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Landmark Study Demonstrates First Successful Long-Term Cryopreservation and Nanowarming of Human-Scale Kidneys

Interdisciplinary research supported by the National Science Foundation Engineering Research Center for [Advanced Technologies for the Preservation of Biological Systems](http://www.atp-bio.org) (ATP-Bio) overcomes a fundamental scaling barrier in organ banking, preserving pig kidneys at -150°C for up to one year with immediate functional recovery upon rewarming, perfusion, and acute transplantation.

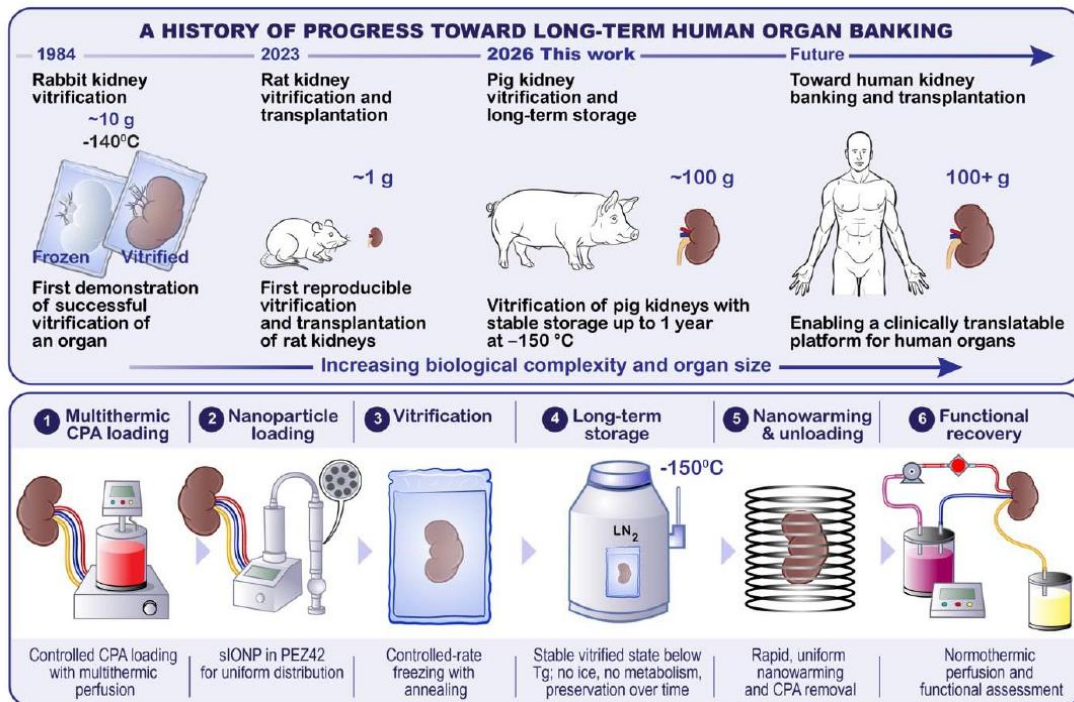
In a major advance for organ preservation, researchers have successfully vitrified, cryogenically stored for up to one year, and nanowarmed human-scale porcine kidneys ($\sim 100\text{ g}$)—a 100-fold increase in organ mass over previous rodent studies. Maintained in a glass-like vitrified state at -150°C , the kidneys suffered minimal structural injury during storage and rewarming, recovering on par with organs exposed only to cryoprotectants. Upon acute transplantation, the organs immediately reperfused with normal vascular flow and produced urine on the operating table. Driven by ATP-Bio's integration of thermal engineering, nanomedicine, and transplant surgery—pairing the novel PEZ42 cryoprotectant with multithermic machine perfusion and radiofrequency nanowarming—this achievement brings long-term cryogenic organ banking one step closer to clinical reality.

"Achieving one-year functional recovery in pig kidneys proves that vitrification and nanowarming can scale to human-sized organs. By overcoming the fundamental limits of organ rewarming, we are transforming cryogenic organ banking from a theoretical concept into a practical clinical future."

Dr. John Bischof (Director of NSF ATP-Bio)

"Extending preservation from hours to months or years will transform organ allocation—allowing us to better match recipients, reduce discard rates, and ultimately save thousands of lives on waiting lists worldwide."

Dr. Erik Finger (Transplant surgeon, University of Minnesota)



Organ cryopreservation progression and workflow.
Historical milestones in organ banking (a) and the step-by-step process of vitrifying, nanowarming, and evaluating human-scale pig kidneys (b).

Key Findings & Technical Innovations

Overcoming the Scale & Thermal Barrier: To bridge the 100-fold mass leap from rodent models to human-scale pig kidneys (~100 g), researchers deployed four integrated technologies: a PEZ42 cryoprotectant formulation that prevents ice formation (<0.2%) even at slow cooling rates, sub-zero multithermic perfusion below –15 °C to suppress chemical toxicity during cryoprotectant loading, a 100-minute thermal annealing hold at –114 °C to prevent structural stress cracking, and radiofrequency nanowarming using silica-coated iron oxide nanoparticles (sIONPs) to achieve rapid, uniform volumetric rewarming (~32 °C/min) in minutes without devitrification.

Ex Vivo Functional Recovery (NMP): During 120 minutes of 37 °C normothermic machine perfusion, vitrified-nanowarmed organs demonstrated functional vascular, excretory, and metabolic recovery. The kidneys exhibited rapid reperfusion, strong blood flow (81.7 mL/min/100 g), low resistance, active creatinine clearance, and robust urine output (375.6 mL/100 g), alongside preserved cortical ATP reserves and reduced lactate levels relative to controls. Crucially, an organ cryogenically banked at –150 °C for 366 days recovered function on par with short-term stored organs (24 hour old storage), confirming long-term banking stability.

Immediate In Vivo Function: In acute porcine transplantation models, vitrified-nanowarmed grafts proved instantly viable upon clamp release. The organs exhibited immediate reperfusion with full color return and normal Doppler blood flow waveforms, followed by prompt in vivo function that produced an average of 181 mL/100 g of urine over the 120-minute post-transplant observation period.

ATP-Bio Affiliated Authors & Contributions

This milestone paper, titled “*Functional recovery of vitrified and nanowarmed human-scale pig kidneys*,” highlights the core mission of the **NSF Engineering Research Center for Advanced Technologies for the Preservation of Biological Systems (ATP-Bio)**: bridging biothermal engineering, physical science, and clinical transplantation.

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Further information/references:

- [MIT Technology Review - Pig kidneys that were “frozen” for a year have been brought back to life](#)
- [BioXriv - Functional recovery of vitrified and nanowarmed human-scale pig kidneys](#)

About NSF ATP-BioSM

NSF ATP-BioSM is a world-class partnership between engineering, medicine, science, education, business, and ethics at six premier research universities. It supports the crucial advancement of biopreservation technologies and enables innovation, commercialization, and diverse workforce development.

NSF ATP-BioSM is co-led by the University of Minnesota (UMN) and Massachusetts General Hospital (MGH). Texas A&M University (TAMU) and the University of California-Riverside (UCR) are core collaborating institutions. The University of California-Berkeley (UCB) and Carnegie Mellon University (CMU) are affiliated partner institutions.

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