Original Article

The value of hand grip strength (HGS) as a diagnostic and prognostic biomarker in congenital heart disease

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Background: In patients with congenital heart disease (CHD), there is little data on the diagnostic and prognostic relevance of hand grip strength (HGS) for clinical assignment, while in the general population the loss of muscle strength and mass is an important risk factor in cardiovascular disease which is conversely associated with morbidity and all-cause mortality. This study aimed to assess the degree of muscle dysfunction using HGS as a biomarker in a large group of patients with CHD who often develop muscle dysfunction.

Methods: In total, 385 patients (27.6±13.1 years, 43% female) were included and assigned to 5 diagnostic groups: complex anomalies (n=131), left heart anomalies/aortopathies (n=107), right heart/pulmonary artery anomalies (n=92), primary left to-right-shunts (n=42) and miscellaneous CHD (n=13). Patients with Fontan circulation, chronic cyanosis, morphologic right systemic ventricle, arterial switch operation, or Ebstein's anomaly were analyzed separately. A control group (CG) consisted of 124 healthy individuals (30.1±12.1 years, 42% female). HGS was measured with a Jamar Hydraulic Hand Dynamometer.

Results: HGS was reduced in CHD patients compared to controls (35.2±14.6 versus 43.7±14.4 kg). Most impairments were present in females (26.1±7.6 kg). Patients with cyanosis had lower HGS values compared to acyanotic CHD patients (P=0.03). Patients with left heart lesions had the highest HSG values (40.7±14.7 kg), while patients with primary left-to-right shunt lesions had the lowest HSG values (30.9±11.3 kg). Within specific groups of cardiac anomalies, patients with Fontan circulation showed the lowest (P=0.033) and patients with a morphologic right system ventricle showed higher results (P=0.004). The late mid-term survival was favorable, and 7 patients (1.8%) died in a median interval of 422 days (range, 206–1,824 days) after HGS-testing.

Conclusions: This study provides the most comprehensive data on the use of HGS in CHD to date. Grip strength is an easily applicable, repeatedly usable and a cost-effective diagnostic tool to gain a quick, quantifiable assessment of the patient's current muscle function as an expression of cardiac fitness. Considering the low number of patients who died in the observation period, HGS may not be a suitable tool for survival assessment or identification of patients at risk. However, HGS is well suited to determine muscle function and strength and thereby to identify and to follow-up patients who have an increased cardiovascular risk.

Keywords: Hand grip strength (HGS); congenital heart disease (CHD); follow-up; prevention

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Introduction

Although today most patients born with congenital heart disease (CHD) survive into adulthood, morbidity and mortality of CHD are still high (1). The natural and unnatural history is often complicated by residues and sequels of the particular CHD, which includes heart failure, pulmonary vascular disease, arrhythmias, multi-organ involvement, comorbidities and cardiac death (2-4).

Depending on the type of CHD and the treatment status, CHD patients may experience muscle mass loss due to low levels of physical activity. Functional exercise capacity and physical reserves are frequently reduced, and may denote patients at risk for hospitalization or death (2,5,6). In order to identify high-risk patients in time, not only an increased awareness of the treating physician is required, but also effective, easily available and cost-effective biomarkers. Research from cardiological fields which are different from CHD suggests that hand grip strength (HGS), measured by a dynamometer, may provide reliable information on the clinical status of a patient and possibly predict adverse outcomes, because muscle strength is associated with all-cause mortality regardless of cardiorespiratory fitness (7-11).

Since there is little data on the use of HGS for clinical assignment in patients with CHD, the objective of this study was to describe the presence and degree of skeletal muscle dysfunction with HGS as an expression of health, fitness and the functional status in a large cohort of patients with CHD. Moreover, the mid-term survival of ACHD should be assessed depending on the HGS-test results.

Methods

This case control study was conducted in the Department of Congenital Heart Disease and Pediatric Cardiology of the German Heart Centre Munich.

All clinical evaluations were part of the regular management of the patients that these required for management of their medical conditions. No additional examination was performed for the sole purpose of the study. All data were assessed and analyzed in an anonymous way. Ethical approval has been waived because it is routine clinical data, and all patients gave written consent to their anonymous publication.

Patients were consecutively included from January 2013 until September 2013 in the order that they presented at our institution and were not selected in prior.

