Minimal incision and less invasive techniques in congenital cardiac surgery: a narrative review

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Background and Objective: Minimal incision and less invasive techniques derive from adult cardiothoracic surgery and they gradually find their application in congenital cardiac surgery. Diffusion of these techniques into congenital cardiac surgery has so far been limited due to case complexity, widespread range of ages and patient dimensions, a need to access multiple segments in a constrained operative field and lack of proper instrumentation. This review endeavors snapshot on techniques currently available with a view of possible future trends.

Methods: Literature and international database search was carried out with the relevant key terms. Findings are presented in correspondence with bi-institutional practices of the authors.

Key Content and Findings: A minimally invasive approach offers an alternative to conventional open surgery in an environment where not only survival matters but also quality-of-life and avoidance of complications. The final aim extends beyond a more appealing scar, it targets reduction of collateral trauma, and morbidity. The actual surgical method is dictated by the extent of anomalies: solitary defects [e.g., atrial septal defect (ASD), ventricular septal defect (VSD), valvar anomalies] can be addressed by direct access via lateral approach, whereas multicompartment complexes [e.g., tetralogy of Fallot (TOF), simultaneous intracardiac/extracardiac anomalies) often necessitate a limited midline approach. Success relies on detailed personalized preoperative planning that involves multimodality advanced imaging, 3D modelling and emulation on physical models or in augmented reality. Precise execution of the surgical plan requires an uncompromised view, mastering new skillsets, proper instrumentation and detailed briefing of the participants. Throughout the entire continuum-of-care, full multidisciplinary team participation and adherence is essential. On a programmatic level it also includes coaching by experts, strict auditing of results, and dedicated institutional support.

Conclusions: Indication for minimally invasive congenital cardiac surgery gradually broadens, however, it is yet to reach complex neonatal/infant procedures involving multiple operative compartments. Progress is documented by the adoption of endoscopy and other visualization modalities, manipulation techniques of robotics and by the emergence of new hybrid procedures.

Keywords: Congenital heart disease (CHD); minimally invasive surgery; surgical techniques

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Introduction

Background

Minimally invasive cardiac surgery (MICS) allows interventions on and inside the structures of the heart and the large vessels without full opening of the chest wall (1). Its primary aim is to reduce the collateral tissue damage, and thus morbidity—without risking the completeness of the surgical repair (2). Perceived advantages of MICS are: faster and better postoperative mobilization and independence of the patients, less infections, less trauma, less blood loss and transfusions, less re-explorations (in experienced programs), less arrhythmias, less posted lactate (2). The spectrum of MICS approaches ranges from partial chest opening to keyhole surgeries performed with endoscopic and robotic manipulation and hybrid performance (3).

Rationale and knowledge gap

Minimally invasive techniques derive from adult cardiothoracic surgery and they gradually find their application in congenital cardiac surgery per 'virtu de necessitate' (virtue of out necessity). Whereas MICS is now a well-established modality in adults (2), minimally invasive congenital cardiac surgery (MICCS) has so far been limited due to case complexity, widespread array of ages and bodyweights of the patients, the need to often address multiple anatomical segments in a constrained operative field, limited access to peripheral cannulation for cardiopulmonary bypass (CPB), and the lack of appropriately-sized instruments (4,5). Since infants and children do not experience major additional morbidity from chest opening *per se*, cosmesis had remained secondary to restoration of viable haemodynamics, i.e., the completeness of the surgical procedure.

Congenital cardiac surgery still carries higher overall risk (6,7). In the words of *John W. Kirklin* [1907–2004], one of the founding fathers of cardiac surgery: '*surgery is always second best. If you can do something else, it's better. Surgery is limited*' (8). Nevertheless, surgeons have always tried to expand those limitations. Advancing initiatives such as technology improvement (miniaturization), augmented visualization (e.g., endoscopy and video-assisted surgery), emerging hybrid modality with project-based teamwork can now join together in a minimal/less invasive approach either to reduce morbidity and provide more appealing cosmesis without jeopardizing quality of the repair and patient safety. There is, however, no unified consensus on the role and approach of MICCS especially in younger children or infants undergoing complex procedures involving more than one cardiac segment. Contemporary reports of MICCS present either case series proposing a particular approach or case reports of extending the boundaries of the modality. Authors of this review—drawing privileged synergy from a coexisting pioneering MICS program for acquired heart disease at their institution—aim to present their own programmatic experience with MICCS and cross examine it with the literature.

Objective

The objective of this narrative review is to present the state of minimally invasive techniques and practices in pediatric and congenital cardiac surgery published in the contemporary medical literature; to evaluate these practices with local institutional experience; to highlight current limitations and contemporary trends and to explore potential avenues for future development. We present this article in accordance with the Narrative Review reporting checklist (available at https://pm.amegroups.com/article/view/10.21037/pm-23-15/rc).

