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CLINICAL RESEARCH
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Open-heart surgery at school age does not affect neurocognitive functioning

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Aims Although neurocognitive problems after open-heart surgery for congenital heart disease are frequent, due to a shortage of prospective studies assessing neurocognitive functioning both before and after the procedure, the exact nature of the deficits usually remains unknown. The present study aims at assessing the neurocognitive effects of, in particular, cardiopulmonary bypass at school age. In addition, surgery-related risk factors for reduced neurocognitive outcome are explored.

Methods and results Participants were aged between 6 and 16 years. Forty-three children indicated for open-heart surgery and a comparison group of 19 children scheduled for interventional cardiac catheterization completed a neurocognitive assessment battery before and 1 year after their procedures. Forty healthy matched controls did so at a 1 year interval. The baseline-to-follow-up outcomes were similar in all three groups. The observed improvements most likely resulted from increased age and the repeated neurocognitive assessment. No risk factors for postsurgical neurocognitive deficits were identified.

Conclusion The present study demonstrates that at school age cardiac surgery using full-flow cardiopulmonary bypass does not affect neurocognitive functioning.

Keywords Congenital heart disease • Open-heart surgery • Cardiopulmonary bypass • Neurocognitive functioning • School age • Risk factors

Introduction

Neurocognitive problems after open-heart surgery for congenital heart disease are common, with deficiencies in attention and speed of information processing, perceptual-organizational abilities, and motor functions being the most prevalent.[1–3] Deficits have also been reported in verbal functions[3–5] and, to a lesser extent, in general intelligence.[3,4,6]

In attempting to explain the neurocognitive difficulties after open-heart surgery, researchers have mainly focused on the role of cardiopulmonary bypass and related surgical risk factors. Results showed that cardiopulmonary bypass may indeed be associated with neurocognitive problems.[2,4,5] Moreover, cardiopulmonary bypass may cause embolic complications, hypoperfusion, ischaemic reperfusion injury, or inflammatory reactions, and, consequently, injury to the central nervous system.[7,8] Other surgical risk factors for neurocognitive or neurological outcome that have been identified include prolonged duration of aortic cross-clamping, lowered pH, decreased haematocrit levels, and elevated blood lactate levels.[2,9–11]

Despite the established associations between surgical risk factors and neurocognitive outcome, the exact nature of the neurocognitive difficulties in children following surgical intervention for congenital heart disease remains unclear. As the majority of these children need cardiac surgery shortly after birth, a pre-operative assessment of their neurocognitive functioning is unfeasible, leaving the question whether the post-operative neurocognitive problems might already have been present prior to surgery unanswered. Studies that did include a pre-operative assessment of (neuro)cognitive functioning indeed demonstrated

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pre-surgical deficits[12–15] and showed that neurocognitive functioning is not necessarily associated with surgical risk factors.[16,17] It has been suggested that not only surgery-related but also disease-related processes (e.g. cyanosis, haemodynamic instability) might be associated with neurocognitive deficits.[12,15]

The few prospective studies that evaluated neurocognitive functioning both before and after open-heart surgery mostly comprised neonates and pre-school children or only used general intelligence measures to identify the effects of the intervention. However, any neurocognitive problems will particularly become apparent at school age and involve specific neurocognitive domains.[18,19] The principal aim of the present study therefore was to determine the effects of cardiopulmonary bypass in a cohort of school-age children by assessing their neurocognitive functioning shortly before and 1 year after the intervention. To our knowledge, ours is the first study to do so. In addition, we explored the surgery-related risk factors for reduced neurocognitive outcome.

Methods

Sample selection and procedure

Eligible were all cardiac patients aged between 6 and 16 years who were awaiting open-heart surgery at the Radboud University Nijmegen Medical Centre between June 2002 and June 2006. To ensure that all neurocognitive findings resulted from no other factors than the congenital heart disease and associated surgery, candidates with physical and mental comorbidities [e.g. syndromes, visual/hearing/speech/motor or cognitive impairments (full-scale IQ below 70), or severe learning difficulties] were excluded, as were children with an insufficient command of the Dutch language and those with serious family problems (i.e. major parental illness).

