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Exploring the current provision of pancreatic transplantations in low- and middle-income countries: Current landscape, challenges, future prospects

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Abstract

This comprehensive review addresses the global health challenge of disparities in pancreas transplant access, particularly in low- and middle-income countries (LMICs) compared to high-income countries. Despite advancements in surgical techniques and immunosuppression for procedures like simultaneous pancreas-kidney, pancreas-after-kidney, and pancreas-transplant alone, LMICs face significant challenges, including limited infrastructure, financial constraints, and a shortage of skilled medical professionals. Donation after brain death remains constrained by sociocultural barriers. Region-specific analyses highlight progress in Latin America, Asia, Russia, and South Africa, showcasing the regional disparities in access and outcomes. Future prospects involve minimally invasive surgeries, telemedicine for enhanced post-operative care, international collaborations with organizations like the European Union of Medical Specialists, and robust funding networks to improve organ availability. In conclusion, the review underscores the importance of multifaceted strategies to address economic, sociocultural, and infrastructural barriers, aiming to improve accessibility, quality, and effectiveness of pancreas transplantation services in LMICs.

Key Words: Pancreatic transplantation; Diabetes mellitus; Global health; Low- and middle-income countries; Transplant surgery

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Core Tip: This review explores the disparities in pancreas transplantation in low- and middle-income countries (LMICs) compared to high-income countries (HICs), emphasizing challenges like economic constraints, cultural beliefs, and limited healthcare infrastructure. Highlighting the importance of donation after brain death (DBD), as well as differences in outcomes of procedures such as simultaneous pancreas-kidney (SPK), pancreas-after-kidney (PAK), and pancreas-transplant alone (PTA) procedures between HICs and LMICs, it calls for increased research and collaboration to promote surgical equity. Collaborating with the European Union of Medical Specialists could support LMICs in establishing robust DBD programs, ultimately improving SPK, PAK, and PTA access and outcomes.

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INTRODUCTION

Pancreas transplantation emerges as a pivotal intervention, particularly in addressing end-stage pancreatic diseases such as type 1 diabetes mellitus[1]. While diabetes mellitus imposes a substantial global burden, affecting over 400 million individuals and contributing to about 5% of all deaths[2], accessibility to pancreas transplantation is markedly uneven. High-income countries (HICs) witness a concentration of procedures due to well-established standards and resources, in stark contrast to the challenges faced by low- and middle-income countries (LMICs), where access remains limited or non-existent despite a growing burden of diabetes and its complications[2].

Over the past few decades, considerable advancements in pancreas transplant surgical techniques and improvements in immunosuppression have been notable, yet these strides have predominantly manifested in HICs, with LMICs often being left behind[3]. The International Pancreas Transplant Registry reports that merely 0.4% of global pancreas transplants between 1980 and 2018 occurred in LMICs, underscoring a profound disparity in availability[4]. Consequently, this review delves into the global health challenge posed by such discrepancies, aiming to explore various pancreas transplantation procedures and their implications. Simultaneous pancreas-kidney transplantation (SPK), the most prevalent type, not only restores glucose and renal function but also demonstrates improved survival and reduced cardiovascular mortality[5]. Alternative approaches, such as pancreas-after-kidney (PAK) transplantation and pancreas-transplant alone (PTA), each offer distinct considerations and outcomes[6,7].

Despite the considerable success of pancreas transplantation in HICs, LMICs grapple with formidable challenges, including limited infrastructure, financial constraints, and a shortage of skilled medical professionals[8]. Acknowledging the broader implications of these challenges, this review addresses the critical global health concern of disparities in

pancreas transplant access. It seeks to explore the socio-economic impact of pancreas transplantation in LMICs, providing insights for evidence-based policies and interventions that can alleviate the barriers faced by these regions. By delving into the current state of pancreas transplants in LMICs, this review illuminates the pressing need for equitable healthcare access on a global scale.

