Healthy Hearts via Live Videoconferencing: An Exercise and Diet Intervention in Pediatric Heart Transplant Recipients

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***Background*—**Pediatric heart transplant recipients have high-risk cardiovascular profiles that can affect their long-term outcomes; however, promoting exercise and healthy diet has not been a major focus in the field. The objective of this study was to test the feasibility and impact of a supervised exercise and diet intervention delivered via live videoconferencing in this population.

***Methods and Results*—**Patients 8 to 19 years of age at least 1 year post heart transplantation were enrolled. The 12- to 16-week intervention phase included live video–supervised exercise (×3/week) and nutrition (×1/week) sessions. The 12- to 16-week maintenance phase included ×1/week live video–supervised exercise and nutrition sessions and ×2/week self-directed exercise sessions. Cardiac, vascular, nutritional, and functional health indices were obtained at baseline, after intervention, and after maintenance. Fourteen patients (median age, 15.2; interquartile range, 14.3–16.7 years) at a median of 3.3 (interquartile range, 1.5–9.7) years after heart transplant completed the intervention. Patients attended 89.6±11% of exercise and 88.4±10% of nutrition sessions during the intervention and 93.4±11% of exercise and 92.3±11% of nutrition sessions during maintenance. After intervention, body mass index percentile (median, −27%; *P*=0.02), endothelial function (median, +0.29; *P*=0.04), maximum oxygen consumption (median, +2 mL/kg per minute; *P*=0.002). Functional Movement Screening total score (median, +2.5; *P*=0.002) and daily consumption of saturated fat (median, −6 g; *P*=0.02) improved significantly. After maintenance, improvements in maximum oxygen consumption (median, +3.2 mL/kg per minute; *P*=0.02) and Functional Movement Screening total score (median, +5; *P*=0.002) were sustained.

***Conclusions*—**In pediatric heart transplant recipients, a live video–supervised exercise and diet intervention is feasible. Our results demonstrate excellent adherence with significant improvements in cardiovascular and functional health.

***Clinical Trial Registration*—**URL: http://www.clinicaltrials.gov. Unique identifier: NCT02519946. **(*J Am Heart Assoc.* 2020;9:e013816. DOI: 10.1161/JAHA.119.013816.)**

Key Words: endothelial function • exercise • heart transplant • live videoconferencing

Despite significant improvements in early survival, long-term survival of pediatric heart transplant recipients remains low, with only 50% of pediatric patients with heart transplant or grafts surviving >17 years after transplant.[1] Cardiac allograft vasculopathy, an accelerated form of coronary artery disease, is a major cause of late mortality.[2] However, transplant recipients also have increased cardiovascular risk profiles that contribute to mortality and morbidity[3,4] and are pharmacologically managed for hypertension and hyperlipidemia.[4] Furthermore, these patients frequently do not exercise because of history of chronic illness, self-restrictions, or parental fear. As clinical focus has been primarily on mortality, there has not been a specific focus on either regular exercise or healthy diet as part of clinical care in this population.

In other pediatric populations, small studies have demonstrated that regular exercise and a healthy diet can improve cardiovascular risk profiles of children at risk; however, most of these studies have been conducted on-site at clinics and suffer from low adherence, with reported adherence rates of <50%.[5] In these pediatric interventions, distance to site,

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Clinical Perspective

What Is New?

- An exercise and diet intervention delivered via live videoconferencing is feasible in pediatric heart transplant recipients.
- One-on-one supervision using live videoconferencing results in excellent adherence to exercise and diet sessions, and this is in contrast to prior pediatric reports on clinic-site interventions where the adherence has been poor.
- A tele–lifestyle intervention can be effective in improving cardiovascular health such as endothelial function and exercise capacity in pediatric heart transplant recipients.

What Are the Clinical Implications?

- The feasibility, high adherence, and the impact of this intervention sets the stage for the next phase, which would be the clinical implementation of live video–supervised exercise and diet programs in pediatric heart transplant care.
- This approach has great potential to improve long-term outcomes in this vulnerable patient population.

transportation difficulties, and school or work obligations have been reported as obstacles that limit adherence.[5] In our center, half of our pediatric heart transplant recipients live farther than 100 miles away, making on-site interventions burdensome for the families.[6]

Telehealth is regarded as an emerging tool to deliver care, removing many of the barriers such as transportation difficulties or school and work obligations.[7,8] Patients can engage in interventions in the comfort of their own home and as their schedule permits.[9] Some pediatric studies have used live videoconferencing to deliver health and behavior modifications in patients with diabetes mellitus and obesity.[10,11] In a pilot study, we demonstrated excellent adherence of obese and overweight youth to a live video–supervised exercise and diet intervention with significant improvement in their cardiovascular risk profile.[11]

In this study, we investigated 2 interconnected objectives: (1) the feasibility and impact of an exercise and nutrition intervention in youth who have undergone heart transplantation, and (2) investigation of delivery of this lifestyle intervention via live videoconferencing. We have previously reported the rationale, design, and methodology of this exercise and diet intervention in pediatric heart transplant recipients delivered via live videoconferencing.[12] In this article, we report the results of this intervention, including adherence to exercise and nutrition sessions as well as the impact of the intervention on cardiac, vascular, nutritional, and functional health measures. We also evaluated whether any improvements achieved during the intervention phase could be sustained during a maintenance phase. Our hypothesis was that participants would attend >80% of the exercise and nutrition sessions.

