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Contents

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AIM AND SCOPE

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ORIGINAL ARTICLE

Observational Study

Estimating pressure gradients by auscultation: How technology (echocardiography) can help improve clinical skills

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Author contributions: Kadle RL assisted in data analysis and contributed extensively to the writing of the manuscript; Phoon CKL designed the research, performed the research, analyzed the data, and wrote and approved the final manuscript.

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Abstract

AIM

To extend our previously-published experience in estimating pressure gradients (PG) *via* physical examination in a large patient cohort.

METHODS

From January 1, 1997 through December 31, 2009, an attending pediatric cardiologist compared clinical examination (EXAM) with Doppler-echo (ECHO), in 1193 patients with pulmonic stenosis (PS, including tetralogy of Fallot), aortic stenosis (AS), and ventricular septal defect (VSD). EXAM PG estimates were based primarily on a murmur's pitch, grade, and length. ECHO peak instantaneous PG was derived from the modified Bernoulli equation. Patients were 0-38.4 years old (median 4.8).

RESULTS

For all patients, EXAM correlated highly with ECHO: ECHO = 0.99 (EXAM) + 3.2 mmHg; r = +0.89; $P < 0.0001$. Agreement was excellent (mean difference = -2.9 ± 16.1 mmHg). In 78% of all patients, agreement between EXAM and ECHO was within 15 mmHg and within 5 mmHg in 45%. Clinical estimates of PS PG were more accurate than of AS and VSD. A palpable precordial thrill and increasing loudness of the murmur predicted higher gradients ($P < 0.0001$). Weight did not influence accuracy. A learning curve was evident, such that the most recent quartile of patients showed ECHO = 1.01 (EXAM) + 1.9, r = +0.92, $P < 0.0001$; during this time, the attending pediatric cardiologist had been > 10 years in practice.

CONCLUSION
Clinical examination can accurately estimate PG in PS, AS, or VSD. Continual correlation of clinical findings with echocardiography can lead to highly accurate diagnostic skills.

Key words: Physical examination; Ventricular septal defect; Clinical skills; Echocardiography; Aortic stenosis; Pulmonary stenosis

Core tip: Knowing pressure gradients across valves, arteries, and ventricular septal defects is important to clinical management of patients. In a large cohort of patients, we have determined the high degree of accuracy of the physical examination against the benchmark Doppler echocardiography. We discuss this clinical approach in the context of clinical practice, technology, and healthcare costs.

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INTRODUCTION

Strong clinical skills, including history-taking and physical diagnostic skills, remain an important part of patient evaluation - central to the practice of medicine. The clinical skills required for auscultation are especially important in childhood, when more than 50% of children have heart murmurs, most of which are benign[1,2]. In recent years however, there have been a decline in clinical examination skills and an increasing reliance on diagnostic testing[3-7].

The gradual loss of emphasis on physical exam skills has several implications[8-11]. The physical exam is an integral part of the doctor-patient relationship, and can also garner otherwise unattainable observations and findings. Additionally, the information obtained from the physical exam can help delineate the need for further testing. Although there have been several initiatives to minimize wasteful testing by focus on clinical examination[12-14], few groups have described specific and learnable techniques to do so.

In this follow-up to a small pilot study[15], our objectives of this study were several-fold. We hoped to further validate our technique of estimating peak pressure gradients through auscultation with a much larger cohort of patients. We also hoped to debunk the idea that the physical exam has a dwindling role in medicine; we believe its use in conjunction with technology can allow for a more accurate clinical assessment. We also hoped to determine the specific situations and characteristics associated with a more accurate physical exam, allowing others to learn this technique as well.