Methods

The present narrative overviews landmarks of the pertinent English-language scientific literature (papers and textbooks) and combines them with the latest available [2014–2018] published outcome data from international databases (9-11). PubMed MEDLINE, Google Scholar and EACTS International Congenital Heart Database searches were performed with the keywords of 'minimally-invasive', 'congenital', 'pediatric', and 'cardiothoracic surgery'. Peer-reviewed articles including original articles, systematic reviews and case reports that described minimally invasive congenital and/or pediatric cardiac surgery were selected. Articles focusing on aspects of MICS for acquired heart disease were only considered for drawing comparisons. Articles not pertaining to the topic, e.g., minimally invasive thoracic surgery, non-cardiac operations utilizing minimally-invasive perfusion techniques in the pediatric age-group were excluded (*Table 1*). Local experience and a perspective on program development is presented from a medium-size tertiary-care congenital cardiac centre as the authors' viewpoint.

Table 1 Search strategy summary

Items	Specification
Date of search	January 1 to March 15, 2023
Resources searched	PubMed MEDLINE, Google Scholar, EACTS International Congenital Heart Database
Keywords used for search	Minimally-invasive, congenital, pediatric, and cardiothoracic surgery
Timeframe	Literature published until search date. EACTS Database results between 2014–2018 were accessed
Inclusion and exclusion criteria	Inclusion: original articles, systematic reviews and case reports in peer-reviewed journals. Language restrictions: English
	Articles not pertaining to minimally invasive surgical procedures for congenital heart disease were excluded
Selection process	L.K. and S.K.S. and reviewed all retrieved articles independently. All authors participated in the final selection of literature suitable for the review

Discussion

The scope of MICCS

In the adult cardiothoracic practice, minimally invasive approach mostly addresses a discrete pathology, e.g., entry-point of the chest and methods append to specific valve procedures, coronary revascularization, etc. (2,12). Congenital cardiac surgery entails with a wide spectrum of anomalies where individual components often conjoin to create complex phenotypes (13). Tetralogy of Fallot (TOF), interrupted aortic arch-ventricular septal defect (VSD)-left ventricle outflow tract obstruction, etc. necessitates surgical performance in different anatomical intra- and extracardiac compartments during the same operation. Majority of the distinct congenital cardiac procedures belong to the complex, most complex classes (11,12). The complex procedures are performed in a highly constrained time-space framework (4). Historically MICCS had been introduced with some gender preference (14) for situations where less complexity and excellent outcomes allowed to consider other aspects, e.g., more appealing scars (15). Scope of indication has gradually broadened and MICCS is now accessible in the pursuit to treat more and hurt less (16). MICCS is yet to capitalize on the emerging adjuvant techniques of endoscopy, robotics and hybrid (see, later).

Preoperative preparation and intraoperative visualization

Careful patient selection for MICS/MICCS is the key in avoiding complications and conversion to full opening (2). Computed tomography (CT) angiography has become the gold standard (17) in cardiovascular imaging for assessing segmental anatomy, structures of region-of-interest as well as topography of the chest with a view of peripheral cannulation. 3D reconstruction of CT images advises on the best surgical approach and steps of the procedure. Preoperative planning by CT scan for minimally/less invasive congenital cardiac reoperations is inevitable in preventing re-entry injury (18). CT datasets along with data from other advanced imaging (3D echocardiography, magnetic resonance imaging) sources enable 3D modelling. Virtual models can be printed as 3D prototypes (physical models) and/or projected into the virtual reality as holograms (19). 3D-printed prototypes allow decision on the cardiac entry, emulation of the operation steps, so that ‘trial-and-error’ improvisation in the operating room (OR) must be avoided (20). Holographic images could be projected in augmented reality on the patient’s chest for the best entry-point (21) (*Figure 1*, *Video 1*).

Holographic images are also integrated into the OR video-recording systems [endoscopic, surgical headlight OR 360-degree cameras, transesophageal echocardiography (TEE), etc.] for reference that increases team participation in the surgical flow and serves as multiple teaching and transmission purposes (22). Detailed preoperative briefing, with written graphic notes has become a standard at the authors’ institution, that enhances communication and teamwork.