Methods

The data that support the findings of this study are available from the corresponding author upon request. The details of the study design have been previously reported and are outlined in Figure 1.[12] To summarize, pediatric heart transplant recipients at least 1 year post transplant were recruited from the Lucile Packard Children's Hospital transplant roster. Subjects were eligible to participate in the intervention if they met the following inclusion criteria: (1) age, 8 to 19 years; (2) transplant at least 1 year before study entry; (3) ability to fast overnight; (4) cardiac clearance by their primary cardiologist; and (5) adult at home to monitor the exercise training sessions for participants <14 years of age. Participants were excluded for the following reasons: (1) experienced rejection within 3 months of the baseline study visit; (2) latex allergy; (3) current acute illness; (4) history of multiorgan transplant (but not including retransplantation). Our inclusion and exclusion criteria were chosen with the following considerations: First, we believe that children younger than 8 years of age would not have been able to navigate the technology to exercise with a trainer on their own without a great deal of support from their parents. Second, some of our vascular testing modalities have been tested only in adolescents >8 years of age, thus further narrowing our age range for inclusion. Finally, we included only patients who received their heart transplant >1 year before study entry and if they had not had an episode of rejection within the prior 3 months, as patients require close and intense clinical monitoring during these times.

Before participation in any study-related activities, participants aged 18 to 19 were asked to sign the consent form, while those aged 8 to 17 were asked to sign the assent form, with their parents signing the consent form. The protocol, including all study-related testing and procedures, was approved by the Stanford University Institutional Review Board. Approval of the protocol was maintained throughout the course of the study.

Study assessments were completed at baseline, 12 to 16 weeks after the baseline assessment (post intervention), and then once again 24 to 32 weeks after the baseline assessment (post maintenance). All study visits were completed in the morning to ensure subject compliance with overnight fasting (at least 12 hours), which was confirmed before study testing, and to reduce variability in study measurements. Study staff were blinded to clinical history and