MATERIALS AND METHODS

The methods are essentially as detailed in our previous report[15]. This study was approved by the Institutional Review Boards at NYU Langone Medical Center and Bellevue Hospital Center (both located in New York, NY, United States). Including our initial cohort of 151 patients[15], a total of 1193 consecutive patients with pulmonary stenosis (PS, n = 563), aortic stenosis (AS, n = 234), or ventricular septal defect (VSD, n = 396) were studied by both auscultation and Doppler echocardiography over a 13-year period between February 1997 and December 2009. Not all patients were diagnosed with these lesions at the visits; some were “first” visits, but the physical examination was characteristic for valvar stenosis or VSD, and therefore a clinical estimate of the pressure gradient could be made even before a diagnosis was established by echocardiography. All levels of PS (including tetralogy of Fallot) and AS, all types of VSDs, and residual lesions after surgical or transcatheter interventions were included. In our patient population, the AS seen was congenital, rheumatic, or postoperative, not the fibrocalcific AS seen in older patients. “Complex” AS or PS (as opposed to valvar AS or PS) denotes non-valvar stenosis, or multi-level stenosis; examples include the PS in patients with tetralogy of Fallot, subvalvular AS and supravalvar AS. It has been standard clinical practice in our pediatric echocardiography laboratory for the author (CKLP), an attending echocardiographer, to examine every patient briefly as time permits; it is felt by at least some echocardiographers, including the author, that this preliminary examination (which may include palpation and auscultation, especially of the heart sounds and murmurs) improves the reliability of the echocardiographic study. This physical examination helps to assess the degree of clinical suspicion and to focus the requested echocardiogram. For lesions with pressure gradients, the author routinely estimates a pressure gradient (see below) before the echocardiographic study. It should be noted this study was started (1997) only 1.5 years following the completion of clinical fellowship training by CKLP; therefore, at the completion of data acquisition (2009), 13.5 years had elapsed since completion of training.

The auscultatory pressure gradient was estimated by an “auscultatory scale” based predominantly on

Table 1 Summary table of key findings for pulmonary stenosis, aortic stenosis, and ventricular septal defect

Lesion	*n*	Mean gradient (mmHg)	Agreement to: ≤ 15 mmHg	≤ 10 mmHg	≤ 5 mmHg	*r*
Pulmonary stenosis						
PS (all)	563	42 ± 28	82%	70%	49%	0.85
Valvar PS	313	36 ± 22	89%	77%	56%	0.85
Complex PS	250	49 ± 32	72%	61%	40%	0.84
PVR	81	48 ± 25	84%	65%	42%	0.86
Aortic stenosis						
AS (all)	234	38 ± 24	81%	71%	49%	0.8
Valvar AS	112	42 ± 24	77%	68%	46%	0.76
Complex AS	122	34 ± 23	85%	75%	52%	0.85
AVR	34	46 ± 22	71%	65%	38%	0.71
Ventricular septal defect						
VSD	396	83 ± 31	70%	60%	36%	0.82

"Complex" AS or PS denotes non-valvar stenosis or multi-level stenosis, such as the PS observed in patients with tetralogy of Fallot. AS: Aortic stenosis; AVR: Aortic valve replacement; CHD: Congenital heart defects; PS: Pulmonary stenosis; PVR: Pulmonary valve replacement; VSD: Ventricular septal defect.

a murmur's perceived predominant frequencies and frequency spread[15,16]. A stethoscope is inched around the chest until the highest frequencies of a murmur are heard. These frequencies are then used to estimate the pressure gradient. As the examiner continued to gain clinical experience, other components of auscultation were incorporated into the clinical estimate of the pressure gradients, including murmur loudness and length. Short murmurs generally comprised < 50% of systole, medium-length 50% to < 100% of systole with a crescendo-decrescendo quality, and long/holosystolic 100% of systole. Gradients were estimated in 5 mmHg range increments (for example, 5-10 mmHg or 25-30 mmHg) and then recorded as a midpoint value [5-10 (= 8 mmHg), 25-30 (= 28 mmHg), *etc.*]. In the remainder of this article, the terms "auscultation" and "auscultatory gradient" will refer to this technique of assessing the frequency composition of a murmur unless otherwise specified.

To avoid bias, the auscultatory gradient was recorded before Doppler echocardiography, and the Doppler examination was performed by a pediatric cardiac sonographer who was unaware of the auscultatory estimate. Echocardiograms performed solely by the author were excluded. In standard fashion, the Doppler beam was aligned as parallel as possible with the blood flow jet, without angle correction, interrogating for the maximal flow velocity from multiple views. The peak instantaneous Doppler pressure gradient was calculated with the modified Bernoulli equation. Any perceived inconsistencies between the auscultatory gradient and the echocardiographic results were resolved with further imaging.

Ideally, patients should be in a calm resting state for both the auscultatory examination and the echocardiogram because changes in activity level will change the cardiac output and therefore flow characteristics, including gradients. Because we do not routinely use conscious sedation, we examined patients in as calm a state as possible, recognizing that variability in the resting state will introduce variability into our assessments.