To identify the specific effects of cardiopulmonary bypass as opposed to the general procedural effects of cardiac surgery, we also enrolled patients awaiting interventional cardiac catheterization using the same inclusion and exclusion criteria. Finally, to control for age and effects of repeated testing on the post-operative neurocognitive changes, we recruited healthy volunteers from regional mainstream primary and secondary schools. The control group was matched for age, sex, educational level, general intelligence, and parental educational level with both patient groups.

Following inclusion into the hospital's waiting lists for open-heart surgery and catheterization or after enrolment (controls), written consent was obtained from the parents and from all children aged over 12 years. The patients were subsequently scheduled for individual neurocognitive assessment at the medical centre. Assessment took place in the period prior to surgery or catheter intervention and again 1 year afterwards. The healthy controls also took all assessments twice with a 1 year interval. The study was approved by the Regional Committee on Research Involving Human Subjects.

Neurocognitive assessment battery

The test battery consisted of standardized tests suitable for our age group and covered the neurocognitive domains known to be at risk in children having undergone open-heart surgery. As behavioural and emotional aspects may affect neurocognitive functioning, these factors were also evaluated.

General intelligence was assessed by means of the Dutch version of the Wechsler Intelligence Scale for Children-Third Edition (WISC-III).[20,21] Three measures were derived: verbal intelligence, performance intelligence, and full-scale intelligence.

Attention and processing speed were evaluated using four tasks: the Letter Detection subtest of the Amsterdam Neuropsychological Test Battery (ANT), the Complex Reaction Time Task (CRT), a computerized drawing task, and the Bourdon-Vos test for sustained attention.[22–25] For the first three tasks, the mean reaction times were derived; for the last task, the mean row completion time was analysed.

Construction, i.e. the ability to assemble the separate parts of a picture and to copy it as a coherent whole, was reflected by the organization score of the Rey–Osterrieth Complex Figure and the standard score of the Developmental Test of Visual-Motor Integration (VMI).[26,27]

Motor speed was measured using a basic finger-tapping task with the mean number of taps being calculated for both hands. We also calculated CRT mean movement times and mean drawing speed on the computerized drawing task.[23,24]

Motor planning and fluency measures were obtained from the computerized drawing task:[24] motor planning was expressed by the mean duration of pauses and movement fluency by the mean number of velocity peaks.

Behavioural and emotional functioning were evaluated using three versions of the Child Behaviour Checklist (CBCL): the Dutch CBCL, the Dutch Teacher Report Form (TRF), and the Dutch Youth Self-Report (YSR).[28–31] Scores indicating internalizing, externalizing, and total problems were computed.

Surgery-related risk factors for reduced neurocognitive outcome

All the children undergoing open-heart surgery had similar conduction of the extracorporeal circulation procedures, using full-flow cardiopulmonary bypass (2.4–3.0 l/min/m^2 body surface area) at moderate hypothermia (25°C nasopharyngeal temperature) during which alpha-stat blood gas management was used and haematocrit levels were kept at 20–25%. Myocardial protection was achieved by intermittent administration of cold crystalline cardioplegic solution into the aortic root. When long cross-clamp times were anticipated, cold blood cardioplegia was administered.

The patients' medical records were checked for anatomic diagnosis, duration of cardiopulmonary bypass, duration of aortic cross-clamping, minimum pH, minimum haematocrit level, and maximum lactate level. Additionally, for all patients the complexity level of cardiac surgery was classified into one of four groups according to the Aristotle™ classification.[32] The Aristotle™ classification of surgery is determined by the potential for hospital mortality, the potential for postoperative morbidity, and the technical difficulty of the procedure.[32]

Statistical analysis

To guarantee adequate matching of the three groups, univariate analyses of variance (ANOVAs) and χ^2 tests were applied. Binomial tests were used to confirm that the patients' behavioural and emotional function scores were comparable to population norms. As no between-group differences were expected, a two-tailed *P*-value of <0.15 was chosen to indicate statistical significance.