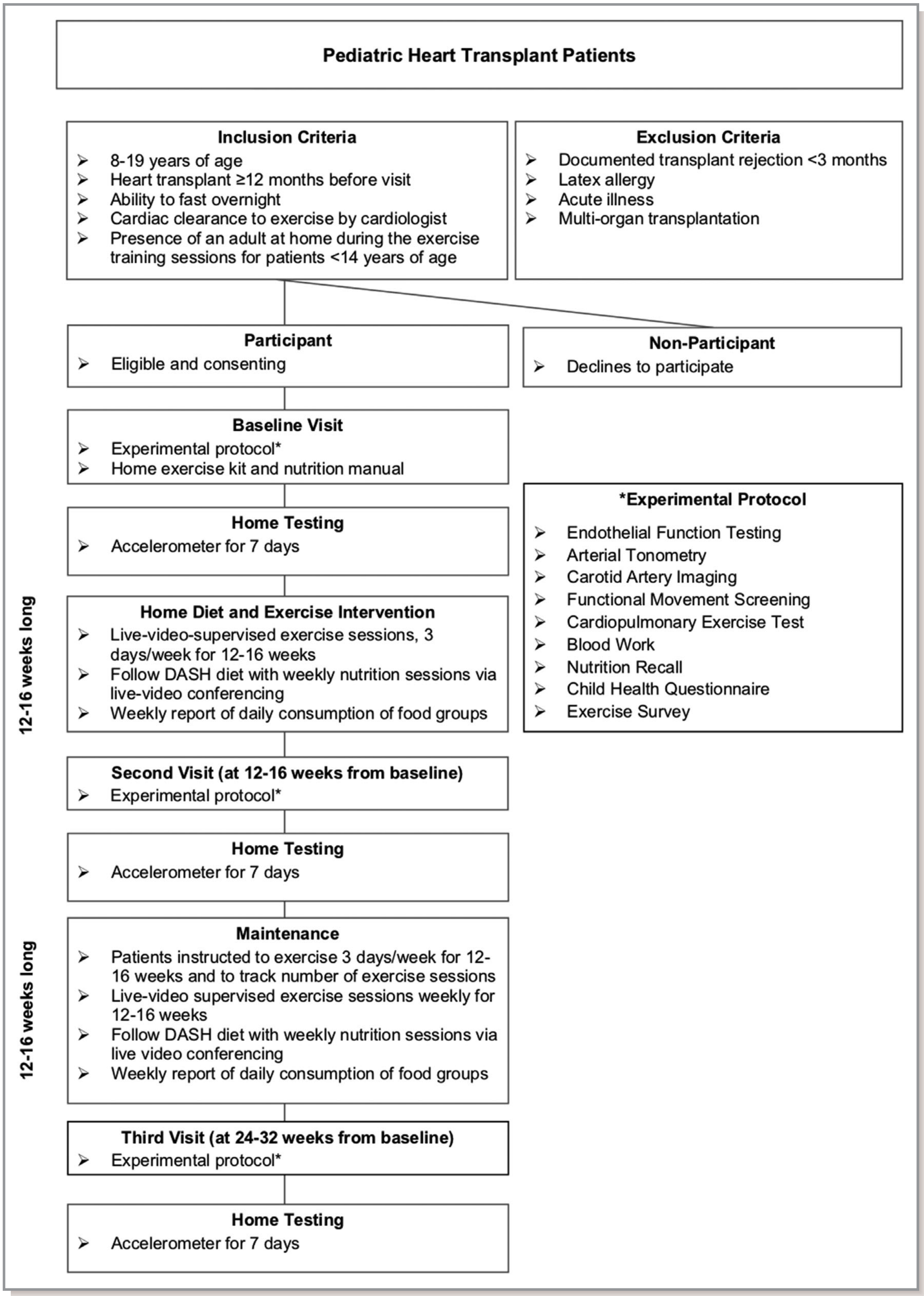

Figure 1. Study overview.

prior study visit measurements. The research coordinator collected information by interview on medical history; use of medications, supplements, and/or vitamins; consumption of alcohol and tobacco in the past 24 hours; recent exposure to tobacco smoke in the past 24 hours; and exercise in the last 72 hours.

Height, weight, and blood pressure were measured at each assessment before testing, as described previously.[12] Study testing included the following 7 components: (1) vascular testing, (2) laboratory blood testing, (3) fitness testing, (4) questionnaires, (5) dietary recall, (6) study education, and (7) physical activity monitoring.

Vascular testing, including the endothelial pulse amplitude test (EndoPAT), arterial tonometry, and carotid ultrasound examinations, was performed according to a previously described protocol.[12] The testing protocol of the EndoPAT (EndoPAT, Itamar Medical Ltd., Caesarea, Israel) has been validated in adults and well studied in pediatric groups; the EndoPAT reports the reactive hyperemia index (RHI) as its measure of endothelial function.[13–15] The EndoPAT machine is used to measure the increase in peripheral blood flow after temporary ischemia of the nondominant arm. EndoPAT uses noninvasive technology with pneumatic probes to capture beat-to-beat recording of the finger arterial pulse-wave amplitude. All data analysis is conducted through the machine's software package and given as the RHI.

Pulse-wave velocity and aortic augmentation index (AIx) are measured using noninvasive applanation tonometry (SphygmoCor, Atcor-Medical, Sydney, Australia). Pulse-wave velocity is calculated by the software using the relative difference in path length between the carotid-femoral arterial sites divided by the difference in transit time. Arterial waveforms are captured over a 10-second interval, and each measurement was reported as mean$\pm$SE by the software.[13] The AIx is measured by applying the pressure tonometer to the subject's right radial artery to capture arterial pressure waves, which are subsequently processed by the software to calculate and reconstruct the central aortic pressure curve. AIx measurements are computed as the ratio (percentage) of the aortic augmentation to the pulse pressure.

A linear array probe (L11-3 MHz, Philips iE33 Ultrasound System, Andover, MA) is used to obtain three 10-second loops taken at anterior, posterior, and lateral angles on the right and left common carotid artery. The carotid intima-media thickness of the far wall of the common carotid artery is measured online by the sonographer using a frame from each of the loops with anterior, posterior and lateral angulations over the length of a 1-cm segment located at the distal aspect of the right and left common carotid artery just proximal to the bifurcation into the internal and external carotid arteries, using commercially available, semi-automated edge-detection software (QLab Philips, iE33, Andover, MA) at end diastole on the R wave.

A phlebotomist performed venipuncture on the participants after completion of all vascular testing. Levels of fasting plasma lipid, low-density lipoprotein, high-density lipoprotein, C-reactive protein, and hemoglobin A_{1c} were measured with standardized methods used at the Stanford Health Care Clinical Laboratories.

Subsequently, all participants underwent cardiopulmonary exercise testing according to a previously described protocol.[12] Maximum oxygen consumption (VO_2 max) and the corresponding percent predicted VO_2 max values were recorded. Functional movement screening (FMS) was performed after completion of the cardiopulmonary exercise testing.[12] Seven movements were each graded on a scale of 0 to 3, with 0 corresponding to the lowest movement ability and 3 indicating the greatest movement ability. A total aggregate score of $\leq$14 (of 21) identifies patients at risk of injury.[16]

Participants and parents were instructed to complete the Child Health Questionnaires (patient and parent forms), a validated pediatric quality-of-life survey, during the visit.[17,18] Following each study visit, participants were instructed to wear an accelerometer (Genactiv; Activinsights, Cambridge, UK) to measure their physical activity for 7 consecutive days. Before each study visit, patients were asked to complete the Automated Self-Administered 24-Hour Dietary Assessment, a 24-hour dietary recall, to track 2 days of weekday meals and 1 weekend day meal, for a total of 3 assessments.[2] Education about study equipment and procedures, including instruction and distribution of study equipment, was completed at the end of the baseline visit.[12] At the postintervention and postmaintenance study visits, patients and parents also were asked to complete feedback surveys to indicate their experiences during the intervention and the maintenance period.