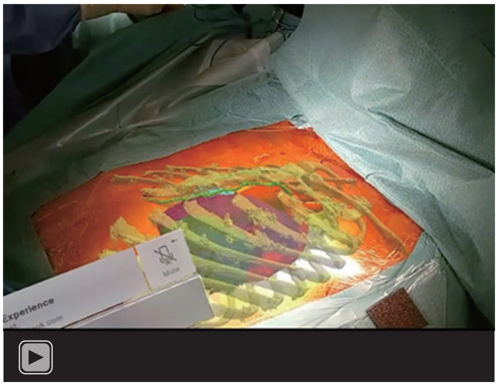
Keeping away from the midline

Keeping away from the midline has been proposed from the adult sternal morbidity (5). The spectrum of anomalies addressed with MICCS arrays from simple defects [atrial septal defect (ASD) sinus venosus ASD (SV-ASD), VSD, subaortic stenosis] to atrioventricular septal defect (AVSD), ToF repair and aortic and mitral valve (MV) repair, further incorporating repairs of AVSD and isolated pulmonary stenosis, extracardiac Fontan, etc. (14-16,23,24). Most reports (25-29) advise that thoracotomies provide adequate approach to more discrete (solitary) anomalies—easily addressed from the ipsilateral side [e.g., ASD, subaortic stenosis, etc. from the right; pulmonary valve, right ventricle outflow tract (RVOT), etc. from the left side]. MICCS via left anterior thoracotomy found a unique surgical (30,31) and hybrid (32,33) application for solving pulmonary valve regurgitation/RVOT problems after ToF repair. In certain anomalies, e.g., SV-ASD with partially anomalous pulmonary venous drainage, scimitar syndrome, etc., the lateral approach has gained recognition for allowing superior access to these anatomical structures (34). A limited midline approach via partial sternotomy is adequate for concurrent extra/intracardiac repairs (authors of this review have performed aortic arch repair + VSD closure from partial ministernotomy). *Figure 2* illustrates minimal/less invasive incisions and their access ranges in congenital and pediatric cardiac surgery.

Lateral approach

Since extrathoracic tissues are quite elastic and the layers easily slide, even small incisions (<3 cm) provide adequate view and most approaches allow muscle-sparing. The various (subaxillary, vertical, horizontal, submammary

Figure 1 Holographic 3D-model of the heart and great vessels is projected onto the patient's chest to assess the best entry-point.



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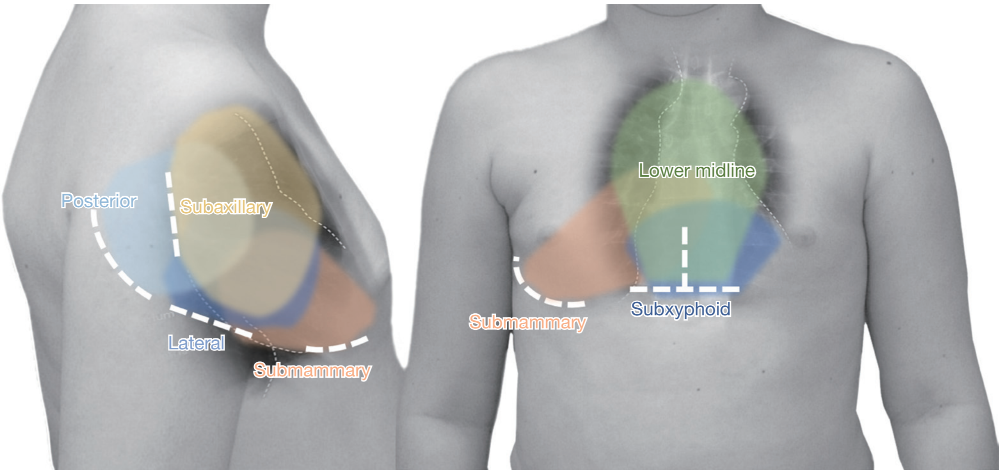

Figure 2 Minimal/less invasive incisions (dashed lines) and their access ranges in congenital and pediatric cardiac surgery.

