Hypertrophic Cardiomyopathy: A Systematic Review

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HYPERTROPHIC CARDIOMYOPATHY (HCM) is a complex and relatively common genetic cardiac disease that has been the subject of intense scrutiny and investigation for more than 40 years. Hypertrophic cardiomyopathy is an important cause of disability and death in patients of all ages, although sudden and unexpected death in young people is perhaps the most devastating component of its natural history. Because of marked heterogeneity in clinical expression, natural history, and prognosis, HCM often represents a dilemma to primary care clinicians and cardiovascular specialists, even to those for whom this disease is a focus of their investigative careers. Controversy abounds with regard to diagnostic criteria, clinical course, and management for which difficult questions often arise, particularly among practitioners infrequently engaged in the evaluation of HCM patients. Consequently, it is timely to place in perspective and clarify many of these relevant clinical issues and profile the rapidly evolving concepts regarding HCM.

METHODS

A systematic search of the medical literature involving 968 articles primarily related to English-language HCM publications (1966-2000) from a varied and extensive number of authors and centers was conducted through MEDLINE or bibliographies of published articles. These studies and others before 1966 were analyzed to create a balanced appraisal of HCM.

Published accounts of HCM have come disproportionately from a relatively small group of highly selected centers in the United States, Canada, and Europe. In addition, perceptions emanating from the author’s more than 25 years of extensive experience with HCM interfaced with the literature analysis. Many clinical HCM studies are observational and retrospective in design because of difficulty in organizing large prospective and randomized clinical trials for a disease with heterogeneous expression, selective referral patterns, and diverse mechanisms for morbidity and mortality. Therefore, in HCM, the level of evidence governing management...
Hypertrophic cardiomyopathy is, however, uncommon proportion of individuals harboring a vascular disease, with reports from many countries. Nevertheless, a substantial proportion of individuals harboring a mutant gene for HCM are probably undetected clinically. Hypertrophic cardiomyopathy is, however, uncommon in routine cardiology practice, affecting no more than 1% of outpatients. This limited exposure of clinicians to HCM understandably accounts for the uncertainty that prevails regarding this disease and its management.

Nomenclature
Since the first modern description in 1958,1 HCM has been known by a confusing array of names, reflecting its clinical heterogeneity and the skewed experience of early investigators. Hypertrophic cardiomyopathy2-6 is the preferred name because it describes the overall disease spectrum without introducing misleading inferences that left ventricular (LV) outflow tract obstruction is an irremovable feature (hypertrophic obstructive cardiomyopathy [HOCM] or idiopathic hypertrophic subaortic stenosis [IHSS]). Indeed, HCM is predominantly a nonobstructive disease; 75% of patients do not have a sizable resting outflow tract gradient.3,4,7

Genetics
Hypertrophic cardiomyopathy is inherited as a mendelian autosomal dominant trait and caused by mutations in any 1 of 10 genes, each encoding proteins of the cardiac sarcomere (components of thick or thin filaments with contractile, structural, or regulatory functions).9,11-13,23-27 The physical similarity of these proteins makes it possible to regard the diverse HCM spectrum as a single disease entity and primary sarcomere disorder. The mechanisms by which disease-causing mutations cause LV hypertrophy (LVH) and the HCM disease state are unresolved, although several hypotheses have been suggested.28

Three of the HCM-causing mutant genes predominate, namely, β-myosin heavy chain (the first identified), cardiac troponin T, and myosin-binding protein C. The other genes each account for a minority of HCM cases, namely, cardiac troponin I, regulatory and essential myosin light chains, titin, α-tropomyosin, α-actin, and α-myosin heavy chain. This diversity is compounded by intragenic heterogeneity, with more than 150 mutations identified, most of which are missense with a single amino acid residue substituted with another.9,11-13,26,27 Molecular defects responsible for HCM are usually different in unrelated individuals, and many other genes and mutations, each accounting for a small proportion of familial HCM, remain to be identified. Contemporary molecular genetic studies throughout the past decade have provided important insights into the considerable clinical heterogeneity of HCM, including the preclinical diagnosis of affected individuals without phenotypic evidence of disease (ie, LVH by echocardiography or electrocardiography [ECG]).23,26 Although DNA analysis for mutant genes is the definitive method for establishing the diagnosis of HCM, it is not yet a routine clinical strategy.9 Because of complex, time-consuming, and expensive techniques, genotyping is confined to research-oriented investigations of highly selected pedigrees. Development of rapid automated screening for genetic abnormalities will permit more widespread access to the power of molecular biology for resolving diagnostic ambiguities.