The neurocognitive baseline performance scores of the three groups were compared to identify existing (pre-intervention) between-group differences. For those variables that were not normally distributed (ANT: reaction time, CRT: reaction time and movement time, computerized drawing task: reaction time, Bourdon-Vos: row completion time), reciprocal transformations were performed and used for analyses. Group differences were analysed for each of the neurocognitive domains by means of multivariate analyses of variance (MANOVAs). Statistical significance was set at $P < 0.05$ (two-tailed).

Repeated measures MANOVAs were conducted to calculate the baseline-to-follow-up change for each of the neurocognitive domains. The effects on the general intelligence measures and the specific neurocognitive domains were investigated separately, again using a two-tailed P-value of <0.05. Besides the *statistical* significance of the groups' baseline-to-follow-up neurocognitive change, the *clinical* significance of the change was calculated for patients having undergone open-heart surgery. Clinically significant change was determined according to the following steps (see Lewis *et al.*,[33] p. 438). First, for each task and each patient, the pre-operative score was subtracted from the post-operative score. From this, the mean change for the healthy controls (calculated by deducting the baseline from the follow-up scores) was subtracted, and the outcome was then divided by the standard deviation of this change in the control group. This yielded *z*-scores of relative change per patient per task. Second, *z*-combined scores were calculated by summing across tasks within neurocognitive domains, divided by the standard deviation of summed *z*-scores in the healthy controls. Clinically significant change was defined as a *z*-combined score of |1.65| and higher on at least one neurocognitive domain or intelligence scale.

For the surgical group, correlations were explored between *z*-combined scores for neurocognitive change and surgical risk factors. Spearman's rank correlations were computed for the risk factors that were not normally distributed (duration of cardiopulmonary bypass and aortic cross-clamping, maximum lactate levels, and Aristotle™ classification). For normally distributed variables (minimum pH and minimum haematocrit levels), Pearson's product-moment correlations were applied. Because of the explorative nature of the analyses, statistical significance was set at a two-tailed P-value of <0.10. All statistical analyses were carried out using the Statistical Package for the Social Sciences (SPSS 12.0).

Results

Baseline characteristics

Of the 89 patients scheduled for open-heart surgery, a total of 27 were excluded due to physical or mental comorbidity ($n = 23$), insufficient command of the Dutch language ($n = 3$), or family problems ($n = 1$). Of the 62 eligible patients, 45 (patient and/or parent) consented to participate. Two were unable to complete the follow-up assessment: one patient died within the 1 year interval and another patient declined because of the recent loss of his father. The final surgical group accordingly consisted of 43 patients (69%).

Of the 38 patients awaiting interventional cardiac catheterization, a total of 13 were excluded due to physical or mental comorbidity ($n = 11$) and insufficient command of the Dutch language ($n = 2$). Of the 25 eligible patients 19 consented to participate (76%), all of whom completed the follow-up assessment.

Of the 41 healthy peers that were initially enrolled and assessed, one proved untraceable for the second assessment due to a change of address. Analyses thus comprised 40 controls.

Table 1 lists the baseline characteristics of all participants and *Table 2* the medical details of the two patient groups. Groups were adequately matched as no significant differences emerged regarding the demographic characteristics and general baseline intelligence scores (*Tables 1* and *3*; ANOVAs and χ^2 tests, $P >$ 0.15). In addition, the CBCL, TRF, and YSR showed the patients' behavioural and emotional scores to be comparable to the Dutch norm scores (data not shown; binomial tests, $P > 0.15$).

