

The Effect of Sodium Dodecyl Sulfate Concentration on the Integrity of Bovine Jugular Veins for Decellularized Pulmonary Xenografts: A Systematic Review

Atiya Nurrahmah^a, Heroe Soebroto^b, Ketut Alit Utamayasa^c,
Arief Rakhman Hakim^b, Ito Puruhito^b

^a Department of Thoracic, Cardiac and Vascular Surgery, Faculty of Medicine, Universitas Airlangga, Surabaya, Indonesia

^b Department of Thoracic, Cardiac and Vascular Surgery, Dr Soetomo General Academic Hospital, Surabaya, Indonesia

^c Department of Child Health, Cardiology Division, Dr. Soetomo General Hospital, Surabaya, Indonesia

ARTICLE INFO

Article history:

Submitted: 4. 11. 2025

Revised: 1. 12. 2026

Accepted: 9. 8. 2026

Available online: 12. 10. 2026

Klíčová slova:

Biologická náhrada

Decelularizovaná extracelulární matrix

Implantace náhradní cévy

Implantace náhradní srdeční chlopně

Jugulární žíly

Tkáňové inženýrství

Vrozená srdeční vada

Keywords:

Bioprosthesis

Blood vessel prosthesis

implantation

Congenital heart defect

Decellularized extracellular matrix

Heart valve prosthesis implantation

Jugular veins

Tissue engineering

SOUHRN

Cíl: Cílem této studie bylo podrobně zkontrolovat údaje o tom, jak koncentrace dodecylsírany sodného (sodium dodecyl sulfate, SDS) ovlivňuje míru zachování extracelulární matrix, její biokompatibilitu, biomechanickou celistvost a účinnost decelularizace boviních hrdečních žil používaných jako prototypy plicních xenograftů.

Metody: V databázích PubMed, Scopus a Google Scholar jsme vyhledali studie na téma decelularizace s použitím SDS publikovaných do července 2025. Mezi vhodné patřily studie popisující výsledky *in vitro*, *in vivo* a translačního výzkumu s uvedením koncentrací SDS (0,5–1 %). Vyhledávané parametry zahrnovaly míru odstranění DNA, zachování extracelulární matrix, výsledky biomechanického testování, cytotoxicitu a průchodnost štepů. Vzhledem k heterogenitě výsledků byla provedena jejich syntéza narativní formou.

Výsledky: Celkem bylo vyhledáno 14 studií. Decelularizace byla úspěšná při hodnotách SDS 0,5–1 %. Při použití SDS v koncentraci 0,5 % se zachovalo více kolagenu a elastinu, nicméně nebyly odstraněny všechny buňky. V koncentraci odstranil 1% SDS více DNA, odstranil ale i glykosaminoglykany a do jisté míry došlo i k odstranění růstových faktorů. Biomechanické testy prokázaly, že pevnost v tahu se sice nezměnila, avšak příliš velká expozice vedla k oslabení konstruktů. *In vitro* došlo při použití 1% SDS ke snížení životaschopnosti buněk. Malý počet studií naznačil uspokojivou krátkodobou průchodnost, zdůraznil rizika kalcifikace a trombózy.

Závěr: Použití SDS zajišťuje účinnou decelularizaci boviních hrdečních žil. Koncentrace 0,5–1 % vyvažují odstranění buněk zachováním extracelulární matrix, ale ani jedna možnost není optimální. Budoucí studie musejí zdokonalit postupy včetně použití enzymatických detergentů a hodnotit dlouhodobé výsledky *in vivo*.

© 2026, ČKS.

ABSTRACT

Objective: The aim of this study was to thoroughly examine the data regarding how SDS concentration affects the extracellular matrix preservation, biocompatibility, biomechanical integrity, and decellularization effectiveness of bovine jugular veins used as pulmonary xenograft prototypes.

Methods: We looked for studies on SDS decellularization of bovine jugular veins in PubMed, Scopus, and Google Scholar until July 2025. Eligible studies comprised *in vitro*, *in vivo*, and translational research evaluating SDS concentrations (0.5–1%). The outcomes extracted encompassed DNA removal, extracellular matrix preservation, biomechanical testing, cytotoxicity, and graft patency. Narrative synthesis was conducted because of heterogeneity.