LITERATURE SEARCH

This comprehensive review on pancreatic transplants in LMICs embraced a diverse range of studies, including observational, case-control, cohort, and randomized controlled trials, ensuring a comprehensive grasp of the subject. The exploration encompassed various databases, such as PubMed, EMBASE, Google Scholar, the Cochrane Library, CINAHL, Scopus, and Scielo, covering publications until January 09th, 2024. Key search terms were selected to align closely with the focus of the review, incorporating keywords such as "pancreas surgery", "pancreas transplantation", "low and middle income countries", and "developing countries". An additional manual search complemented the electronic database exploration and involved reviewing reference lists of key articles to capture any significant studies potentially missed during the initial search. LMICs were defined as per the World Bank Classification. The review focused on English articles, excluding standalone abstracts, unpublished studies, and trial protocols. Each identified paper underwent meticulous screening for relevance and quality.

CURRENT LANDSCAPE OF PANCREATIC TRANSPLANTS IN LMIC

Navigating the intricate terrain of pancreatic transplants within LMICs reveals a multifaceted panorama marked by both advancements and challenges. Consequently, scrutinizing the pivotal domains encompassing treatment accessibility, survival rates, treatment unavailability, and the repercussions of postoperative complications on the holistic quality of life for individuals undergoing pancreatic transplantation is necessary to delineate the current state of pancreatic transplants in LMICs. Analysis of transplant related health policies Ensuring access to life-saving treatments is crucial for patients in LMICs grappling with end-stage pancreatic diseases. A promising avenue in this endeavor involves examining organ donor policies, where significant policy modifications have expanded eligibility criteria for pancreatic transplantation. Notably, Brazil exemplifies this approach, experiencing a substantial increase in PTA procedures following a policy adjustment that broadened eligibility to include individuals with two or more secondary diabetic complications[9]. This strategic shift significantly augmented the number of PTAs performed, highlighting the pivotal role of policy flexibility in enhancing treatment availability. Similarly, China's landscape of SPK transplants, primarily serving type 2 diabetic patients, has witnessed a notable rise in annual procedures. This surge is intricately linked to advancements in health policy, such as expanding insurance provisions, expanding eligibility criteria for pancreatic transplants and increasing funding leading to the establishment of additional transplant centers nationwide. This expansion has effectively broadened the geographical reach of pancreatic transplantation services, enhancing treatment accessibility for individuals grappling with type 2 diabetes-related complications[10]. While certain LMICs exhibit notable progress in pancreatic transplantation provisions, the landscape remains heterogeneous. In Turkey, for instance, stringent eligibility criteria often lead to the exclusion of a significant majority of patients from the pancreas transplant list, citing reasons such as elevated cardiovascular risk. Consequently, these patients either do not make it onto the transplant list or face suspension. While this dynamic keeps the SPK wait list relatively short, it diminishes the driving force and motivation of dedicated transplant teams and relevant organizations[11]. Moreover, in countries like Turkey, organ transplantation priority policies pose additional obstacles to accessing SPKs. In contrast to HICs like the United Kingdom, where deceased kidneys are prioritized for patients awaiting pancreas transplants, fostering more effective SPKs, such prioritization is often absent in LMICs like Turkey[11]. Moreover, in LMICs, organ donor policies often adopt a restrictive stance, resulting in diminished organ availability. Unlike HICs, which commonly utilize a diverse range of options such as donation after brain death (DBD), donation after circulatory death, and segmental pancreas living donation for pancreas transplants, most LMICs limit themselves predominantly to DBDs[11]. This stark contrast highlights the more constrained approach of LMICs in harnessing various donor sources for pancreas transplantation, often limiting the pool of available organs, consequently limiting the number of pancreatic transplants performed[11]. Within orthodox and conservative religious communities in LMICs, societal norms pose an additional barrier. A pertinent example is observed in countries like Bangladesh, where religious rulings, as indicated by fatwas issued by religious leaders, often serve as impediments, hindering candidates from accessing pancreas transplants. This occurs despite the existence of legal provisions that allow for such medical interventions[12]. Region specific analysis a thorough analysis of prevailing trends highlights a significant and rapid expansion of pancreatic transplant services in LMICs. Region-specific examinations underscore distinct patterns in Latin America, where Brazil leads with 3150 pancreas transplants as of 2021, marking a substantial 43% increase from 2015 to 2019[13]. Argentina also shows notable progress, surpassing 1000 pancreas transplants since its induction in 1996[13]. Despite the absence of national registries, published studies reveal modest yet noteworthy strides in pancreatic transplant provisions in Colombia and Chile[13]. Similar trends are observed in Eurasia, particularly in Russia. Since the introduction of whole-organ SPK transplants from deceased donors in 2005, pancreas transplant provision has significantly expanded. Pioneering centers like the Petrovsky Russian Research Center of Surgery and the Medical Research Institute of Transplantology and Artificial Organs initiated successful programs post-2005. By early 2021, 210 pancreatic transplant procedures were performed across nine centers in Russia, primarily focusing on SPK transplants from deceased donors, highlighting Russian transplant surgeons' commitment to enhancing

