Anesth Pain Med. 2015 December; 5(6): e32105. doi: 10.5812/aapm.32105

Published online 2015 December 5. **Review Article**

The Preoperative Patient With a Systolic Murmur

Brian Cowie[1,*]

[1]Department of Anaesthesia, St. Vincent's Hospital, Melbourne, Australia

*Corresponding author: Brian Cowie, Department of Anaesthesia, St. Vincent's Hospital, 41 Victoria Parade, Fitzroy 3065, Melbourne, Australia. Tel: +61-39288 2211, E-mail: brian.cowie@svhm.org.au

Received 2015 August 4; **Accepted** 2015 September 4.

Abstract

Context: Patients with undifferentiated systolic murmurs present commonly during the perioperative period. Traditional bedside assessment and auscultation has not changed significantly in almost 200 years and relies on interpreting indirect acoustic events as a means of evaluating underlying cardiac pathology. This is notoriously inaccurate, even in expert cardiology hands, since many different valvular and cardiac diseases present with a similar auditory signal.

Evidence Acquisition: The data on systolic murmurs, physical examination, perioperative valvular disease in the setting of non-cardiac surgery is reviewed.

Results: Significant valvular heart disease increases perioperative risk in major non-cardiac surgery and increases long term patient morbidity and mortality. We propose a more modern approach to physical examination that incorporates the use of focused echocardiography to allow direct visualization of cardiac structure and function. This improves the diagnostic accuracy of clinical assessment, allows rational planning of surgery and anaesthesia technique, risk stratification, postoperative monitoring and appropriate referral to physicians and cardiologists.

Conclusions: With a thorough preoperative assessment incorporating focused echocardiography, anaesthetists are in the unique position to enhance their role as perioperative physicians and influence short and long term outcomes of their patients.

Keywords: Systolic Murmurs, Echocardiography, Perioperative Period, Anaesthesia

1. Context

A thorough history and physical examination is the cornerstone of every preoperative anaesthesia consultation. This process is actively taught in medical schools across the world and is assessed in the final fellowship examination for the Australian and New Zealand college of anaesthetists (ANZCA). Generations of us have entered the operating rooms with a stethoscope around our necks, diligently auscultating the precordium, listening intently for acoustic events and trying to correlate these findings with underlying structural cardiac disease.

However, increasingly in anaesthesia we have realized that there is benefit in direct visualization of structures, rather than using other traditional techniques. We use video and fibreoptic laryngoscopy to view the larynx and verify double lumen tube position, instead of blind intubation and auscultation. We use ultrasound to visualize nerves and vessels for regional anaesthesia and vascular cannulation, rather than rely on variable anatomical landmarks.

Physical examination has been performed by physicians for thousands of years and has been described by the Pharaoh's and Hippocrates (1). In 1816, a French physician Rene Laennec, is widely credited with inventing the stethoscope whilst looking after a young obese woman with heart failure. Unable to palpate the heart and uncomfortable putting his head directly on to the breast of a young woman, he used a rolled up piece of paper to amplify the cardiac sounds and keep his distance from the patient (2). He called this device the stethoscope, with 'stethos' meaning chest and 'skopos' meaning to see or observe in Greek, despite not actually seeing or observing the heart (2).

Soon after, James Hope, an English physician, accurately described that most systolic murmurs were caused by abnormal flow across the aortic or pulmonary valves, or regurgitant flow from high to low pressure chambers with mitral or tricuspid regurgitation (3). The general principles of bedside cardiovascular examination remained essentially unchanged for almost 200 years until the widespread expansion and adoption of bedside echocardiography across perioperative, internal medicine and critical care specialities (1, 4-19).

We aimed to review the up to date assessment and management of the preoperative patient with a systolic murmur.

2. Evidence Aquisition

In this review, a PubMed search using the terms murmur, systolic murmur, preoperative/perioperative, physical/clinical examination, auscultation, transthoracic echocardiography, anaesthesia/anesthesia/anesthesiology, aortic stenosis, aortic regurgitation, aortic sclerosis, mitral regurgitation, tricuspid regurgitation, hypertrophic cardiomyopathy, flow murmur, valvular heart disease, pulmonary hypertension, non-cardiac surgery have been used. We have also searched the websites of the American society of echocardiography, American Heart association and American college of cardiology. A focused review of management of the preoperative patient with an undifferentiated systolic murmur in non-cardiac surgery is presented.

3. Results

3.1. Limitations of Physical Examination

Purists often bemoan the supposed decline in clinical assessment skills of junior staff and residents (20). Yet even in the hands of an experienced cardiologist, physical examination has limited sensitivity and specificity for evaluating patients with an undifferentiated murmur. Aortic stenosis was missed 30% of the time, mitral valve prolapse 45% of the time, aortic regurgitation and intraventricular pressure gradients over 80% of the time (21). In particular, physical examination was unreliable at diagnosis of the murmur if more than one lesion was present, such as mixed aortic and mitral valve disease (missing 45% of these). In addition, the severity of aortic stenosis could not reliably be diagnosed by clinical assessment alone, particularly in patients with left ventricular dysfunction (21). Furthermore, physical examination is unable to reliably assess the functional consequences of valvular heart disease on right and left ventricular function and pulmonary hypertension (22).

United States medical residents were only able to correctly identify 20% of cardiac pathology when played prerecorded auscultatory sounds (23). This number did not change significantly with seniority of the trainees and was similar across Canadian and British trainees (24). We are unaware of any data specifically evaluating auscultatory skills of anaesthesia trainees.

Auscultation alone is not a reliable screening tool and has been shown to miss 90% of patients with rheumatic heart disease (25). Compared with echocardiography, auscultation was found to have a low sensitivity (less than 50%), low positive predictive value (less than 10%), with most cases of significant cardiac pathology being missed and is no longer recommended as a screening tool for rheumatic heart disease (26).

A very brief 2 hour tutorial in focused bedside ultrasound greatly improved the diagnostic accuracy of medical students and junior residents with no prior echocardiography experience, over and above that obtained with history, physical examination and an ECG, with sensitivity increasing from 25 to 75%) (15).

3.2. How Big is The Problem?

Focused transthoracic echocardiography (TTE) has been increasingly described in the perioperative period (4, 6, 7, 11, 18, 27-32). Despite the expansion of preoperative anaesthesia clinics, patients still regularly arrive in the operating room with undifferentiated murmurs and a recent series suggested this accounted for almost 60% of focused TTE's in the perioperative period (27).

Systolic murmurs are common in the elderly and occur in over 30% of patients (1, 33). In an unselected fractured neck of femur population, 30% of patients had mild aortic stenosis or aortic sclerosis and 8% of patients had moderate or severe aortic stenosis (33). In the patients with a murmur, 30% of patients have a normal TTE and concerningly, 30% of patients with some degree of aortic stenosis do not have a murmur. However, when a murmur is heard in this population, the likelihood of moderate to severe aortic stenosis increases 8.5 fold (33).

As anaesthetists, we are regularly faced with the challenge of how to manage the patient with a murmur. Given the limitations of physical examination in detecting significant valvular heart disease, we were previously faced with the dilemma of proceeding with the case with uncertainty regarding the cardiac status, or postponing the case and waiting for formal TTE. This may be unacceptable with time critical surgical emergencies or surgical oncology.

One view point is that patients don't need formal or even limited TTE and we should care for all patients as though they have severe cardiac disease, refusing to tolerate absolute or relative hypotension in elderly patients and using invasive arterial pressure monitoring more commonly (34). However, invasive arterial pressure monitoring is not without complications (35). The choice of anaesthesia and rational use of fluids and vasoactive drugs would differ greatly between patients with aortic stenosis, hypertrophic cardiomyopathy, mitral and tricuspid regurgitation, all of whom may present with a systolic murmur.