Results: There were fourteen studies in total. SDS at 0.5–1% successfully accomplished decellularization. SDS 0.5% kept collagen and elastin better, however it could have left some cells behind. SDS 1% cleared more DNA, but it also depleted glycosaminoglycans and made it harder for growth factors to stay in place. Biomechanical tests showed that the tensile strength was the same, but too much exposure made the constructs weaker. *In vitro*, cell viability diminished on 1% SDS scaffolds. Limited *in vivo* trials indicated satisfactory short-term patency but emphasized dangers of calcification and thrombosis.

Conclusion: SDS is effective for bovine jugular vein decellularization. Concentrations of 0.5–1% balance cellular clearance with matrix preservation, but neither is optimum. Future study should refine procedures, include enzymatic detergents, and evaluate long-term *in vivo* outcomes.

Address: Heroe Soebroto, MD, PhD, Department of Thoracic, Cardiac and Vascular Surgery, Dr. Soetomo General Academic Hospital, Surabaya, Indonesia,
e-mail: heroe.soebroto@fk.unair.ac.id

DOI: 10.33678/cor.2026.074

Introduction

A common feature of congenital heart diseases such as pulmonary atresia and tetralogy of Fallot is right ventricular outflow tract obstruction (RVOTO). A right ventricle–pulmonary artery (RV-PA) conduit, first introduced by Rastelli in 1969, frequently becomes necessary for surgical repair.¹ Despite the widespread availability, homograft's and bovine jugular vein xenografts have a limited supply, and xenografts have been associated to thrombosis, calcification, and immunogenic degeneration.^{2,3}

The aim of tissue engineering is to develop vascular scaffolds that are secure for the body. Decellularized pulmonary homograft's (DPH) demonstrate enhanced long-term patency relative to natural bovine xenografts.⁴ Unfortunately, homograft's are frequently not available, especially in regions with limited resources. Developing decellularized pulmonary xenografts (DPX) from bovine jugular veins may provide a cost-effective and affordable alternative.^{5–7}

Sodium dodecyl sulfate (SDS) is a hydrophilic detergent that is one of the most widely used to eliminate cells. It dissolves down membranes and removes nuclear material, but it might also disrupt collagen, elastin, and glycosaminoglycans (GAGs).^{6,8} The proper dosage of SDS requires a balance between removing cells quickly and keeping the extracellular matrix intact.

This systematic review analyzes the effect of SDS concentration (in particular, 0.5% and 1%) on the decellularization of bovine jugular veins, focusing on: (1) How ef-

fectively cellular material is removed aside; (2) maintaining the extracellular matrix (collagen, elastin, GAGs) intact; (3) biomechanical characteristics; (4) cytotoxicity and recellularization potential; (5) preclinical graft patency

Materials and methods

Search strategy

A systematic search was performed in **PubMed**, **Science Direct**, and **BMC** until July 2025. PRISMA 2020 guidelines was utilized. The keywords were "Sodium Dodecyl Sulfate", "decellularized extracellular matrix", "jugular veins", "bovine jugular veins", and "pulmonary xenograft". Boolean operators („AND", „OR") were applied to optimize the search.

Eligibility criteria

Included were experimental in vitro or in vivo studies and translational reports studying SDS decellularization of bovine jugular veins. Non-bovine studies, non-SDS protocols, case reports, inadequate original data, review articles, and articles not published in English were excluded.

Data extraction and analysis

The information extracted included SDS concentration, exposure duration, decellularization efficiency, extracellular matrix preservation, biomechanical properties, cytotoxicity, and in vivo outcomes. SYRCL's risk of bias tool was used to determine the quality of the studies.