Table 1 Overall sample demographics

	Surgery (*n* = 43)	Catheterization (*n* = 19)	Control (*n* = 40)
Age (years), Mean (SD)	11.6 (3.1)	11.0 (2.6)	11.7 (2.8)
Sex, *n* (%)			
Male	20 (46.5)	12 (63.2)	17 (42.5)
Education, *n* (%)			
Primary	23 (53.5)	13 (68.4)	21 (52.5)
Lower secondary	13 (30.2)	5 (26.3)	12 (30.0)
Higher and pre-university	7 (16.3)	1 (5.3)	7 (17.5)
Education father, *n* (%)			
Low	13 (30.2)	7 (36.8)	11 (27.5)
Intermediate	10 (23.3)	8 (42.1)	12 (30.0)
High	20 (46.5)	4 (21.1)	17 (42.5)
Education mother, *n* (%)			
Low	16 (37.2)	7 (36.8)	10 (25.0)
Intermediate	18 (41.9)	9 (47.4)	15 (37.5)
High	9 (20.9)	3 (15.8)	15 (37.5)

Neurocognitive effects of cardiac surgery using cardiopulmonary bypass

Table 3 lists the baseline and follow-up results for the three groups. At baseline, none of the neurocognitive domains showed significant group differences (MANOVAs, $P > 0.05$).

Changes between baseline and follow-up scores were analysed to establish the effect of the open-heart procedure on the children's general intelligence and neurocognitive functioning. *Table 4* shows the results of the repeated measures MANOVAs. Both main effects for group and time of assessment and the interaction effects between group and time of assessment are shown. No significant main effects were found for group, reflecting that general intelligence and neurocognitive functioning did not differ between the three groups. Significant main effects were found for time of assessment, implying that general intelligence and neurocognitive functioning had changed significantly from baseline to follow-up. Further inspection of the results revealed enhanced performance on all tasks, except for verbal intelligence and the VMI. No significant interaction effects were found, indicating similar baseline-to-follow-up changes for all three groups of participants.

In addition to group effects, neurocognitive change after open-heart surgery was investigated for all patients individually. More than one-third (35%) of the children who had undergone open-heart surgery showed clinically significant improvement on at least one neurocognitive domain or intelligence measure, whereas 12% showed post-operative decline.

Table 2 Patient details

Medical features	Surgery (*n* = 43)	Catheterization (*n* = 19)	
Diagnosis, *n* (%)			
Atrial septal defect	4 (9.3)	3 (15.8)	
Ventricular septal defect	2 (4.7)	2 (10.5)	
Atrioventricular septal defect	3 (6.9)		
Aortic stenosis and incompetence or aortic pathology	14 (32.6)	9 (47.4)	
Mitral valvar anomalies	3 (6.9)		
Ebstein's malformation	1 (2.3)		
Pulmonary atresia with ventricular septal defect	2 (4.7)		
Pulmonary venous abnormalities	2 (4.7)		
Tetralogy of Fallot	4 (9.3)		
Multiple cardiac anomalies (incl. transposition great arteries)	8 (18.6)	5 (26.3)	
Aristotle™ classification of surgery, *n* (%)			
1	5 (11.6)		
2	14 (32.6)		
3	16 (37.2)		
4	8 (18.6)		
Surgery-related risk factors	**Mean**	**SD**	**Range**
Duration of cardiopulmonary bypass (min)	201.7	120.4	44–570
Duration of aortic cross-clamping (min)	109.4	69.9	12–325
Minimum pH	7.32	0.05	7.18–7.41
Minimum haematocrit (L/L)	0.29	0.05	0.17–0.43
Maximum lactate (mmol/L)	2.57	1.89	1.0–9.3

Note that in one patient with end-stage heart failure, the cardiopulmonary bypass lasted exceptionally long, i.e. 570 min, due to the complexity of the surgical procedure.

Surgery-related risk factors for reduced neurocognitive outcome

Correlations were computed (*Table 5*) to establish whether neurocognitive changes after open-heart surgery were associated with specified surgical risk factors but none were found (Spearman's correlations and Pearson's correlations, $P > 0.10$).

Discussion

The present study sought to investigate the neurocognitive effects of open-heart surgery with full-flow cardiopulmonary bypass at school age using a prospective design with assessments both before and 1 year after the procedure. The use of a comparison group, i.e. children scheduled for interventional cardiac catheterization, as well as a matched healthy control group allowed differentiation between the explicit effects of cardiopulmonary bypass and any general effects of hospitalization, anaesthesia, increased age, and repeated neurocognitive testing.