Focused TTE can be performed in just 5 - 10 minutes immediately at the bedside and is non invasive with no known risks. It allows accurate identification of the etiology of the murmur, the severity of the stenotic or regurgitant lesion and its effects on right and left ventricular function and pulmonary artery pressure 6. In a small study, we have recently shown that anaesthesia trainees with limited training are able to reliably diagnose and quantify aortic stenosis from normal with focused TTE (36). Medical students with limited training using small portable TTE devices, have significantly higher diagnostic accuracy than experienced cardiologists with physical examination. This includes valvular

heart disease (93% vs 62%) and left ventricular size and function (37).

In addition, anaesthesia colleges worldwide are increasingly emphasizing the role of the anaesthetist as the perioperative physician (38-41). This encompasses not just our expertise during the relatively brief period in the operating room. As such, is it acceptable to assess a patient, hear a murmur and then proceed, without actually evaluating underlying cardiac structure and function? Patients may survive regardless of the surgery or anaesthesia, but if we are to be true perioperative physicians, we must be actively involved in what happens to the patient before and after the surgery. We may be the first physician to document potential cardiac pathology during our clinical assessment, that requires appropriate investigation and follow up. An otherwise well patient with no regular general practitioner, presenting for elective carpal tunnel release under local anaesthesia and sedation, is an opportunity for us as perioperative physicians to evaluate the patient outside of the ten minute superficial surgery. Releasing the flexor retinaculum may improve the paraesthesia in her hand, but it won't save her life. Hearing the loud ejection systolic murmur in the aortic area, confirming severe aortic stenosis with a focused TTE in the preanaesthesia room, then organizing appropriate referral to a cardiac multidisciplinary team for a timely aortic valve replacement just might.

A focused preoperative TTE does not aim to replace a thorough physical exam, nor does it aim to replace a formal cardiology TTE. Rather, we need to reevaluate the way we examine patients and the tools we use and consider that bedside echocardiography is an extension of the stethoscope we already carry and integrate this into our assessment. Why would we use a version of the same device invented nearly 200 years ago, that clearly has limitations and relies on indirect acoustic patterns? When we have ready access to non-invasive echocardiography, with no known risks, that allows direct visualization of cardiac structures. This improves the diagnostic accuracy of cardiac physical examination by more than 50%, finds unsuspected but clinically relevant abnormalities in 20% and importantly when integrated with clinical examination has a negative predictive value of > 95% (1). Roelandt initially described this as an 'ultrasound stethoscope' and emphasizes its importance as an extension of physical examination (1).

Full functioning ultrasound machines have reduced in size from large platforms the size and weight of an adult male (still commonly present in cardiology departments), to smaller semiportable devices the size of a laptop computer often present in perioperative areas, and now miniature devices the size of a smart phone weighing just a few hundred grams (1, 42). TTE is recommended for the initial evaluation of known or suspected valvular heart disease in recent North American and European guidelines (22).

3.3. Common Causes of Preoperative Systolic Murmurs

3.3.1. Aortic Stenosis

Whilst a late a peaking systolic murmur, delayed carotid pulsation and soft or absent second heart sound may be useful in detecting significant aortic stenosis (43), no clinical examination findings have a high sensitivity or specificity for diagnosing severe aortic stenosis (44). Echocardiography is required to reliably exclude severe aortic stenosis when this is suspected (45). This is particularly so if more than one cause of a systolic murmur is present and in the presence of left ventricular dysfunction (21).

Severe aortic stenosis has long been recognized as a risk factor for major adverse cardiac events (MACE) in non-cardiac surgery. The initial Goldman Cardiac Risk Index showed patients with severe aortic stenosis had a perioperative mortality of 13% compared to 1.6% in patients without aortic stenosis (46). More recent data suggests this rate has declined, perhaps because of increased recognition of aortic stenosis as a risk factor and subsequent alterations in anaesthesia management, perioperative monitoring, aggressive haemodynamic management and less invasive surgery (47). Even with these advances, moderate and severe aortic stenosis doubles the risk of mortality (2.1%) and triples the risk of perioperative myocardial infarction (3%) in non-cardiac surgery compared with non-aortic stenosis patients (48). This was particularly so for patients having high risk surgery, symptomatic aortic stenosis, coexisting mitral regurgitation or coronary artery disease 48. Concomitant ventricular dysfunction and pulmonary hypertension have been identified as additional risk factors, with 14% of patients with moderate and severe aortic stenosis having MACE in a recent series (49).

Another recent study in patients undergoing intermediate and high risk non-cardiac surgery identified severe aortic stenosis has a risk factor for MACE (18.8% vs 10.5% in controls), with most adverse events being new or worsened cardiac failure (50). Severe aortic stenosis did not significantly increase 30 day mortality but strongly increased 1 year mortality (18.8 vs 7%). Elevated right ventricular systolic pressure was also noted as increasing early and late mortality. Emergency surgery was identified as a particularly high risk event (50). This strongly reinforces the importance of our role as perioperative physicians with appropriate referral to cardiology, for potential open or transcutaneous aortic valve replacement, even after surgery is complete.

Additional data suggests that the risk of MACE is increased to 31% in patients with severe aortic stenosis and 11% of patients with moderate aortic stenosis undergoing noncardiac surgery (51).

A smaller study in patients with asymptomatic severe

aortic stenosis suggested that low and intermediate risk non cardiac surgery could be undertaken, but with a higher incidence of intraoperative hypotension and vasoactive drug use (52).

Several small studies suggest that superficial, low risk surgery under local anaesthesia and sedation can be performed safely (53).

In elderly fractured neck of femur patients, a recent large series from Northern Ireland suggested an overall incidence of aortic stenosis of 6.9%, diagnosed with auscultation and confirmed with TTE. In the 272 patients with aortic stenosis, there were no significant differences in 30 day and 1 year mortality rates. However, there was a strong trend for the use of invasive arterial blood pressure monitoring and general anaesthesia for increasingly severe aortic stenosis. There was a non-significant trend towards less invasive surgery with fewer hemiarthroplasties in the severe group (54).

An additional study in the United Kingdom performed bedside targeted TTE in almost all patients presenting for fractured neck of femur surgery (33). Moderate or severe aortic stenosis was present in 8% of patients, with mild aortic stenosis or aortic sclerosis present in 30% of patients. Around 30% of these patients had a systolic murmur with 31% of these patients having a normal TTE. It is not clear how thoroughly anesthetists, geriatricians and orthopaedic residents examined patients in this study as clinical examination was not standardized. However, this is likely to reflect real world practice. Concerningly, 31% of patients with some degree of aortic stenosis did not have a systolic murmur, including 23% patients with moderate and severe aortic stenosis, with these patients having surgery without a diagnosis of aortic stenosis.

A small study using anaesthetist performed focused TTE suggested improved one year mortality in fractured neck of femur patients undergoing preoperative TTE. Pathophysiological abnormalities not detected on clinical assessment were common, with 34% of patients hypovolaemic, 20% patients have evidence of cardiac failure, 14% of patients having aortic stenosis and 11% of patients with pulmonary hypertension (32).

As well as the additional risk aortic stenosis adds to non cardiac surgery, recent data suggests that non-cardiac surgery may accelerate the rate of progression of aortic stenosis, perhaps related to increased inflammation during the perioperative period (55).

Outside of the increased risk in the operating room, aortic stenosis is the commonest valvular disease in the Western world, affecting up to 7% of the population over 65. In this group, it is mostly calcific degenerative disease on a previously normal tricuspid valve, or disease of a congenital bicuspid valve. A bicuspid aortic valve is the commonest congenital cardiac anomaly, occurring in 1% - 2% of the population 45. In a series of aortic valve replacements, 50% of patients had a bicuspid aortic valve and they have earlier onset aortic stenosis (56, 57). These patients are also at risk of aortic regurgitation, dilation and dissection of their ascending aorta, so appropriate referral and follow up is essential, with many bicuspid aortic valve patients needing cardiac surgery at some point in their lifetimes (57, 58).