Age, weight, diagnoses, and history of interventions were obtained from the patient reports.

The relationship between the auscultatory and Doppler pressure gradients was assessed by simple linear regression. Agreement was assessed by Bland-Altman analysis[17]. Results are expressed as mean ± SD. Differences were analyzed with a 2-tailed Student *t* test. Comparison of categorical variables was performed with chi-square analysis or Fisher's exact test. Statistical significance was set at $P < 0.05$.

RESULTS

Patient demographics

Patients were 0-38.4 years old (mean 6.8 years, median 4.8), weighing 0.83-129 kg (mean 26.8 kg, median 18.2). There were 339 patients between 0-1 years of age (infants); 270 patients > 1 year-5 years (toddlers and young children); 311 patients between > 5 years-12 years (school-age children); 200 patients between 12-18 years (adolescents); and 73 patients older than 18 years (adults).

Accuracy and correlations of various congenital cardiac conditions

For all patients, auscultation correlated highly with echocardiography: ECHO= 0.99 (AUSC) + 3.2 mmHg; r = +0.89 (r^2 = +0.79); P < 0.0001 (Figure 1A). Agreement was excellent [mean difference between clinical exam and echo = -2.9 ± 16.1 mmHg (SD), also as seen in the Bland-Altman analysis, Figure 1B]. In 78% of all patients, agreement between auscultation and echocardiography was within 15 mm Hg; in 67%, within 10 mmHg; and in 45%, within 5 mmHg (Figure 1C). Clinical estimates of PS pressure gradients were more accurate than of AS and VSD (Table 1). Valvar PS appeared to be more accurately estimated than other lesions, and VSD showed the worst agreement overall.