practices for patients with type 1 diabetes seeking insulin independence[14]. The examination of pancreatic transplants in LMICs in Asia highlights a degree of heterogeneity. Despite the region's high prevalence of diabetes and associated mortality, pancreatic transplant provision is concentrated in specific nations, with limited data available for others. The Shiraz transplant center in Iran stands out as a significant player, having conducted over 268 transplants as of 2020, supported by contributions from other centers in Tehran and Mashhad, albeit in smaller volumes[15]. Countries like China and India demonstrate well-established pancreatic transplant programs. China, in particular, has experienced a substantial increase, surpassing 600 pancreatic transplants by 2023[10]. The literature extensively discusses pancreatic transplant outcomes from various centers across India, highlighting widespread attention and interest in the field[16,17]. However, the challenge of treatment unavailability persists, especially in LMICs like China, where the prevalent gap between demand and delivery of transplants underscores the need for adequate infrastructure and a skilled workforce to address this disparity[10]. Overcoming the obstacle of treatment unavailability hinges on ensuring sufficient resources and capacity in pancreatic transplantation within LMICs. Despite the global expansion of pancreas transplant services, growth in certain regions remains confined to specific nations. In Africa, pancreas transplantation services are predominantly concentrated in South Africa, notably at the Wits Donald Gordon Medical Center in Johannesburg since 2004. By December 2013, this center had executed 72 pancreas transplants, with 93.1% being SPK procedures[17]. Beyond South Africa, pancreas transplantation activities across the broader African continent are relatively limited. The Maghreb states, including Algeria, Morocco, and Tunisia, exhibit gradual progress, primarily relying on living donors for kidney and liver transplants. Moreover, Nigeria has embarked on kidney transplantation using living donors since 2000, fostering a growing number of active public and private transplant programs[18]. However, central African nations face a dearth of local transplant programs, often necessitating the referral of candidates abroad for such procedures. Consequently, South Africa retains its prominence as the central hub for pancreas transplants in Africa, highlighting a concentration of expertise and infrastructure in this specialized field[19]. Analysis of surgical techniques and patient outcomes significant strides toward enhancing pancreatic transplant surgical techniques have been witnessed in LMICs. Surgeons in certain LMICs have stood at the forefront of transplant surgical innovation, reducing complication rates and improving surgical efficacy. The Tianjin SPK procedure, pioneered by Chinese surgeons, exemplifies this innovation, departing from conventional Roux-en-Y methods to a side-to-side graft duodenum to the recipient's jejunum anastomosis for enteric drainage. This groundbreaking strategy, coupled with systemic venous drainage for endocrine secretion management, marks a milestone in refining patient outcomes within LMICs[10,19]. Moreover, surgeons in other LMICs have embraced advanced techniques, contributing to improved patient outcomes. In Russia, the adoption of innovative surgical approaches, such as retroperitoneal graft placement with systemic venous and enteric drainage, has further enhanced treatment efficacy[20]. These methodological refinements underscore a collective commitment within the field to continually optimize surgical practices in LMICs, translating into enhanced patient care and treatment efficacy. Survival rates serve as pivotal indicators of pancreatic transplant procedure efficacy. In some nations, such as Argentina, promising outcomes have been observed. PTA for type 1 diabetes, five-year survival rates for patients and grafts reached 86% and 60%, respectively[21]. Similarly, innovative approaches in China have led to encouraging three-year survival rates for pancreas and kidney grafts at 92.2% and 90.2%, aligning closely with those in HICs[21]. This underscores the impact of advancements in surgical techniques and immunosuppression on favorable outcomes in pancreatic transplantation in LMICs[21]. However, postoperative complications remain prevalent in pancreatic transplants within LMICs, significantly impacting patients' quality of life. For instance, patients with marginal renal function often face progressive deterioration post-transplantation, necessitating dialysis or subsequent kidney interventions[9]. LMICs like China and Russia exhibit analogous trends, with complications such as duodenal leaks and early graft rejection contributing to short-term graft function challenges[14,21,22]. Addressing these challenges requires concerted efforts to mitigate complications and enhance patient outcomes in pancreatic transplantations within LMICs. This discussion is summarized in Table 1.