In either case, aortic stenosis is an active process of lipid accumulation, inflammation and calcification from laying down of bone by osteoblast like cells (45, 56). It shares many pathophysiological features with atherosclerosis and coronary artery disease, with the two being strongly associated. Up to 75% of elderly patients with severe aortic stenosis have significant coronary artery disease, increasing as patients age (59). Despite these similarities, no medical therapy has been shown to be beneficial in slowing the progression of aortic stenosis, including several studies looking at statins (56).

The diagnosis is made by clinical assessment encompassing a focused TTE. Severity is classified using clinical and anatomic descriptions (such as heavily calcified and restricted) and quantified haemodynamically using continuous wave Doppler and measuring the peak aortic jet velocity across the aortic valve. This is quick, straightforward, well validated, less prone to errors than measuring aortic valve areas and is still emphasized as a key component of assessment of severity in the recent American Heart Association guidelines (22, 60). A calcified aortic valve with a peak aortic jet velocity of over 4 metres/second confirms the diagnosis of severe aortic stenosis (60). This usually corresponds with a mean gradient of over 40 mm Hg and an aortic valve area of less than 1.0 cm^2. This will identify most patients with significant aortic stenosis. Using the simplified Bernoulli formula (Pressure gradient (mmHg) = 4 x velocity $(m/s)^2$), the pressure gradient across the valve can be estimated.

Patients with peak aortic jet velocities of over 5 metres/second are classified as very severe aortic stenosis in recent guidelines (60). (Table 1)

Aortic valve area calculations are performed routinely in formal cardiology TTE and may be indicated in select circumstances where patients have low flow across the aortic valve, such as severe left ventricular dysfunction or in patients with severe left ventricular hypertrophy, small left ventricular cavity size and small stroke volumes. In these situations, aortic jet velocity and pressure gradients may underestimate the severity of aortic stenosis, despite small valve areas (60).

If patients have symptomatic severe aortic stenosis, aortic valve replacement is indicated. This is either surgically or more recently with percutaneous transcatheter aortic valve implantation (TAVI) in elderly, frail patients previously not considered surgical candidates (60). This would be indicated with or without impending surgery with untreated symptomatic severe aortic stenosis having a 5 year mortality of 50% - 60% (56).

This should be strongly considered before undertaking major, high risk elective surgery.

Balloon valvotomy is not recommended to 'get a patient through' major surgery, with a limited benefit and high risk of complications (47).

In asymptomatic patients with moderate and severe aortic stenosis, the rate of sudden death is 1.5% and cardiovascular death 3.7% over an 18 month follow up period61. Patient education and appropriate referral to a cardiologist for regular follow up with formal echocardiography is indicated, to assess the progression of the disease. In truly asymptomatic patients, it may be reasonable to proceed with low and intermediate risk surgery. A clinical dilemma arises in that up to 50% of supposedly asymptomatic patients with aortic stenosis will become symptomatic with exercise testing or stress echocardiography (61). These patients are not truly asymptomatic but have adjusted the speed of activities of daily living to compensate for the increasing afterload from the aortic stenosis. Some of these patients have elevated exercise induced pulmonary artery pressures, impaired augmentation of left ventricular ejection fraction and dramatically increased pressure gradient across the aortic valve (> 20 mmHg) during stress echocardiography, which implies more severe disease (61). These patients are not truly asymptomatic and have an 8 fold increased risk of cardiac events and are 5.5 times more likely to die suddenly. Aortic valve replacement may be indicated (61).

3.3.2. Aortic Sclerosis

Aortic sclerosis is a common thickening and calcification of the aortic valve leaflets found in 30% - 40% of elderly patients. It is often associated with an ejection systolic murmur indistinguishable from aortic stenosis, related to mild flow acceleration and turbulence across the aortic valve (peak velocity < 2 metres/second) (62). There is no significant leaflet restriction or obstruction to flow. It can readily be detected with focused echocardiography and distinguished from aortic stenosis by the leaflet mobility and lack of high velocity flow across the valve. Around 5% - 10% of patients with aortic sclerosis will proceed to moderate or severe aortic stenosis over a 7 year period (63). It not clear which patients will or won't progress but severity of calcification seems to be a predictor (62). Given aortic sclerosis shares many pathophysiological features of atheroma, statins and antihypertensive agents have been used in an attempt to slow progression, but without success (62).

Aortic valve sclerosis did not influence perioperative cardiovascular events or mortality in patients undergoing vascular surgery (64). Proceeding with non-cardiac surgery seems reasonable along with later referral to a cardiologist.

Aortic sclerosis is a marker of increased cardiovascular risk and independently doubles the risk of cardiac death and acute coronary syndromes (62). Whilst it may not be a haemodynamically significant lesion, the murmur is not innocent and does give early information about increased likelihood of coronary and carotid artery disease (62).

3.3.3. Aortic Regurgitation

Generations of medical trainees have been tormented by senior mentors for missing this early diastolic murmur at the bedside or hearing a systolic murmur. However, with the increasing use of echocardiography, it has become apparent that most patients with aortic regurgitation actually have a more easily heard systolic murmur (27, 65). Aortic regurgitation results from inadequate closure of the aortic valve leaflets because of abnormal leaflets or a dilated aortic root. Left ventricular end diastolic volume increases and total stroke volume increases, with some going forward into the aorta and some returning to the left ventricular through the regurgitant aortic valve. With increased total stoke volume and flow across the aortic valve in systole, peak aortic flow velocity increases and a systolic murmur is heard (65, 66). Up to 90% of patients with significant aortic regurgitation have a systolic murmur with only 15% having an audible diastolic murmur (65). An audible systolic murmur should prompt a search for aortic valve disease with focused TTE.

Limited data suggests that moderate to severe aortic regurgitation is not benign and significantly increases risk in patients undergoing non-cardiac surgery. Cardiopulmonary complications are three times more likely (16.2 vs 5.4%) and postoperative death five times more likely (9 vs 1.8%), particularly in patients with impaired left ventricular function, renal dysfunction and those undergoing high risk surgery (67). Mild to moderate asymptomatic disease is usually well tolerated and surgery should proceed (46).

Aortic regurgitation is mostly commonly caused by a bicuspid aortic valve or calcific aortic valve disease in the Western world, so regardless of the current surgery, postoperative referral to a cardiologist is reasonable for appropriate follow up as the disease is often progressive (68). Severity of aortic regurgitation can be assessed qualitatively with focused TTE by evaluating the regurgitation jet width to left ventricular outflow tract ratio. Mild disease (regurgitation jet width: left ventricular outflow tract 30%), moderate (30% - 60%) and severe aortic regurgitation (> 60%) can be determined rapidly, albeit with some limitations (22).

3.3.4. Mitral regurgitation

In general, regurgitant valvular disease has been thought to be better tolerated than stenotic valvular disease in the perioperative period (46). However, recent data suggests that patients undergoing non-cardiac surgery with moderate to severe mitral regurgitation are not without risk (69).

Trivial mitral regurgitation is seen on echocardiogra-

phy in 40% of otherwise healthy patients (70).

Mitral regurgitation is not a benign disease and has a sudden death rate of 1.8% per year in the community, regardless of etiology (71). Symptomatic patients and those with reduced left ventricular ejection and atrial fibrillation are at additional risk (71).

Broadly, mitral regurgitation can be defined as primary, where regurgitation is the result of abnormal mitral valve leaflets. Or secondary, where the mitral leaflets are structurally normal but where abnormal left ventricular geometry occurs with left ventricular dilation and dysfunction, dilation of the mitral annulus and tethering of chordae and mitral leaflets (22, 72). This is usually due to ischaemic heart disease or dilated cardiomyopathy and is sometimes called ischaemic mitral regurgitation (72). These are really different diseases but both share left ventricular volume overload with progressive left ventricular dilation, left atrial dilation and elevated pulmonary pressures (72). Assessing left ventricular systolic function is challenging with focused echocardiography because the left ventricular contractility is often impaired, despite normal left ventricular ejection on TTE, because much of the ejected volume enters the low pressure chamber left atrium. By time the left ventricle is dilated with impaired left ventricular ejection fraction, left ventricular systolic function is severely impaired with worse prognosis (22). Additional echocardiographic techniques such as global longitudinal strain are required to detect more subtle decreases in left ventricular function in patients with normal ejection fraction and these are outside the scope of a focused TTE (73).