Intervention

Patients began their exercise and nutrition sessions the week following the completion of wearing the 7-day accelerometer. The 12- to 16-week supervised exercise and diet intervention delivered via live videoconferencing was led $\times$3/week by an American Council on Exercise certified exercise trainer or his trainee via live videoconferencing. Participants were given all necessary equipment including a weighted medicine ball, resistance band with door attachment, sliders, a jump rope, and a tablet with Internet connection.[12] Each session lasted 60 minutes and included a brief questionnaire before starting the exercise to gauge how each participant was feeling before the start of the session. The intervention incorporated resistance and aerobic training with sessions gradually increasing in intensity with additional reps or less rest between sets of exercises. Exercise intensity was rated on a scale of 1 to 10 by participants and is adjusted as necessary for increased or decrease intensity. The study coordinator, who was trained by a certified registered dietitian, met with the participants $\times$1/week via live videoconferencing to deliver the nutrition sessions. The Dietary Approaches to Stop Hypertension program and manual were used to lead the nutrition sessions.[19,20] The nutritional sessions included weekly review of a take-home manual that provided informational sheets on serving recommendations, foods, and recipe suggestions compliant with the dietary intervention. Goals were set weekly for fruits (up to 5 servings a day), vegetables (up to 5 servings a day), and dairy (up to 3 servings a day) during weekly nutrition sessions. Participants were also encouraged to lower their daily servings of foods high in sodium and fat. All sessions were completed over VSee, a Health Insurance Portability and Accountability Act–compliant platform for live videoconferencing.[21,22] After completion of the intervention phase, participants returned for the postintervention assessment visit.

Maintenance

Following the second study visit (postintervention), patients were asked to wear the accelerometer for 7 consecutive days as per study protocol and then began their maintenance period. The maintenance phase began after the postintervention study visit for an additional 12 to 16 weeks of the study. During the maintenance phase, patients were instructed to exercise ×2/week on their own, and they had 1 live video–supervised exercise and 1 live video–supervised nutrition session/week.[12] The exercise session was led by the certified exercise trainer, and the nutrition session was led by the study coordinator. Participants reported their self-directed exercise to the trainer during each weekly exercise session. After completion of the maintenance phase (at weeks 24–36), patients returned for the postmaintenance assessment visit.

Statistical Methods

Statistical calculations for sample size as well as exercise and nutrition session adherence were followed, as previously described.[12] Graphical methods were used to assess whether data were normally distributed. Nonparametric statistical analysis methods were used, as data were not normally distributed. Paired comparisons between baseline and postintervention measurements were performed using the Wilcoxon signed-rank test. Similarly, paired comparisons between baseline and postmaintenance measurements were compared using the Wilcoxon signed-rank test. The median and interquartile range at baseline, postintervention, and postmaintenance visits for key variables were graphically represented using box and whisker plots. In post hoc secondary analyses, paired comparisons were repeated among patients who had abnormal vascular function at baseline.[12] Statistical significance was defined at $P<0.05$, and all statistical analyses were performed using STATA version 14.2 (StataCorp, College Station, TX).

Results

Patients and Adherence

At baseline, patients were a median age of 15.2 (interquartile range [IQR], 14.3–16.7) years and a median of 3.3 (IQR, 1.5–9.7) years after transplant (Table 1). They live a median of 98 (IQR, 82–255) miles from the center. Fourteen patients completed the 12- to 16-week intervention, and 13 patients completed the additional 12- to 16-week maintenance phase. One patient withdrew after the postintervention study visit and did not complete the maintenance phase but completed the postmaintenance lipid testing while a clinical blood draw was obtained. This patient reported lack of time and family issues as the main reasons for withdrawing from the maintenance period. The results from this participant were included in the final analysis. Baseline health indices of the first 13 enrolled patients have previously been reported.[12] Table 2 summarizes the number of patients with abnormal baseline health indices.[12,14,23–27]

Impact of Intervention on Cardiac, Vascular, Nutritional, and Functional Indices

The 14 participants who completed the intervention attended on average 89.6±11% of scheduled exercise sessions and 88.4±10% of scheduled nutrition sessions. The most common reasons for missing scheduled exercise or nutrition sessions included needing recovery time from biopsy procedures, feeling too ill or too tired to exercise, being unable to connect to the Internet, or forgetting the scheduled session.

Post intervention, body mass index (BMI) percentile (median, −27%; P=0.02), endothelial function (RHI) (median, +0.29; P=0.04), VO_2 max (median, +2 mL/kg per minute; P=0.002), percent predicted VO_2 max (median, +6.4%; P=0.002), FMS total score (median, +2.5; P=0.002), and daily consumption of saturated fat (median, −6 g; P=0.02) improved significantly (Table 3 and Figure 2). Some of these improvements even resulted in normalized indices. Specifically, at baseline, all 14 patients had abnormal VO_2 max values, and 11 of these 14 patients had abnormal percent predicted VO_2 max (<70%). Four of these 11 patients normalized their VO_2 max after intervention on the basis of published normative data.[24] Similarly, endothelial function was impaired in 11 of 14 patients (79%) at baseline (RHI <1.9) on the basis of values reported in healthy normal-weight pediatric populations.[14] Post intervention, RHI was >1.9 in 4 of these patients. In addition, 5 of these 14 patients had abnormal FMS total score at baseline (FMS total score <14).[16] Postintervention FMS total score improved significantly, with only 1 patient remaining "at risk" for injury (median, +2.5; P=0.002).

