

How to set-up a program of minimally-invasive surgery for congenital heart defects

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Background: Mid-line sternotomy is the commonest incision for cardiac surgery. Alternative approaches are becoming fashionable in many centres, amidst some reluctance because of learning curves and overall complexity. Our recent experience in starting a new program on minimally invasive pediatric cardiac surgery is presented. The rationale for a stepwise onset and the short-medium term results for a three-year span are displayed.

Methods: A three-step schedule is planned: First, an experienced surgeon (A) starts performing simple cases. Second, new surgeons (B, C, D, E) are introduced to the minimally invasive techniques according to their own proficiency and skills. Third, the new adopters are enhanced to suggest and develop further minimally invasive approaches. Two quality markers are defined: conversion rate and complications.

Results: In part one, surgeon A performs sub-mammary, axillary and lower mini-sternotomy approaches for simple cardiac defects. In part two, surgeons B, C, D and E are customly introduced to such incisions. In part three, new approaches such as upper mini-sternotomy, postero-lateral thoracotomy and video-assisted mini-thoracotomy are introduced after being suggested and developed by surgeons B, C and E, as well as an algorithm to match cardiac conditions and age/weight to a given alternative approach. The conversion rate is one out of 148 patients. Two major complications were recorded, none of them related to our alternative approach. Four minor complications linked to the new incision were registered. The minimally invasive to mid-line sternotomy ratio rose from 20% in the first year to 40% in the third year.

Conclusions: Minimally invasive pediatric cardiac surgery is becoming a common procedure worldwide. Our schedule to set up a program proves beneficial. The three-step approach has been successful in our experience, allowing a tailored training for every new surgeon and enhancing the enthusiasm in developing further strategies on their own. Recording conversion-rates and complications stands for quality standards. A twofold increase in minimally invasive procedures was observed in two years. The short-medium term results after three years are excellent.

Keywords: Sternotomy; minimally invasive; sub-mammary; axillary; thoracoscopy; video-assisted

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Introduction

Surgical closure of cardiac defects via a full mid-line sternotomy has been considered the gold standard for over 50 years. The rise of interventional cardiology and new techniques like laparoscopy or thoracoscopy have prompted some groups to explore alternative approaches to median sternotomy (1-7). New adopters and reluctant ones have their own reasons. Added complexity, longer overall and ischemic times and even results account for the balance of the latter.

Among the most frequent alternative approaches (*Figure 1*) we find: lower mini-sternotomy (8-11), right sub-mammary (1,12-16), postero-lateral thoracotomy (17,18) and right axillary incisions (19-23). Main advantages are cosmesis and earlier recovery, as well as saving blood products and lower infection rates. On the other hand, a steep learning curve and technical difficulties in handling some steps (myocardial protection, de-airing maneuvers, and so on) discourage many surgeons to include these minimally invasive procedures within their routine practice.

Trying to schedule a program for starting and teaching minimally invasive pediatric cardiac surgery is a step forward. Few reports can be found in the literature on the topic, if any, except for the right mini-thoracotomy approach employed for mitral repair (23-27) in adult cardiac surgery. In the next paragraphs, we will depict our experience in developing a minimally invasive pediatric cardiac surgery program, pointing out the steps followed as well as the insights provided by the new adopters.

Methods

Upon arrival to a medium-volume centre in which approximately two hundred pump cases per year are carried out, Surgeon A is expected to develop a program of minimally-invasive pediatric cardiac surgery. He has been performing minimally invasive procedures for twelve years in two previous institutions and has produced several papers on the topic (6,16,22,23,28,29), as well as many presentations in local meetings.

The strategy to establish a new program is split in three parts, assuming some overlapping rather than a formal schedule in a three year analysis:

- (I) Performing minimally invasive cases (surgeon A) with every member of the surgical team (surgeons, anesthesiologists, perfusionists, scrub nurses) to let them become familiar and confident with the new