Patients with moderate to severe mitral regurgitation having non-cardiac surgery had a higher incidence of death, myocardial infarction, heart failure and stroke (22 vs 16%) (69). Patients with ischaemic cardiomyopathy and severe left ventricular dysfunction (left ventricular ejection fraction < 35%) had an almost 40% risk of adverse events (46, 69).

Qualitative severity of mitral regurgitation can be achieved quickly using colour flow Doppler with focused echocardiography and looking at regurgitant jet area (70). When this fills up more than 40% of the left atrium or the jet reaches the roof, this implies severe mitral regurgitation (22). More sophisticated techniques outside the scope of focused echocardiography are required for quantitative assessment (22, 70).

When significant mitral regurgitation is associated with abnormal leaflets or impaired left ventricular function, postoperative cardiology referral is indicated even if surgery proceeds, given the likelihood of disease progression, left ventricular dysfunction and pulmonary hypertension and effects on short and long term mortality.

3.3.5. Hypertrophic Cardiomyopathy/Left Ventricular Outflow Obstruction

Hypertrophic cardiomyopathy is a relatively common genetic cardiomyopathy (1 in 500), characterized by marked and asymmetrical left ventricular hypertrophy, particularly the septum, in a non-dilated left ventricle (74). The systolic murmur arises because of left ventricular outflow tract obstruction, which occurs in 30% of patients at rest and up to 70% of patients with exercise, involving pressure gradients > 30 mmHg. Systolic anterior motion of the mitral valve (SAM), usually results in mitral regurgitation, also contributing to the murmur. This occurs because of high velocity flow in the narrow left ventricular outflow tract, causing dragging of the anterior leaflet into the outflow tract. Effects of anaesthesia on loading conditions can worsen this gradient (75).

Patients with hypertrophic cardiomyopathy have an increased risk of sudden death from ventricular arrhythmias, which is in the order of 1% - 5% (75), so cardiology referral is appropriate regardless of the immediate surgery planned.

Limited data suggests that hypertrophic cardiomyopathy triples the risk of death and perioperative myocardial infarction during non-cardiac surgery (75). Invasive arterial monitoring, minimizing conditions that exacerbate the left ventricular outflow obstruction (low preload, low afterload, increased contractility) and immediate access to a debrillator are reasonable management strategies in cases that must proceed.

3.3.6. Tricuspid Regurgitation

At least trivial tricuspid regurgitation is present in the majority of patients and is normal and of no haemodynamic significance (76). When present, this is usually associated with structurally normal leaflets but may be associated with right or left heart disease and pulmonary hypertension (77). There is virtually no data on non-cardiac surgery in patients with tricuspid regurgitation but moderate and severe tricuspid regurgitation does worsen outcomes in cardiac surgery (77). In fact, there is no mention of tricuspid regurgitation in the recent perioperative cardiovascular evaluation guidelines (46).

From a focused TTE perspective, tricuspid regurgitation is the basis on which estimations of right ventricular systolic pressure occur (6). When present, a search for left heart disease, an evaluation of right ventricular function and an estimate of pulmonary pressures should occur. Severity of tricuspid regurgitation does not closely relate to the pulmonary artery pressure (76).

Even with mild to moderate pulmonary hypertension, the risk of perioperative death is 7% and major complications is 30% in major non-cardiac surgery (78). Patients are more haemodynamically unstable, have longer ICU and hospital stays with more frequent readmissions (79). Major emergency surgery and right ventricular dysfunction are particular problems (46, 80). Despite not appearing in risk prediction models, pulmonary

hypertension of any cause is increasingly recognized as a major predictor of risk in non-cardiac surgery (81). Patients and surgeons should be counseled regarding the risks of non-essential major surgery, with consideration to not proceeding when pulmonary hypertension is severe (81).

Perioperative factors such as increased pulmonary vascular resistance with positive pressure ventilation, hypoxaemia, hypercapnoea and uncontrolled pain, all increase pulmonary artery pressures which can initiate right ventricular failure. Systemic hypotension in patients with increasing right heart pressures provokes right ventricular ischaemia and worsened right ventricular function (81).

Major non-cardiac surgery should be performed in referral centres with experience in managing patients with pulmonary hypertension (46).

3.3.7. Flow Murmur

Flow murmurs are common and represent 20% of patients referred for echocardiography for an undifferentiated systolic murmur (21). They most commonly occur in younger patients and in mid- systole. In adults, these usually result from mildly increased flow velocities in the left or right ventricular outflow tract, across the aortic valve or in the mid left ventricular cavity (21). Elevated cardiac output with anxiety, the surgical stress response, pregnancy and perioperative anaemia are contributory factors. A recent focused TTE series showed no perioperative complications in patients with an isolated flow murmur (49). Unfortunately, even in experienced cardiology hands, the sensitivity of physical examination in detecting these innocent murmurs is only 67% (21) so a focused TTE is indicated to exclude significant cardiac disease and confirm the diagnosis. No additional follow up is required.

3.4. Should We Perform Echocardiography On All Of Our Patients?

Given the limitations of physical examination, some would argue that focused TTE should be performed routinely. As yet, there are no large outcome studies that support this. Whilst not specifically evaluating preoperative systolic murmurs, a recent very large retrospective cohort study with over 250,000 patients and over 40,000 having preoperative TTE, was unable to demonstrate an improved survival or reduced length of stay in major non-cardiac surgery (82). In fact, preoperative echocardiography was associated with small increases in 30 day, 1 year mortality and length of stay (82). In addition, the same group in a similarly large retrospective cohort study were unable to show any benefit to a preoperative medical consultation performed by internal medicine based physicians before major non-cardiac surgery (83). Preoperative consultation was associated with increased short and long term mortality, increased length of stay, increased preoperative testing and increased pharmacological interventions (83). Presumably internal medicine physicians would perform a thorough clinical assessment focusing on medical rather than anaesthesia issues, yet this is not clearly helpful in the preoperative period.

Whilst clinical examination is so fundamental in medical practice, it has rarely been subjected to rigorous scientific evaluation. Whilst all anaesthetists would wish to know their patient had severe aortic stenosis before major non-cardiac surgery, it may be that the interventions and change in management (such invasive arterial blood monitoring and use of alpha agonists to maintain blood pressure) are not as helpful as we would imagine and could actually be harmful. Similarly, findings on focused echocardiography could result in delays to otherwise urgent or cancer surgery which could also unnecessarily harm a patient. Either way, they are certainly not evidence based.

As yet, there is no high quality data to justify the use of routine echocardiography in the perioperative period.

3.5. Future Research Areas

There is a paucity of literature on evaluation of cardiovascular physical examination findings. There is little evidence base for minimum training requirements required for anaesthetists to acquire and maintain basic focused TTE skills. There is as yet not high quality outcome data supporting the use of focused TTE in preoperative patients. Such a study would be possible in fractured neck of femur patients for example, where the incidence of systolic murmurs is high. Patients could be randomized to the use of physical examination alone or physical examination with focused echocardiography in the event of detecting a murmur. Early and late outcomes and hospital length of stay could be evaluated. However, the sample size of this study would need to be large and Wijeysundera et al. have estimated that over 9,000 patients would be required based on a 7.5% control group mortality, to show a 20% relative reduction with preoperative echocardiography (two sided alpha 0.05 and 80% power) (82).

3.6. Training and Accreditation

There is a very comprehensive document outlining recommendations for Focused Cardiac Ultrasound from the American society of echocardiography (16). However, this is an expert consensus statement that offers no specific recommendations for training and accreditation. Similarly, it also avoids specific recommendations for maintainence of competency and quality assurance. The document recognizes the increasing use of focused TTE as an adjunct to physical examination. It discusses that a training program should incorporate didactic education and background knowledge, hands on scanning and image interpretation (16).