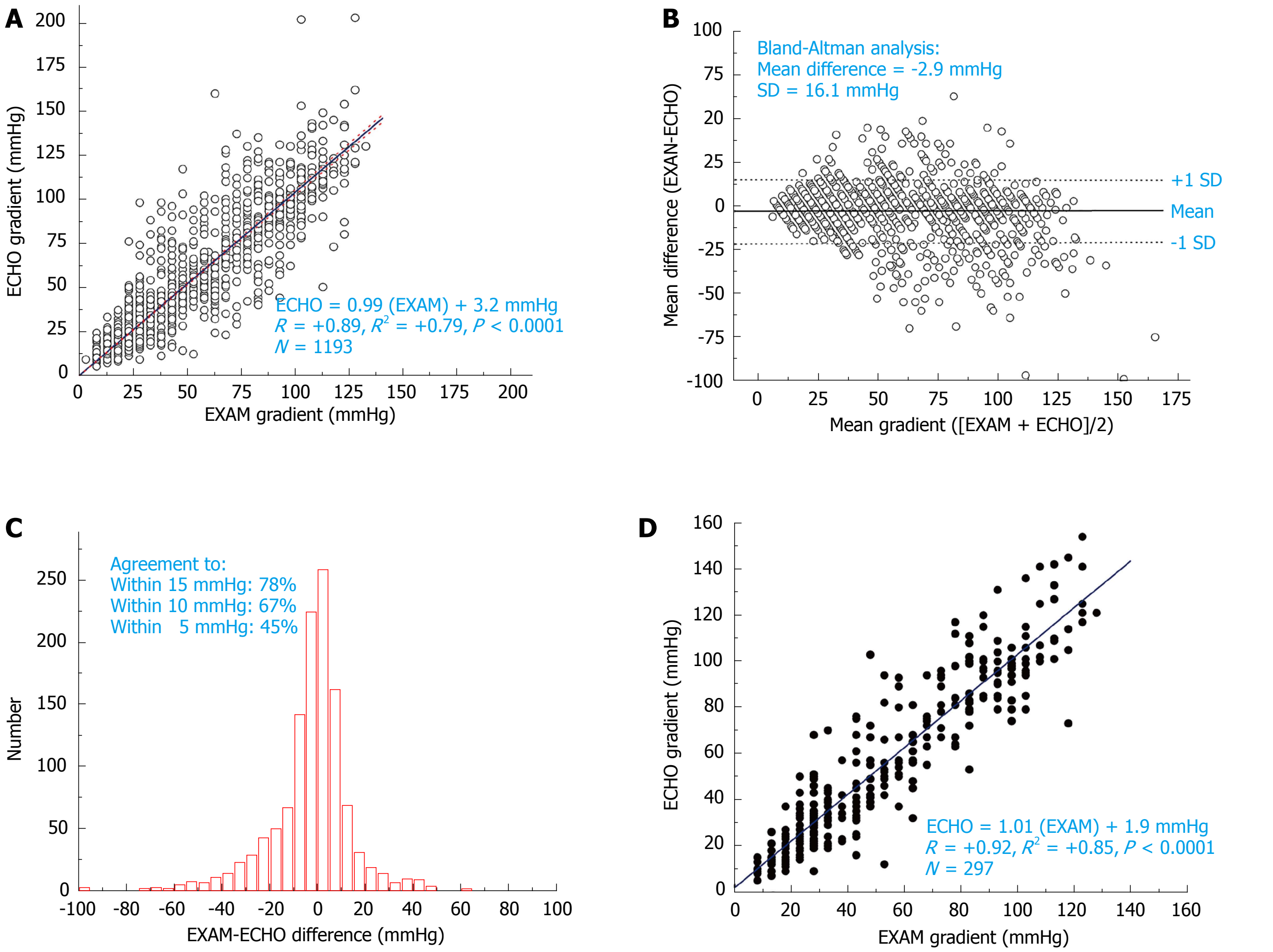

Figure 1 Accuracy and correlations of various congenital cardiac conditions. A: Regression plot of all patients; B: Bland-Altman plot; C: Histogram displaying spread between the Doppler and physical examination gradients, and the agreement between Doppler and physical examination to within 15, 10, and 5 mmHg; D: Regression plot of most recent quartile of patients.

A learning curve was evident. Overall agreement and correlation in the original published cohort of 151 patients [ECHO = 0.99 (AUSC) + 7.12, r = +0.84 (r^2 = +0.71)] were worse (Phoon 2001); the most recent quartile of patients showed ECHO = 1.01 (AUSC) + 1.9, r = +0.92 (r^2 = +0.85), P < 0.0001 (n = 297) (Figure 1D). The initial cohort[15] corresponded to a time period from early 1997 through mid-1998, while the most recent quartile of data corresponded to a time period from mid-2007 through end of 2009; thus, there was a 10-year difference in clinical experience.

Correlates with patient factors affecting accuracy

Increasing loudness of the murmur (standard 1-6 grade scale) predicted higher gradients (r = +0.54, P < 0.0001), with the largest gap occurring between grades 2 (mean PG: 36 ± 29 mmHg) and 3 (mean PG: 63 ± 35 mmHg) (Figure 2A). Similarly and as expected, a palpable precordial thrill predicted significantly higher gradients [all P < 0.0001: PS: 32 ± 22 mmHg (no thrill) *vs* 67 ± 25 (+thrill); AS: 31 ± 20 *vs* 59 ± 29; VSD: 80 ± 31 *vs* 101 ± 28] (Figure 2B, C). Despite the highly significant differences in patients with and without a palpable precordial thrill, there was considerable overlap in the pressure gradients. Possible influencing factors are shown in Table 2. Heavier weight and prior surgery did not appear to influence accuracy. Infants and young toddlers appeared to be less accurately assessed. Although a previous echocardiogram (and therefore possibly knowledge of the previous gradient) exhibited a better correlation, the correlation coefficient even during a "first" visit was very high (Table 2).

In several cases, the physical examination "trumped" the echocardiogram, although this represented a small percentage of all patients. Nearly all were VSD's, for which Doppler echocardiography underestimated the predicted peak gradient due to a suboptimal Doppler incident angle (Table 3). In such cases, the VSD gradient alone would have predicted the presence of pulmonary hypertension.

DISCUSSION

This large dataset extends our previous observations and confirms that physical examination, relying mainly