We did not find any negative effects of the open-heart procedure, neither on the general intelligence measures, nor on any of the neurocognitive domains assessed. The reverse was true in that the children had augmented pre- to post-operative performance scores on most of the measures. In 35% of the children, the enhanced performance after open-heart surgery reflected a true improvement of functioning on at least one neurocognitive domain or intelligence measure. As post-operative decline only occurred in 12% of the children, the progress in neurocognitive functioning after 1 year was not only statistically but also clinically relevant.

As the improvements found in the surgical group were similar to the advances obtained in the catheterization group and in the healthy controls, evidently neither the use of cardiopulmonary bypass nor general characteristics of the medical intervention (e.g. anaesthesia and hospitalization) had negatively affected neurocognitive functioning. Accordingly, the specific surgical risk factors (duration of cardiopulmonary bypass, duration of aortic cross-clamping, minimum pH, minimum haematocrit level, and maximum lactate level) and the overall complexity of the surgical procedure (Aristotle™ classification) were not associated with neurocognitive change. Therefore, the improved baseline-to-follow-up performances were most likely attributable to factors associated with neurocognitive testing in general. If they resulted from increased age, one would expect improvements on all tasks, except for those that use age-corrected standard scores (e.g. intelligence measures and the VMI). Since this was the case (with verbal intelligence and VMI being the exceptions), the results indeed seem to reflect an effect of age. However, increased age alone could not account for all improvements obtained seeing that the age-corrected scores for performance intelligence and full-scale intelligence both showed significant

Table 3 Neurocognitive performance scores at baseline and 1 year follow-up for all three groups

	Surgery (*n* = 43)		Catheterization (*n* = 19)		Control (*n* = 40)	
	Baseline	**Follow-up**	**Baseline**	**Follow-up**	**Baseline**	**Follow-up**
General intelligence						
WISC[a]: verbal intelligence	98.7 (14.3)	99.7 (14.8)	99.7 (8.7)	97.6 (8.4)	103.4 (12.6)	101.2 (13.7)
WISC: performance intelligence	97.9 (11.3)	103.5 (13.6)	97.8 (13.6)	108.1 (13.3)	102.1 (11.5)	109.4 (12.7)
WISC: full-scale intelligence	98.3 (13.3)	101.7 (14.6)	98.6 (10.7)	102.6 (11.0)	103.2 (12.1)	105.6 (13.4)
Attention and processing speed						
ANT[b]: reaction time	1.44 (0.59)	1.11 (0.43)	1.41 (0.51)	1.18 (0.33)	1.23 (0.41)	1.01 (0.31)
CRT[c]: reaction time	0.38 (0.09)	0.35 (0.08)	0.35 (0.08)	0.34 (0.07)	0.35 (0.08)	0.33 (0.06)
Drawing task: reaction time	1.23 (0.46)	0.90 (0.20)	1.14 (0.32)	0.99 (0.29)	1.10 (0.38)	0.89 (0.21)
Bourdon-Vos: row completion time	17.21 (5.68)	13.91 (3.63)	17.27 (5.85)	15.20 (4.89)	16.33 (4.83)	13.96 (3.66)
Construction						
Rey[d] Copy: organization score	6.91 (3.67)	8.63 (3.24)	6.68 (3.22)	7.16 (3.45)	6.88 (3.06)	7.50 (2.72)
VMI[e]: standard score	92.67 (9.79)	95.44 (10.35)	93.89 (10.26)	93.95 (10.78)	94.50 (13.47)	94.48 (13.50)
Motor speed						
Finger-tapping: no. preferred hand	43.67 (7.31)	47.59 (6.49)	45.47 (7.94)	48.67 (6.52)	47.54 (10.94)	49.83 (8.27)
Finger-tapping: no. non-preferred hand	37.73 (7.96)	41.64 (7.77)	40.56 (7.78)	42.89 (7.27)	40.60 (8.37)	43.90 (7.48)
CRT: movement time	0.25 (0.07)	0.22 (0.05)	0.25 (0.07)	0.20 (0.05)	0.22 (0.05)	0.21 (0.05)
Drawing task: drawing speed	2.96 (0.99)	3.45 (1.09)	3.22 (1.05)	3.44 (0.79)	3.23 (0.82)	3.45 (0.89)
Motor planning and fluency						
Drawing task: duration of pauses	0.64 (0.30)	0.52 (0.27)	0.62 (0.31)	0.52 (0.26)	0.48 (0.23)	0.44 (0.26)
Drawing task: no. of velocity peaks	4.85 (0.68)	4.72 (0.64)	5.02 (0.67)	4.56 (0.50)	4.73 (0.76)	4.52 (0.72)