Inclusion criteria for the present study were a confirmed diagnosis of CHD. Exclusion criteria were obvious signs of muscle weakness or musculoskeletal abnormalities, lack of cognitive competence to consent to research, and refusal to consent. Also excluded were severely disabled patients with decompensated heart failure and patients confined to bed by illness.

Medical records were reviewed for patient demographics, cardiac and non-cardiac diagnosis, surgical, interventional or electrophysiological procedures, clinical condition and medication.

The severity of congenital heart anomaly was categorized as mild (ACC-Class I), moderate (ACC-Class II), or severe (ACC-Class III) according to Warnes (12,13). Likewise, disorders not mentioned in this classification were similarly classified according to the experience of the German Heart Center Munich. In addition, patients were assigned to one of five major groups depending on the type of underlying CHD: (I) complex CHD; (II) left heart anomalies/aortopathies; (III) right heart anomalies/anomalies of pulmonary valve or pulmonary artery; (IV) primary left-to-right shunt—either at pre-tricuspid or post-tricuspid level, or (V) other congenital heart anomalies (12).

Patients with Fontan circulation or severe chronic cyanosis (defined as arterial oxygen saturation ≤90%), or with a morphologic right systemic ventricle (transposition of the great arteries after Mustard or Senning procedure; congenitally corrected transposition of the great arteries), or with transposition of the great arteries after arterial switch operation, or with Ebstein's anomaly, were analyzed separately.

Patients with CHD were compared with a control group (CG) of 124 healthy individuals who showed no pathological clinical signs of the musculoskeletal system.

The control subjects were volunteers recruited from a range of high schools, colleges, universities, companies and administration organizations in our geographical region.

HGS was measured according to a standardized protocol using a Jamar Hydraulic Hand Dynamometer (Jamar Hydraulic Hand Dynamometer Model 5030J1; Sammons Preston, Bolingbrook, IL, USA) (14). As recommended by the American Society of Hand Therapists, patients were instructed to sit in an upright position with shoulders adducted, elbow-flexed at 90°and forearms in neutral position (8,15). All participants were encouraged to give their best effort in isometric grip strength, with one repetition for each hand. The test was repeated 3 times, alternating between each hand. The maximum values of each hand were determined. Only maximum values of the dominant hand were used for statistical analysis. Age and

sex differences were considered in a linear regression. HGS was classified as normal if the results fell within the 95% confidence interval or higher and abnormal if their results fell below this level.

In addition, all included patients were reevaluated from January until August 2018 in our outpatient clinic, or were contacted by telephone for the assessment of mid-term survival.

Statistical analysis

The descriptive data were expressed in mean values and standard deviations (mean ± SD). Differences in HGS between CHD, the healthy CG and CHD subgroup analysis were evaluated using linear regression models with gender and age as covariates. P-values <0.05 in a two-sided analysis were considered significant. STATA 14.2 (STAT Corp.) was used for statistical analysis.

Results

A total of 385 patients with CHD were suitable for the present analysis and were enrolled. The diagnosis of CHD was made in accordance to the specific expert guidelines (16,17). General characteristics and detailed underlying diagnosis are listed in *Table 1*. A total of 166 patients (43%) were female. Mean age at time of study inclusion was 27.6±13.1 years. The CG consisted of 124 healthy individuals. Mean age at the time of study inclusion was 30.1±12.1 years, 52 patients (42%) were female. Out of the 385 patients 320 (83%) had at least one previous heart operation for their CHD; 65 patients (16.9%) had not undergone any cardiac surgery (*Tables 2,3*).

The classification according to the recommendations of the American College of Cardiology (ACC-Classification), modified by the Munich experience (12), showed simple defects in 57 (15%), moderate defects in 124 (32%), and severe defects in 204 (53%) cases.

Assigned to the type of underlying CHD 131 (34%) patients had complex CHD, 107 (30%) had left heart anomalies/aortopathies, 92 (24%) had right heart anomalies/anomalies of pulmonary valve or pulmonary artery, 42 (11%) had primary left-to-right shunt—either at pre-tricuspid or post-tricuspid level, and 13 (3.4%) had other congenital heart anomalies.