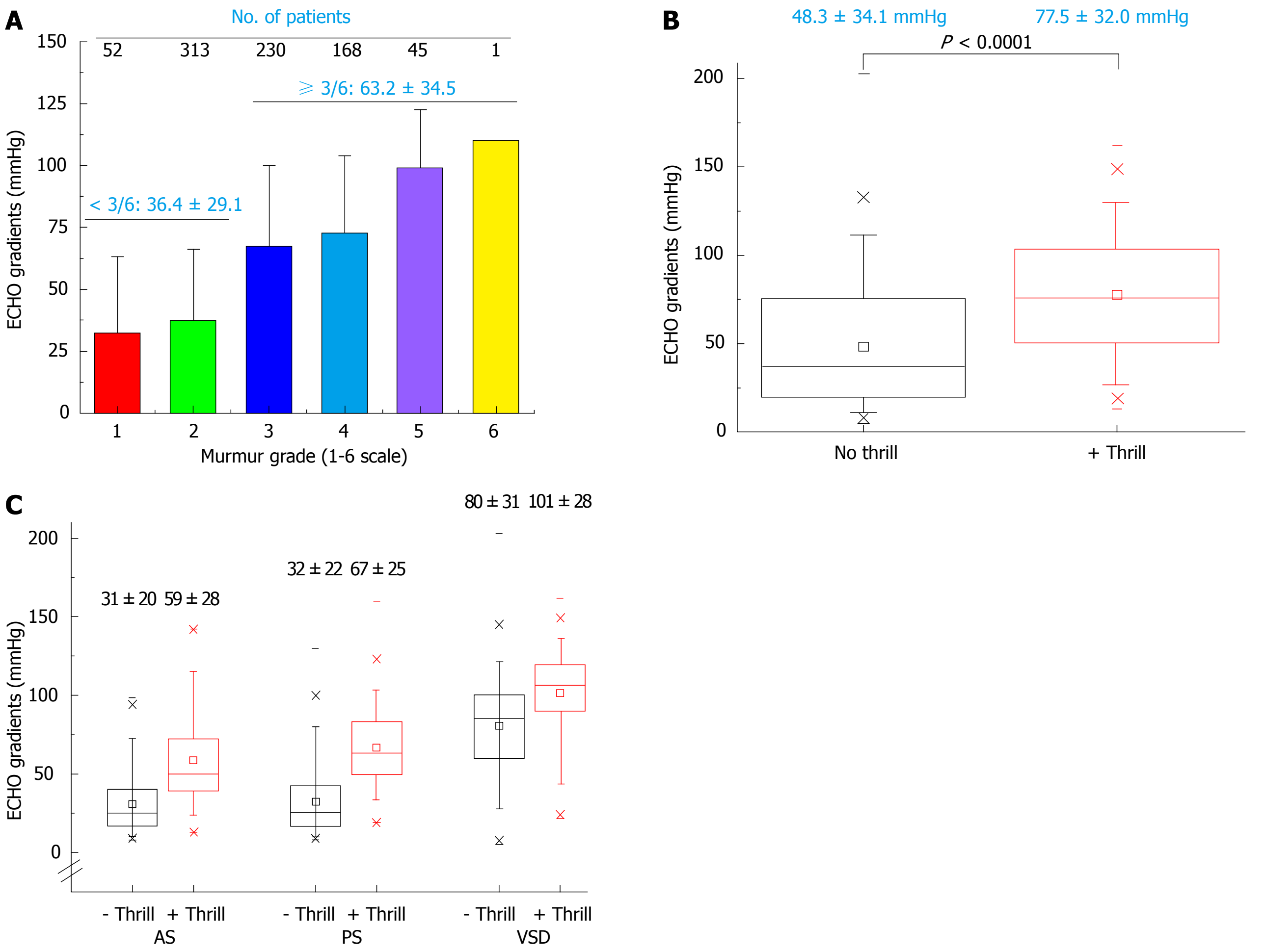

Figure 2 Correlates with patient factors affecting accuracy. A: Loudness of heart murmur (standard grade system, 1-6) plotted against peak Doppler ("ECHO") gradient; B: Box-and-whiskers plot of Doppler peak gradients in the absence and presence of a palpable thrill, all patients; C: Box-and-whiskers plots of specific congenital lesions (aortic stenosis, pulmonic stenosis, ventricular septal defect), thrill absent *vs* thrill present.

on auscultation, can be very accurate in determining pressure gradients. We emphasize that our purpose was not to diagnose specific conditions *de novo*, but to evaluate pressure gradients clinically. Other studies have previously demonstrated that the cardiac physical exam, specifically auscultation, can accurately distinguish benign from pathologic murmurs[15,18-24]. Although these studies look at auscultation in general, they do not specifically analyze pressure gradients. We have now in more detail analyzed some of those aspects of clinical auscultation, as well as patient characteristics, which impact the accuracy of the physical examination. A key finding in this study is how technology - in this case, echocardiography - can help improve clinical skills, presumably by providing feedback to the examiner.