Note that the values are displayed as means (SDs). Time is in seconds.
[a]WISC: Wechsler Intelligence Scale for Children.
[b]ANT: Amsterdam Neuropsychological Test Battery.
[c]CRT: Complex Reaction Time Task.
[d]Rey: Rey–Osterrieth Complex Figure.
[e]VMI: Developmental Test of Visual-Motor Integration.

augmentation (not only in the patients, but also in the controls). As performance intelligence is known to be sensitive to test-retest effects,[20] our assessment paradigm may account for these latter improvements.

The presented findings are in contrast with what would be expected from earlier research that did demonstrate neurocognitive problems after open-heart surgery.[1–5] The incongruity may be explained by procedural differences. First, with today's rapid advances in surgical and anaesthetic techniques, the outcomes of surgery that took place several years ago may perhaps no longer compare to the outcomes that can be achieved with the current methods. Secondly, surgical techniques varied between studies. Whereas we made use of full-flow cardiopulmonary bypass at moderate hypothermia, many earlier studies applied deep hypothermic circulatory arrest, the neurocognitive risks of which are known to be higher than those associated with cardiopulmonary bypass.[4,34] Studies that like ours investigated pre- and post-operative neurocognitive functioning involving cardiopulmonary bypass without deep hypothermia and circulatory arrest likewise failed to detect any negative effects.[16,17] Thirdly, many of the earlier studies focused on neonates or infants rather than school-age children. Research has shown that central nervous system injury (for instance periventricular leukomalacia) after open-heart surgery is more common in neonates than it is in older infants.[35] Therefore, heart surgery at a very young age might have a greater impact on the immature brain and further development, and might therefore be associated with higher risks of neurocognitive problems. Finally, since most previous studies lacked a pre-operative assessment, they could not preclude that (part of) the neurocognitive problems might have been present prior to surgery. An earlier comparative study of ours confirmed this supposition. Relative to healthy peers, our cardiac patients showed specific neurocognitive difficulties in motor planning and visual memory prior to their open-heart procedure (Van der Rijken *et al*., submitted for publication). Other prospective studies also identified pre-surgical neurocognitive problems.[12,14,15] Thus, irrespective of open-heart surgery, children with congenital heart disease might already present with (mild) neurocognitive deficits.

Limitations

To ensure that the outcomes would stem from the children's heart conditions and ultimately from the associated open-heart surgery rather than from diminished physical or mental capacity of any kind, we applied strict exclusion criteria. We are aware that this yielded a cohort of relatively well-functioning children. The selection criteria applied limit the generalization of our results to all

Table 4 Neurocognitive change from baseline to 1 year follow-up: effects for and interaction between group (surgery, catheterization, and control) and assessment (baseline and follow-up)

	Main effect				Interaction effect	
	Group		Assessment		Group × Assessment	
	F	*P*	*F*	*P*	*F*	*P*
General intelligence						
WISC[a]: verbal intelligence	0.82	0.44	1.93	0.17	2.42	0.09
WISC: performance intelligence	1.90	0.16	69.00	0.00	1.89	0.16
WISC: full-scale intelligence	1.39	0.25	18.63	0.00	0.37	0.69
Attention and processing speed	1.51	0.16	**112.31**	**0.00**	1.73	0.09
ANT[b]: reaction time			252.65	0.00		
CRT[c]: reaction time			12.76	0.00		
Drawing task: reaction time			52.41	0.00		
Bourdon-Vos: row completion time			181.80	0.00		
Construction	0.42	0.80	**3.87**	**0.02**	1.13	0.34
Rey[d] Copy: organization score			7.31	0.01		
VMI[e]: standard score			0.76	0.39		
Motor speed	0.54	0.83	**14.90**	**0.00**	0.88	0.54
Finger-tapping: no. preferred hand			27.57	0.00		
Finger-tapping: no. non-preferred hand			38.74	0.00		
CRT: movement time			13.47	0.00		
Drawing task: drawing speed			10.19	0.00		
Motor planning and fluency	1.45	0.22	**12.53**	**0.00**	1.70	0.15
Drawing task: duration of pauses			11.73	0.00		
Drawing task: no. of velocity peaks			18.26	0.00		