Recently, missense mutations in the gene that encodes the γ-2 regulatory subunit of the adenosine monophosphate-activated protein kinase (PRKAG2) have been reported to cause familial Wolff-Parkinson-White syndrome associated with conduction abnormalities and LVH30,31 (because of glycogen accumulation in myocytes).31 This syndrome is most appropriately regarded as a metabolic storage disease distinct from HCM, which is caused by mutations in genes encoding sarcomeric proteins. Therefore, management and risk assessment of patients with Wolff-Parkinson-White syndrome and cardiac hypertrophy should not be predicated on data derived from patients with HCM.

Of potential importance for understanding HCM pathophysiology are genetic animal models (ie, transgenic mice and rabbits)12-25 and spontaneously occurring animal diseases.36 In particular, domestic cats with heart failure commonly show a disease with clinical and morphologic features remarkably similar to HCM in humans.36

Diagnosis
Clinical diagnosis of HCM is established most easily and reliably with 2-dimensional echocardiography7 by imaging the hypertrophied but nondilated LV chamber, in the absence of another cardiac or systemic disease (eg, hypertension or aortic stenosis) capable of producing the magnitude of hypertrophy evident (FIGURE 1 and FIGURE 2A).19,22 Hypertrophic cardiomyopathy may be initially suspected because of a heart murmur (occasionally during preparticipation sports examinations).43 Positive family history, new symptoms, or abnormal ECG pattern2,44,45 across the broad disease spectrum of HCM, the physical examination may not be a reliable method for clinical identification, given that most patients do not have LV outflow tract obstruction and most of the well-documented physical findings (eg, loud systolic heart murmur and bifid arterial pulse) are limited to patients with outflow gradients.

With regard to pedigree assessment, it is obligatory for the proband to be informed of the familial nature and auto-
somal dominant transmission of HCM. Screening of first-degree relatives, including history taking and physical examinations, and 2-dimensional echocardiography and ECG should be encouraged, particularly if adverse HCM-related events have occurred in the family.

In clinically diagnosed patients, increased LV wall thicknesses range widely from mild (13-15 mm) to massive (≥30 mm [normal, ≤12 mm]), including the most substantial in any cardiac disease, namely, up to 60 mm (Figure 1). In trained athletes, modest segmental wall thickening (ie, 13-15 mm) raises the differential diagnosis between extreme physiologic LVH (ie, athlete’s heart) and mild morphologic expressions of HCM, which can usually be resolved with noninvasive testing. Magnetic resonance imaging may be of diagnostic value when echocardiographic studies are technically inadequate or in identifying segmental LVH undetectable by echocardiography.

The 12-lead ECG pattern is abnormal in 75% to 95% of HCM patients and typically demonstrates a wide variety of patterns. Normal ECGs are most commonly encountered in family members identified as part of pedigree screening or when associated with mild localized LVH. Only a modest relation between ECG voltages and the magnitude of LVH assessed by echocardiography is evident. Nevertheless, ECGs have diagnostic value in raising a suspicion of HCM in family members without LVH on echocardiogram and in targeting athletes for diagnostic echocardiography as part of preparticipation screening.

However, not all individuals harboring a genetic defect will express the clinical features of HCM, such as LVH by echocardiography, abnormal ECG results, or cardiac symptoms. Molecular genetic studies have, in fact, demonstrated that there is no minimum wall thickness required for HCM at a given time in life, and it is not unusual for children younger than 13 years to carry a mutant HCM gene without LVH, underscoring the lack of productivity in preadolescent echocardiographic screening. Substantial LV remodeling with spontaneous appearance of hypertrophy typically occurs with accelerated body growth during adolescence, and morphologic expression is usually completed at physical maturity (about 17-18 years of age). Abnormalities on 12-lead ECG and non–preload-dependent measures of diastolic dysfunction with tissue Doppler ultrasonography may precede the appearance of hypertrophy, providing clues to impending LVH.

Figure 1. Heterogeneity in the Pattern and Extent of Left Ventricular (LV) Wall Thickening in HCM

Echocardiographic parasternal long-axis stop-frame images obtained in diastole showing A, massive asymmetric hypertrophy of ventricular septum (VS) with wall thickness >50 mm; B, pattern of septal hypertrophy in which the distal portion is considerably thicker than the proximal region at mitral valve level; C, hypertrophy sharply confined to basal (proximal) septum just below aortic valve (arrows); D, hypertrophy confined to LV apex (asterisk), consistent with the designation of apical hypertrophic cardiomyopathy (HCM); E, relatively mild hypertrophy in a concentric (symmetric) pattern with each segment of ventricular septum and LV free wall showing similar or identical thicknesses (paired arrows); F, inverted pattern of hypertrophy in which anterior VS is less substantially thickened than the posterior free wall (PW), which is markedly hypertrophied (ie, 40 mm). Calibration marks are 1 cm apart. Ao indicates aorta; AML, anterior mitral leaflet; and LA, left atrium. Reproduced from Klues et al with the permission of Elsevier Science, Inc.
Novel diagnostic criteria for HCM have recently emerged and are based on genotype-phenotype studies showing incomplete disease expression with absence of LVH in adult individuals, most commonly due to cardiac myosin-binding protein C or troponin T mutations. In both cross-sectional and serial echocardiographic studies, mutations in the myosin-binding protein C gene may demonstrate age-related penetrance of the HCM phenotype in which delayed de novo onset of LVH may occur in midlife and later. Such adult morphologic conversions dictate that it is no longer possible to use a normal echocardiogram to offer definitive reassurance at maturity (or even in middle age) that asymptomatic family members are free of a disease-causing mutant HCM gene; this observation probably necessitates a strategy of postadolescent echocardiographic examinations every 5 years.

