Innovation: Biodegradable Mesh for Aortic Support in Cardiovascular Surgery

Dr. Radhakrishnan Pradeep Kumar

MS MCh CTVS AIIMS, Post - doctoral Fellow CTVS (SCTIMST) Fellow in ECMO (TSS, ISCU), FACC, FIACS, CPDH IISc, Global MBA, Fellow GAPIO, Vice Chairman IC Stem Cell Research Cardiac Surgery AMTZ, Chief Translational Research Cardiac Surgery Arkivis, Chief Cardiac Surgical Simulation One learning, Program Coordinator TAH and MCS, Hon Distinguished Fellow GAPIO, Mentor World Innovation Hub, Prof YANS Medical Institute Trivandrum, Hon Visiting Professor CTVS THI & TMRI, Dr Gayathri Ananyajyothi Ambat, MBBS, GIMSR, Gitam University, Dr Nihas Nazer, MS, MCh CTVS, Jayadeva Institute of Cardiology, Dr Y A Nazer MS, MCh CTVS AIIMS, Chairman and Director YANS Medical Institute Trivandrum

Abstract: ***Biodegradable meshes offer a promising solution to many challenges in cardiovascular surgery, particularly in minimizing long - term complications and facilitating natural tissue regeneration. Their potential applications, such as in aortic root stabilization, congenital heart defect repairs, and vascular grafts, are drawing significant attention in research.***

Keywords: Biodegradable Mesh, Tissue engineering, Aortic root stabilisation, Drug eluting scaffolds

1. Introduction

The development of biodegradable meshes for applications such as aortic root stabilization and other cardiovascular interventions represents a transformative innovation in cardiac surgery. These devices aim to provide structural support during critical periods of tissue remodelling while gradually dissolving, minimizing long - term complications, and avoiding challenges associated with permanent synthetic materials.

2. Concept of Biodegradable Mesh

Biodegradable meshes are engineered using materials that degrade safely within the body over a predefined period. The design involves:

1) **Temporary Mechanical Support:**
- Provides immediate structural reinforcement to prevent further dilation or rupture of the aorta.
- Supports tissue remodelling and healing, allowing the native aortic wall to regain strength.

2) **Gradual Degradation:**
- Materials break down into biocompatible byproducts (e. g., lactic acid, glycolic acid) that are metabolized and excreted without harm.

3) **Biostimulation:**
- Advanced meshes may incorporate bioactive agents (e. g., growth factors, anti - inflammatory drugs) to promote tissue regeneration and prevent fibrosis.

Advantages Over Permanent Meshes

1) **Reduced Risk in Redo Surgeries**:
- Unlike permanent meshes, which integrate with surrounding tissues, biodegradable meshes dissolve, leaving the aorta accessible for future interventions.

2) **Minimized Chronic Complications:**
- Eliminates the risk of late infection or inflammatory responses associated with permanent synthetic materials.
- Avoids stress - induced aneurysms adjacent to the supported segment.

3) **Enhanced Natural Healing:**
- Facilitates natural strengthening of the aortic wall through remodelling and biostimulation, potentially restoring the native anatomy.

4) **Adaptability for Pediatric Use:**
- Particularly beneficial for younger patients, as it allows the aorta to grow without the constraints of a permanent device.

Material and Design Innovations

1) **Polymers**:
- Materials like polylactic acid (PLA), polyglycolic acid (PGA), and polycaprolactone (PCL) are commonly used for their predictable degradation profiles and biocompatibility.

2) **Smart Mesh Designs:**
- Multilayered structures with varied degradation rates to provide phased support.
- Embedded drug - eluting properties for anti - inflammatory or anti - thrombotic effects.

3) **Nanotechnology Integration:**
- Nanoscale coatings or fibres can enhance the strength and bioactivity of the mesh.

Biodegradable Mesh for Aortic Root Stabilization

Innovative Modelling

Objective: Use a biodegradable mesh to stabilize the aortic root in patients with connective tissue disorders (e. g., Marfan syndrome) while allowing natural healing.