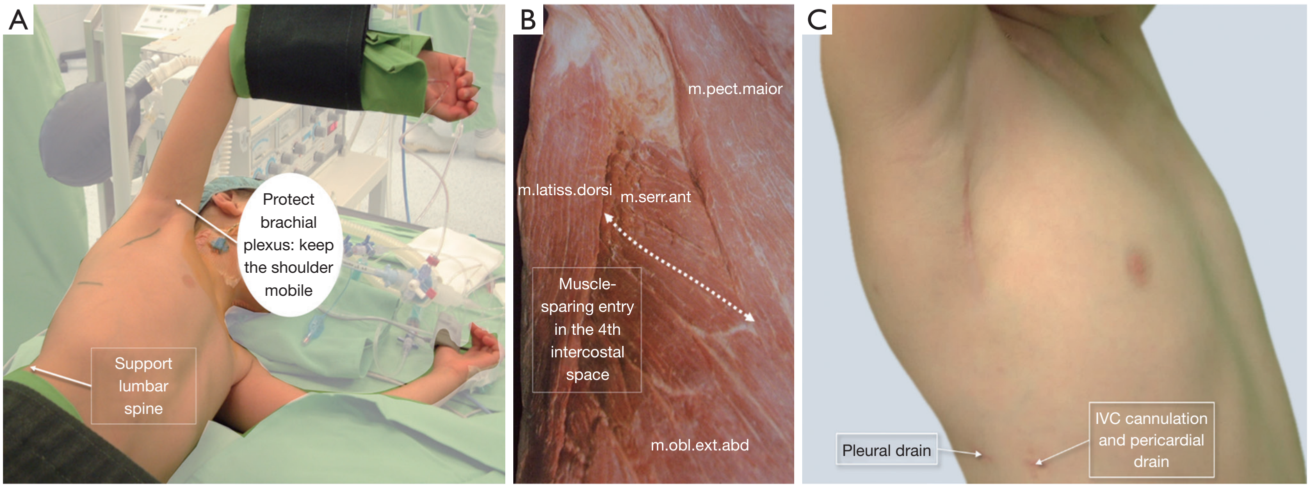

Figure 3 Right subaxillary muscle-sparing thoracotomy for less invasive open-heart surgery. (A) Patient's position for aortic valve and left ventricle outflow tract surgery. (B) Surgical anatomy for muscle-sparing entry; the dotted line with arrows represents the site of muscle spreading; (C) surgical scar with alternative IVC cannulation through the chest drain site. IVC, inferior vena cava.

Video 2 Right subaxillary muscle-sparing thoracotomy for less invasive open-heart surgery: flap-double patch repair of sinus venosus atrial septal defect and partially anomalous pulmonary venous drainage.

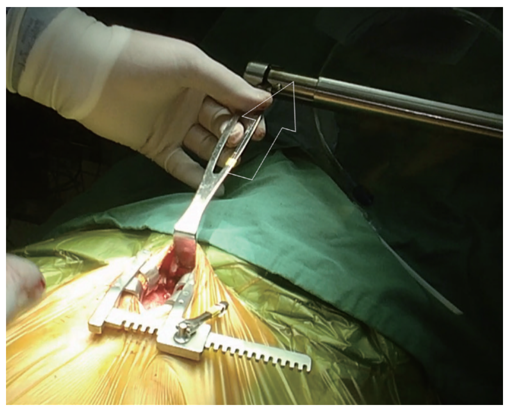

Figure 4 Ministernotomy: the sternum is lifted anterior and cranially (arrow) by a retractor mounted on an external framework.

skin incisions will eventually arrive at a posterior, lateral, or anterior intercostal opening. Single lung ventilation (when double-lumen endotracheal intubation is available), retraction sutures help in gradual development of view by pulling and stabilizing the mediastinal structures towards the operator. A word of caution should be mentioned in keeping the phrenic nerve in view all the time, so its inadvertent injury and/or stretching by the stay sutures could be prevented. We found CO_2-insufflation an important tool in preventing accidental air-embolism. Brachial plexus neuropraxia is prevented by proper positioning by leaving the shoulder mobile (*Figure 3*, *Video 2*). It is of note that we gradually abandon lateral decubitus position and abduction of the upper extremity as mediastinal structures move away from the operator by gravity; patients are now placed in supine position with ipsilateral side slightly elevated.

Ministernotomy

Ministernotomy exploits the pliability of sternum in younger age so that it can be suspended by a retractor

Figure 5 Postoperative scar after ministernotomy.

mounted on an external framework (*Figure 4*).

A lower vertical or—less frequently—horizontal incision is followed by the separation of the rectus sheaths in the linea alba and the xyphysternum. It allows adequate view to thymus, innominate vein and arch vessels and for intracardiac procedures. Underneath, the minimal skin incision, a full sternotomy can be performed, because when the sternum is only partially incised, its lower part tends to protrude outward during healing process (35). The access permits full central cannulation for CPB. At the authors institutions, ministernotomy is routinely utilized for most extra/intracardiac repairs (ASD, VSD, ToF, arch repair, etc.) in infants and children. Its drawback that a 3-cm anterior scar still remains postoperatively (*Figure 5*).

Endoscopic approach

Endoscopic approach has become the gold standard in thoracic surgery and MICS, however, endoscopic and video-assisted congenital cardiac surgery lags behind despite impressive surgical series (36-38). Endoscopy has so far proven useful either in non-bypass relatively simple procedures patent ductus arteriosus ligations, vascular rings (37) and various one-compartment [ASD, VSD, MV open-heart repairs] in larger children with peripheral cannulation (36). Conventional endoscopic instrumentation lacks the dexterity required for delicate cardiac surgical procedures, and the loss of depth perception caused by two-dimensional monitors further increases operative obstacles (39). With the advent of smaller endovision systems, proper-sized instruments, endoscopy will definitely extend towards smaller children and multi-compartment lesions.