Paradoxically, a small distinctive subset of HCM patients (ie, about 5%-10%) evolve into the end stage (or “burned-out” phase) characterized by LV wall thinning, cavity enlargement, and systolic dysfunction often resembling dilated cardiomyopathy and producing relentlessly progressive and irreversible heart failure. It is also possible that other adults experience subtle regression in wall thickness with aging (not linked with clinical deterioration), reflecting gradual, widespread remodeling. Therefore, the HCM phenotype is not a static disease manifestation; LVH can appear at virtually any age and increase or decrease dynamically throughout life.

HCM Phenotype and Morphologic Features

Left Ventricular Hypertrophy. Structural heterogeneity in HCM is considerable, with no single pattern of LVH regarded as typical (Figure 1). Although many patients show diffusely distributed LVH, almost one third have mild wall thickening localized to a single segment, including the apical form that appears most commonly in Japanese people (Figure 1D). Left ven...
tricular hypertrophy is characteristi-
cally asymmetric, with the anterior sep-
tum usually predominant (Figure IA-D,
F; Figure 2A), although a few patients
show a symmetric (concentric) pattern
(Figure IE).5,16,19 Distribution of LV wall
thickening shows no direct linkage to
outcome, although distal hypertrophy is
associated with the absence of obstruct-
ion.15,19 Young children may present with
LVH resembling HCM as part of other
disease states (eg, Noonan syndrome,
mitochondrial myopathies, and meta-
bolic disorders) unrelated to HCM-
causing sarcomere protein mutations.
Other markers of HCM that are not
obligatory prerequisites for diagnosis
include a hypercontractile LV and
dynamic subaortic obstruction typi-
ically produced by mitral valve systolic
regurgitation (Figure 1E).15,16,19
Distribution of LV wall
thickening usually predominates in the
apical portions of LV wall (average, 33%)
and is more extensive in young pa-
tients who die of their disease.72,74,75
Such myocardial scarring supports clinical
evidence that ischemia frequently occurs
within the natural history of HCM and
may serve as the substrate for prema-
ture heart failure–related death.74 It is
also evident that the cardiomyopathic
process in HCM is not confined to areas
of gross wall thickening and that nonhy-
pertrophied regions also contribute to
ischemia or impaired diastolic func-
tion.86,88,89,91,94-96
Disorganized cellular architecture,1,71-73,75 myo-
cardial scarring,73,76,83-85,90 and expanded inter-
istitium (matrix) collagen83,97 probably
serve as arrhythmogenic substrates
predisposing to life-threatening elec-
trical instability. This substrate is
likely the source of primary ventricu-
ticular tachycardia and ventricular fibril-
lation, which appear to be the pre-
dominant mechanisms of sudden
death,98-101 either primarily or in asso-
ciation with triggers intrinsic to the
disease process, namely, myocardial
ischemia, systemic hypertension,
supraventricular tachyarrhythmias, or
environmental variables (eg, intense
physical exertion).
Penetration and variability of pheno-
typic expression are undoubtedly influ-
enced by factors other than disease-
causing mutant genes such as modifier
genes (eg, angiotensin-converting enzyme
genotype).102,103 Coexistent hypertension,
or lifestyle. Indeed, several phenotypic
manifestations of HCM do not primar-
ily involve sarcomeric proteins, includ-
ing increased interstitial collagen,83,97 ab-
normal intramural arteries,76,77 and mi-
tral valve malformations such as elongated
leaflet10-12 or direct papillary muscle in-
sertion into the mitral valve.17
Clinical Course
Hypertrophic cardiomyopathy is unique
among cardiovascular diseases by vir-
tue of its potential for clinical presenta-
tion during any phase of life (from in-
fancy to >90 years of age).† Although
adverse clinical consequences have been
recognized for many years, particularly
†References 1-8, 19, 20, 51, 52, 54, 98, 99, 105-
115.