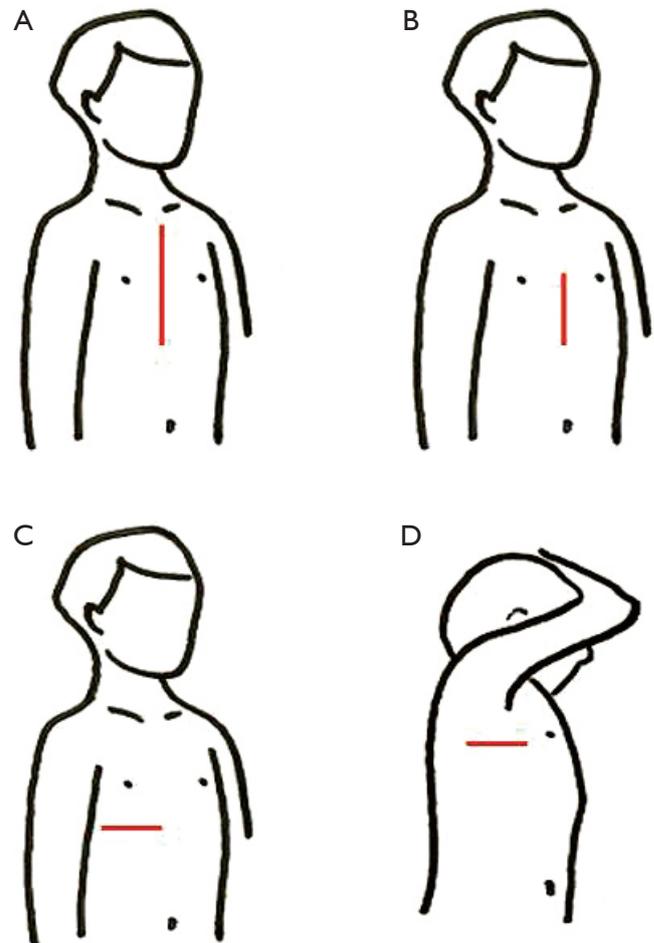


Figure 1 Range of approaches introduced by the leading surgeon. (A) Full mid-line sternotomy; (B) lower mid-line sternotomy; (C) right sub-mammary approach; (D) right axillary incision.

approaches;

- (II) Introducing new surgeons to minimally invasive surgery in a stepwise and customized way, according to expertise and skills;
- (III) Developing new strategies together, particularly enhanced by the young staff members.

On the other hand, some quality indicators will be measured, such as:

- (I) Conversion rate. If so, was it to sternotomy or another incision?
- (II) Complications. Trying to figure out whether the alternative approach is to blame for the drawback or if any other cause was responsible for it.

To begin with, a minimally invasive incision will be

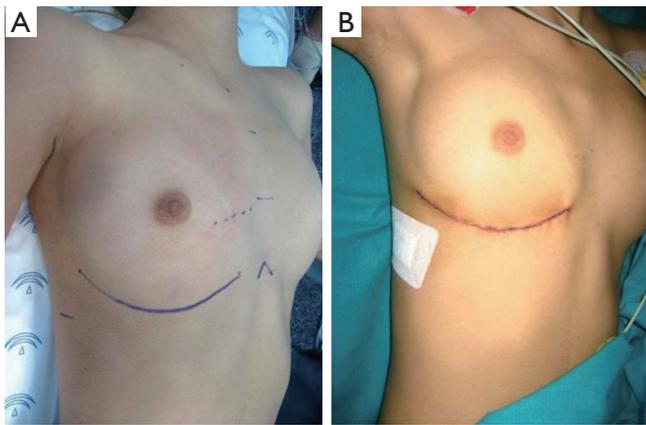


Figure 2 Sub-mammary approach in an adolescent female. Note the landmarks (A) and final aesthetic result (B).

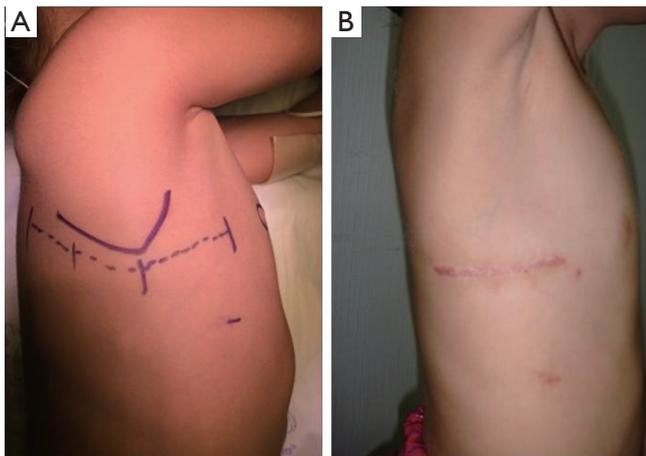


Figure 3 Right horizontal axillary incision. Note the landmarks between the nipple and the tip of the scapula as well as the proposed conversion to a postero-lateral incision if needed (A). Final result six months later (B).