In the entire cohort of 385 patients 17 (4.4%) had a Fontan-circulation, and 24 (6.2%) had chronic cyanosis. Thirty-six patients, including 25 (6.5%) patients after Mustard or Senning procedure for complete transposition of the great arteries, as well as 11 (2.9%) patients with congenitally corrected transposition of the great arteries had a morphologic right systemic ventricle. An arterial switch operation for transposition of the great arteries was performed in 25 patients (6.5%), and 22 patients (5.7%) had Ebstein's anomaly.

In the entire group of patients with CHD HGS was 35.1±14.6 kg and significantly reduced compared to the healthy CG (43.2±14.7 kg, P<0.001) (*Figure 1*) on average −5.71 kg (95% CI: −7.61 to −3.81 kg), controlled for sex and age.

Patients with left heart anomalies (Group II) showed highest values for HGS compared to the entire CHD group (mean 40.7±14.7 kg) and did not differ from the CG (P=0.102).

The lowest HGS (mean of 30.9±11.3 kg) was verified in patients with previous primary left-to-right shunts—either at pre-tricuspid or post-tricuspid level. In this group, HGS was −12.36 kg (95% CI: −16.67 to −8.04 kg) lower compared to healthy controls (*Figure 2A*).

Within the three ACC groups, there were no significant differences concerning HGS (P=0.207). CHD patients with cyanosis had −3.25 kg (95% CI: −6.18 to −0.31 kg) lower HGS values compared to acyanotic CHD patients (P=0.03). If controlled for sex and age, there were no significant differences detected (P=0.130).

Male subjects with CHD had significantly higher HGS values (mean 42.0±14.9 kg) compared to female subjects with CHD (mean 26.1±7.6 kg). Male subjects with CHD had −5.62 kg (95% CI: −8.37 to −2.87 kg) HGS compared to healthy male controls (P<0.001), female subjects with CHD had −6.00 kg (95% CI: −8.14 to −3.86 kg) HGS compared to healthy female controls, both controlled for age (P<0.001) (*Figure 1*).

Regarding specific groups of disorders, patients with a morphologic right system ventricle showed better results in HGS (5.56 kg, 95% CI: 1.75 to 9.37 kg) (P=0.004) whereas patients with Fontan circulation exhibit significantly lower HGS values (−5.43 kg, 95% CI: −10.44 to −0.43 kg) (P=0.033) (*Figure 2B*) compared to the entire CHD group, controlled for age and gender. In patients with a TGA after arterial switch operation or Ebstein's anomaly those marked differences could not be detected.

During the observation period, only seven (1.8%) of the 385 patients enrolled in the study died. The mean time interval between the date of the test and the date of death was 422 days (range, 206–1,824 days). Detailed information

Table 1 Patient demographics (n=385): type, number and percentage of CHD

Group	Congenital heart disease	N (% of total)
Group I: complex forms (n=131)	• Univentricular heart	22 (5.7)
	o Fontan circulation	17 (4.4)
	o Palliated univentricular hearts	5 (1.3)
	• Pulmonary atresia with intact ventricular septum	5 (1.3)
	• Ebstein's anomaly	22 (5.7)
	• Malposition of the great arteries	72 (18.7)
	o Complete transposition (TGA)	58 (15.1)
	o Congenitally corrected transposition	11 (2.9)
	o Double outlet right ventricle with TGA	3 (0.8)
	•Truncus arteriosus communis	10 (2.6)
Group II: left heart anomalies, including aortic anomalies (n=107)	• Aortic valve anomalies	63 (16.4)
	• Aortic coarctation	43 (11.2)
	• Others	1 (0.3)
Group III: right heart anomalies, or pulmonary artery anomalies (n=92)	• Pulmonary atresia with ventricular septal defect	24 (6.2)
	• Tetralogy of Fallot	49 (12.7)
	• Double outlet right ventricle - Fallot type	6 (1.6)
	• Pulmonary artery anomalies	13 (3.4)
Group IV: primary left-to-right shunt—either at pre-tricuspid or post-tricuspid level (n=42)	• Pre-tricuspid shunts	26 (6.8)
	o Atrial septal defect	21 (5.5)
	o Partial anomalous pulmonary venous connection	1 (0.3)
	o Partial atrioventricular septal defect	4 (1.0)
	o Others	1 (0.3)
	• Post-tricuspid shunts	16 (4.2)
	o Ventricular septal defect	10 (2.6)
	o Atrioventricular septal defect	5 (1.3)
	o Aorto-pulmonary window	1 (0.3)
Group V: miscellaneous CHD (n=13)	• Hypertrophic cardiomyopathy, congenital	1 (0.3)
	• Mitral valve disease, congenital	9 (2.3)
	• Tricuspid valve disease, congenital	1 (0.3)
	• Non-compaction cardiomyopathy	1 (0.3)
	• Others	1 (0.3)
Included in total		385 (100.0)

CHD, congenital heart disease.