Historically, misperceptions regard-
ing the clinical significance of HCM have
prevailed because of its relatively low
prevalence in cardiac populations,20,21
extreme heterogeneity,5,32 and skewed
patterns of patient referral that created
important selection biases.111,121,122
Indeed, much of the data assembled
throughout the past 40 years have been
disproportionately generated by a few
tertiary centers largely composed of patients
preferentially referred because of their
high-risk status or severe symptoms
requiring specialized care such as sur-
gery.111,121,122 Hence, the older literature
was dominated by the most adverse con-
sequences of HCM, while clinically stable,
asymptomatic, and elderly patients were
underrepresented.105,112-115,121
Consequently, the risks of HCM would
appear to have been overestimated by de-
pendence on frequently cited, ominous
mortality rates of 3% to 6% annu-
ally.108,119 These figures, based largely on
skewed tertiary-center experience, have
contributed greatly to the misguided per-
ception that HCM is a generally unfa-
orable disorder. Recent reports through-
out the last 7 years from less selected
regional or community-based HCM pa-
tient cohorts cite much lower annual
mortality rates, about 1%,120-126 not dis-
similar to that for the general adult US
population.111 Such data provide a more
balanced view in which HCM may be asso-
ciated with important symptoms and
premature death but more frequently
with no or relatively mild disability and
normal life expectancy.103,111,113,115,121,124
Elderly HCM patients (≥75 years)
have been reported to compose as much
as 25% of an HCM cohort, with only a
minority having severe manifestations of
heart failure.115 Outflow obstruction is
commonly evident in patients of
advanced age (ie, in about 40%), sug-
gest-ing that subaortic gradients may be
well tolerated for long periods without
adverse consequences. Indeed, HCM in
elderly patients can be a genetic disor-
der caused by dominant sarcomere pro-
tein mutations most commonly in car-

HYPERTROPHIC CARDIOMYOPATHY

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Hypertrophic cardiomyopathy (HCM) clinical subgroups are not necessarily mutually exclusive; overlap or progression from one subgroup to another may occur (thin solid and dashed arrows). Most patients with HCM who are at high risk of sudden death or who develop atrial fibrillation are initially in the “None or Mild Symptoms” clinical subgroup. Asterisk indicates that patients with a positive genotype and negative phenotype may subsequently show morphologic conversion to the HCM phenotype with left ventricular hypertrophy (usually in adolescence, but also in mid-life or later). Dagger indicates that drug therapy may include β-blockers, calcium channel blockers (particularly verapamil), disopyramide, as well as diuretic agents. Double dagger indicates that for major interventions, obstructive HCM is generally regarded as a left ventricular outflow gradient of approximately 50 mm Hg at rest or with provocative maneuvers; in this context, nonobstructive HCM is regarded as a left ventricular outflow gradient of less than approximately 30 to 50 mm Hg at rest as well as with provocative maneuvers. Width of the arrows from the overall HCM population represent the approximate relative proportion of patients with HCM within each major clinical subgroup. Adapted from Spirito et al7 with permission of the Massachusetts Medical Society.
An important but complex objective has been the identification of such higher-risk individuals among the vast HCM spectrum. For example, sudden death can be the initial manifestation of HCM, and such patients usually have no or only mild prior symptoms. Although sudden death occurs most commonly in children and young adults, risk extends across a wide age range through midlife and beyond; therefore, achieving a particular age does not confer immunity to sudden catastrophe. Sudden death occurs most commonly during mild exertion or sedentary activities but is not infrequently related to vigorous physical exertion. Indeed, HCM is the most common cause of cardiovascular sudden death in young people, including trained competitive athletes (most commonly in basketball and football and in black athletes).

The majority of HCM patients (55%) do not demonstrate any of the acknowledged risk factors in this disease, and it is exceedingly uncommon for such patients to die suddenly; the subset at increased risk appears to comprise about 10% to 20% of the HCM population. Highest risk for sudden death in HCM has been associated with any of the following noninvasive clinical markers (Figure 3): prior cardiac arrest or spontaneous sustained ventricular tachycardia; family history of premature HCM-related death, particularly if sudden, in close relatives, or multiple; syncope and some cases of near-syncpe, particularly when exertional or recurrent, or in young patients when documented as arrhythmia-based or clearly unrelated to neurocardiogenic mechanisms; multiple and repetitive or prolonged bursts of nonsustained ventricular tachycardia on serial ambulatory (Holter) ECG recordings; hypotensive blood pressure response to exercise, particularly in patients younger than 50 years; and extreme LVH with maximum wall thickness ≥30 mm, particularly in adolescents and young adults.

The latter risk factor emanates from a continuous, direct relationship between maximum LV wall thickness and sudden death, which supports the magnitude of LVH as a determinant of prognosis in HCM. Exceptions to that association are a few highly selected HCM families with multiple sudden deaths and mild LVH caused by troponin T mutations. Description of the total HCM risk profile is probably incomplete, and no single disease feature or test is capable of stratifying risk in all patients.

There is only a suggested association but no clinically relevant and independent linkage between sudden death and outflow obstruction, although data on particularly large (≥100 mm Hg) gradients are limited. One report suggests that short, tunneled (bridged) segments of left anterior descending coronary artery, mediated by ischemia, independently convey increased risk for cardiac arrest in children with HCM.