Table 1. Patient Demographics and Adherence Data

					Intervention						Maintenance					
	Sex	Age, y	Time Since Transplant	Distance to Center	Exercise Sessions Comp.	Exercise Sessions Sched.	% of Exercise Sessions Comp.	Nutrition Sessions Comp.	Nutrition Sessions Sched.	% of Nutrition Sessions Comp.	Exercise Sessions Comp.	Exercise Sessions Sched.	% of Exercise Sessions Comp.	Nutrition Sessions Comp.	Nutrition Sessions Sched.	% of Nutrition Sessions Comp.
1	Female	16.5	1.5	94.7	29	31	93.55%	12	12	100.00%	…	…	…	…	…	…
2	Male	14.3	2.4	88.5	21	27	77.78%	12	12	100.00%	…	…	…	…	…	…
3	Female	15.5	1.4	257	27	45	60.00%	10	14	71.43%	…	…	…	…	…	…
4	Male	16.3	5.4	44.4	46	49	93.88%	14	17	82.35%	11	11	100%	15	15	100%
5	Female	10.1	5.6	82	42	51	82.35%	12	15	80.00%	10	11	91%	10	11	91%
6	Female	17.5	12.5	253	44	45	97.78%	15	15	100.00%	12	12	100%	7	8	88%
7	Male	14.1	12.3	256	41	42	97.62%	11	12	91.67%	17	17	100%	14	14	100%
8	Female	14.9	1.0	82	46	47	97.87%	13	13	100.00%	13	13	100%	13	13	100%
9	Female	17.5	1.8	766	36	39	92.31%	10	12	83.33%	13	13	100%	13	13	100%
10	Female	13.2	4.1	766	43	45	95.56%	10	12	83.33%	13	13	100%	13	13	100%
11	Male	16.7	16.5	165	29	33	87.88%	10	12	83.33%	8	11	73%	8	11	73%
12	Female	14.7	9.7	33.1	36	44	81.82%	13	15	86.67%	8	11	73%	8	11	73%
13	Male	17.4	1.3	101	47	48	97.92%	16	16	100.00%	13	13	100%	13	13	100%
14	Female	14.6	2.0	37.9	39	40	97.50%	9	12	75.00%	10	11	91%	10	11	91%

Comp. indicates completed; Sched., scheduled.

Table 2. Baseline Data for Selected Cardiovascular, Functional, and Nutritional Indices (n=14)

	Median	IQR
Body mass index percentile, %	66*	27–97
VO_2 max, mL/min per kg	23.3	19.4–28.1
Percent predicted VO_2 max, %	57.5†	49.0–69.7
Functional movement screening total score	16‡	14–17
Time in sedentary activity, %	68.2	66.1–79.9
Right carotid intima-media thickness, mm	0.423§	0.406–0.443
Reactive hyperemia index	1.39‖	1.20–1.55
Carotid-femoral pulse-wave velocity, m/s	5.7¶	5.4–6.1
C-reactive protein, mg/dL	0.3#	0.2–1.2
Saturated fat, g	28**	14–44
Sodium, mg	2741††	2171–3784

IQR indicates interquartile range; VO_2 max, maximum oxygen consumption.
*Five patients abnormal at <5% or >95%.[23]
†Eleven patients abnormal at <70%.[24]
‡Five patients "at risk for injury" at total Functional Movement Score ≤14.[25]
§Five patients abnormal at ≥0.439 mm as per our laboratory controls.
‖Eleven patients abnormal at <1.9.[14]
¶Twelve patients with increased arterial stiffness for age (pulse-wave velocity ≥5.5 m/s for 15–19 years, ≥4.5 m/s for 10–14 years of age).[26]
#Four patients abnormal at ≥0.9 mg/dL as per Stanford laboratory reference values.
**Seven patients above daily recommendation of 16 g, as per dietary guidelines based on an average of 2000 calories a day.
††Seven patients above daily recommendation of 2300 mg.[27]

The changes in AIx adjusted to a standard heart rate of 75 beats per minute (AIx75 bpm), pulse-wave velocity, carotid intima-media thickness, and accelerometry data did not demonstrate significant change, even in subanalyses in patients with abnormal baseline values.

Cardiac, Vascular, Nutritional, and Functional Indices After Maintenance

During the maintenance phase, 13 participants completed 93.4±11% of scheduled exercise sessions (1 supervised session/week) and 92.3±11% of the scheduled nutrition sessions. All participants self-reported exercising on their own at least 2 additional times per week, although these exercise sessions were not scheduled. Types of exercise included walking, playing basketball, exercising at the gym, and biking.