Table 2 Demographic and clinical characteristics of ALL patients and controls

Descriptives	CHD-patients	Controls	P values
n	385	124	
Age (years)	27.6±13.1	30.1±12.1	0.059
Sex, n (%)			
Male	219 (56.9)	72 (58.1)	0.818
Female	166 (43.1)	52 (41.9)	
BMI (kg/m^2)	22.8±4.6	NA	–
Cyanosis, primary (n)	178	NA	–
Cyanosis, secondary (n)	24	NA	–
Modified ACC-severity	385	NA	–
I (mild), n (%)	57 (14.8)	NA	–
II (moderate), n (%)	124 (32.2)	NA	–
III (severe), n (%)	204 (53.0)	NA	–
Operated, n (%)	320 (83.1)	NA	–
Hand grip strength in kg (mean ± SD)	35.2±14.6	43.7±14.4	<0.001

ACC, American College Cardiology; BMI, body mass index; NA, not applicable.

Table 3 Demographic and clinical characteristics of all included patients, classified into the five diagnosis groups

Descriptives	I: complex, n (%)	II: left heart lesions, n (%)	III: right heart lesions, n (%)	IV: primary left-right shunts, n (%)	V: miscellaneous, n (%)	P values
n	131 (34.0)	107 (27.8)	92 (23.9)	42 (10.9)	13 (3.4)	–
Age (years)	27.5±12.2	25.5±11	27.3±14	34.5±18	24.7±11	0.004
Sex						
Male	72 (55.0)	78 (72.9)	47 (51.1)	16 (38.1)	6 (46.2)	0.001
Female	59 (45.0)	29 (27.1)	45 (48.9)	26 (61.9)	7 (53.8)	
BMI (kg/m^2)	23.1±4.7	23.3±4.6	22.3±4.7	22.5±4.3	21.4±3.7	0.35
Cyanosis, primary (n)	98	0	80	0	0	–
Cyanosis, secondary (n)	12	0	9	3	0	–
Modified ACC-Severity	131	107	92	42	13	–
I (mild)	0	26 (24.3)	2 (2.2)	21 (50.0)	8 (61.5)	–
II (moderate)	20 (15.3)	53 (49.5)	33 (35.9)	15 (35.7)	3 (23.1)	–
III (severe)	111 (84.7)	28 (26.2)	57 (62.0)	6 (14.3)	2 (15.4)	–
Operated (n)	127 (96.9)	79 (73.8)	86 (93.5)	25 (59.5)	3 (23.1)	–
Hand grip strength in kg (mean ± SD)	34.8±14.5	40.0±14.6	31.8±14.7	30.9±11.3	35.4±13.2	<0.001

ACC, American College Cardiology; BMI, body mass index.

is given in *Table 4*. The causes of death have not been established.

Discussion

In patients with CHD only scarce data exists about muscle strength and muscular endurance as indicators of physical and muscular fitness and as predictors of morbidity and mortality (18-21). In contrast, in the general population, several clinical and epidemiological studies have shown the predictive value of declining HGS concerning morbidity and all-cause mortality in the short and long-term (8,22-25).

In patients with CHD, this study provides the so far most comprehensive data on the use of HGS as a biomarker, including 385 children and adults (43% female, mean age 27.6±13 years; adults ≥18 years: n=277) with nearly all types and severity levels of CHD. The study demonstrates that HGS measured by a Hydraulic Hand Dynamometer can easily be used for the assessment of cardiac health, fitness and functional status.

Even if the mortality of patients with CHD has decreased, the morbidity is still high due to residua, sequelae or complications, and therefore most CHD defects require lifelong experienced cardiological follow up (26-30).