defined as “surgical approach other than full mid-line sternotomy to perform open heart surgery with extracorporeal circulation”. Three main surgical approaches were introduced by surgeon A: sub-mammary, axillary and lower mini-sternotomy. A single alternative incision gives way either to cannulation maneuvers and correction, with the philosophy of “same steps, same tools, same risks, different approach”. Later in the program (as will be thoroughly displayed in Results and Discussion) several new approaches were added: upper mini-sternotomy, postero-lateral thoracotomy and video-assisted mini-thoracotomy (for which several ports were necessary). Not included in the tables, some off-pump cases

via thoracotomy and thoracoscopy were performed, as some experience was acquired by the team.

Before starting any procedure, the proposed incision is drawn with a sterile pen for teaching purposes. Should an enlargement or conversion be needed, security margins are settled (e.g., lower mini-sternotomy enlargement to full sternotomy, or axillary incision conversion to postero-lateral one). Brief description of the minimally invasive approaches:

- (I) Sub-mammary. Supine position with the right shoulder slightly elevated and the right arm suspended over the head. Skin incision under the right sub-mammary crease (or 6th intercostal space in children). *En-bloc* dissection of subcutaneous tissue and pectoral muscle (30,31). Cage-rib entry in the 4th intercostal space. Full cannulation and correction under cardioplegic arrest (Figures 1C,2);
- (II) Axillary. Decubitus lateral position with the right arm suspended over the head. Skin incision in the axillary groove, between anterior and posterior lines. *Serratus* and *latissimus dorsi* muscles sparing (28) technique. Cage-rib entry in the 4th intercostal space. Full cannulation and correction under cardioplegic arrest (Figures 1D,3);
- (III) Lower mini-sternotomy. Supine position. Skin vertical incision below an imaginary line connecting both nipples. Partial lower sternotomy. Regular spreader plus cephalad traction of the sternum. Full cannulation and correction under cardioplegic arrest (Figures 1B,4);
- (IV) Upper mini-sternotomy. Supine position. Skin vertical incision above an imaginary line connecting both nipples. Partial upper sternotomy. Full cannulation and correction under cardioplegic arrest;
- (V) Postero-lateral thoracotomy. Decubitus lateral position with the right arm suspended over the head. Skin incision between anterior axillary line and spine (the tip of the scapula being the mid-point). Cage-rib entry in the 4th intercostal space. Full cannulation and correction under cardioplegic arrest (Figure 3A);
- (VI) Video-assisted mini-thoracotomy. Supine position with the right shoulder slightly elevated and the right arm secured below the axilla. Mini-skin incision under the right sub-mammary crease. Right jugular and right femoral (arterial and venous) cannulation to institute by-pass. Additional ports for video-assistance, aortic clamp and others.

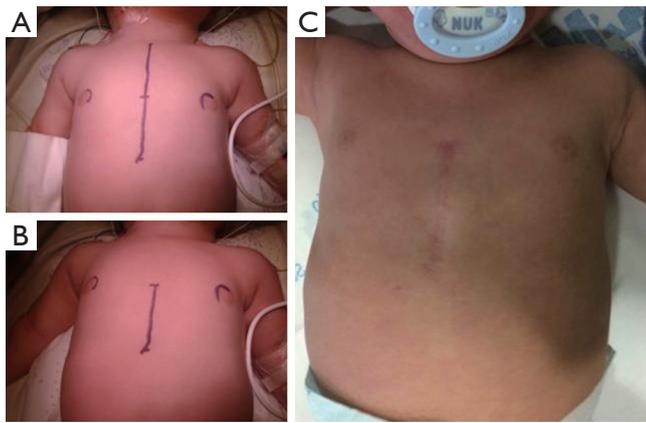


Figure 4 Lower mid-line sternotomy. Full mid-line sternotomy (upper left) as compared to lower mini-sternotomy (lower left). Result at discharge on 7th postoperative day.