Comparison of different lesions: PS, AS, VSD

Pressure gradients have been examined in dogs, and have been found to both correlate with echocardiographic findings[25-28] and be associated with severity of disease[29]. These studies corroborate the validity of our findings, and we further show its applicability to human subjects. Several groups have shown that examination can diagnose both AS and PS successfully[30-36]. Diagnosis of VSDs by clinical exam is also accurate but can be imperfect for major VSDs[37]. Our study takes these analyses further by laying out a specific auscultatory technique to assess heart murmurs, and by continually correlating clinical findings with echocardiographic data to improve accuracy. We demonstrate that auscultation has the greatest accuracy in predicting pressure gradients in PS, and is still accurate but less so in VSD. We speculate that the murmur of PS is consistently directed in a similar direction in nearly all patients, whereas VSD jets would exhibit far more variability that may change their auscultatory characteristics. We additionally experienced several cases in which echocardiography underestimated the severity of the murmur, or missed the etiology of a murmur completely, demonstrating the significance of auscultation in a clinical exam.

When to be careful: Accuracy is affected by certain patient variables

Several auscultatory characteristics have been identified to predict pathologic disease, such as holosystolic timing, harshness, grade 3 or more, or palpable

Table 2 Summary table of variables that might affect accuracy of clinical estimates of gradients

Variable	*n*	Mean gradient (mmHg)	Agreement to: ≤ 15 mmHg	≤ 10 mmHg	≤ 5 mmHg	*r*
Weight						
≤ 10 kg	367	61 ± 32	71%	61%	42%	+0.81
> 10 to 20 kg	270	57 ± 36	79%	69%	46%	+0.92
> 20 to 40 kg	236	53 ± 38	81%	71%	48%	+0.91
> 40 to 70 kg	237	49 ± 34	81%	67%	42%	+0.91
> 70 kg	82	45 ± 35	85%	74%	48%	+0.88
Age						
< 2 yr	414	60 ± 32	71%	62%	42%	+0.83
≥ 2 yr	779	52 ± 36	81%	70%	46%	+0.91
Prior echo?						
No prior	321	61 ± 36	72%	64%	43%	+0.85
+Prior	872	53 ± 35	79%	68%	45%	+0.90
Operative status (all CHD)						
No operative	688	65 ± 37	74%	64%	43%	+0.89
Post-operative	505	42 ± 27	82%	70%	46%	+0.87

CHD: Congenital heart defects.

Table 3 Examples of cases when physical examination "trumped" echocardiography or echocardiography presented misleading data

Case	Age (yr)	Lesion	Clinical Gradient	DOPP Gradient	Comment
1	6.7	Supravalvar PS s/p repair of TOF with homograft from RV to PA	63	24	Homograft poorly visualized; tricuspid regurgitation jet predicted a systolic RV pressure of 66 mmHg plus the right atrial v-wave, so the PS gradient was significantly underestimated by DOPP
2	6.9	VSD, s/p repair of TOF	70	66	Prior echocardiograms did not visualize VSD; exam led to finding of a tiny residual VSD
3	10.8	VSD	88	63	Poor DOPP incident angle predicted pulmonary hypertension
4	0.005	VSD	68	NA	VSD was so tiny and anterior, a jet could not be obtained for a DOPP gradient
5	4.3	VSD	73	61	BP 104/50; poor DOPP incident angle predicted pulmonary hypertension
6	0.01	VSD	88	48	Technician obtained initial VSD DOPP gradient of 28 mmHg; exam prompted a search for a better DOPP angle
7	2.8	VSD	83	55	Poor DOPP incident angle predicted pulmonary hypertension; tricuspid regurgitation jet predicted normal PA pressures
8	5.5	VSD, s/p repair	98	62	Poor DOPP incident angle predicted pulmonary hypertension; tricuspid and pulmonary regurgitation jets predicted normal PA pressures
9	3.8	VSD	73	53	Poor DOPP incident angle predicted pulmonary hypertension; tricuspid regurgitation jet predicted normal PA pressures
10	15.4	VSD, Shone's complex with minimal LV outflow tract obstruction	93	63	Poor DOPP incident angle predicted pulmonary hypertension
11	15.7	VSD	118	73	Poor DOPP incident angle predicted pulmonary hypertension, even though the VSD was 2.8 mm in diameter; tricuspid and pulmonary regurgitation jets predicted normal PA pressures