Presentation of HCM in young children is exceedingly uncommon and usually creates a clinical dilemma because of diagnosis (often fortuitous) so early in life and the uncertainty regarding risk over such long periods. Studies of HCM in children report annual mortality rates of 2% (community-based populations) to 6% (tertiary referral cohorts). It has been proposed, based on genotype-phenotype correlations, that the genetic defects responsible for HCM could represent the primary determinant and stratifying marker for sudden death risk, with specific mutations conveying either favorable or adverse prognosis. For example, some β-myosin heavy chain mutations (eg, Arg403Gln and Arg719Gln) and some troponin T mutations may be associated with a higher frequency of premature death compared with other mutations, such as those of myosin-binding protein C (InsG791) or α-tropomyosin (Asp175Asn). However, caution is warranted before strong conclusions are drawn regarding prognosis based solely on the available epidemiologic genetic data, which are relatively limited and skewed by virtue of selection bias toward high-risk families. Access to the molecular biology of HCM does not yet represent a clinically relevant strategy that routinely affects disease management.

Prognosis attached to adult gene carriers without LVH appears to be mostly benign. There is no available evidence to justify routinely precluding genotype-positive–phenotype-negative individuals of any age from most activities or employment opportunities.

The role of invasive strategies such as electrophysiologic testing with programmed ventricular stimulation and the significance of induced arrhythmias in detecting the substrate for ventricular fibrillation in individual HCM patients are unresolved. Limitations include the infrequency with which monomorphic ventricular fibrillation is provoked and the nonspecificity of rapid polymorphic ventricular tachycardia and ventricular fibrillation.

Although attention has understandably focused on high-risk HCM patients, the absence of risk factors and certain clinical features can be used to develop a profile of HCM patients at low likelihood for sudden death caused by life-threatening rhythm disturbances, as well as other adverse events (eg, at a rate of <1% annually). Adult patients most likely at lowest risk are those with no or only mild congestive symptoms in the absence of the following: family history of HCM-related premature death; syncope (or near-syncpe) judged unlikely to be neurocardiogenic in origin; nonsustained ventricular tachycardia during ambulatory Holter ECGs; marked LV outflow gradient of at least 50 mm Hg; substantial LVH (wall thickness ≥20 mm); left atrial enlargement (>45 mm); and hypotensive blood pressure response to exercise. Such patients with favorable prognosis constitute an important proportion of the overall HCM population and generally

References 3, 7, 11-13, 23, 24, 26, 27, 41, 42, 47, 134-136, 139-141.
deserve a measure of reassurance regarding their disease.3,7

Most HCM patients should undergo a risk stratification assessment (probably with the exception of patients older than 60 years) that requires, in addition to careful history taking and physical examination, noninvasive testing with 2-dimensional echocardiography, 24- or 48-hour ambulatory Holter ECGs, and treadmill (or bicycle) exercise testing. Such evaluation and follow-up should be carried out by (or involve) qualified specialists in cardiovascular medicine.

Prevention. In HCM, treatment strategies to reduce risk for sudden death have been historically predicated on drugs such as β-blockers, verapamil, and antiarrhythmic agents (ie, quinidine, procainamide, and amiodarone).4,116,117,143-145 Nevertheless, there is little evidence144 that prophylactic pharmacological strategies and rhythm-modulating drugs effectively reduce risk for sudden death; furthermore, because of its potential toxicity, amiodarone is unlikely to be tolerated throughout the long risk periods characteristic of young HCM patients. Therefore, there would appear to be little justification for prophylactic drug treatment in asymptomatic HCM patients, whether or not they are judged to be at high risk.145

At present, the implantable cardioverter-defibrillator (ICD) appears to be the most effective treatment modality for the high-risk HCM patient, with the potential to alter natural history (Figure 3).2,3,7,8,10 In a large multicenter study, ICDs aborted potentially lethal ventricular tachyarrhythmias and restored sinus rhythm in almost 25% of patients throughout a brief 3-year follow-up.28 Appropriate device interventions occurred at 11% annually for secondary prevention (implant following cardiac arrest) and 5% annually for primary prevention (implant based on risk factors), usually in patients with no or only mild prior symptoms.28 Patients receiving appropriate shocks were young (mean, 40 years), and ICDs often remained dormant for prolonged periods before discharging (up to 9 years), emphasizing the unpredictability of sudden death events in HCM.