There are no currently objective or well validated tools to determine competency in focused or any other echocardiography (16, 84). There is recognition that novice echocardiographers can acquire specific skills in echocardiography in just 20 - 30 studies (5, 8, 9, 12, 14, 16, 17, 19, 85-87). However, none of these studies specifically examine the skillset required for evaluation of the preoperative patient with a systolic murmur. Interestingly, when images are taken as part of an extended physical examination as we are proposing, a written record of the findings in the examination section of patient chart is all that is recommended, rather than formal recording of images (16). There is also acknowledgement that focused echocardiography is increasing being performed by non-cardiology physicians (16, 84). Intensive care physicians have produced a document outlining "International consensus statement on training standards for advanced critical care echocardiography" (88). This document has been endorsed by intensive care societies in Europe, North America, and Australasia. In short, this encompasses basic and advanced critical care echocardiography (13). Basic echocardiography involves screening for severe valvular dysfunction and causes of cardiovascular collapse with parasternal short and long axis, apical four chamber and subxiphoid views (13).

Basic echocardiography would involve 10 hours of course work (lectures, internet based curriculum) and 30 fully supervised TTE studies (13). A single centre study with echo novice ICU trainees suggested that 12 hours of lectures, interactive cases and hands on scanning with 33 TTE's are adequate for achieving basic critical care echocardiography skills (19). These kind of numbers would be achievable for all anaesthetists and ideally, all practicing anaesthetists would aim to get to this level as a minimum. Additionally, this level could be supported in the FANZCA curriculum for current and future trainees. Some very limited perioperative data is consistent with these numbers (36, 89).

Advanced echocardiography involves 40 hours of didactic learning (lectures, internet) with performance of at least 100 TTE's and a minimum of 35 TOE's (13, 88). There is no data to support the 100 TTE's but there is limited data to suggest that critical care physicians that are novice echocardiographers need at least 31 TOE studies before competence in haemodynamic evaluation of ICU patients is achieved (90). Some form of certification exam for competency based assessment seems reasonable for advanced practictioners and there are currently North American, European and Australian versions of this (13). The increasing use of echocardiography simulators are acknowledged and whether this would impact on the above training numbers is unclear (88).

It is unrealistic to believe that all anaesthetists will reach an advanced level. However, in a large university department, aiming to have all trainees and all anaesthetists at basic level, with several members at advanced level to support those at basic level and support training for those heading towards advanced level seems reasonable. Our current model is we have 6 advanced practioners whom are all experienced cardiac anaesthetists, with one person per day providing support to the operating rooms in the event of a focused TTE being required. This involves either supervising a basic practitioner (trainee or consultant) or directly performing the study. Interesting studies are saved on a computerised database and a written report is generated for all patients. A weekly echocardiography review meeting with both advanced and basic practitioners selects both TTE and TOE studies with specific learning highlights for group education and quality assurance.

Our department's current recommendation for senior trainees wishing to pursue advanced level echocardiography, is to do a one year provisional fellowship in cardiac anesthesia in a major centre, where exposure to perioperative TTE and TOE is routine and trainees will personally perform and review several hundred echocardiograms, followed by completion of one of the certification exams. Local University of Melbourne based courses provide a high quality platform to acquire echocardiography knowledge for basic or advanced trainees but still require hands on clinical exposure for training in image acquisition and interpretation of images in a clinical context.

Table 1. Aortic Stenosis and Peak Jet Velocity

Aortic Stenosis Severity	Peak Aortic Jet Velocity, m/s
Normal	0.8 - 1.9
Mild	2 - 2.9
Moderate	3 - 3.9
Severe	4 - 4.9
Very severe	> 5

4. Conclusions

Systolic murmurs are common and may be a sign of significant valvular heart disease, which increases perioperative morbidity and mortality. Our traditional physical examination model and auscultation with a stethoscope, whereby indirect acoustic events are interpreted as underlying structural cardiac disease, has not changed significantly in almost two centuries and is notoriously inaccurate. Focused bedside TTE is an extension of our clinical assessment allowing direct visualization of cardiac structure and function; accurate diagnosis of the etiology of the undifferentiated murmur; assessment of the severity and haemodynamic consequences of valvular heart disease on left and right ventricular function and pulmonary artery pressures. Unnecessary delays waiting for formal TTE are avoided. This allows appropriate informed consent for patients and surgeons, risk stratification, anaesthesia planning in the operating room and postoperative period. Referral to physicians and cardiologists for treatment and long term follow up in patients with severe valvular heart disease, cardiac risk factors or those with disease likely to progress is facilitated. This enhances our role as perioperative physicians with the potential to influence short and long term patient outcomes. Whilst few would argue about the value of performing cardiovascular evaluation and focused TTE in preoperative patients with a murmur, scientifically robust outcome data are lacking.