BP: Blood pressure; DOPP: Doppler echocardiography; LV: Left ventricular; PA: Pulmonary artery; PS: Pulmonary stenosis; RV: Right ventricular; TOF: Tetralogy of Fallot; VSD: Ventricular septal defect.

precordial thrill[24,38]. We confirmed such factors can be used to estimate pressure gradients clinically, specifically the loudness of the murmur and the presence of a palpable thrill. Somewhat surprisingly, neither heavier weight nor prior surgery worsened clinical accuracy, even though we had wondered if adipose or scar tissue would impact the auscultated frequency spectrum of heart murmurs.

We believe several teaching points can be made from our data. Although the data exhibit much overlap, the presence of a precordial thrill may help differentiate higher gradients in PS and AS, although this appears to be much less useful with VSD's. For both PS and AS, the presence of a thrill is likely to indicate a pressure gradient of > 40-45 mmHg. Infants and toddlers also are more difficult to assess clinically.

Philosophical and practical issues

Our study raises the question of whether clinical skills such as these are important in the current era of medical practice. It is debatable or even unlikely a study such as this will impact use of technology or healthcare costs significantly. Nevertheless, it is our impression that: (1) some cases were diagnosed based primarily on clinical findings, and echocardiography played a limited or initially misleading role; and (2) our data exposes some strengths and weaknesses of the cardiac physical examination with regards to estimating pressure gradients. We and others continue to believe the gradual loss of emphasis on physical exam skills has several implications.

The physical exam is a central part of the doctor-patient relationship. The intimate contact of a physical exam not only gives the patient a sense of comfort and confidence in their physician, but can itself help the patient heal[10,11,39,40]. Besides the desired dynamic bedside skills help to create, there is also a great deal of information obtained through the physical exam that might otherwise be lost[11,41]. Many clinical signs and symptoms cannot be classified by technology alone, and can only be appreciated with a thorough physical exam. Fred discussed the implications of over-reliance on CT scans in the diagnosis of patients, including delays in treatment by waiting for a CT scan to confirm a diagnosis that can be made by physical examination alone[9]. McGee described several instances where the physical exam bested technological testing, including reactive arthritis and pericarditis[42].

However, as Verghese *et al*[39] argue, it is not a fight of physical exam skills *vs* technology, but the attempt to merge these two to produce the optimal comprehensive exam. Ippisch *et al*[43] demonstrated this with regards to cardiology specifically. Neither the physical exam nor a hand-carried echocardiography machine were as accurate as the two used together[6]. We conclude that technology does not erode physical exam skills but in fact improves both bedside skills and clinical judgment. Technology and clinical examination can and should go hand-in-hand for optimal patient care. "It has to make sense"[16].

Balancing exam with technology

Recently, several groups have discussed the development of technologies that can assist physicians in analyzing heart murmurs, including computer-assisted auscultation and artificial neural networks[44,45]. Heart murmurs are complex sounds that can nevertheless be analyzed by a simple frequency analysis, which can be done either with advanced technologies or with a trained ear and a stethoscope.

It has been shown that physicians listening to recorded heart sounds can accurately distinguish innocent from pathologic murmurs[46-48]. Therefore, telecardiology (tele-auscultation) may find potential use in areas where access to echocardiography is limited. Many rural areas, both in the United States and around the world, do not have either an echocardiography machine or a trained echocardiographer. Doctors trained to auscultate for peak pressures could feasibly receive digital heart sounds from remote areas, and improve remote diagnostic capabilities.

Cost considerations

As physicians move away from their stethoscopes, they increasingly rely on diagnostic testing that may be unnecessary and is often uninformed, and certainly costly. Unfortunately in our study, it is impossible to know how many patients could have avoided an echocardiogram, based purely on auscultatory estimation of a pressure gradient; other clinical questions may also prompt an echocardiogram. Nevertheless, in response to the increasing impact of echocardiography on health care costs, the ACCF and the ASE prepared a 2011 revision on appropriate use criteria (AUC) for echocardiography[14] More recently AUC has also been described for pediatric echocardiography, specifically to determine the need for TTE as an initial diagnostic tool in the outpatient setting[13]. The AUC are not absolute, but should be applied to clinical exams to determine when an echocardiogram is appropriate. We believe that an increased focus on auscultation would aid in this.

