascularized coverage and reinforcement

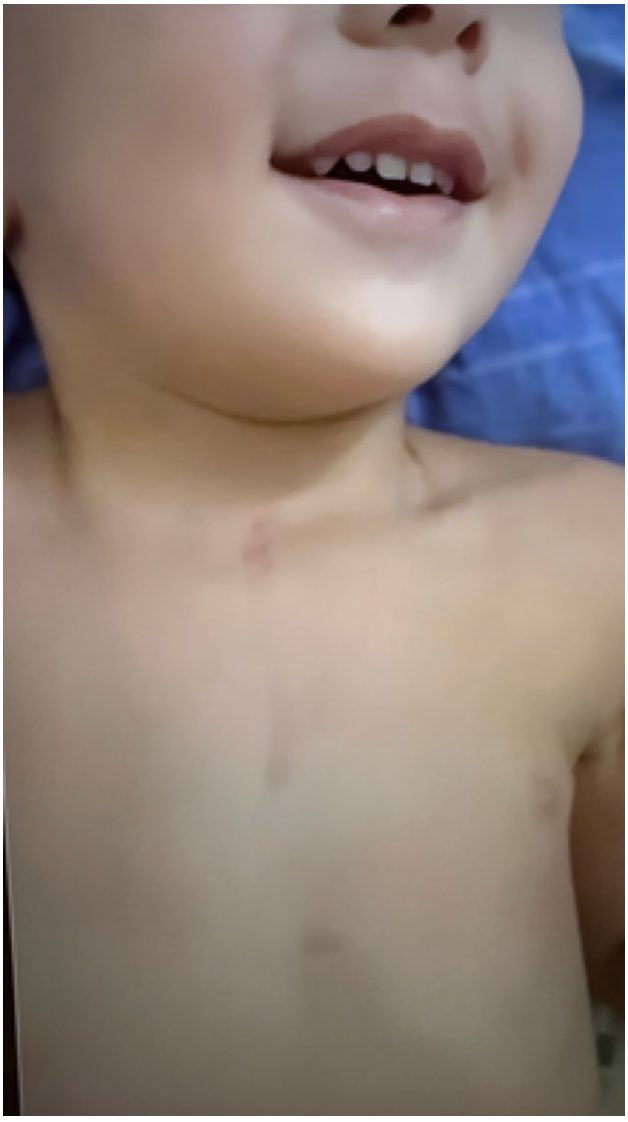

Fig. 6 Postoperative clinical appearance at follow-up showing a well-healed incision line, stable chest wall, and satisfactory cosmetic outcome

Author contributions
H.K.E.: Surgery, concept, surgery, data curation, writing – original draft.M.Y.: Surgery, concept, methodology, supervision, critical review.M.O.Ö.: Surgery, critical review.All authors approved the final manuscript.

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Data availability
All relevant data are included in this article. Additional information is available from the corresponding author upon reasonable request.

Declarations

Ethics approval
According to institutional policy, single-patient case reports do not require IRB approval. All procedures complied with the Declaration of Helsinki.

Informed consent
Written informed consent was obtained from the patient's legal guardians for publication of this case and accompanying images.

Competing interests
The authors declare no competing interests.

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