CHALLENGES

Economic barriers to service expansion

Limited access to transplant services in LMICs stems from a shortage of specialized facilities and medical professionals in transplantation, resulting in a notably low number of pancreatic transplants[11,23-25]. The multidisciplinary nature of the transplant team, involving nephrologists, endocrinologists, and auxiliary roles, exacerbates the challenge due to the chronic shortage of such personnel in LMICs[11,16,23,24]. Infrastructural deficiencies pose a significant barrier to the provision of pancreatic surgical procedures in a majority of LMICs. For instance, several African nations, including Algeria, Côte d'Ivoire, Ethiopia, Kenya, and Uganda, grapple with a substantial shortage of organ transplantation centers, critically impeding the ability to offer pancreatic transplants in the region[25]. Additionally, these nations lack adequate facilities for crucial aspects of patient preparation, such as tissue typing, cross-matching, and certain viral studies, necessitating overseas involvement, which not only introduces delays but also inflates the overall cost of transplantation[25]. Furthermore, the absence of sufficient capabilities for histological evaluation of biopsy specimens poses challenges in the prompt management of rejections and infections, adding another layer of complexity to the transplantation process[25]. Moreover, the challenges in expanding pancreatic transplants in LMICs are exacerbated by poor infrastructure, insufficient institutional support, and a lack of technical skills, including a shortage of human resources. The absence of financial protection and inadequate national and international funding further impede progress in organ transplantation and the availability of essential immunosuppressive therapies[26]. The foundation of developing pancreatic transplantation services lies in a skilled workforce; pancreatic transplantation provision requires close coordination among

Table 1 Summary of current landscape of pancreatic transplants in low- and middle-income countries

Aspect	Summary
Health policies in low- and middle-income countries	Varied approaches in organ donor policies in low- and middle-income countries. Relaxation in eligibility criteria in certain nations is associated with increased transplantation activity. Stringent eligibility criteria and organ-transplantation priority policies in countries like Turkey pose challenges. Sociocultural factors, especially religious prohibitions, hinder organ donation in low- and middle-income countries, impacting organ availability
Region-specific analysis of pancreatic transplant provision	Significant progress in Latin America, particularly Brazil and Argentina. Russia has expanded pancreas transplant provision since 2005. Established programs in Asia face challenges such as treatment unavailability and regional disparities. South Africa remains the focal point for pancreas transplants in Africa, with limited activity in other regions. Heterogeneous landscape with variations in transplant numbers and challenges across different regions
Analysis of surgical techniques and patient outcomes	Surgeons in low- and middle-income countries, including China and Russia, have advanced pancreatic transplant surgical techniques. Reduction in complications and improved efficacy seen in innovative approaches. Promising survival rates in certain nations, like China, emphasize the impact of surgical advancements and immunosuppression. Persistent postoperative complications in low- and middle-income countries, including renal function deterioration and graft challenges, necessitate focused improvement efforts