Similarly, limited reports are as yet available on robotic cardiac surgery in children (40,41). Robots operate with high-resolution, binocular, three-dimensional, magnified views of operative fields and with highly maneuverable arms handling delicate tissues and anastomoses (39) that offers a great advantage for babies.

Hybrid cardiac surgery/catheter strategies emerge as a new modality where the surgeon allowing access and performing parts of the procedure and the invasive cardiologist employing catheter interventional methods complements each other in tandem fashion (3). Availability of this modality is evolving and now includes perventricular VSD closure (42), pulmonary valve replacement (33), pulmonary artery stenting (43), pulmonary vein stenosis dilation/stenting (44), selective pulmonary artery banding with PDA stenting for hypoplastic left heart syndrome (45,46), etc. Hybrid approach can help critically-ill patients with intractable (non-cardiac) conditions, where minimalization of collateral morbidity is key (47). In a broader sense, hybrid approach illustrates progress in therapy from open access towards catheter-based procedures. *Table 2* summarizes the various aspects of MICCS entry approaches.

Conversion to full chest opening

Conversion to full chest opening is rare and it is mainly associated with an unsuspected anatomical entity translating into an intractable technical problem, e.g., venous anomaly prohibiting proper drainage, restricted access/visibility, coronary anomaly. Similarly, high body mass index (BMI) can lead to an inadequate view/access that could prompt to conversion at a highest rate of 36% (48); experienced MICCS programs report around 2–5% (25,27,28). Authors of this review did not face the situation for conversion, however; intraoperative disintegration of right ventricle-to-pulmonary artery conduit necessitated extension of the incision.

Cannulation technique

The biggest challenge faced in MICCS is cannulation for CPB (49). Neck access via the internal jugular vein and common carotid artery is the favored peripheral cannulation sites in neonates and smaller children (<5–6 years or <30 kg) (50). Despite these patients are vulnerable to sustain cerebral injury (51), cervical cannulation—especially

Table 2 Selected aspects of MICCS entry approaches

Approach/incision	Suitability for	Advantage	Disadvantage	Possible complication
Minithoracotomy		Direct access to selected lesions; no midline scar	Mostly single compartment access; constrained operative field; difficult access for cannulation	Phrenic nerve palsy; bleeding; postoperative pain
Right	Right or left-sided lesions			
Subaxillary	ASD, VSD, iAVD, AoV, LVOT			
Posterior	MV, ASD, pulmonary veins			
Posterolateral, anterior, submammary	ASD, VSD, iAVD, AoV, LVOT, MV			
Left	PDA, CoA, LAA, LV apex, pulmonary veins			
Ministernotomy	Multi-compartment lesions	Intracardiac and great vessels, thymus	Midline scar	Lower sternum deformity
Lower partial	ASD, VSD, ToF, etc.	Multi-compartment access		
Subxiphoid	VAD, PM implantation, PVR	Limited access		
Endoscopy, robotics	ASD, SV-ASD, PDA	Potential benefits; miniaturization; 3D visualization	Single compartment access; limited MICCS experience	Limited MICCS experience
Hybrid	Stage-1 palliation for HLHS, musc-VSD, (Redo-) PVR/RVOT	Possible benefits Broadening scope	Mostly single compartment access	Stage-1: uncertain long-term outcomes, additional scar

MICCS, minimally invasive congenital cardiac surgery; ASD, atrial septal defect; VSD, ventricular septal defect; iAVD, incomplete atrioventricular septal defect; AoV, aortic valve; LVOT, left ventricle outflow tract; MV, mitral valve; PDA, patent arterial duct; CoA, aortic coarctation; LAA, left atrial appendage; LV, left ventricle; ToF, tetralogy of Fallot; VAD, ventricular assist device; PM, pacemaker; PVR, pulmonary valve replacement; SV-ASD, sinus venosus atrial septal defect; HLHS, hypoplastic left heart syndrome; RVOT, right ventricle outflow tract.

for a shorter duration of procedural CPB—balances with the flow requirements allowed by the larger vessels (52). Femoral cannulation is applicable over 15 kg (52). As most congenital procedures involve an intracardiac part, drainage of both caval territories as well as venting of the left heart is necessary. Due to the elasticity of pediatric soft tissues, however, central cannulation and venting across the operative area is usually possible (53). A useful alternative is to introduce the inferior vena cava cannula via the opening of the chest drain (*Figure 3C*). Since miscellaneous venous anatomies often encountered with congenital cardiac phenotypes, strategic placement of peripheral cannulation requires detailed preoperative diagnosis and planning (54). Extracorporeal circulation by peripheral cannulation drains dilated cardiac chambers and thus facilitate surgical manipulations before entering the chest and is an important adjunct in avoiding serious complication during redo chest entry (55,56).