Table 1 Number of procedures performed by surgeon and year

Surgeon	Year			Total
	2013	2014	2015	
A	15	12	21	48
B	7	8	6	21
C	10	12	22	44
D	8			8
E		8	19	27
Total	40	40	68	148

Correction under cardioplegic arrest.

Results

Part one

Surgeon A began his program with sub-mammary, axillary and lower mini-sternotomy cases alternatively, according to age/weight and cardiac condition of every patient. This way, ventricular septal defect (VSD) cases were corrected by mini-sternotomy, atrial septal defect (ASD) patients through an axillary approach, and women with well-defined sub-mammary groove were entered by a sub-mammary incision. The initial three months was time enough to get everyone in the cardiac team comfortable with the changes.

Part two

Surgeons B, C and D were sequentially introduced to

lower mini-sternotomy and sub-mammary approaches, according to their own interest and skills. Simple cases (ostium secundum ASD) were selected for this purpose to begin with, followed by VSD closure through lower mini-sternotomy in a customized pattern for every surgeon. By the end of the first year, all surgeons had already performed ASD and VSD cases through lower mini-sternotomy and some ASD closures through a sub-mammary approach.

Surgeon D moved to a different Center in another Country and was substituted by surgeon E, who took up quickly the same method of learning, following the way of surgeons B and C.

On the other hand, Surgeons B and C considered the axillary approach rather cumbersome, and suggested starting a postero-lateral one before attempting the former.

Part three

Surgeon C introduced the upper mini-sternotomy approach for aortic valve surgery with the advice of an adult cardiac surgeon.

As previously stated, the right postero-lateral thoracotomy was suggested by surgeons B and C (and surgeon E, later on) as an initial step before taking up the axillary incision.

Surgeon B suggested moving forward and attempting a thoracoscopic approach. He reviewed the literature (32-37) and contacted a pediatric surgeon with experience in the field from our own Center. After assisting him in thoracoscopic patients (pediatric surgery) and attending a specific course in minimally-invasive thoracoscopy (surgeons B and C), a new program was started.

Surgeon E displayed a sort of algorithm for case-approach, according to age/weight & cardiac defect, resulting in a tailored minimally invasive approach for any given patient.

Table 1 depicts the amount of patients operated on by a minimally invasive approach by every surgeon during the three consecutive years. When compared to the total amount of patients, the ratio of mini-invasive to total pump-cases increased twofold between 2013 and 2015. We have to take into account that 2014 was the first year for Surgeon E, which could explain why the figures are so close between 2013 (20%) and 2014 (22.5%), rather than displaying a steady progression along the three year span.

Increase in percentage of mini-invasive pump cases.

(I) 2013: 40/201 (20%)

(II) 2014: 40/178 (22.5%)

(III) 2015: 68/166 (40%)

Table 2 displays the different approaches by every

Table 2 Number of procedures performed by surgeon and approach

Surgeon	Approach						Total
	Lower mini-sternotomy	Sub-mammary	Axillary	Lateral-posterior thoracotomy	Upper mini-sternotomy	Thoracoscopy	
A	17	6	22	3			48
B	10	4		3	1	3	21
C	25	11		2	4	2	44
D	7	1					8
E	19	4		2	2		27
Total	78	26	22	10	7	5	148

surgeon. All of us are confident with the lower mini-sternotomy and sub-mammary ones. Only surgeon A is performing the axillary incision up to now, because the remaining staff members feel more comfortable with the postero-lateral approach. The upper mini-sternotomy, introduced by surgeon C, has been taken up by surgeons B and E as well, for aortic valve patients. The video-assisted thoracotomy, led by surgeon B, is applied for *ostium secundum* ASD patients by surgeons B and C.