Note that for each of the neurocognitive domains, repeated measures MANOVAs were used. Only when multivariate results were significant (in bold), univariate results were evaluated. F is the value of the F-statistic.
[a]WISC: Wechsler Intelligence Scale for Children.
[b]ANT: Amsterdam Neuropsychological Test Battery.
[c]CRT: Complex Reaction Time Task.
[d]Rey: Rey–Osterrieth Complex Figure.
[e]VMI: Developmental Test of Visual–Motor Integration.

Table 5 Correlation coefficients of surgical risk factors and neurocognitive change after cardiac surgery with cardiopulmonary bypass

	Verbal intelligence	Performance intelligence	Full-scale intelligence	Attention and processing speed	Construction	Motor speed	Motor planning and fluency
Duration of CPB[a]	−0.03	0.02	−0.01	0.17	−0.04	0.14	−0.07
Duration aortic cross-clamp	−0.03	0.00	−0.02	−0.08	−0.11	−0.01	−0.01
Minimum pH	0.21	−0.08	0.08	0.05	−0.08	−0.10	0.17
Minimum haematocrit	0.10	0.04	0.09	−0.24	−0.10	−0.06	0.02
Maximum lactate	−0.15	0.10	−0.05	0.20	0.09	0.25	−0.13
Aristotle™ classification	−0.07	−0.11	−0.06	0.03	−0.22	0.09	0.06

Note that *z*-combined scores were used for the analysis of neurocognitive change. For all outcome measures, except for motor planning and fluency, positive *z*-scores indicate post-operative improvement. For motor planning and fluency, positive *z*-scores indicate post-operative deterioration.
[a]CPB: cardiopulmonary bypass.

cardiac patients indicated for open-heart surgery and complicate comparisons with previous research. It is likely that we would have found more performance deficits if we had adopted less stringent criteria. However, as it was our primary goal to investigate the effects of open-heart surgery, we were less interested in pre-surgical deficits that might be unrelated to the heart condition and thus its repair. Although the exclusion of children with any physical or mental comorbidity probably has reduced the number and severity of neurocognitive problems, it did allow a clear interpretation of the results.

Because most neurocognitive problems following open-heart procedures will not become manifest until the child has reached school age, we chose to test children scheduled for surgery at age 6 to 16 years, which by definition is a comparatively small pool. The resultant relatively small sample size might have reduced the chances of finding significant group differences. Nevertheless, as all our findings, both the between-group and the individual results, pointed in the same direction, the results seem robust.

The diagnoses of the two cardiac groups varied somewhat since in our selection procedure we had made no allowance for cardiac diagnoses. However, our study focused on the effects of surgery rather than the effects of cardiac diagnosis. As we investigated neurocognitive functioning both before and after cardiac treatment, cardiac diagnosis was controlled for and had not influenced the outcomes.

Conclusions

When performed at school age, open-heart surgery using full-flow cardiopulmonary bypass at moderate hypothermia does not negatively affect the children's neurocognitive functioning. One year after the procedure, all showed improved functioning on the general intelligence measures and on the neurocognitive domains of attention and processing speed, construction, motor speed, and motor planning and fluency. As the improvements in the post-surgery group resembled those found in the catheterized group and in the healthy peer group, they most likely resulted from increased age and repeated neurocognitive testing. Although meriting replication, the present findings suggest that current surgical and interventional techniques for congenital cardiac disorders do not put school-age children at risk of developing neurocognitive problems.