Postoperative management and complications

MICCS is reported to have less collateral tissue damage that theoretically translates into reduced intensive care unit (ICU) and hospital length of stay (LOS) after MICCS is typically 1 day shorter than with full chest opening (16,57,58), lower use of blood products (2,10), less pain and a more expedited recovery (59). Thoracotomies, in contrast to partial sternotomy, however, involve more muscle stretching, and so, administration of local anesthetic via thoracic paravertebral block cannula is recommended (57,60). Early complications of MICCS include phrenic nerve palsy associated with right thoracotomy, especially in adolescents with deeper mediastinal structure and more traction on the pericardium (61). Submammary and anterior thoracotomy incision may affect late breast development (62).

Table 3 summarizes the various aspects and parameters related to MICCS. Reports in the scientific literature are

Table 3 Various aspects and parameter related to MICCS

Parameter	Observation and comment	References
Optimal age, weight	Mini-sternotomy: from 2 weeks to prepubescents; 3.5 to 20 kg	(63)
	Lateral approach: from 6–9 months; from 6 kg (optimal weight around 10–15 kg)	(23-28)
Peripheral cannulation	Recommended above 15 kg bodyweight	(14,50,52,64)
Procedural length, CPB, AoCC	MICCS has longer/similar procedural length	(15,58,65)
	No significant difference in CPB, AoCC durations from full opening	(26-28,63,64)
Conversion rate to full opening	0.1–0.2%	(14,15,25,26,28)
IPPV	Typically, less than 6 h	(14,15,23-28,63,64)
Analgesia	MICCS is associated with reduced analgesia need	(60,66)
Blood conservation	Reduced utilization of transfusions	(2,10)
Complication	Overall minimal complication rate with MICCS: (I) permanent AV block, 0.1–1%; (II) pneumothorax, 0.1–0.9%; (III) pericardial/pleural effusion, 0.1–0.9%; (IV) postoperative bleeding requiring exploration, 0.1–0.6%; (V) reoperation for residual defects, 0.2–0.5%	(14,15,23-28,57,63, 64,66)
LOS	MICCS is associated with one day shorter LOS than full opening	(16,57,58)
Implications on costs	Difficult to quantify for inhomogeneity and lack of data. MICCS may theoretically reduce costs	(57,67)

MICCS, minimally invasive congenital cardiac surgery; CPB, cardiopulmonary bypass; AoCC, aortic cross-clamp time; IPPV, intermittent positive pressure ventilation; AV, atrioventricular; LOS, length of stay.

difficult to extrapolate and unify for the heterogeneity of patient populations, diagnoses, procedural protocols in different institutional settings and individual surgeons' and teams' preferences (67).

MICCS program building

Our cardiac surgical heritage stands on the shoulder of pioneering giants who had had the courage and stamina to implement new techniques and modalities, sometimes, by trespassing established boundaries (68). Such an individual achievement and even bravado is no longer possible as clinical practice improvement is imprisoned in multilevel regulations (69-71). It is, therefore, an imperative that adult and congenital surgeons learn from one another (72). *Table 4* summarizes differences between MICS for acquired heart disease and minimal invasive and less invasive techniques in adult and pediatric age congenital cardiac surgery by institutional experience. In conclusion, a synergy is observed between the MICS (i.e., acquired heart disease) and MICCS (congenital anomalies) teams at the authors' institutions, where the 'adult' team contributes with the experience from standardized, high-volume MICS procedures whereas the pediatric team capitalizes on the experience with pathological and physical subtleties. Cooperation must extend to the Heart Team in view of hybrid approaches and—in another dimension—to the multidisciplinary team to deal with comorbidities, sociopsychological aspects of especially adult congenital heart disease (ACHD) patients.

As mentioned, minimally invasive cardiac surgical techniques mostly derive from the adult practice and their implementation for the widespread range of the paediatric cardiac population is only possible as a programmatic change. Multidisciplinary communication provides flexible learning opportunities (20). The steep learning curve (73) and consistently maintained results both at individual and team level mandates proper mentoring, readily available at larger centers (74,75). Proctorship by an established minimally invasive cardiac program is strongly recommended (2). As for a new clinical modality, strong institutional commitment is essential for accessible resources: equipment, i.e., special instruments and toolkit, dedicated premises (e.g., hybrid OR), provision of working routines. Commitment of the entire multidisciplinary team creates alliance that is a key for development, preserving

Table 4 Differences between MICS for acquired heart disease and minimal invasive and less invasive techniques in adult and pediatric age congenital cardiac surgery by institutional experience