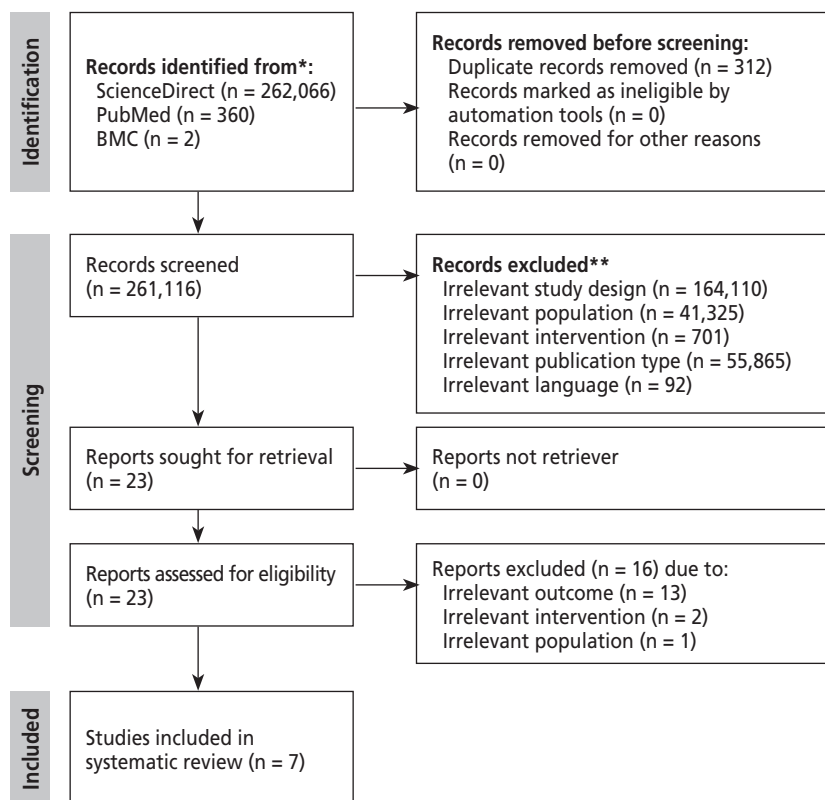


Fig. 1 – PRISMA.
Identification of studies via databases and registers.

Results

Study selection

The systematic search identified 262,428 records: Pubmed (n=360), Science Direct (n=262,066), and BMC (n=2). 312 duplicates were removed; 262,116 records were screened. 261,093 articles were excluded due to irrelevant study design, population, intervention, publication type, or language. Sixteen studies were subsequently removed after full-text screening. Finally, seven studies were included in the systematic review total (Fig. 1).^{4–5,9–13} Moreover, all included studies were considered high quality studies using SYRCL's risk of bias tool. **Table 1** describes the outcomes of the studies.

Decellularization efficiency

SDS succeeded in over 90% nuclear clearance across numerous studies. SDS 1% consistently resulted in greater in-scope DNA removal compared to 0.5%, even though residual cellular fragments were occasionally detected in

the latter. More clearance makes immunogenicity less, but it also makes ECM damage more likely to occur.^{4,9–13}

Extracellular matrix preservation

Histology showed that SDS 0.5% was more effective at maintaining collagen and elastin intact.^{9–10,12,13} In contrast, 1% SDS results in GAG depletion and less preservation of growth factors, which could make it more difficult for recellularization.

Biomechanical integrity

The maximum tensile strength and burst pressure of SDS-treated grafts were identical to those of native veins. But prolonged exposure (>14 days) damaged scaffold mechanics.^{4,5,11} The best possible results depend on balancing both concentration and duration.

Cytotoxicity and recellularization

MTT assays showed reduced cell viability on 1% SDS scaffolds, suggesting residual cytotoxicity or ECM disrupti-