various health professionals, including transplant surgeons, nephrologists, pathologists, and highly trained nurses. However, LMICs face an acute shortage of healthcare workers, especially in regions such as Africa[25]. The number of surgeons, especially transplant surgeons, remains largely undocumented on the African continent, whereas, among the 47 countries in sub-Saharan Africa, only 15 have available data on nephrologists, highlighting the scarcity of specialized professionals in the region. The challenges are further compounded by limited opportunities, employment uncertainties, and poor financial conditions, leading to a significant brain drain of highly skilled LMIC healthcare workers in developed countries[26,27]. LMICs, characterized by low *per capita* gross-economic incomes, face economic barriers to pancreas transplantation, particularly in countries like India, where costs are extremely exorbitant in both the public healthcare system and tenfold higher in private healthcare systems[28]. This poses a significant financial burden to patients and services. The inflated costs associated with organ transplants and postoperative therapies, coupled with insufficient financial backing in many states, significantly contribute to the hurdles associated with organ transplantation[28].

Challenges to organ procurement

In certain LMICs, sociocultural factors, particularly strong religious prohibitions against post-mortem body disfigurement, notably in Islamic countries, present a significant hurdle to posthumous organ donation[12]. Conservative interpretations of religious doctrines perceive the human body as sacrosanct, discouraging alterations not deemed medically necessary[12]. Despite progress in some regions, persistent public hesitation impacts the establishment of organ registries and banks, with legislative barriers, particularly concerning the definition of 'brain death' in some South Asian countries, leading to delays in organ extraction[12]. Moreover, the prevailing practice of prioritizing family consent over the deceased's wishes potentially renders organs legally unusable[12]. Donors in LMICs carry multiple risk factors that impede the viability of a transplanted pancreas. Factors such as cardio-cerebrovascular causes of death, older donor age, obesity, and prolonged retrieval and storage times have a detrimental effect on pancreas viability[24,28]. In LMICs, a substantial 42% of donor pancreases face rejection based on age criteria alone[24]. The higher prevalence of cardiovascular diseases and diabetes in these regions further constricts the potential donor pool while simultaneously increasing the demand for pancreas transplants[29]. This intricate interplay of risk factors poses a substantial barrier to successful pancreas transplantation in LMICs. In numerous LMICs, the commercialization of donation practices is discouraged by local regulations, which permit organ donation exclusively from individuals related by blood or marriage. While these regulations are implemented to reject and deny organ trafficking and transplant tourism, they inadvertently reduce the availability of organs in these nations[30]. Waiting lists for pancreas transplantation in LMICs are often truncated due to endemic factors such as cardiovascular diseases and a sedentary lifestyle, excluding many individuals from transplant candidacy[11,15,16]. Nonetheless, outliers with waiting times for SPKs reported as high as 2.5 years exist, suggesting variability in waiting periods[9]. Prolonged waiting times are associated with higher recipient mortality, prompting the liberalization of donor selection criteria, a concerning trend that may contribute to a cyclical pattern[31]. The psychological impact on recipients, including post-pancreas transplant anxiety, is noted, potentially exacerbated by an extended treatment burden[35]. This longer treatment burden can also exact an economic toll, with accumulating costs of insulin and dialysis affecting individuals possibly already facing financial distress[32].

Post-operative care

Addressing post-transplant care for pancreas transplants in LMICs presents multifaceted challenges. Central to success is the meticulous management of immunosuppression and graft surveillance. Lehmann *et al*[33] emphasize the importance of stringent immunosuppression management for mitigating risks such as severe hypoglycemia and preserving long-term graft function. However, LMICs face constraints in healthcare infrastructure and limited access to specialized care, hindering ongoing patient monitoring and intervention[33]. Post-operative complications, re-operations, and the lifelong requirement for immunosuppressants further compound the economic challenges associated with pancreas transplantation, as evidenced by cost analyses[34]. This trend is reflected in other LMIC nations; studies on South Africa, for instance, highlight similar challenges for patients obtaining insurance coverage[17]. The post-operative landscape is further complicated by potential complications such as graft thrombosis, bleeding, infection, and pancreatitis, requiring timely and effective management. Spetzler *et al*[35] underscore the intricacies of managing duodenal leaks, emphasizing