Sudden death prevention with the ICD is most strongly warranted for patients with prior cardiac arrest or sustained spontaneous ventricular tachycardia. Although multiple risk factors convey increasingly greater sudden-death risk,47 a single major risk factor in an individual patient may be sufficient to justify strong consideration for primary prevention with an ICD. Nevertheless, uncertainty persists regarding precisely which HCM patients with only 1 risk factor should be candidates for prophylactic ICD treatment,41,42,98 and therefore individual clinical judgment taking into account the overall clinical profile, including age, apparent strength of the risk factor identified, and the level of risk acceptable to the patient and family, may be necessary to definitively resolve many of these clinical decisions. Also, physician and patient attitudes toward ICDs (and also access to the devices) can vary considerably among countries and cultures and profoundly affect clinical decision making.72,98,146

Intense physical exertion constitutes a sudden-death trigger in susceptible individuals.43 Therefore, to reduce risk, disqualification of athletes with unequivocal evidence of HCM from most competitive sports has been prudently recommended by a national consensus panel.147

Atrial Fibrillation. Atrial fibrillation is the most common sustained arrhythmia in HCM, accounting for unexpected hospital admissions and unscheduled work loss, and therefore usually justifies aggressive therapeutic strategies (Figure 3). Paroxysmal episodes or chronic AF ultimately occur in 20% to 25% of HCM patients, increase in incidence with age, and are linked to left atrial enlargement.111,120,129-131 Atrial fibrillation is reasonably tolerated by about one third of patients and is not an independent determinant of sudden death.130 However, AF is associated with embolic stroke (incidence, about 1% annually; prevalence, 6%), leading to death and disability most frequently in the elderly,130 as well as progressive heart failure, particularly when AF onset occurs before 50 years of age and is associated with basal outflow obstruction.130

Paroxysmal AF may be responsible for acute clinical decompensation, requiring electrical or pharmacological cardioversion.6,7,8 Although data in HCM patients are limited, amiodarone is regarded as effective for reducing AF recurrences. In chronic AF, β-blockers and verapamil effectively control heart rate, although A-V node ablation with permanent ventricular pacing may occasionally be necessary. Because of the potential for clot formation and embolization, anticoagulant therapy with warfarin is indicated in patients with either recurrent or chronic AF. Since 1 or 2 paroxysms of AF have been associated with the risk for systemic thromboembolism in HCM, the threshold for initiation of anticoagulant therapy should be low.130,131 However, such clinical decisions should be tailored to the individual patient after the obligatory lifestyle modifications, risk of hemorrhagic complications, and expectations for compliance have been considered.

Heart Failure. Presentation. Symptoms such as exertional dyspnea, orthopnea, paroxysmal nocturnal dyspnea, and fatigue are common, characteristically in the presence of normal or supranormal LV contractility and independent of whether outflow obstruction is present (Figure 3).2,3,8,148-154 Such symptoms of HCM-related heart failure are usually deferred until adulthood but may occur at any age.

Marked symptom progression (to New York Heart Association classes III and IV) is relatively infrequent, developing in about 15% to 20% of an unselected population, and such exertional disability may evolve at varying rates; deterioration is often gradual and punctuated with long periods of stability and day-to-day variability (Figure 3).2,3,7

Congestive symptoms and exertional limitation in HCM appear to be largely the consequence of diastolic dysfunction in which impaired LV relaxation, increased chamber stiffness, and compromised left atrial systolic function impede filling, leading to elevated left
atrial and LV end-diastolic pressures with reduced stroke volume and cardiac output. These mechanisms result in pulmonary congestion with diminished exercise performance\(^1\)\(^4\)\(^8\)\(^-\)\(^{154}\) evidenced by reduced peak oxygen consumption.\(^{155}\) However, heart failure related to diastolic dysfunction may also be intertwined with other pathophysiological mechanisms such as myocardial ischemia, outflow obstruction, and AF.\(^3\)\(^,\)\(^7\)\(^,\)\(^130\)

Chest pain suggestive of myocardial ischemia (with angiographically normal coronary arteries), either typical or atypical of angina, is a symptom commonly associated with exertional dyspnea.\(^2\)\(^,\)\(^8\)\(^,\)\(^9\)\(^1\)\(^-\)\(^9\)\(^3\) Myocardial perfusion defects, net lactate release during atrial pacing, and blunted coronary flow reserve constitute evidence of ischemia likely caused at least in part by an abnormal microvasculature.\(^7\)\(^6\)\(^-\)\(^8\)\(^2\)\(^,\)\(^4\)\(^8\)\(^-\)\(^8\)\(^8\)\(^,\)\(^156\)\(^,\)\(^157\)

The role of ischemia in risk stratification is unresolved, in part because the clinical assessment of ischemia (and that of diastolic dysfunction) have been limited by an inability to noninvasively measure these abnormalities with quantitative precision.