References

1. Roelandt JR. The decline of our physical examination skills: is echocardiography to blame? *Eur Heart J Cardiovasc Imaging.* 2014;**15**(3):249–52. doi: 10.1093/ehjci/jet195. [PubMed: 24282219]
2. Scherer JR. Before cardiac MRI: Rene Laennec (1781-1826) and the invention of the stethoscope. *Cardiol J.* 2007;**14**(5):518–9. [PubMed: 18651515]
3. McGee S. Etiology and diagnosis of systolic murmurs in adults. *Am J Med.* 2010;**123**(10):913–921 e1. doi: 10.1016/j.amjmed.2010.04.027. [PubMed: 20920693]
4. Botker MT, Vang ML, Grofte T, Sloth E, Frederiksen CA. Routine pre-operative focused ultrasonography by anesthesiologists in patients undergoing urgent surgical procedures. *Acta Anaesthesiol Scand.* 2014;**58**(7):807–14. doi: 10.1111/aas.12343. [PubMed: 24865842]
5. Bustam A, Noor Azhar M, Singh Veriah R, Arumugam K, Loch A. Performance of emergency physicians in point-of-care echocardiography following limited training. *Emerg Med J.* 2014;**31**(5):369–73. doi: 10.1136/emermed-2012-201789. [PubMed: 23428721]
6. Cowie BS. Focused transthoracic echocardiography in the perioperative period. *Anaesth Intensive Care.* 2010;**38**(5):823–36. [PubMed: 20865866]
7. Diaz-Gomez JL, Perez-Protto S, Hargrave J, Builes A, Capdeville M, Festic E, et al. Impact of a focused transthoracic echocardiography training course for rescue applications among anesthesiology and critical care medicine practitioners: a prospective study. *J Cardiothorac Vasc Anesth.* 2015;**29**(3):576–81. doi: 10.1053/j.jvca.2014.10.013. [PubMed: 25622973]
8. Gaspar HA, Morhy SS, Lianza AC, de Carvalho WB, Andrade JL, do Prado RR, et al. Focused cardiac ultrasound: a training course for pediatric intensivists and emergency physicians. *BMC Med Educ.* 2014;**14**:25. doi: 10.1186/1472-6920-14-25. [PubMed: 24502581]
9. Kimura BJ, Amundson SA, Phan JN, Agan DL, Shaw DJ. Observations during development of an internal medicine residency training program in cardiovascular limited ultrasound examination. *J Hosp Med.* 2012;**7**(7):537–42. doi: 10.1002/jhm.1944. [PubMed: 22592969]
10. Kini V, Mehta N, Mazurek JA, Ferrari VA, Epstein AJ, Groeneveld PW, et al. Focused Cardiac Ultrasound in Place of Repeat Echocardiography: Reliability and Cost Implications. *J Am Soc Echocardiogr.* 2015;**28**(9):1053–9. doi: 10.1016/j.echo.2015.06.002. [PubMed: 26165448]
11. Kratz T, Campo Dell'Orto M, Exner M, Timmesfeld N, Zoremba M, Wulf H, et al. Focused intraoperative transthoracic echocardiography by anesthesiologists: a feasibility study. *Minerva Anestesiol.* 2015;**81**(5):490–6. [PubMed: 25220551]
12. Martin LD, Ziegelstein RC, Howell EE, Martire C, Hellmann DB, Hirsch GA. Hospitalists' ability to use hand-carried ultrasound for central venous pressure estimation after a brief training intervention: a pilot study. *J Hosp Med.* 2013;**8**(12):711–4. doi: 10.1002/jhm.2103. [PubMed: 24243560]
13. Mayo PH. Training in critical care echocardiography. *Ann Intensive Care.* 2011;**1**:36. doi: 10.1186/2110-5820-1-36. [PubMed: 21906268]
14. Mozzini C, Garbin U, Fratta Pasini AM, Cominacini L. Short training in focused cardiac ultrasound in an Internal Medicine department: what realistic skill targets could be achieved? *Intern Emerg Med.* 2015;**10**(1):73–80. doi: 10.1007/s11739-014-1167-3. [PubMed: 25492052]
15. Panoulas VF, Daigeler AL, Malaweera AS, Lota AS, Baskaran D, Rahman S, et al. Pocket-size hand-held cardiac ultrasound as an adjunct to clinical examination in the hands of medical students and junior doctors. *Eur Heart J Cardiovasc Imaging.* 2013;**14**(4):323–30. doi: 10.1093/ehjci/jes140. [PubMed: 22833550]
16. Spencer KT, Kimura BJ, Korcarz CE, Pellikka PA, Rahko PS, Siegel RJ. Focused cardiac ultrasound: recommendations from the American Society of Echocardiography. *J Am Soc Echocardiogr.* 2013;**26**(6):567–81. doi: 10.1016/j.echo.2013.04.001. [PubMed: 23711341]
17. Stokke TM, Ruddox V, Sarvari SI, Otterstad JE, Aune E, Edvardsen T. Brief group training of medical students in focused cardiac ultrasound may improve diagnostic accuracy of physical examination. *J Am Soc Echocardiogr.* 2014;**27**(11):1238–46. doi: 10.1016/j.echo.2014.08.001. [PubMed: 25216765]
18. Tanzola RC, Walsh S, Hopman WM, Sydor D, Arellano R, Allard RV. Brief report: Focused transthoracic echocardiography training in a cohort of Canadian anesthesiology residents: a pilot study. *Can J Anaesth.* 2013;**60**(1):32–7. doi: 10.1007/s12630-012-9811-8. [PubMed: 23096236]
19. Vignon P, Mucke F, Bellec F, Marin B, Croce J, Brouqui T, et al. Basic critical care echocardiography: validation of a curriculum dedicated to noncardiologist residents. *Crit Care Med.* 2011;**39**(4):636–42. doi: 10.1097/CCM.0b013e318206c1e4. [PubMed: 21221001]
20. Fred HL. Hyposkillia: deficiency of clinical skills. *Tex Heart Inst J.* 2005;**32**(3):255–7. [PubMed: 16392201]
21. Attenhofer Jost C, Turina J, Mayer K, Seifert B, Amann FW, Buechi M, et al. Echocardiography in the evaluation of systolic murmurs of unknown cause ∗ ∗Access the "Journal Club" discussion of this paper at http://www. elsevier.com/locate/ajmselect. *Am J Med.* 2000;**108**(8):614–20. doi: 10.1016/s0002-9343(00)00361-2. [PubMed: 10856408]
22. Nishimura RA, Otto CM, Bonow RO, Carabello BA, Erwin JP, Guyton RA, et al. 2014 AHA/ACC Guideline for the Management of Patients With Valvular Heart Disease: Executive Summary. *J Am College Cardiol.* 2014;**63**(22):2438–88. doi: 10.1016/j.jacc.2014.02.537.
23. Mangione S, Nieman LZ. Cardiac auscultatory skills of internal medicine and family practice trainees. A comparison of diagnostic proficiency. *JAMA.* 1997;**278**(9):717–22. [PubMed: 9286830]
24. Mangione S. Cardiac auscultatory skills of physicians-in-training: a comparison of three English-speaking countries. *Am J Med.* 2001;**110**(3):210–6. doi: 10.1016/s0002-9343(00)00673-2. [PubMed: 11182108]
25. Marijon E, Ou P, Celermajer DS, Ferreira B, Mocumbi AO, Jani D, et al. Prevalence of rheumatic heart disease detected by echocardiographic screening. *N Engl J Med.* 2007;**357**(5):470–6. doi: 10.1056/NEJMoa065085. [PubMed: 17671255]