Aspects	MICS for acquired heart disease	ACHD	PCHD	Institutional experience
Presentation	Adult age and parameters		Widespread age/bodyweight range	ACHD capitalizes on adult MICS techniques
Pathologies	Single compartment pathologies (e.g., ischaemic heart disease, valve problems, ASD); high case volume; repetition is common		Often multi-compartment scenarios, high variety; case repetition is rare	ACHD is suitable for standardization, whereas PCHD mostly requires individual planning
Procedures	Adult MICS techniques applicable (e.g., valve repair/replacement)		Wide variety of individual procedures; extracardiac/intracardiac procedures (e.g., aortic arch repair and intracardiac repair)	MICCS standardization for PCHD in progress
Cannulation for CPB	Peripheral access		Central access; jugular access in selected cases	Miniaturization could lower the bodyweight for peripheral cannulation in pediatric MICCS
Perioperative setting	Heart-team	Close cooperation of the multidisciplinary CHD team with adult MICS team is mandatory		

MICS, minimally invasive cardiac surgery; CHD, congenital heart disease; ACHD, adult congenital heart disease; PCHD, pediatric age congenital heart disease; ASD, atrial septal defect; CPB, cardiopulmonary bypass; MICCS, minimally invasive congenital cardiac surgery.

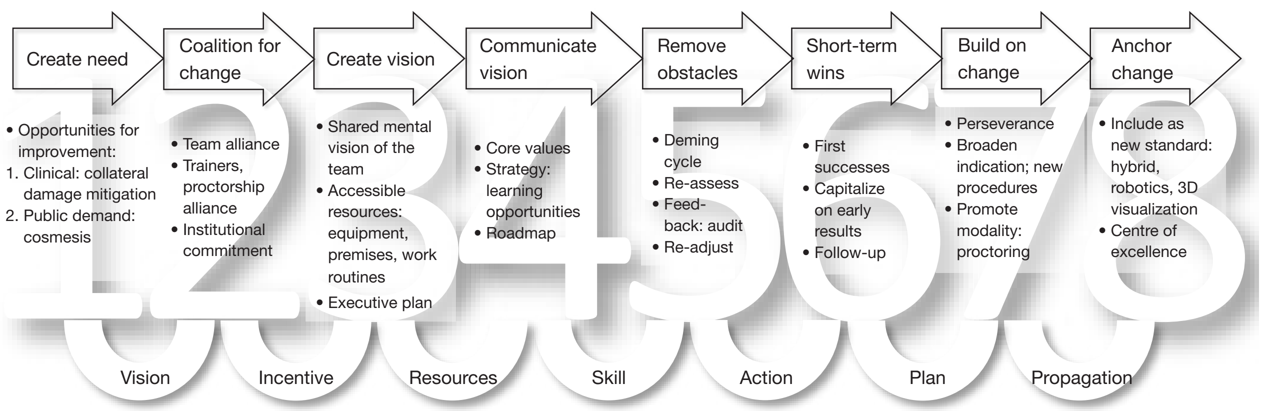

Figure 6 The 8-step model of change adapted for a successful MICCS program. MICCS, minimally invasive congenital cardiac surgery.

high standards along the entire continuum-of-care. Team empowerment also introduces the best motivation for change which itself is inevitable (76). *Figure 6* illustrates the chain of change adapted for a holistic MICCS scenario.

Future trends

It is expected that development of the art of MICCS will extend into two directions: (I) indication for minimally invasive methods will range to complex neonates. The very instability of these fragile patients will invoke new and less invasive approaches. A view on the history of pediatric cardiac surgery demonstrates that multidisciplinary synergy lessens risk, e.g., in the case of Rashkind-septostomy instead of Blalock-Hanlon septectomy (77), or more recently, PDA or RVOT stenting, instead of Blalock-Taussig-shunt (78). For complete complex neonatal repairs, a similar trend is expected that will capitalize on the advances of all related disciplines, and perhaps, more on the non-related ones (79). Nevertheless, there are multiple barriers of space- and time-constraints still need to conquered (57). (II) Reoperations could also be a promoter of MICCS involving