**Drug Treatment Strategies.** If exertional symptoms of heart failure intervene, it is conventional to initiate pharmacological therapy with negative inotropic drugs such as \(\beta\)-adrenergic blockers or verapamil, independent of whether outflow obstruction is present (Figure 3).\(^3\)\(^,\)\(^8\)\(^,\)\(^1\)\(^0\)\(^-\)\(^1\)\(^6\)\(^2\)\(^,\)\(^2\)\(^8\)\(^,\)\(^3\)\(^8\)\(^,\)\(^1\)\(^6\)\(^3\)\(^-\)\(^1\)\(^6\)\(^5\) Patients who do not experience improvement of symptoms with one drug may subsequently benefit from the other, but combined administration is not advantageous.\(^3\)

However, verapamil may be deleterious to some patients with severe outflow gradients and heart failure,\(^8\)\(^,\)\(^1\)\(^6\)\(^3\) and some investigators favor disopyramide (often with a \(\beta\)-blocker) for such severely symptomatic patients with obstruction and verapamil or \(\beta\)-blockers in patients who do not develop obstruction.\(^1\)\(^6\)\(^4\)\(^-\)\(^1\)\(^6\)\(^6\) There are comparatively few data available regarding the use of other calcium channel blockers such as dil-tiazem in HCM for relief of symptoms. Patients who develop severe symptoms of heart failure associated with systolic dysfunction and deteriorate into the end stage require alternative drug treatment with diuretics, vasodilators, and digitalis.\(^3\)\(^,\)\(^7\)\(^,\)\(^8\)\(^,\)\(^6\)\(^1\)\(^,\)\(^1\)\(^6\)

\(\beta\)-Blockers may mitigate predominantly provocative gradients (induced with interventions such as physiologic exercise or Valsalva maneuver, isoproterenol infusion, or amyl nitrite inhalation),\(^2\) and disopyramide may reduce some subaortic gradients at rest,\(^1\)\(^6\)\(^4\)\(^-\)\(^1\)\(^6\)\(^6\) mediated by ventricular afterload reduction and slowing of the LV ejection acceleration.\(^1\)\(^6\)\(^6\) For patients with outflow obstruction, risk for bacterial endocarditis (usually involving the mitral valve) dictates prophylactic administration of antimicrobial drugs, primarily to patients with obstruction, before dental procedures or surgery.\(^1\)\(^6\)\(^8\)

**Surgical Treatment.** Should severe heart failure–related symptoms become unrelenting and refractory to pharmacological treatment, and lifestyle unacceptable, subsequent therapeutic decisions are determined largely by whether basal obstruction to LV outflow is present (peak instantaneous gradient \(\geq 50\) mm Hg) (Figure 3).\(^3\)\(^,\)\(^4\)\(^,\)\(^6\)\(^-\)\(^8\)

Throughout the past 40 years, the experience of many centers worldwide has caused the ventricular septal myotomy–myectomy operation (Morrow procedure) to become established as the standard therapeutic option (ie, “gold standard”) for adults and children with obstructive HCM and severe drug-refractory symptoms.\(^3\)\(^,\)\(^6\)\(^,\)\(^8\)\(^,\)\(^1\)\(^6\)\(^3\)\(^-\)\(^1\)\(^6\)\(^5\) However, operative candidates represent only a small (5%) although important subset of the overall HCM population.\(^7\)

Operation requires resection of a small amount of muscle (about 5 g) from the proximal septum extending just beyond the distal margins of mitral leaflets, thereby abolishing any significant impedance to LV outflow.\(^1\)\(^6\)\(^9\) Other surgeons have used a low-profile mitral valve prosthesis in patients judged to have unfavorable septal morphology\(^1\)\(^7\)\(^,\)\(^1\)\(^7\) or with intrinsic mitral valve disease (such as myxomatous degeneration) accounting for severe mitral regurgitation.\(^1\)\(^8\)\(^3\)\(^,\)\(^1\)\(^8\)\(^3\) Papillary muscle insertion directly into the mitral valve, producing muscular midcavity obstruction, requires distally extended septal resection or valve replacement.\(^1\)\(^7\)\(^,\)\(^1\)\(^8\)\(^0\)

Myotomy–myectomy performed at experienced surgical centers in the absence of associated conditions has acceptably low operative mortality (\(\leq 2\%\)). Most patients (about 70%) achieve subjective improvement in symptoms and exercise capacity 5 years or longer after their operation and often for extended periods. Improved metabolic and hemodynamic measures\(^1\)\(^8\) associated with symptomatic benefit following myotomy–myectomy appear to be largely the consequence of abolition or substantial reduction in basal outflow gradient\(^1\)\(^7\)\(^0\)\(^-\)\(^1\)\(^8\)\(^4\) and normalization of LV pressures (in \(>90\%\) of patients),\(^3\)\(^,\)\(^6\)\(^,\)\(^8\)\(^,\)\(^1\)\(^6\)\(^9\)\(^-\)\(^1\)\(^8\)\(^3\) as well as alleviation of the mild to moderate mitral regurgitation that is secondary to obstruction.\(^1\)\(^8\)\(^3\) Patients in whom severe refractory symptoms can be linked to large outflow gradients present only under provokable conditions, such as elicited physiologically with exercise, may also benefit from myotomy–myectomy.\(^1\)\(^7\)\(^5\)