Table 2 Summary of challenges impeding the provision of pancreatic transplant services in low- and middle-income countries

Challenges	Key points
Economic barriers to service expansion	Limited access in low- and middle-income countries due to facility shortages, lack of specialized personnel, and infrastructural deficiencies. Financial burden on patients in countries like India. Brain drain of healthcare workers from low- and middle-income countries
Challenges to organ procurement	Sociocultural factors, religious prohibitions, legislative barriers, and donor risk factors hinder organ procurement in low- and middle-income countries. Commercialization of organ procurement is discouraged, impacting availability. Varied waiting times and limited donor lists due to endemic factors
Post-operative care	Challenges in immunosuppression management, limited healthcare infrastructure, economic constraints, and complications like graft thrombosis, bleeding, and infections. Resource constraints in low- and middle-income countries affect post-transplant care and monitoring. Urgent need for enhanced healthcare infrastructure

the need for immediate and competent care. However, the limited capacity of LMICs to address such complications due to resource constraints highlights a critical gap in post-transplant care[35]. Success in post-transplant care relies on regular monitoring to detect and manage complications like graft rejection and infections. The scarcity of advanced diagnostic tools and laboratory services in LMICs, as discussed above, poses significant challenges to effective post-operative care, emphasizing the urgent need for enhanced healthcare infrastructure[36]. Comprehensive efforts are required to bridge these gaps and ensure holistic post-transplant care for pancreas transplant recipients in LMICs. This discussion is summarized in Table 2.

DISCUSSION

There are significant differences between countries regarding the feasibility and practice of pancreas transplantation, which makes it challenging to provide universal recommendations for its implementation. Unlike kidney and liver transplantation, where establishing living donor programs is often feasible, pancreas transplantation predominantly relies on cadaveric donations. Although some successful cases of living donor segmental transplantation have been noted, nearly 100% of pancreas transplants are performed using brain-dead or asystole donors[37]. This reliance on cadaveric donations underscores the importance of having a robust infrastructure and cultural acceptance of organ donation. Countries with limited experience and culture in cadaveric donation programs may find it particularly difficult to initiate pancreas transplantation programs. Therefore, establishing a strong foundation for cadaveric organ donation is essential. This could involve community education campaigns to promote organ donation and collaborations with established transplantation centers for knowledge transfer and training. The future trajectory of pancreas transplantation holds significant promise, with anticipated advancements arising from innovative surgical techniques, global collaborations, and the integration of evolving healthcare technologies. To effectively address current challenges, a comprehensive approach is imperative, involving policy reforms, community engagement, and strategic investments in healthcare infrastructure and professional development. One primary step toward improving access to pancreatic transplants in LMICs is enhancing patient perspectives and acceptance of such procedures. Religious beliefs significantly shape attitudes toward organ donation in many LMICs, particularly in regions where posthumous organ donation may conflict with prevailing religious doctrines. Countries with more established transplantation programs, such as Brazil, Turkey, and South Africa, have made strides in addressing these challenges through public education and community engagement. However, in many parts of Africa and Asia, religious prohibitions remain a substantial barrier to the development of pancreas transplantation programs. To overcome these barriers, fostering dialogue between healthcare providers, religious leaders, and communities will be crucial. By engaging with religious authorities to provide clear guidelines on organ donation that align with religious values, countries can work to shift public perceptions and encourage greater participation in cadaveric organ donation programs. This approach, coupled with community-driven education campaigns, would serve as a vital first step toward overcoming religious resistance and advancing pancreas transplantation in regions where such barriers remain prevalent. Efforts to overcome sociocultural and legislative obstacles should encompass community engagement, educational campaigns, and collaborative initiatives with religious leaders to cultivate a positive perception of organ donation[38]. Addressing legislative ambiguities surrounding organ extraction procedures is crucial to streamline the donation process. In Bangladesh, diverse opinions among Muslim scholars regarding vital organ donation have arisen due to the absence of clear rulings in primary sources of Islamic jurisprudence, such as the Quran and Hadith[12]. Despite the absence of legislation limiting organ donation and transplantation, confusion exists among Bangladeshis regarding posthumous organ donation[12]. The "Iranian" model, which employs a government-sponsored paid living unrelated donor transplant program, has ethical concerns but has led to increased deceased donor transplants since the Brain Death Legislation's approval in 2000[39]. Thus, legal frameworks play a pivotal role in influencing donation patterns and transplant practices. The evolution of pancreas transplantation necessitates continuous refinement of surgical methodologies, with a strong emphasis on training and innovation. Initiatives focusing on organ procurement training and advancements in minimally invasive techniques hold substantial potential for enhancing donor organ retrieval and recipient implantation, thereby reducing complications and improving overall outcomes[40]. Proficiency in training specialists involved in organ procurement is crucial for ensuring widespread access to pancreas transplantation procedures. For instance, in Turkey, optional funded training courses targeting intensive care specialists and donor coordinators have been implemented, aiming to expand the donor pool and