1) **Surgical Procedure:**
- Implantation of the biodegradable mesh around the aortic root during valve - sparing surgery.
- Mesh provides immediate mechanical support, preventing further dilation.

2) **Degradation and Remodelling:**
- Over 12 - 24 months, the mesh degrades while stimulating collagen deposition and tissue regeneration.
- Regular imaging confirms a restored, stable aortic wall.

3) **Outcome:**
- A functional and structurally sound aortic root without the complications associated with permanent synthetic materials.

Challenges and Research Directions

1) **Material Safety and Longevity:**
- Ensuring that degradation byproducts are non - toxic and do not trigger inflammatory responses.

2) **Predictable Degradation Profiles:**
- Fine - tuning the degradation rate to match the healing timeline of the aortic wall.

3) **Clinical Trials:**
- Rigorous testing to assess long - term safety and efficacy compared to permanent meshes.

4) **Cost and Manufacturing:**
- Making these advanced meshes accessible and affordable for widespread clinical use.

3. Discussion

Potential Impact on Cardiovascular Surgery

Biodegradable meshes could revolutionize the treatment of aortic aneurysms, dissection, and connective tissue disorders by offering a safer, less invasive, and more adaptive alternative to permanent devices. Their development will likely draw from multidisciplinary collaboration across material science, bioengineering, and cardiology.

Current Progress and Advantages

One of the key advantages of biodegradable meshes is their ability to provide temporary structural support while allowing natural tissue growth. For instance, materials like polylactic acid (PLA) and polyglycolic acid (PGA) have demonstrated excellent compatibility and degradation profiles. This characteristic is particularly advantageous in pediatric surgeries, where the device degrades as the child grows, avoiding reoperations required for permanent implants [1, 2].

Another advantage is their use as scaffolds for tissue - engineered vascular grafts. Shinoka and Breuer demonstrated that endothelial cell - seeded biodegradable scaffolds encourage neo tissue formation, reducing the risk of graft - related complications like thrombosis [3]. Similarly, fibrin - polylactide composite scaffolds have been effective in small - calibre vessel reconstructions, showing robust tissue integration and long - term patency [6].

Moreover, drug - eluting biodegradable meshes are emerging as multifunctional devices, addressing inflammation and thrombosis while promoting healing. For example, drug - eluting biodegradable stents have shown reduced restenosis rates, a critical limitation of their metallic counterparts [7].

4. Challenges and Limitations

Despite their promise, biodegradable meshes face several challenges. Premature degradation under high - stress cardiac environments can compromise mechanical support, especially in applications like aortic root stabilization. Adjusting the degradation rate to match tissue healing remains a critical area of research [1].

Another challenge is achieving adequate initial strength without sacrificing flexibility. Huang et al. highlighted that while biodegradable materials offer excellent tissue compatibility, their mechanical properties are often insufficient for high - stress applications [2].

Further, long - term clinical data on biodegradable meshes are limited, with most studies focusing on animal models or small patient cohorts. Shinoka and Breuer's work on tissue - engineered vascular grafts, while promising, still requires validation in large - scale trials [3]. Similarly, research on drug - eluting biodegradable scaffolds, like those discussed by Jung et al., needs broader clinical application and monitoring [7].

5. Future Directions

Future innovations are expected to focus on composite materials that integrate biodegradable polymers with bioactive agents. These materials could provide tailored degradation profiles and additional therapeutic benefits, such as growth factor delivery for enhanced healing [6, 7].

Moreover, the development of smart biodegradable materials, capable of responding dynamically to physiological conditions, is a promising frontier. For instance, meshes that adapt their degradation rate based on tissue remodelling signals could revolutionize applications in pediatric cardiovascular surgery [1].

Finally, rigorous clinical trials are essential to validate these innovations. Large - scale studies, incorporating diverse patient demographics and long - term follow - up, are critical to ensuring the safety and efficacy of biodegradable meshes across various cardiovascular applications [3]. By addressing these challenges and building on current advancements, biodegradable meshes have the potential to significantly enhance the safety, effectiveness, and personalization of cardiovascular interventions

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