Consistent relief of severe symptoms following surgery is evidence that marked outflow gradients and increased LV systolic pressure are of clinical significance to many patients. However, outflow obstruction is not deleterious to all patients, since it is now evident that large gradients may be tolerated for long periods with no or little disability.\(^1\)\(^1\) Consequently, although the outflow gradient is a highly visible and quantifiable component of HCM, it is also typically labile and hemodynamically sensitive to alterations in ventricular volume and systemic vascular resistance,\(^2\)\(^4\)\(^,\)\(^5\)\(^,\)\(^1\)\(^8\)\(^7\)\(^-\)\(^1\)\(^8\)\(^9\) even after standing or a heavy meal, and should not be regarded as equivalent to the disease itself.\(^1\)\(^9\)\(^0\)\(^,\)\(^1\)\(^9\)\(^1\) Although major interventions can be advantageous by reducing the outflow gradient when it is judged to be persistent and the cause of severe symptoms, the presence per se of subaortic obstruction unassociated with marked disability is rarely the sole justification for such treatment.\(^1\)\(^9\)\(^1\)
Alternatives to Surgery. Some operative candidates may not have ready access to major centers experienced with myotomy-myectomy because of geographical factors, or they may not be regarded as favorable operative candidates because of concomitant medical conditions, advanced age, prior cardiac surgery, or insufficient motivation.7

Therefore, 2 treatment options have emerged as potential alternatives to surgery for selected patients (Figure 3). First, in uncontrolled and observational studies, chronic dual-chamber pacing was associated with amelioration of symptoms and reduction of outflow gradient in many HCM patients.192-198 However, several randomized crossover clinical trials reported that subjective symptomatic benefit during pacing frequently occurs with little objective evidence of improved exercise capacity194-196 and can be largely explained as a placebo effect.192,195,196,198 Although pacing is not a primary treatment for HCM, 1 study showed that elderly patients (older than 65 years), a subgroup for which alternatives to surgery are often desirable, experienced objective improvement in symptoms with pacing.195 While myotomy-myectomy provides superior results to pacing in most patients, a dual-chamber pacing trial prior to myotomy-myectomy could be of value in selected candidates, given that pacing (1) is implicitly less invasive than surgery or alcohol septal ablation, (2) is a more widely accessible method to the practicing cardiologist, (3) can permit more aggressive drug treatment by obviating concern for drug-induced bradycardia, (4) may be withdrawn, and (5) does not obviate subsequent implementation of invasive procedures. Pacing does not reduce sudden-death risk significantly193,196 or trigger LV remodeling.195

A second alternative therapy to surgery is the recently developed alcohol septal ablation technique, which is a percutaneous coronary artery intervention using methods and technology available for atherosclerotic coronary artery disease.200-205 Absolute alcohol (about 1-4 mL) is introduced into the target septal perforator coronary artery branch to produce myocardial infarction, which in turn reduces basal septal thickness and motion, enlarges the LV outflow tract, and decreases mitral valve systolic anterior motion, thereby mimicking the hemodynamic consequences of myotomy-myectomy.200-203 Indeed, reductions in outflow gradient associated with alcohol septal ablation have been reported to be similar to those resulting from myotomy-myectomy,205 although a recent comparative analysis showed surgery to be superior to ablation in reducing resting and provoking gradients.207 Also, similar proportions of ablation and surgical patients have been reported to show subjective200-203 and objective204 improvements in congestive symptoms and quality of life over relatively short periods, largely in observational studies; in addition, there are unconfirmed claims of diffuse regression of LVH following ablation.204 However, alcohol septal ablation in HCM has not yet been subjected to the scrutiny of randomized or controlled studies.191,200

Septal ablation is associated with operative morbidity and mortality, similar to that of myotomy-myectomy; complications include permanent pacemaker for high-grade A-V block, coronary dissection, and large anterior infarction.200-203 In contrast to that for surgery, the postprocedural follow-up for alcohol septal ablation is relatively brief (about 3-5 years compared with 40 years for myotomy-myectomy).101

Furthermore, ablation alone potentially creates a permanent, electrically unstable substrate for lethal reentrant ventricular tachyarrhythmias by virtue of the healed intramyocardial septal scar in some HCM patients who are already undoubtedly predisposed to arrhythmogenesis; this consideration raises some uncertainty regarding the long-term risks of alcohol septal ablation.101

Heart Transplantation. Therapeutic options are considerably limited for patients who have the nonobstructive form of HCM and experience drug-refractory severe symptoms, including those in the end-stage phase.61 This subset of patients, among the broad HCM spectrum, may become candidates for heart transplantation.61,82

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