optimize waitlist management[11]. Integrating these courses into foundational training programs for specialists could provide early exposure to the intricacies of pancreas transplantation, potentially fostering better-prepared specialists. This training's significance is underscored by its potential to reduce time spent in the donor intensive care unit, subsequently decreasing the risk of pancreatic allograft thrombosis[40]. Additionally, research focusing on complications unique to LMICs is essential to enhance post-transplant care and minimize associated costs[41]. Tailored approaches informed by research in these regions can optimize the efficiency of pancreas transplantation procedures. The integration of state-of-the-art technologies, including gene editing and regenerative medicine, holds the potential to revolutionize pancreas transplantation. Advances in laparoscopic biopsies in Argentina showcase the safety and diagnostic efficacy of this method, allowing for an in-depth exploration of pancreas allograft characteristics[42]. This methodological advancement facilitates research aimed at identifying prognostic indicators and developing precision medicine. Personalized medicine, tailoring immunosuppressive regimens to individual patients, shows promise in minimizing adverse effects and enhancing graft survival. As patient-specific factors become better understood, personalized approaches may become integral for optimizing long-term outcomes in pancreas transplantation, emphasizing a shift towards individualized and targeted therapeutic interventions. The extensive implementation of telemedicine is anticipated to augment post-operative care and follow-up, particularly in LMICs. Remote monitoring and consultations offer a means to overcome geographical barriers, facilitating timely interventions and elevating overall patient management. Telemedicine serves as a platform for mentorship and collaboration among specialists, eliminating the need for physical presence in the same operating room and transcending geographical limitations. This technological advancement has the potential to enhance accessibility to specialized healthcare services, fostering improved patient outcomes and facilitating collaborative knowledge exchange among healthcare professionals. Fostering international collaborations is paramount for improving pancreas transplantation in LMICs. Shared expertise, knowledge transfer, cost-sharing, and collaborative research initiatives can help bridge the gap in healthcare infrastructure and address the shortage of skilled professionals, facilitating increased access to transplantation services. The European Union of Medical Specialists (UEMS) plays a pivotal role in this effort by overseeing quality control and accreditation of transplant centers and specialists through its Transplant Division, which includes Boards of Surgeons, Medical Specialists, Transplant Coordinators, and Immunologists. These groups regulate training and accreditation in transplantation, allowing them to collaborate on mentorship programs designed to enhance the skills and knowledge of healthcare professionals in LMICs. By establishing partnerships with organizations like the UEMS, LMICs can benefit from their expertise and resources, ultimately leading to improved transplantation practices. Such collaborations could facilitate the development of structured training programs, ensure adherence to best practices, and promote a culture of quality in pancreas transplantation, which is crucial for the success of these programs in resource-limited settings. The establishment of a robust funding network is essential, providing crucial financial support for various aspects of pancreas transplantation. This assistance is vital for equipment acquisition and enhancing healthcare professionals' skills through advancements in surgical techniques[11, 42]. Financial support is pivotal for technological upgrades aimed at optimizing the overall efficiency of pancreas transplantation procedures. Moreover, financial backing is imperative for improving healthcare infrastructure, particularly in the context of efficient transport routes, which are critical for the timely and secure transit of organs in pancreatic transplants[11]. Well-established transport routes are fundamental to ensuring the success of transplantation procedures[11]. Alongside financial support, standardized and comprehensive policies are crucial, tailored to address unique challenges in LMICs. These policies should encompass diverse measures, including financial support mechanisms such as bursaries and healthcare insurance, streamlined organ procurement processes, and targeted specialist training programs. This comprehensive approach aims to create a sustainable ecosystem for pancreas transplantation in resource-constrained regions[42]. This comprehensive strategy, encompassing advancements in training, innovative technologies, international collaborations, and robust policy frameworks, positions pancreas transplantation on a trajectory of continual improvement, ensuring its viability and success in diverse global contexts. This discussion is summarized in Table 3.