Table 1 – Outcomes of the studies

Study	Decellularization efficiency	Extracellular matrix preservation	Biomechanical integrity	Cytotoxicity and recellularization	Preclinical outcomes
Bobylev et al. (2024) ⁴	Decellularized homografts and SDS-treated bovine conduits showed effective DNA removal with high clearance rates.	Good ECM preservation in decellularized homografts and SDS-treated BJV conduits.	SDS-treated grafts retained mechanical properties similar to native tissues.	No major cytotoxicity reported; SDS-treated conduits functioned well.	SDS-treated homografts showed good early outcomes and hemodynamics.
Hao et al. (2023) ⁵	Not primary focus, but used clinically acceptable BJV conduits with prior processing.	ECM status not explicitly detailed but clinical results were acceptable.	Mechanical integrity maintained over medium-term use in clinical settings.	Not reported.	SDS-processed conduits demonstrated mid-term success.
Dalgliesh et al. (2018) ⁹	Decellularization efficiency is a key to reducing antigenicity; SDS helps achieve this when optimized.	Proper SDS use helps minimize antigenicity by preserving ECM.	Biomechanical outcomes are favourable when SDS exposure is optimized.	SDS-treated scaffolds showed potential when thoroughly rinsed.	SDS-based processing, when optimized, helps reduce xenograft immune reactions.
Lin et al. (2018) ¹⁰	SDS effectively achieves >90% nuclear clearance.	SDS 0.5% maintained collagen/elastin well; important for scaffold functionality.	SDS preserved mechanical strength with proper exposure duration.	0.5% SDS showed high cell compatibility; 1% requires extended rinsing.	SDS-treated grafts showed positive short-term outcomes; long-term studies ongoing.
Sembirning et al. (2022) ¹¹	SDS 0.5–1% achieved excellent decellularization; higher concentrations increased removal.	SDS 0.5% showed strong preservation of key ECM elements.	SDS 0.5% maintained tensile strength and structure.	SDS 0.5% supported stem cell attachment and viability.	SDS grafts showed promising animal model results.
Soebroto et al. (2024) ¹²	SDS 0.5% effective, though ASB-16 offered additional benefits.	SDS preserved structure, with ASB-16 offering enhanced performance in specific contexts.	Not reported.	SDS performed well, ASB-16 showed additional benefit in specific assays.	<i>In vitro</i> study; SDS effects promising but require <i>in vivo</i> validation.
Faulk et al. (2014) ¹³	SDS effectively removes cellular components while maintaining overall structure with proper use.	SDS preserved matrix elements well under controlled exposure.	SDS-treated scaffolds maintained acceptable mechanical integrity when applied correctly.	With adequate washing, SDS-treated scaffolds supported recellularization.	SDS treatment offers reliable structural preparation for further testing.

on.¹² On the other hand, 0.5% SDS scaffolds facilitated better stem cell attachment and proliferation.

Preclinical outcomes

Short-term patency of SDS-decellularized bovine jugular conduits was shown in animal models; however, at mid-term follow-up, complications like calcification and stenosis were observed.¹⁰ These results imply that SDS by itself might not offer sustained durability.

Alternatives and future directions

Zwitterionic detergents like ASB-16 maintain ECM more effectively but are actually expensive and less accessible.⁹ Hybrid methods mixing SDS with enzymatic digestion or nuclease washes could improve outcomes.

In environments with limited resources, SDS-decellularized bovine jugular veins provide a feasible start for the manufacture of locally produced xenografts. But long-term durability is still not proven, and it may be necessary to add anti-calcification or bioactive modifications to the composition.

Discussion

In the context of tissue-engineered pulmonary xenografts, decellularization of bovine jugular veins using sodium dodecyl sulfate (SDS) has shown promise but requires careful optimization of detergent concentration, exposure time, and post-processing steps to ensure safety and clinical applicability. This discussion examines the principal concerns regarding decellularization efficacy, extracellular matrix (ECM) preservation, mechanical stability, cytotoxicity and recellularization potential, preclinical translation, and prospective developments.

Decellularization efficiency

The crucial step to decellularization is getting rid of cellular and nuclear material. Residual DNA levels exceeding 50 ng/mg of dry tissue indicate immunogenic risk, whereas the histological absence of nuclei constitutes a vital quality standard. Numerous studies demonstrate that SDS concentrations ranging from 0.5% to 1% reliably attain over 90% nuclear clearance.^{8,13} Protocols utilizing 1% SDS resulted in more significant DNA removal compared to 0.5% SDS, but at the expense of more ECM disruption.