After maintenance, BMI percentile (median, −37%; P=0.006), AIx75 bpm (median, −10.5%; P=0.04), VO_2 max (median, +3.2 mL/kg per minute; P=0.02), percent predicted VO_2 max (median, +3.2 mL/kg per minute; P=0.02), and FMS total score (median, +5; P=0.002) remained improved when baseline and the postmaintenance visit data were compared (Figure 2 and Table 4).

In a subanalysis of patients with abnormal baseline values, daily consumption of saturated fat (median, −10.1 g; P=0.03) remained improved from postintervention to postmaintenance. Additionally, for those with abnormal baseline sodium values, daily consumption of sodium (median, −575.7 mg; P=0.046) not originally improved after intervention improved after maintenance.

Socioeconomic Status

Median home income based on zip code for our 14 participants was $50 914 (IQR, $45 748–$74 776). Two of 14 participants were from single head-of-household families on the basis of self-reports. One of these participants had the lowest adherence to the intervention, at only 60% to exercise and 71% to nutrition sessions, and did not complete the maintenance phase. The other participant had 88% adherence to the exercise and 83% adherence to the nutrition portions of the intervention. The same participant had 73% adherence to the exercise and 73% adherence to the nutrition portions of the maintenance phase.

Survey Results

In the feedback survey conducted at the completion of the study, all but 1 of the participants indicated that they "agree" or "strongly agree" that participating in the study improved their health; 1 participant reported that they were "unsure." All parents reported that they either "agree" or "strongly agree" with the statement: "I think MY CHILD has learned new exercises that will help him/her be healthy and strong." In the additional comments of the survey section, participants commented that they "really liked it" and that "the intervention helped me to learn how to exercise." One parent wrote, "My son has more awareness of nutrition, and especially a need for fruits and vegetables. He is also a lot more confident in his abilities to exercise." Another patient sent us a thank you note, mentioning that "over the course of the duration of the study all of you have helped me grow stronger, build my stamina, and gain confidence in my abilities to start playing all the sports I always wanted to. I finally have the strength, confidence, and physical abilities to start doing things I wanted to such as joining a competitive badminton league, biking to school on my own, playing with my dog, and playing mild sport games in PE with my friends." All patients and parents reported that they would appreciate continued communication with an exercise trainer and nutrition coach, ranging from once a month to ×3/week.

Discussion

The aim of this study was to demonstrate if a lifestyle intervention delivered via live videoconferencing to a specific,

Table 3. Cardiac, Vascular, Nutritional, and Functional Health Indices From Baseline and Postintervention

	n*	Baseline Mean	Baseline (s)†	Baseline Median	Baseline IQR	Postintervention Mean	Postintervention (s)†	Postintervention Median	Postintervention IQR	Difference Between Visits‡	*P* Value§
Anthropometric measures											
Height, m	14	162.3	10.8	161.7	14.0	163.4	10.6	162.0	14.2	+0.4	0.007
Weight, kg	14	64.9	26.4	57.6	34.9	66.4	25.3	59.0	30.5	+1.4	0.02
Body mass index, kg/m^2	14	24.2	7.8	21.6	12.6	24.5	7.7	22.3	10.5	+0.7	0.03
Body mass index percentile, %	14	62.0	33.6	66.0	70.0	48.9	37.1	39.0	68.8	−27	0.02
Waist-hip ratio, %	12	84.0	6.0	82.0	6.9	82.0	6.2	82.4	10.2	0	0.27
Blood pressure profile											
Systolic blood pressure, mm Hg	14	118.4	11.0	115.0	10.0	116.9	8.5	118.5	11.1	+3	0.83
Diastolic blood pressure, mm Hg	14	73.1	7.5	73.0	12.0	73.0	6.9	73.3	6.9	0	0.95
Mean blood pressure, mm Hg	14	89.1	7.8	87.0	9.0	88.3	6.2	90.4	8.2	+3	0.88
Systolic blood pressure percentile, %	14	68.4	18.2	65.5	26.0	66.0	28.0	79.5	37.5	+14	1.00
Diastolic blood pressure percentile, %	14	71.9	20.2	77.5	36.0	72.0	20.1	75.5	19.5	−2	0.92
Vascular testing											
Endothelial function											
Reactive hyperemia index	13	1.47	0.33	1.39	0.35	1.75	0.44	1.68	0.55	+0.29	0.04
Arterial stiffness											
Right carotid intima-media thickness, mm		0.423	0.019	0.423	0.037	0.431	0.032	0.415	0.044	−0.008	0.29
Left carotid intima-media thickness, mm		0.424	0.025	0.413	0.030	0.431	0.029	0.417	0.041	+0.003	0.41
Radial artery augmentation index 75 bpm, %	12	−1.5	9.1	0.5	9.8	−10.7	10.5	−10.5	15.0	−11	0.07
Carotid-femoral pulse-wave velocity, m/s	14	5.7	0.8	5.7	0.7	5.6	0.8	5.5	0.6	−0.2	0.85
Right common carotid artery											
Elastic modulus, mm Hg	14	379	133	341	158	393	119	341	177	0	0.75
Beta index	14	2.57	0.27	2.56	0.42	2.64	0.28	2.67	0.37	+0.11	0.38
Left common carotid artery											
Elastic modulus, mm Hg	14	388	128	349	204	391	131	382	114	+32.5	0.95
Beta index	14	2.60	0.30	2.54	0.52	2.63	0.33	2.63	0.42	+0.09	0.66
Laboratory blood testing											
Total cholesterol, mg/dL	14	136.7	25.1	135.5	43.0	136.5	27.0	133.5	27.8	−2	0.92
Triglycerides, mg/dL	14	78.9	47.4	60.5	33.0	95.4	64.4	68.0	92.3	+7.5	0.40