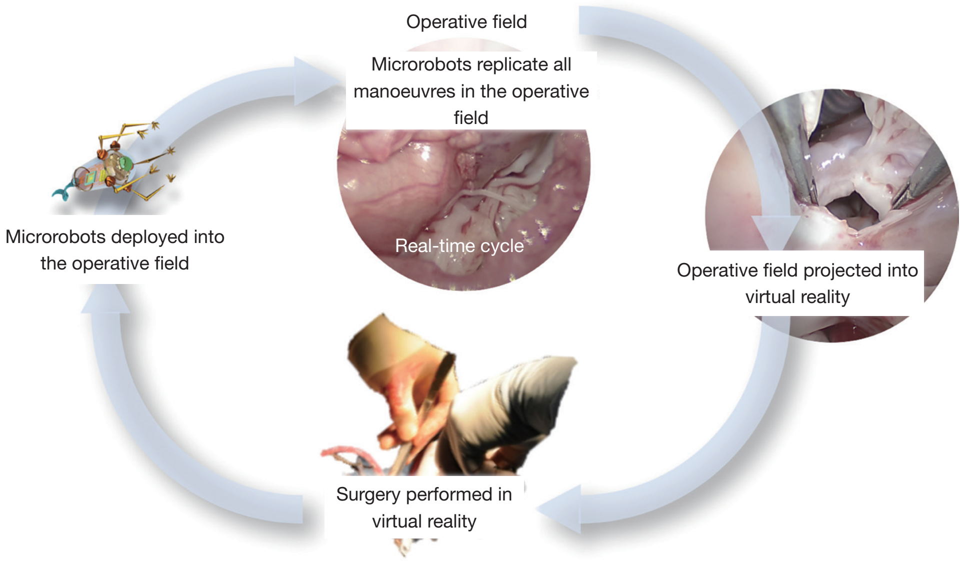

Figure 7 Futuristic vision of performing intracardiac procedures in virtual reality replicated by untethered microrobots with modular arms.

hybrid techniques, advances in translational research and biofabrication that respectively reduce procedural risk (individual patient benefit) and to save the burden of multiple open replacements of traditional biologic tissue valves and conduits (public health benefit) (80,81). Improved preoperative imaging, emulation techniques complemented with intraoperative 3D visualization (e.g., virtual/augmented reality) and manipulation (e.g., robotics) will broaden the scope of indication for MICCS (82). Microrobots show the potential to revolutionize medicine and surgery (83). Magnetically powered microrobots have already been utilized in selected indications in interventional cardiology and cardiac surgery (84). Cutting edge research in this field aims for lightweight, untethered, wirelessly controllable and powered devices with modular arms that could be deployed into the operative field to perform new procedures never before possible (85,86). *Figure 7* illustrates the authors' vision of performing intracardiac procedures on beating heart without CPB.

Surgery is an essentially multifactorial, multitasking activity, where time-information constraints are prone to cause individual and team cognitive dissonance and distress (87). Change is always stressful (76). MICCS is to be complemented by the accomplishments of the allied and non-allied disciplines, e.g., information technology, material science; these should assist in reducing the risk for patients and the stress for the personnel. Congenital cardiac surgery sprouted off from the trunk of surgery via cardiothoracic surgery some 60 years ago. The first congenital surgeons spent considerable time in the surgical laboratory and pathology museum. The next generation of surgeons may well come from scientific labs and/or from gaming platforms.

Strengths and limitations

MICCS is a strengthening and broadening modality in an evolving technical and intellectual multidisciplinary environment. MICCS holds the promise to replicate MICS experience in adults in reducing morbidity, possibly decreasing medical costs by the avoidance of complications, LOS, and resource utilization. Thus, MICCS has its strengths in communication/cooperation with its adult counterparts. That synergy could well open up this market for accelerated innovation in miniaturization from the industry.

Congenital cardiac surgery—in comparison with surgery for acquired heart disease—features widespread presentations and pathologies that make MICCS procedural standardization difficult. At present, technical limitations persist to extend MICCS to neonatal, infant multicompartment procedures and peripheral cannulation. As constant repetition of standard MICCS is limited, proficiency may take a longer time to acquire. Technical difficulties in the learning phase may associate with longer CPB and myocardial ischaemia durations. Lack of access to proctorship also hamper development. Diverse institutional and technical background and financial abilities in which individual surgical teams operate result in that no unified MICCS approach is currently adopted. The phenomenon surfaces as publication bias which makes evaluation of MICCS' current state uncertain.

Conclusions

This review only offers a snapshot on MICCS as a developing modality. It may seem that cosmesis drives MICS/MICCS efforts, however, it is the reduction of collateral trauma, and morbidity that the modality primarily targets. MICCS offers an alternative to conventional open surgery in an environment where not only survival matters but also quality-of-life and avoidance of complications. MICCS relies on careful personalized planning and execution throughout the entire continuum-of-care, and so, it requires full multidisciplinary team buy-in. Indication of MICCS gradually broadens, however, it is yet to reach complex neonatal/infant procedures involving multiple operative compartments. Progress in MICCS not only mandates a development of new multimodality imaging-emulation and manipulation techniques, but new materials and equipment, and perhaps a change of mindset, too.

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Footnote

Reporting Checklist: The authors have completed the Narrative Review reporting checklist. Available at https://pm.amegroups.com/article/view/10.21037/pm-23-15/rc

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The guardians of the patients on the figures and videos gave their written consent to the publication of the photographs and videos.

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