For a proper patient assessment, it is mandatory to understand the unique medical, social and psychological effects of living with a chronic heart disease from childhood, and for the clinical assignment it is worth knowing that only a loose correlation exists between the patient's subjective perceived health status and the objective clinical status. Because the pathoanatomical and pathophysiological complexity of CHD causes diagnostic problems, there is a deep need for a reliable, easily applicable, repeatedly usable and cost-effective diagnostic and prognostic marker, which allows gaining a rapid, quantifiable assessment of the current condition of the patient. This is of outstanding importance, as the clinical impression of the treating physician can be misleading, especially if he is not experienced in the evaluation of the particular disorder. Furthermore, a decline in the functional status, defined as the ability to perform daily live activities, is challenging to assess in patients with CHD because the definition is vague and measurement is difficult (15). Moreover, several studies have suggested that the severity of the CHD and the illness course are only marginally associated with patient's health perception, the

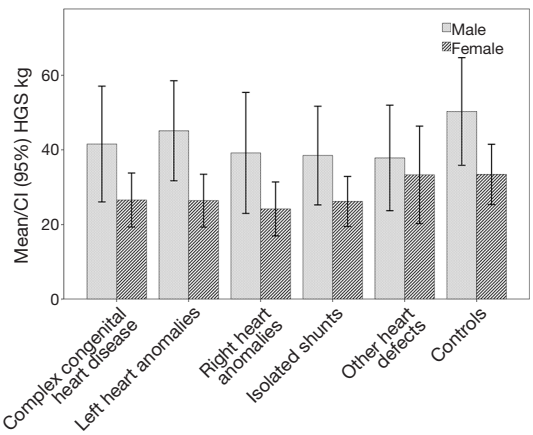

Figure 1 Mean hand grip strength in male and female patients with congenital heart disease, compared to healthy controls.

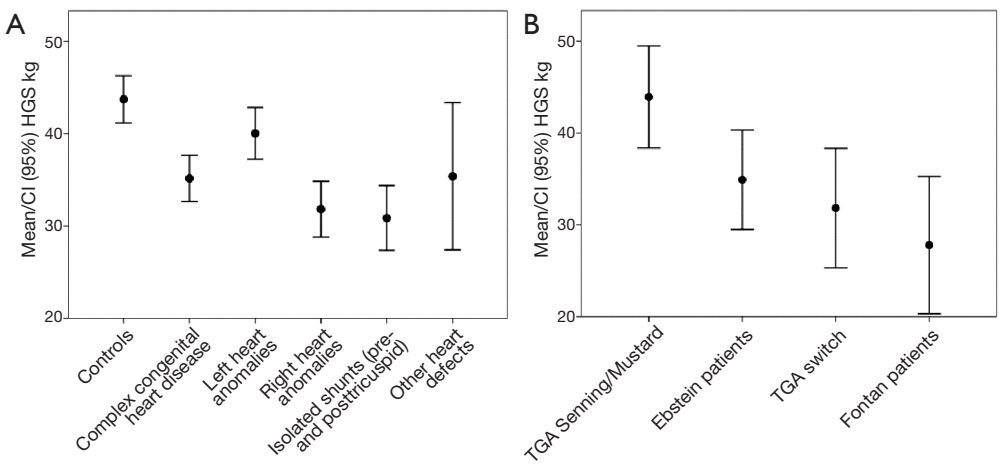

Figure 2 Comparison of mean hand grip strength (HGS) values. (A) Mean HGS in patients with congenital heart disease, assigned to the five major groups, compared to healthy controls. (B) Differences in mean HGS analyzed in specific subgroups.

Table 4 Clinical data of patients who died during the follow-up period

Descriptives	Mean/median [min–max]	Patient I	Patient II	Patient III	Patient IV	Patient V	Patient VI	Patient VII
Congenital cardiac anomaly		PAPVR	CCTGA	TOF	CCTGA	TOF	UVH pall.	VSD
Operated (O) or interventionally treated (I)	86% operated	O	O	O	O	O	O	O
Cyanosis (+)	43% cyanosis			+		+	+	
ACC-severity class	43% moderate/57% severe	Moderate	Severe	Moderate	Severe	Severe	Severe	Moderate
Sex	29% female/71% male	Female	Male	Male	Male	Male	Male	Female
Year of birth		1953	1978	1997	1958	1989	1977	1989
Year of death		2014	2015	2014	2014	2013	2015	2018
BMI (kg/m^2)	24.3/23.2 [19.5–32.4]	23.20	24.20	19.50	23.10	32.40	25.40	22.10
Age at death (years)	37/36 [17–60]	60	36	17	55	24	38	29
Interval since test (days)	681/422 [206–1,824]	343	692	422	341	206	940	1,824
HGS (kg)	28.9/28 [15–58]	28	29	28	28	58	15	16