Table 3 shows the distribution of diagnosis and surgeons. Simple conditions, like ASD (*ostium secundum*, *sinus venosus*, *ostium primum*) and VSD have been performed by every surgeon (excepting surgeon D, who left earlier). To sum up, these simple cases account for more than 80% of the whole number of minimally-invasive pump cases. Regarding VSD's alone, which has been approached by lower mini-sternotomy, the progression has been steady along the three years with a well-defined step up:

- (I) 2013: 32/40 (80%)—12 VSD
- (II) 2014: 35/40 (87%)—12 VSD
- (III) 2015: 58/68 (82%)—20 VSD

More complex cases (complete atrio-ventricular septal defect, subaortic myectomy (Morrow), scimitar syndrome, tricuspid valve repair) have been performed by surgeon A, expanding the indications of minimally invasive surgery as experience is gained.

Table 4 summarizes the data relating to the approach and cardiac defect, independently of the surgeon. ASD and VSD are the commonest conditions, as expected. Lower mini-sternotomy is the most prevalent approach, given its simplicity (in fact, it is the first alternative incision learned) and the wide range of cardiac defects corrected through this pathway. The sub-mammary incision has been used for any type of ASD and few others; the axillary approach for *ostium secundum* and *sinus venosus* ASD, only. At the moment, the

upper mini-sternotomy is indicated for aortic valve purposes and the video-assisted thoracotomy for *ostium secundum* defects.

Not included in Table 4 which describes pump cases only, some patients were operated on via left thoracotomy without cardio-pulmonary by-pass (one sling left pulmonary artery, two patients with anomalous drainage of left upper pulmonary veins) and video-assisted thoracoscopy [one pericardial window and one left atrial appendage ablation (38) plus clip-exclusion].

Conversion rate

An axillary approach for a *sinus venosus* ASD had to be converted to a postero-lateral one (just enlarging the skin incision backwards and splitting the *latissimus dorsi* muscle). Despite the conversion, the postero-lateral approach can still be considered a minimally invasive one. No other conversion was required.

Complications

An *ostium primum* patient died because progression of diffuse pulmonary vein stenosis three months after repair. A VSD patch-closure developed aortic regurgitation (excessive trimming of redundant tricuspid tissue which happened to be stuck to an aortic cusp) and was re-operated two days later. A valve repair proved unsuccessful and ended up in a Ross-Konno procedure. Two patients (ASD and VSD) required revision for bleeding. The initial approach in all four cases had been via lower mini-sternotomy.

One ASD patient approached via sub-mammary incision developed transient phrenic palsy and continuous pleural effusions. An analysis of the pleural fluid showed lidocaine and, after removal of the trans-thoracic anesthetic line

Table 3 Number of procedures performed by surgeon and diagnosis

Surgeon	Procedure							Total
	OS ASD	SV ASD	OP ASD	VSD	CAVSD	Aortic	Others	
A	18	5	4	11	7		3	48
B	8	2	3	7		1		21
C	18	3	5	14		4		44
D	6		1	1				8
E	8	4	5	8		2		27
Total	58	14	18	41	7	7		148

ASD, atrial septal defect; OS, ostium secundum; SV, sinus venosus; OP, ostium primum; VSD, ventricular septal defect; CAVSD, complete atrio-ventricular septal defect.

Table 4 Relationship between approach and diagnosis along the study period

Approach	Procedure					Total
	OS ASD	SV ASD	OP ASD	VSD	Others	
Lower mini-sternotomy	17	1	15	41	4	78
Sub-mammary	16	4	3		3	26
Axillary	17	5				22
Upper mini-sternotomy					7	7
Lat-post thoracotomy	3	4			3	10
Thoracoscopy	5					5
Total	58	14	18	41	17	148

ASD, atrial septal defect. OS, ostium secundum; SV, sinus venosus; OP, ostium primum; VSD, ventricular septal defect.

(which was dislodged), both effusion and phrenic palsy resolved. A 55-kg child developed compartment syndrome in the right leg after peripheral cannulation for a video-assisted thoracotomy ASD repair. It was the only case in whom the femoral artery was directly cannulated instead of a graft interposition.

Discussion

Many groups have shifted towards the minimally invasive surgical approaches in pediatrics (1-7). The rationale, beyond cosmesis, is offering the same results with new incisions, when catheter-based interventional procedures are also difficult or contra-indicated. Maybe the future will rely on totally robotic (32) or endoscopic (33-37) surgery, but, for the time being, offering alternative approaches is interesting. Some teams are keen on a single particular approach, whereas others prefer to be familiar with many of them (4-6). Whether this is a strategy or a matter of evolution is beyond the scope of this paper.