Limitations

This technique has been proven rigorously for one cardiologist only. The study period corresponded to this cardiologist's early and middle career. Of note, in our original study, we validated the auscultatory scale using a senior pediatric cardiology fellow. In our anecdotal experience, several other individuals have mastered this technique to some degree. Similar to our findings, others have shown that attention to clinical examination skills can allow residents and students to improve their physical exam skills and diagnoses[1]. Moreover, similar findings in animal studies as cited above further validate our approach[25-29].

This study was performed primarily in children but included heavier children as well as some adults. Still, this data may not be applicable to adults with calcific valve disease or other pathologies not addressed in this study. In addition, pressure gradients depend on flow, and the true severity of a valvar or arterial obstruction may not be reliably assessed when there is myocardial failure. For instance, severe AS in adults may present with only a short, unimpressive midsystolic murmur or even no murmur at all. Finally, we did not test this technique for diastolic gradients.

Conclusions and future directions

Physical examination can accurately estimate pressure gradients in most patients with PS, AS, or VSD. An accurate physical examination may provide data that may be missed by technology, contribute to the patient-doctor relationship, and has a role for the cost-conscientious physician. And it may prove useful in areas with limited access to technological resources. We do not propose that the physical exam should replace echocardiography, but believe that the use of the two in conjunction allows for the optimal patient assessment. Contrary to the belief that technology erodes clinical skills, continual correlation of clinical findings with a technological "gold standard" such as echocardiography can lead to highly accurate diagnostic skills and improved clinical judgment, thereby enhancing clinical skills training and further substantiating the value of clinical examination.

COMMENTS

Background

Strong clinical skills, including physical examination skills, remain central to the practice of medicine. In recent years, there has been a much-decried decline in clinical examination skills. The authors had performed a small pilot study over 15 years ago with 151 patients that indicated that physical examination can be very accurate in determining pressure gradients across stenosis or septal defects.

Research frontiers

Very little research is being performed to help clinicians improve clinical skills, or to determine the strengths and/or weaknesses of clinical examination. Moreover, very little is known about how technology such as imaging can help clinicians improve their physical examination skills.

Innovations and breakthroughs

In pediatric cardiology, physical examination is felt to be very accurate in determining normal from abnormal heart murmurs. What is not known, however, is whether the physical examination can accurately predict pressure gradients in aortic stenosis, pulmonary stenosis, and ventricular septal defect. Knowledge of such pressure gradients helps guide clinical management. Almost no work has been done on this area.

Applications

Honing physical examination skills such as being able to predict pressure gradients has two potential benefits: (1) The clinician may rely less on technology and therefore may reduce the use of expensive testing (imaging); and (2) The clinician may use the physical examination findings in conjunction with testing (imaging) to come to a better overall evaluation of the patient.

Terminology

Aortic stenosis (AS): Anatomical obstruction to blood flow at any level, including subaortic stenosis, valvar aortic stenosis, supravalvar aortic stenosis (narrowing of the ascending aorta). In this project, aortic stenosis did not include coarctation of the aorta; Pulmonary stenosis (PS): Anatomical obstruction to blood flow at any level, including subpulmonary or infundibular stenosis, valvar stenosis, and supravalvar stenosis (narrowing of the main pulmonary artery). For the purposes of this project, the authors did not include stenoses of the peripheral branch pulmonary arteries; Ventricular septal defect (VSD): the authors included VSD's at any site, including perimembranous, muscular, and supracristal (subpulmonary) VSD's; Doppler echocardiography, peak instantaneous pressure gradient: For aortic or pulmonary stenosis, there will be a higher-pressure site (proximal to the obstruction) and a lower-pressure site (distal to the obstruction). For ventricular septal defects, the higher-pressure site is generally the left ventricle, while the lower-pressure site is the right ventricle. The difference in pressures (ΔP) between the two sites in the heart or arteries can be estimated using the Doppler principle on echocardiography systems; most commonly, one uses the modified Bernoulli equation, $\Delta P = 4V^2$, where V is the maximal velocity across the region of interest (stenosis or VSD) as acquired from the Doppler ultrasound transducer.

Peer-review

This is a well-written and interesting paper demonstrating how clinical auscultation in expert hands may approximate echo results. The results are important in an era of considerable expenses in technology and of looking down on clinical examination.

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