Conflict of interest: none declared.

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CLINICAL VIGNETTE

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An unusual cause of cardiomegaly

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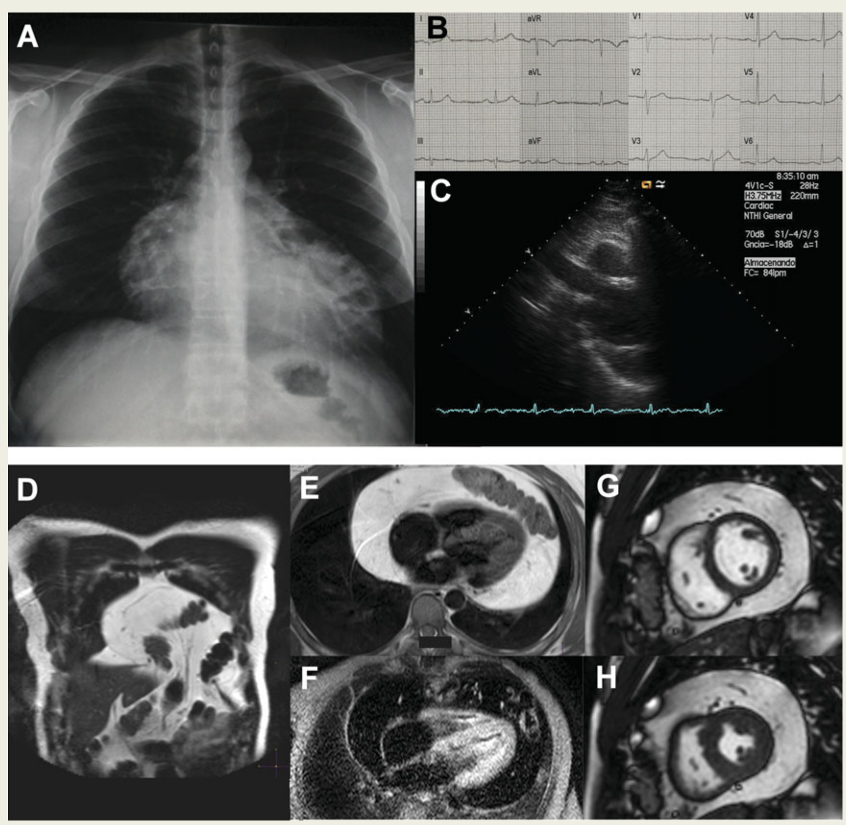

A 38-year-old male patient was referred to our institution to study the origin of global cardiomegaly observed in a chest radiograph (*Panel A*). No remarkable data were reported in his medical record excepting hip fracture at the age of 3 after a road traffic accident, which required surgery. He was asymptomatic and medical examination was normal. Electrocardiogram (EKG) was also normal (*Panel B*).

Normal size of both ventricles was observed in echocardiography (*Panel C*); an echolucent space existed behind the posterior wall suggesting pericardial effusion. No echocardiographic signs of tamponade existed.

Magnetic resonance imaging (MRI) was performed to complete the study because of poor acoustic window. A large intrapericardial diaphragmatic herniation was diagnosed in black-blood T1-weighted coronal and axial images (*Panels D* and *E*), containing transverse colon and omentum, fat content was confirmed with fat suppression prepulse (*Panel F*). The herniation did not compromise ventricular function (*Panels G* and *H*). Conservative management with close follow-up was decided due to preference of the patient. He has remained asymptomatic for 12 months since the diagnosis.

Diaphragmatic rupture and intrapericardial herniation are generally the result of blunt trauma and increased intraabdominal pressure, generally in a motor vehicle accident. The diagnosis of this condition may be immediate, because of acute symptoms including cardiac tamponade, or delayed (average interval between injury and diagnosis: 4.8 years). We report a case of a massive intrapericardial herniation, which has probably remained asymptomatic for 35 years. This case also illustrates limitations of echocardiography to evaluate pericardial diseases; MRI has excellent contrast resolution and is an excellent technique to evaluate integrity of the diaphragm.