ACC, American College of Cardiology; BMI, body mass index; HGS: hand grip strength; PAPVR, partial anomalous pulmonary venous return; CCTGA, congenitally corrected transposition of the great arteries; TOF, tetralogy of Fallot; UVH pall., univentricular heart; VSD, ventricular septal defect.

supposed condition and the quality of life (31). Therefore, subjective statements of patients regarding their current being have to be put into a proper perspective.

By applying clinical examination, technical methods, stress tests and modern biomarkers, it is possible to better classify the current health state. However, the results of complex clinical, technical, or laboratory studies are often inconclusive, contradictory and certainly associated with considerable costs. Besides, several studies have contradicted the assumption, that a significant association exists between systemic ventricular function and health status (31).

Without any doubt, cardiopulmonary exercise testing is an objective diagnostic and prognostic instrument for the assessment of patients with CHD (5,32). However, this method is time-consuming, costly, and requires a lot of experience for a proper interpretation of the results. In comparison, the current study reveals that HGS-measurement is an easy applicable test that can be incorporated into the physical examination in order to help objectively assess the current state of muscular fitness (15).

Various studies in patients without CHD could reveal that reduced muscle strength, measured by HGS, was associated with an increased mortality risk (23,24,33,34).

The current data from patients with CHD proves that muscular function, measured by HGS, is decisively influenced by the type and status of the heart defect, the initial morphological diagnosis, the severity of the disease, to previous surgical or interventional procedures, criteria such as residuals, sequels and complications (e.g., cyanosis). Comparing the results from the study cohort with data from 124 healthy controls reveals that HGS in patients with CHD in general is significantly reduced.

The most pronounced impairments are present in female CHD-patients ($P<0.001$). This can be explained at least in part by the fact that hand strength depends on hand length, which varies according to gender, with men generally having larger hands (35). Age and gender stratified normative data for HGS are available from the literature (36).

A striking observation is that in our patients HGS was significantly lower in patients with cyanosis if compared to acyanotic patients ($P=0.03$). This might be consistent with previous studies detecting in children and adults with cyanotic CHD abnormalities in skeletal muscle metabolism presumably contributing to the reduced exercise tolerance in the affected patients.

The highest HSG values had patients with left heart lesions and did not differ from the CG ($P=0.102$). Surprising is the fact that HGS was lowest in patients with primary left-to-right shunt lesions ($P<0.001$), as from the clinical experience these patients usually mostly have mild

CHD, a nearly well-preserved cardiac function and fewer medical problems relative to the patients in other CHD-groups. One might suspect that this is based on a bias, as patients with an uncomplicated course of a simple left-to-right shunt lesion are rarely seen in a tertiary care center, and the included patients had concomitant, perhaps non-cardiac problems.

Between specific groups of disorders (Fontan circulation, morphologic right systemic ventricle, TGA after arterial switch operation, Ebstein's anomaly) also marked differences could be detected, where patients with Fontan circulation exhibited the lowest (P=0.033), and patients with a morphologic right system ventricle showed better HGS-values (P=0.004).

Our results are at least partly consistent with results from other studies in CHD, which contain conflicting data. While some studies verify a normal muscle development, others report on a reduced HGS (18,19,37,38). The informative value of these data is, however, limited because of low numbers of patients included, the predominance of children, the lack of complex anomalies and missing data about the clinical outcome.

The mechanism, however, by which low muscle strength develops and how it might predispose to an adverse outcome or death is widely unknown. HGS may be controlled by multiple physiological systems and there are certain considerations that particularly patients with heart failure or multiple chronic diseases suffer from skeletal muscle atrophy, altered muscle metabolism, and reduced mitochondrial-based enzyme levels that may lead to decreased muscle force. Moreover, reduced oxygen delivery to peripheral and respiratory muscles from reduced blood supply and/or hypoxemia may result in hypoxic muscle tissue, an increased CO_2 retention and maladaptive changes in skeletal muscle (39-43). Low HGS could also be associated with subclinical inflammation, hyperthyroidism, increased interleukin-6, defects in insulin resistance and glucose metabolism and reduced insulin-like growth factor I (IGF-I) (43).