Continued

Table 3. Continued

	n*	Baseline Mean	Baseline (s)†	Baseline Median	Baseline IQR	Postintervention Mean	Postintervention (s)†	Postintervention Median	Postintervention IQR	Difference Between Visits‡	*P* Value§
High-density lipoprotein, mg/dL	14	54.5	16.0	57.5	31.0	54.4	12.2	52.5	19.8	−5	0.95
Low-density lipoprotein, mg/dL	14	66.3	23.6	63.0	29.0	63.0	22.3	60.5	15.5	−2.5	0.38
C-reactive protein, mg/dL	14	0.9	1.0	0.3	1.0	0.8	0.3	0.8	0.25	−0.15	0.12
Fasting glucose, mg/dL	12	98.1	9.7	99.5	13.0	97.1	10.5	97.5	10.8	−2	0.69
HbA_{1c}, %	14	5.2	0.4	5.2	0.2	5.4	0.4	5.4	0.3	+0.1	0.28
Fitness testing											
VO_2 max, mL/min per kg	14	22.8	6.5	23.3	8.7	24.8	6.4	25.3	6.6	+2.0	0.002
Percent predicted VO_2 max, %	14	59.5	18.8	57.5	20.7	63.6	16.5	64.0	22.0	+6.4	0.002
Maximum heart rate, bpm	14	150	18	147	23	155	18	159	19	+12	0.07
Functional movement screening total score	14	15.8	3.1	16.0	3.0	18.3	2.2	18.5	3.3	+2.5	0.002
Dietary recall											
Total calories, kcal	11	1655	568	1634	977	1797	602	1740	863	+105	0.29
Sodium, mg	11	2935	1168	2741	1613	2906	1056	2844	1732	+103	0.86
Potassium, mg	11	1947	1091	1869	1762	2818	1009	2709	1487	+840	0.06
Saturated fat, g	11	26.6	15.6	28.3	30	23.2	14.4	22.2	22.1	−6	0.02
Physical activity monitoring											
Time in sedentary activity, %	10	71.8	9.7	68.2	13.8	72.0	12.4	76.3	17.8	+8.1	0.51
Time in light activity, %	10	10.1	2.6	10.4	3.4	10.5	3.4	10.2	3.1	−0.2	0.37
Time in moderate activity, %	10	17.0	6.5	19.0	9.3	16.8	8.7	12.6	13.6	−6.4	0.51
Time in vigorous activity, %	10	1.1	0.9	1.4	1.5	0.7	0.7	0.6	0.9	−0.8	0.51
Child Health Questionnaire											
Physical functioning	12	81.5	16.5	87.0	28.9	84.9	18.0	91.0	16.7	+4	0.37
Role/social limitations: emotional	12	81.5	29.3	94.5	22.2	73.2	34.3	88.9	42.7	−6	0.29
General health perceptions	12	53.5	20.4	49.6	19.9	57.6	13.5	56.9	10.5	+7	−.24

HbA_{1c} indicates hemoglobin A_{1c}; IQR, interquartile range; VO_2 max, maximum oxygen consumption.
*Number of participants with complete data at both baseline and post-intervention visits.
†Standard deviation.
‡Difference between the median value at postintervention and the median value at baseline.
§Paired comparisons between baseline and postintervention measurements performed using the Wilcoxon signed-rank test.