26. Roberts KV, Brown AD, Maguire GP, Atkinson DN, Carapetis JR. Utility of auscultatory screening for detecting rheumatic heart disease in high-risk children in Australia's Northern Territory. *Med J Aust.* 2013;**199**(3):196–9. [PubMed: 23909543]
27. Cowie B. Three years' experience of focused cardiovascular ultrasound in the peri-operative period. *Anaesthesia.* 2011;**66**(4):268–73. doi: 10.1111/j.1365-2044.2011.06622.x. [PubMed: 21401539]
28. Dennis AT. Transthoracic echocardiography in obstetric anaesthesia and obstetric critical illness. *Int J Obstet Anesth.* 2011;**20**(2):160–8. doi: 10.1016/j.ijoa.2010.11.007. [PubMed: 21315578]
29. Terkawi AS, Karakitsos D, Elbarbary M, Blaivas M, Durieux ME. Ultrasound for the anesthesiologists: present and future. *ScientificWorldJournal.* 2013;**2013**:683685. doi: 10.1155/2013/683685. [PubMed: 24348179]
30. Haji DL, Royse A, Royse CF. Review article: Clinical impact of non-cardiologist-performed transthoracic echocardiography in emergency medicine, intensive care medicine and anaesthesia. *Emerg Med Australas.* 2013;**25**(1):4–12. doi: 10.1111/1742-6723.12033. [PubMed: 23379446]
31. Neelankavil J, Howard-Quijano K, Hsieh TC, Ramsingh D, Scovotti JC, Chua JH, et al. Transthoracic echocardiography simulation is an efficient method to train anesthesiologists in basic transthoracic echocardiography skills. *Anesth Analg.* 2012;**115**(5):1042–51. doi: 10.1213/ANE.0b013e318265408f. [PubMed: 22822190]
32. Canty DJ, Royse CF, Kilpatrick D, Bowyer A, Royse AG. The impact on cardiac diagnosis and mortality of focused transthoracic echocardiography in hip fracture surgery patients with increased risk of cardiac disease: a retrospective cohort study. *Anaesthesia.* 2012;**67**(11):1202–9. doi: 10.1111/j.1365-2044.2012.07300.x. [PubMed: 22950446]
33. Loxdale SJ, Sneyd JR, Donovan A, Werrett G, Viira DJ. The role of routine pre-operative bedside echocardiography in detecting aortic stenosis in patients with a hip fracture. *Anaesthesia.* 2012;**67**(1):51–4. doi: 10.1111/j.1365-2044.2011.06942.x. [PubMed: 22023667]
34. White S. Routine echocardiography or invasive blood pressure monitoring for fractured neck of femur? *Anaesthesia.* 2013;**68**(3):300–1. doi: 10.1111/anae.12166. [PubMed: 23384259]
35. Garg K, Howell BW, Saltzberg SS, Berland TL, Mussa FF, Maldonado TS, et al. Open surgical management of complications from indwelling radial artery catheters. *J Vasc Surg.* 2013;**58**(5):1325–30. doi: 10.1016/j.jvs.2013.05.011. [PubMed: 23810262]
36. Cowie B, Kluger R. Evaluation of systolic murmurs using transthoracic echocardiography by anaesthetic trainees. *Anaesthesia.* 2011;**66**(9):785–90. doi: 10.1111/j.1365-2044.2011.06786.x. [PubMed: 21707561]
37. Kobal SL, Trento L, Baharami S, Tolstrup K, Naqvi TZ, Cercek B, et al. Comparison of effectiveness of hand-carried ultrasound to bedside cardiovascular physical examination. *Am J Cardiol.* 2005;**96**(7):1002–6. doi: 10.1016/j.amjcard.2005.05.060. [PubMed: 16188532]
38. Butterworth J, Green JA. The anesthesiologist-directed perioperative surgical home: a great idea that will succeed only if it is embraced by hospital administrators and surgeons. *Anesth Analg.* 2014;**118**(5):896–7. doi: 10.1213/ANE.0000000000000217. [PubMed: 24781556]
39. Webster NR. The anaesthetist as peri-operative physician. Editorial. *Anaesthesia.* 2000;**55**(9):839–40. doi: 10.1046/j.1365-2044.2000.01722.x. [PubMed: 10947744]
40. Shafer SL, Donovan JF. Anesthesia & Analgesia's collection on the perioperative surgical home. *Anesth Analg.* 2014;**118**(5):893–5. doi: 10.1213/ANE.0000000000000213. [PubMed: 24781555]
41. Schug SA. The surgeon and the anaesthetist: providing patient care as a perioperative team. *ANZ J Surg.* 2008;**78**(7):521–2. doi: 10.1111/j.1445-2197.2008.04560.x. [PubMed: 18593399]
42. Krishnamoorthy VK, Sengupta PP, Gentile F, Khandheria BK. History of echocardiography and its future applications in medicine. *Crit Care Med.* 2007;**35**(8 Suppl):S309–13. doi: 10.1097/01.CCM.0000270240.97375.DE. [PubMed: 17667454]
43. Etchells E, Bell C, Robb K. Does this patient have an abnormal systolic murmur? *JAMA.* 1997;**277**(7):564–71. [PubMed: 9032164]
44. Munt B, Legget ME, Kraft CD, Miyake-Hull CY, Fujioka M, Otto CM. Physical examination in valvular aortic stenosis: correlation with stenosis severity and prediction of clinical outcome. *Am Heart J.* 1999;**137**(2):298–306. doi: 10.1053/hj.1999.v137.95496. [PubMed: 9924164]
45. Ramaraj R, Sorrell VL. Degenerative aortic stenosis. *BMJ.* 2008;**336**(7643):550–5. doi: 10.1136/bmj.39478.498819.AD. [PubMed: 18325966]
46. Fleisher LA, Fleischmann KE, Auerbach AD, Barnason SA, Beckman JA, Bozkurt B, et al. 2014 ACC/AHA guideline on perioperative cardiovascular evaluation and management of patients undergoing noncardiac surgery: a report of the American College of Cardiology/American Heart Association Task Force on practice guidelines. *J Am Coll Cardiol.* 2014;**64**(22):e77–137. doi: 10.1016/j.jacc.2014.07.944. [PubMed: 25091544]
47. Samarendra P, Mangione MP. Aortic stenosis and perioperative risk with noncardiac surgery. *J Am Coll Cardiol.* 2015;**65**(3):295–302. doi: 10.1016/j.jacc.2014.10.051. [PubMed: 25614427]
48. Agarwal S, Rajamanickam A, Bajaj NS, Griffin BP, Catacutan T, Svensson LG, et al. Impact of aortic stenosis on postoperative outcomes after noncardiac surgeries. *Circ Cardiovasc Qual Outcomes.* 2013;**6**(2):193–200. doi: 10.1161/CIRCOUTCOMES.111.000091. [PubMed: 23481524]
49. Cowie B. Focused transthoracic echocardiography predicts perioperative cardiovascular morbidity. *J Cardiothorac Vasc Anesth.* 2012;**26**(6):989–93. doi: 10.1053/j.jvca.2012.06.031. [PubMed: 22920841]
50. Tashiro T, Pislaru SV, Blustin JM, Nkomo VT, Abel MD, Scott CG, et al. Perioperative risk of major non-cardiac surgery in patients with severe aortic stenosis: a reappraisal in contemporary practice. *Eur Heart J.* 2014;**35**(35):2372–81. doi: 10.1093/eurheartj/ehu044. [PubMed: 24553722]
51. Kertai MD, Bountioukos M, Boersma E, Bax JJ, Thomson IR, Sozzi F, et al. Aortic stenosis: an underestimated risk factor for perioperative complications in patients undergoing noncardiac surgery. *Am J Med.* 2004;**116**(1):8–13. [PubMed: 14706659]
52. Calleja AM, Dommaraju S, Gaddam R, Cha S, Khandheria BK, Chaliki HP. Cardiac risk in patients aged >75 years with asymptomatic, severe aortic stenosis undergoing noncardiac surgery. *Am J Cardiol.* 2010;**105**(8):1159–63. doi: 10.1016/j.amjcard.2009.12.019. [PubMed: 20381670]
53. Catacutan T, Usmani A, Aneja A. Does a systolic murmur heard in the aortic area need to be further evaluated prior to elective surgery? *Cleve Clin J Med.* 2007;**74 Suppl 1**:S21–3. [PubMed: 18376498]
54. McBrien ME, Heyburn G, Stevenson M, McDonald S, Johnston NJ, Elliott JR, et al. Previously undiagnosed aortic stenosis revealed by auscultation in the hip fracture population--echocardiographic findings, management and outcome. *Anaesthesia.* 2009;**64**(8):863–70. doi: 10.1111/j.1365-2044.2009.05960.x. [PubMed: 19604190]
55. Amaki M, Anzai T. Does major noncardiac surgery accelerate the progression of aortic stenosis? - Role of inflammation. *Circ J.* 2015;**79**(4):766–7. doi: 10.1253/circj.CJ-15-0204. [PubMed: 25753854]
56. Czarny MJ, Resar JR. Diagnosis and management of valvular aortic stenosis. *Clin Med Insights Cardiol.* 2014;**8**(Suppl 1):15–24. doi: 10.4137/CMC.S15716. [PubMed: 25368539]
57. Lewin MB, Otto CM. The bicuspid aortic valve: adverse outcomes from infancy to old age. *Circulation.* 2005;**111**(7):832–4. doi: 10.1161/01.CIR.0000157137.59691.0B. [PubMed: 15723989]
58. Michelena HI, Desjardins VA, Avierinos JF, Russo A, Nkomo VT, Sundt TM, et al. Natural history of asymptomatic patients with normally functioning or minimally dysfunctional bicuspid aortic valve in the community. *Circulation.* 2008;**117**(21):2776–84. doi: 10.1161/CIRCULATIONAHA.107.740878. [PubMed: 18506017]
59. Goel SS, Ige M, Tuzcu EM, Ellis SG, Stewart WJ, Svensson LG, et al. Severe aortic stenosis and coronary artery disease--implications for management in the transcatheter aortic valve replacement era: a comprehensive review. *J Am Coll Cardiol.* 2013;**62**(1):1–10. doi: 10.1016/j.jacc.2013.01.096. [PubMed: 23644089]
60. Otto CM, Nishimura RA. New ACC/AHA valve guidelines: aligning definitions of aortic stenosis severity with treatment recommendations. *Heart.* 2014;**100**(12):902–4. doi: 10.1136/heartjnl-2013-305134. [PubMed: 24615508]