Residual nuclear remnants occasionally observed with 0.5% SDS demonstrate the difficulty of balancing the reduction of immunogenicity with the preservation of ECM.⁹ From an immunological point of view, incomplete decellularization poses a risk of retaining antigenic material that could induce graft rejection.⁶

Extracellular matrix preservation

SDS is a strong ionic detergent that dissolves down cellular membranes and changes the structure of ECM proteins. Recent evidence shows that 0.5% SDS preserves collagen I/III and elastin better than 1% SDS, which causes glycosaminoglycan (GAG) loss and less retention of growth factors.^{4,13}

Histological and immunohistochemical analyses show that laminin and fibronectin expression diminish follow-

ing high SDS exposure, thus preventing adhesion and recellularization potential.¹⁰ Composite protocols, such as 0.25% SDS in conjunction with non-ionic detergents, can maintain ECM ultrastructure while allowing effective decellularization.¹²

Biomechanical integrity

Mechanical competence is essential for the long-term sustainability of vascular grafts. Research suggests that SDS-treated bovine veins preserve burst pressure and tensile strength comparable to native tissue when exposure durations are regulated.¹⁵ However, extended SDS treatment (over 14 days) decreases compliance and mechanical stability, potentially undermining in vivo performance.

Therefore, the concentration and the duration of time that detergent is used are two variables that need to be optimized. Brief exposure to 0.5% SDS combined with enzymatic digestion seems to give beneficial results.

Cytotoxicity and recellularization

Residual SDS is difficult to completely remove and represents a major cytotoxic risk. In vitro assays show that scaffolds treated with 1% SDS demonstrate lower cell viability compared to those treated with 0.5% SDS. This is probably because of interactions between the detergent and the proteins.^{8,13} On the other hand, scaffolds that were treated with lower concentrations of SDS made it more straightforward for stem cells to attach to them and grow.⁴

Extended washing, perfusion-based rinsing, and chemical neutralization using substances like calcium chloride are examples of mitigation techniques. Hybrid protocols can further reduce cytotoxic effects while increasing recellularization potential by combining SDS with nonionic detergents or enzymatic digestion.¹²

Preclinical translation and immunogenicity

SDS-decellularized bovine jugular veins demonstrated improved hemodynamics and short-term patency in animal models.¹⁵ However, long-term follow up shows complications like calcification, stenosis, and intimal hyperplasia.¹⁵ These results suggest that chronic graft degeneration may not be inhibited by detergent-based decellularization alone.

A significant obstacle to developing immune tolerance is residual antigenicity, especially xenogeneic epitopes.⁶ Therefore, to support host integration, adjunctive modifications such as heparinization, growth factor incorporation, and anti-calcification treatments are needed.¹⁰

Alternative and hybrid approaches

Despite SDS's effectiveness, shortcomings led to research into alternative detergents. Although they are more expensive and less successful at removing nuclear remnants, zwitterionic agents (CHAPS, ASB-16) provide better ECM preservation.¹² Triton X-100 and other nonionic detergents are milder but insufficient for thick vascular tissues.⁷

Simultaneous combining of SDS with DNase, RNase, or nonionic detergents is a hybrid strategy that improves clearance and reduces ECM disruption.¹⁶ Vacuum-assisted

washing and perfusion-based decellularization improve detergent removal and decreased cytotoxicity.¹⁷

Clinical and translational implications

SDS-decellularized bovine jugular veins provide a practical and affordable substitute for homograft's in limited-resource regions. However, standardized procedures that guarantee safety, reproducibility, and sterility is necessary for clinical translation. One major obstacle is still regulatory compliance, which includes validating DNA removal, ECM integrity, and detergent clearance.¹⁵

Future clinical trials must evaluate host immune responses, durability, and growth potential in addition to patency, especially in pediatric populations where conduit growth is important.

Conclusion

In conclusion, SDS is an effective, readily available detergent for decellularizing the bovine jugular vein. Concentrations between 0.5 and 1% maintain a balance between clearing cells and keeping the matrix intact. SDS 0.5% helps keep the structure of the cells better, while SDS 1% makes sure that all of the cells are removed while it also makes the matrix more unstable and more toxic to cells.

Further study should:

1. Establish SDS protocols similar with specific times for exposure.
2. Consider the combination with enzymatic or zwitterionic detergents.
3. Review the long-term preclinical and clinical patency outcomes.
4. Establish protocols that are cost-effective and work in areas with limited resources.