Table 3 Summary of future prospects for improving pancreatic transplant provisions in low- and middle-income countries

Area	Summary
Advancements in surgical techniques	Continuous refinement of surgical methodologies is crucial for the evolution of pancreas transplantation. Initiatives focusing on minimally invasive surgical techniques show potential for enhancing donor organ retrieval, reducing complications, and improving outcomes
Enhanced focus on research	State-of-the-art technologies, including gene editing and regenerative medicine, have the potential to revolutionize pancreas transplantation. Advances in laparoscopic biopsies showcase safety and diagnostic efficacy, aiding research in identifying prognostic indicators and developing precision medicine
Telemedicine implementation	Telemedicine's extensive implementation is expected to augment post-operative care in low- and middle-income countries. Remote monitoring and consultations overcome geographical barriers, facilitating timely interventions and collaborative knowledge exchange among specialists
International collaborations	Fostering international collaborations is paramount for addressing healthcare infrastructure gaps and the shortage of skilled professionals. Shared expertise, knowledge transfer, and collaborative research initiatives can increase access to transplantation services in low- and middle-income countries
Robust funding network and policies	A robust funding network is essential for various aspects of pancreas transplantation, including equipment acquisition, skills enhancement, and technological upgrades. Comprehensive policies addressing unique challenges in low- and middle-income countries, including financial support mechanisms, streamlined organ procurement processes, and targeted specialist training

	programs, create a sustainable ecosystem
Increasing availability of pancreas organs	Strategies to increase the availability of pancreas organs for transplants should be incorporated into future plans. Efforts to overcome sociocultural and legislative obstacles, including community engagement and educational campaigns, are essential for cultivating a positive perception of organ donation
Legal frameworks and ethical considerations	Addressing legislative ambiguities surrounding organ extraction procedures is crucial for streamlining the donation process. Models like the "Iranian" government-sponsored living unrelated donor transplant program, while raising ethical concerns, demonstrate increased deceased donor transplants with proper legislation

CONCLUSION

In conclusion, the intricate landscape of pancreas transplantation in LMICs underscores the pressing need for multifaceted solutions to overcome existing challenges. The envisioned future of pancreas transplantation holds tremendous potential, with ongoing advancements in surgical techniques, international collaborations, and the integration of cutting-edge healthcare technologies. Initiatives focusing on training, innovations, and personalized approaches promise to optimize outcomes and address disparities unique to LMICs. However, the realization of this promising future hinges on sustained efforts, including robust funding networks, standardized policies, and community engagement, thereby fostering a conducive environment for enhanced accessibility, quality, and effectiveness of pancreas transplantation in resource-constrained regions.

FOOTNOTES

Author contributions: Bharadwaj HR conceptualized and designed the research study, performed the literature review, and drafted the manuscript; Tan JK designed the research study and contributed to the manuscript; Ali SH performed the research and assisted with data analysis; Shah MH conducted the literature review and contributed to the manuscript; Nicholas A performed the research and assisted in data collection; Mohamed Ahmed KAH contributed to the research design and manuscript review; Irfan K assisted with data collection and manuscript editing; Dalal P, Mehta A contributed to data analysis and manuscript review; Awuah WA assisted with the literature review and manuscript editing; Dhali A provided oversight on the research design and reviewed the manuscript.

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