61. Magne J, Lancellotti P, Pierard LA. Exercise testing in asymptomatic severe aortic stenosis. *JACC Cardiovasc Imaging.* 2014;**7**(2):188–99. doi: 10.1016/j.jcmg.2013.08.011. [PubMed: 24524744]
62. Nightingale AK, Horowitz JD. Aortic sclerosis: not an innocent murmur but a marker of increased cardiovascular risk. *Heart.* 2005;**91**(11):1389–93. doi: 10.1136/hrt.2004.057117. [PubMed: 15797932]
63. Cosmi JE, Kort S, Tunick PA, Rosenzweig BP, Freedberg RS, Katz ES, et al. The risk of the development of aortic stenosis in patients with "benign" aortic valve thickening. *Arch Intern Med.* 2002;**162**(20):2345–7. [PubMed: 12418948]
64. Valentijn TM, Hoeks SE, Bakker EJ, Voute MT, Chonchol M, van de Luijtgaarden KM, et al. Influence of aortic valve calcium on outcome in patients undergoing peripheral vascular surgery. *Am J Cardiol.* 2012;**110**(8):1195–9. doi: 10.1016/j.amjcard.2012.05.062. [PubMed: 22748354]
65. Heidenreich PA, Schnittger I, Hancock SL, Atwood JE. A systolic murmur is a common presentation of aortic regurgitation detected by echocardiography. *Clin Cardiolo.* 2004;**27**(9):502–6. doi: 10.1002/clc.4960270905.
66. Lee D, Chen CH, Hsu TL, Chiang CE, Wang SP, Chang MS. Reappraisal of cardiac murmurs related to aortic regurgitation. *Zhonghua Yi Xue Za Zhi (Taipei).* 1995;**56**(3):152–8. [PubMed: 8854436]
67. Lai HC, Lai HC, Lee WL, Wang KY, Ting CT, Hung CJ, et al. Impact of chronic advanced aortic regurgitation on the perioperative outcome of noncardiac surgery. *Acta Anaesthesiol Scand.* 2010;**54**(5):580–8. doi: 10.1111/j.1399-6576.2009.02171.x. [PubMed: 19930243]
68. Nishimura RA, Otto CM, Bonow RO, Carabello BA, Erwin J3, Guyton RA, et al. 2014 AHA/ACC Guideline for the Management of Patients With Valvular Heart Disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *Circulation.* 2014;**129**(23):e521–643. doi: 10.1161/CIR.0000000000000031. [PubMed: 24589853]
69. Bajaj NS, Agarwal S, Rajamanickam A, Parashar A, Poddar KL, Griffin BP, et al. Impact of severe mitral regurgitation on postoperative outcomes after noncardiac surgery. *Am J Med.* 2013;**126**(6):529–35. doi: 10.1016/j.amjmed.2012.12.005. [PubMed: 23587300]
70. Zoghbi W. Recommendations for evaluation of the severity of native valvular regurgitation with two-dimensional and doppler echocardiography. *J Am Soc Echocardiograph.* 2003;**16**(7):777–802. doi: 10.1016/s0894-7317(03)00335-3.
71. Grigioni F, Enriquez-Sarano M, Ling LH, Bailey KR, Seward JB, Tajik AJ, et al. Sudden death in mitral regurgitation due to flail leaflet. *J Am College Cardiol.* 1999;**34**(7):2078–85. doi: 10.1016/s0735-1097(99)00474-x.
72. Nishimura RA, Otto C. 2014 ACC/AHA valve guidelines: earlier intervention for chronic mitral regurgitation. *Heart.* 2014;**100**(12):905–7. doi: 10.1136/heartjnl-2014-305834. [PubMed: 24688115]
73. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *Eur Heart J Cardiovasc Imaging.* 2015;**16**(3):233–70. doi: 10.1093/ehjci/jev014. [PubMed: 25712077]
74. Stroumpoulis KI, Pantazopoulos IN, Xanthos TT. Hypertrophic cardiomyopathy and sudden cardiac death. *World J Cardiol.* 2010;**2**(9):289–98. doi: 10.4330/wjc.v2.i9.289. [PubMed: 21160605]
75. Hreybe H, Zahid M, Sonel A, Good CB, Shaver J, Saba S. Noncardiac surgery and the risk of death and other cardiovascular events in patients with hypertrophic cardiomyopathy. *Clin Cardiol.* 2006;**29**(2):65–8. doi: 10.1002/clc.4960290206. [PubMed: 16506641]
76. Cowie B, Kluger R, Rex S, Missant C. The utility of transoesophageal echocardiography for estimating right ventricular systolic pressure. *Anaesthesia.* 2015;**70**(3):258–63. doi: 10.1111/anae.12861. [PubMed: 25388528]
77. De Bonis M, Taramasso M, Lapenna E, Alfieri O. Management of tricuspid regurgitation. *F1000Prime Rep.* 2014;**6**:58. doi: 10.12703/P6-58. [PubMed: 25184048]
78. Price LC, Montani D, Jais X, Dick JR, Simonneau G, Sitbon O, et al. Noncardiothoracic nonobstetric surgery in mild-to-moderate pulmonary hypertension. *Eur Respir J.* 2010;**35**(6):1294–302. doi: 10.1183/09031936.00113009. [PubMed: 19897552]
79. Kaw R, Pasupuleti V, Deshpande A, Hamieh T, Walker E, Minai OA. Pulmonary hypertension: an important predictor of outcomes in patients undergoing non-cardiac surgery. *Respir Med.* 2011;**105**(4):619–24. doi: 10.1016/j.rmed.2010.12.006. [PubMed: 21195595]
80. Meyer S, McLaughlin VV, Seyfarth HJ, Bull TM, Vizza CD, Gomberg-Maitland M, et al. Outcomes of noncardiac, nonobstetric surgery in patients with PAH: an international prospective survey. *Eur Respir J.* 2013;**41**(6):1302–7. doi: 10.1183/09031936.00089212. [PubMed: 23143546]
81. Minai OA, Yared JP, Kaw R, Subramaniam K, Hill NS. Perioperative risk and management in patients with pulmonary hypertension. *Chest.* 2013;**144**(1):329–40. doi: 10.1378/chest.12-1752. [PubMed: 23880683]
82. Wijeysundera DN, Beattie WS, Karkouti K, Neuman MD, Austin PC, Laupacis A. Association of echocardiography before major elective non-cardiac surgery with postoperative survival and length of hospital stay: population based cohort study. *BMJ.* 2011;**342**:d3695. doi: 10.1136/bmj.d3695. [PubMed: 21724560]
83. Wijeysundera DN, Austin PC, Beattie WS, Hux JE, Laupacis A. Outcomes and processes of care related to preoperative medical consultation. *Arch Intern Med.* 2010;**170**(15):1365–74. doi: 10.1001/archinternmed.2010.204. [PubMed: 20696963]
84. Via G, Hussain A, Wells M, Reardon R, ElBarbary M, Noble VE, et al. International evidence-based recommendations for focused cardiac ultrasound. *J Am Soc Echocardiogr.* 2014;**27**(7):683 e1–683 e33. doi: 10.1016/j.echo.2014.05.001. [PubMed: 24951446]
85. Martin LD, Howell EE, Ziegelstein RC, Martire C, Shapiro EP, Hellmann DB. Hospitalist performance of cardiac hand-carried ultrasound after focused training. *Am J Med.* 2007;**120**(11):1000–4. doi: 10.1016/j.amjmed.2007.07.029. [PubMed: 17976430]
86. Hellmann DB, Whiting-O'Keefe Q, Shapiro EP, Martin LD, Martire C, Ziegelstein RC. The rate at which residents learn to use hand-held echocardiography at the bedside. *Am J Med.* 2005;**118**(9):1010–8. doi: 10.1016/j.amjmed.2005.05.030. [PubMed: 16164888]
87. Siqueira VN, Mancuso FJ, Campos O, De Paola AA, Carvalho AC, Moises VA. Training Program for Cardiology Residents to Perform Focused Cardiac Ultrasound Examination with Portable Device. *Echocardiography.* 2015;**32**(10):1455–62. doi: 10.1111/echo.12887. [PubMed: 25604804]
88. Expert Round Table on Echocardiography in ICU. International consensus statement on training standards for advanced critical care echocardiography. *Intensive Care Med.* 2014;**40**(5):654–66. doi: 10.1007/s00134-014-3228-5. [PubMed: 24615559]
89. Royse CF, Seah JL, Donelan L, Royse AG. Point of care ultrasound for basic haemodynamic assessment: novice compared with an expert operator. *Anaesthesia.* 2006;**61**(9):849–55. doi: 10.1111/j.1365-2044.2006.04746.x. [PubMed: 16922751]
90. Charron C, Vignon P, Prat G, Tonnelier A, Aegerter P, Boles JM, et al. Number of supervised studies required to reach competence in advanced critical care transesophageal echocardiography. *Intensive Care Med.* 2013;**39**(6):1019–24. doi: 10.1007/s00134-013-2838-7. [PubMed: 23344838]