Worldwide, children with congenital heart disease could have a bigger opportunity to use pulmonary conduits if SDS-decellularized bovine jugular xenografts become optimized.

Conflict of interest

None declared.

References

1. Konstantinov I, Rosapepe F, Dearani J, Alexi-Meskishvili V, Li J. A Tribute to Giancarlo Rastelli. *Ann Thorac Surg* 2005;79:1819–1823.
2. Egidio Assenza G, Krieger EV, Baumgartner H, et al. AHA/ACC vs ESC Guidelines for Management of Adults With Congenital Heart Disease: JACC Guideline Comparison. *J Am Coll Cardiol* 2021;78:1904–1918.
3. Hasan AA, Abu Lehyah NAA, Al Tarawneh MK, et al. Incidence and types of congenital heart disease at a referral hospital in Jordan: retrospective study from a tertiary center. *Front Pediatr* 2023;11:1261130.
4. Bobylev D, Horke A, Avsar M, et al. Matched comparison of decellularized homografts and bovine jugular vein conduits for pulmonary valve replacement in congenital heart disease. *Cell Tissue Bank* 2024;25:55–66.
5. Hao S, Zou M, Cao F, et al. Medium-term outcomes of bovine jugular valved conduits for right ventricular outflow tract reconstruction in children: a retrospective cohort study from China. *Transl Pediatr* 2023;12:1842–1852.
6. Keane TJ, Swinehart IT, Badylak SF. Methods of tissue decellularization used for preparation of biologic scaffolds and in vivo relevance. *Methods*. 2015;84:25–34.
7. Gilbert TW, Sellaro TL, Badylak SF. Decellularization of tissues and organs. *Biomaterials* 2006;27:3675–3683.
8. Crapo PM, Gilbert TW, Badylak SF. An overview of tissue and whole organ decellularization processes. *Biomaterials* 2011;32:3233–3243.
9. Dalgliesh AJ, Parvizi M, Lopera-Higuita M, et al. Graft-specific immune tolerance is determined by residual antigenicity of xenogeneic extracellular matrix scaffolds. *Acta Biomater* 2018;79:253–264.
10. Lin CH, Hsia K, Ma H, et al. In Vivo Performance of Decellularized Vascular Grafts: A Review Article. *Int J Mol Sci* 2018;19:2101.
11. Sembiring YE, Ledyastatin RA, Nurrahmah A, et al. Comparative Assessment of Various Concentration and Exposure Time of Sodium Dodecyl Sulfate as Decellularization Agents for Small-Vessels Vascular Tissue Engineering. *Open Access Macedonian Journal of Medical Sciences* 2022;10.
12. Soebroto H, Mahyudin F, Mastutik G, et al. ASB-16 was superior to SDS 0.5% as a decellularization agent: An in vitro study using bovine pericardium. *Journal of Medicinal and Pharmaceutical Chemistry* 2024;6:1028–1041.
13. Faulk DM, Carruthers CA, Warner HJ, et al. The effect of detergents on the basement membrane complex of a biologic scaffold material. *Acta Biomater* 2014;10:183–193.
14. Sembiring YE, Wijaya R, Puruhito, et al. Comparison Of Bovine Mesenteric Artery With Bovine Mesenteric Vein Patency As Xenograft In *Oryctolagus Cuniculus* Carotid Artery. *European Journal of Molecular & Clinical Medicine* 2021;7:3356–3361.
15. Wainwright JM, Hashizume R, Fujimoto KL, et al. Right ventricular outflow tract repair with a cardiac biologic scaffold. *Cells Tissues Organs* 2012;195:159–170.
16. Syedain ZH, Meier LA, Bjork JW, et al. Implantable arterial grafts from human fibroblasts and fibrin using a multi-graft pulsed flow-stretch bioreactor with noninvasive strength monitoring. *Biomaterials* 2011;32:714–722.
17. Nicholls DL, Rostami S, Karoubi G, Haykal S. Perfusion decellularization for vascularized composite allotransplantation. *SAGE Open Med* 2022;10:20503121221123893.