Currently, the range of incisions different from a full mid-line sternotomy is rich enough to provide us many options. Interestingly, among the literature reviewed, some papers underline the steps to set up programs (24-27). Particularly relevant is the publication by Bonaros *et al.* (32), in which the authors split every procedure in several parts and analyze them separately, so as to accurately depict anyone's learning curve. Not only did we need to start a new program, but also to teach and enhance our young staff to develop their own ideas.

The three-step approach to introduce a program of minimally invasive surgery in a new place has proved successful for several reasons. First of all, the results are good and patients/parents are satisfied. Part one (surgeon A introducing the program) allows all members in theatre to get in touch with the novelty, and surgeon A to realize who is enthusiastic and who is reluctant. This way, approaches could be decided according to individual skills and preferences in customized patterns in part two (surgeons B, C, D and E being introduced). Most important was the

honest attitude of the staff, not assuming to tackle incisions considered difficult (e.g., axillary one) and suggesting new approaches (part three). As responsible of the team, surgeon A considered not to get involved in the new programs of upper mini-sternotomy for aortic valve cases and video-assisted thoracotomy for ASD patients. The rationale was to let surgeons B and D lead their own projects before incorporating new forthcoming members (E and A): pupils became teachers.

More complex cases were added as experience was gained. Thus, particularly in the last of the three years, the young surgeons were taking up simple cases while surgeon A was performing difficult ones (AVSD, scimitar). As a result, the percentage of minimally invasive cases rose to 40%, doubling the initial rate of 20% during the first year. The lesson is to couple any single patient to a surgeon who is keen either on the defect or on a particular approach, so as to match them in the algorithm of mini-invasive surgery (6,38,39).

Regarding the conversion rate, only one patient had to be switched. The take-home message in a minimally invasive program is trying to convert any patient (when needed) to another minimally invasive approach in an expeditious way. The incision was converted from axillary to postero-lateral incision (again, minimally invasive) by just prolonging posteriorly the already drawn surgical mark and severing the *latissimus dorsi* muscle. The new program of video-assisted mini-thoracotomy is growing-up under the readiness to convert incisions to a full sub-mammary one, if needed. To date, it has not been necessary to convert a mini-thoracotomy to full mid-line sternotomy.

Before embarking on a minimally invasive program, one has to assume that any drawback is going to be regarded as linked to the alternative approach. Whether it is true or not is irrelevant, unless invasive and minimally-invasive patients are matched. Some of the minor complications we found were definitely related to the approach, like the transient phrenic palsy and the compartment syndrome (40). We have learned how to avoid them (41) in the future.

After gathering some experience, the question is how to move forward with the program? There is no clear answer, since not all surgeons are at the same level of proficiency, or are still in their learning curve. Thinking in terms of contraindications rather than indications, as a last step of training, could be a reasonable marker. In other words, we are not expecting for the “perfect patient” to come and be an ideal candidate for a minimally invasive approach. We rather think about the contraindications, if any, for a minimally invasive procedure in every patient.

The enthusiasm showed by the team members towards new alternative approaches was overwhelming. Not only did the young surgeons take up the new methods quickly (part two), but they quickly suggested new ones to be introduced (part three). To be honest, I had to change my mind from the aphorism “*same steps, same tools, same risks, different approach*” after the video-assisted mini-thoracotomy program was started. The shift from a different single incision to multi-small approaches one was not in my mind previously, but deserves all credit because it stands for a new paradigm of surgery. The more alternative approaches (5,39) we can offer, the better for the cosmesis of the patients.

Conclusions

Minimally invasive pediatric cardiac surgery is currently becoming a routine practice in many centers worldwide. The different approaches need their own learning curve, either straightforward or a steep one. Our recent experience demonstrates that a comprehensive, three-step schedule allows a safe and custom-made approach to train new surgeons in the field, and enhances enthusiasm in developing further strategies on their own.

A record of conversion-rate and complications should be used as marker of performance and quality standard. The new adopters can take their own training pace according to their level and skills. Interestingly, the wider the offer of approaches, the more ideas come up for new alternative minimally invasive methods. A twofold increase in minimally invasive procedures was observed in two years. The short-medium term results after three years are excellent.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: The study was approved by our institutional ethics committee.

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