Certainly, HGS measurement, has some shortcomings as it is only an indicator of upper body strength and muscle function and cannot be accurately performed in patients who are unable or not willing to properly grip the dynamometer (15). However, from other studies data exist that handgrip strength is closely related to lower extremity force (39).

Further research is therefore needed to determine the potential benefits of using HGS as examination tool. It should be clarified more intensely, if a decrease in HGS over time is a predictor of a higher risk of dying from any cause, from heart disease, and of heart attacks or stroke. Therefore, in addition, the causative genetic, biological, and biochemical influences on muscle metabolism and function in CHD have to be elucidated (9). It has to be uncovered whether fitness interventions and inclusion in exercise-based rehabilitation programs, as recommended by the European Society of Cardiology for all adults with CHD, can help to improve muscle strength (44). Also the importance of supportive measures, including dietary counseling, nutritional supplementation, must be verified (6). Finally, it has to be elucidated in larger and in longer term studies whether changes of behavior and lifestyle can improve outcome and reduce the cardiovascular risk as well as morbidity and mortality of patients with CHD.

An important additional information concerns the prognostic significance of the HGS test in patients with CHD. Here, our results differ significantly from those of other patient collectives where the predictive value of the test for mortality assessment was high. For a prognosis of mortality, it is advisable to take an HGS measurement several times at defined points in time and thus to document the change in cardiac fitness in a way that can be easily implemented in everyday clinical routine. More valid information can be derived from the change of the HGS than from a punctual measurement at an unspecified point in time. Due to the low mortality rate in this sample, it is recommended to include larger samples in the future study with regard to a prediction of mortality.

Therefore, to get a reliable impression of the clinical status it may be more important to determine the individualized best result of each patient and to follow this, than to look for a group effect.

Study limitations

Certain limitations should be borne in mind when assessing our results. Strengths include the large sample size of enrolled patients with almost all types and severity grades of CHD.

This study was limited by the fact that only patients who agreed to participate voluntarily were included. It is not known to what extend the motivation of the patients may have biased the observations, as it is well known that individuals who volunteer to participate in research studies differ from those who do not choose to participate. Moreover, HGS cannot be accurately performed in

patients who are unable or not willing to properly grip the dynamometer. One could also assume that handgrip strength is primarily an indicator of upper body strength and muscle function, but it is closely correlated with the lower extremity force (33).

In order to better correlate the entire clinical situation with the HGS data, comparative data on CPET, imaging modalities and biomarkers would be helpful. Since these tests are not routine, but only dependent on the clinical indication, we cannot provide data on these. Besides, in this study echocardiographic or invasive data about ventricular performance during exercise are lacking. However, until now it is unclear if even under resting conditions a significant correlation between systemic ventricular function and health status exists.

Another limitation is that the reasons for the reduction of HGS in CHD could not be explained, but the current study was not designed to prove cause and effect.

Finally, the sample of patients may not represent the pattern of CHD in the community and does not represent the typical population of CHD seen by a general practitioner, by a normal cardiologist or even in departments for cardiology.

Conclusions

In conclusion, functional status is difficult to assess in patients with CHD. The reasons and pathomechanisms for the alteration of physical performance in the included patients with CHD, expressed as reduction of HGS, could not be explained, but it may be speculated that they are depending of the severity of CHD, residual defects, myocardial and respiratory function and the level of individual physical activity and fitness. Although HGS may not be a suitable tool for assessing survival probability or identifying high-risk patients, the test is well suited to provide a reliable impression of functional muscle status as an indicator of the overall clinical situation of the patient.

Over and above that seems to be important to follow the included patients for some years to see whether HGS is of any significance beyond current assessments, particularly to identify patients at higher risk for cardiovascular complications or even death.

Acknowledgments

None.

Footnote

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

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. Ethical approval has been waived because it is routine clinical data, and all patients gave written consent to their anonymous publication.

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