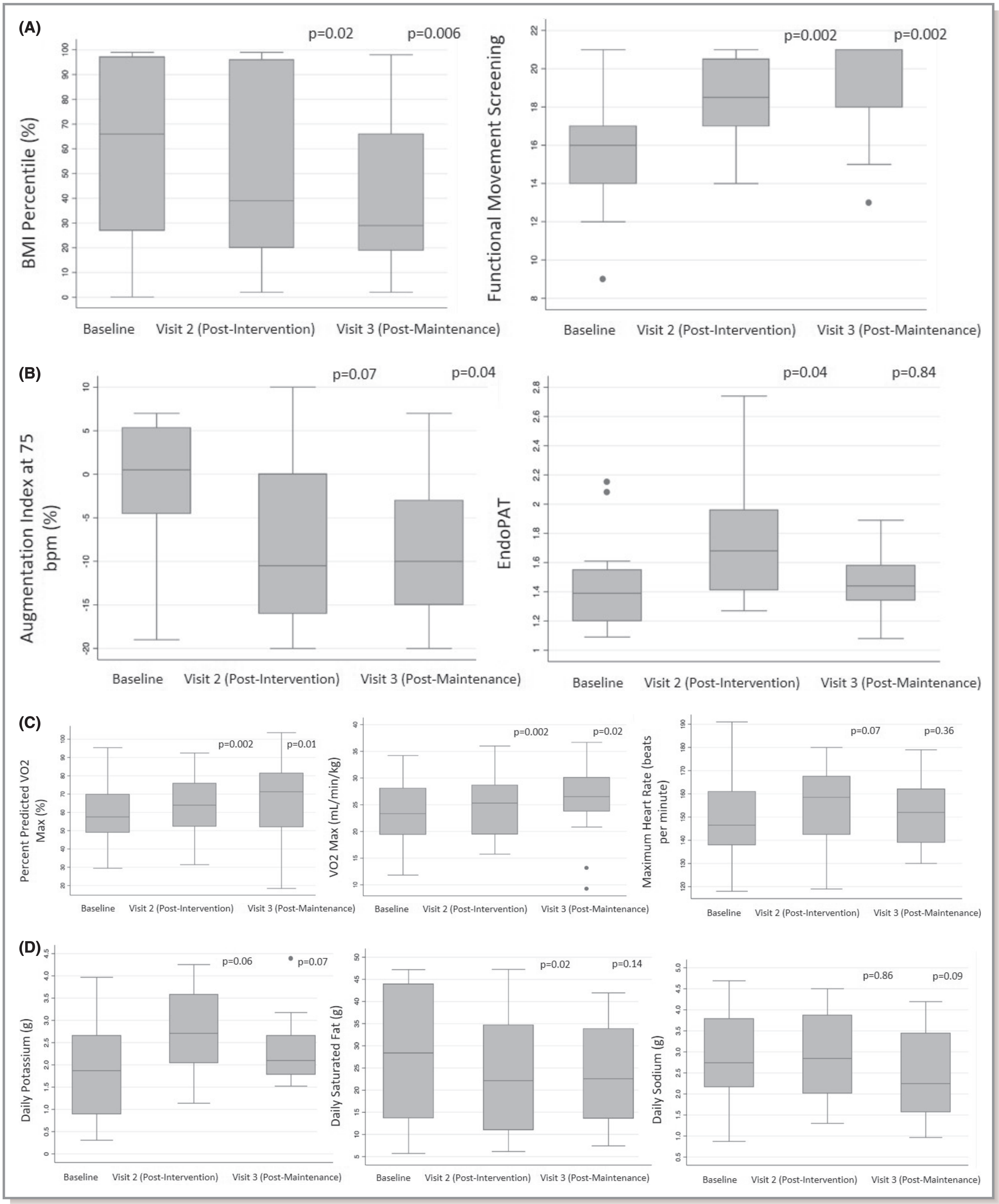

Figure 2. Improved fitness, vascular, and nutritional indices at baseline, after intervention, and after maintenance. **A**, Body mass index (BMI) percentile and functional movement screening (FMS); (**B**) arterial stiffness (augmentation index), endothelial function (EndoPAT); (**C**) percent predicted maximum oxygen uptake (VO_2 max) and VO_2 max, and maximum heart rate; (**D**) daily intake of potassium, saturated fat, and sodium.

Table 4. Cardiac, Vascular, Nutritional, and Functional Health Indices From Baseline and Post-Maintenance

	n*	Baseline Mean	Baseline (s)[†]	Baseline Median	Baseline IQR	Postmaintenance Mean	Postmaintenance (s)[†]	Postmaintenance Median	Postmaintenance IQR	Difference Between Visits[‡]	*P* Value[§]
Anthropometric measures											
Height, m	13	162.3	10.8	161.7	14.0	164.8	10.6	164.0	15.4	+2.35	0.002
Weight, kg	13	64.9	26.4	57.6	34.9	63.1	22.8	56.7	20.3	−0.9	.15
Body mass index, kg/m^2	13	24.2	7.8	21.6	12.6	22.9	6.3	21.4	5.1	−0.2	0.81
Body mass index percentile, %	13	62.0	33.6	66.0	70.0	43.0	35.8	29.0	47.0	−37	0.006
Waist-hip ratio, %	11	80.0	10.0	82.0	6.9	81.9	5.6	79.8	6.0	−0.02	0.21
Blood pressure profile											
Systolic blood pressure, mm Hg	13	118.4	11.0	115.0	10.0	115.0	11.7	115.3	14.3	0	0.25
Diastolic blood pressure, mm Hg	13	73.1	7.5	73.0	12.0	73.3	7.4	72.7	12.3	0	0.81
Mean blood pressure, mm Hg	13	89.1	7.8	87.0	9.0	86.1	8.7	87.0	14.3	0	0.12
Systolic blood pressure percentile, %	13	68.4	18.2	65.5	26.0	56.7	27.8	62.0	49.0	−3.5	0.18
Diastolic blood pressure percentile, %	13	71.9	20.2	77.5	36.0	71.0	18.2	73.0	33.0	−4.5	0.60
Vascular testing											
Endothelial function											
Reactive hyperemia index	12	1.47	0.33	1.39	0.35	1.47	0.20	1.44	1.44	+0.05	0.84
Arterial stiffness											
Right carotid intima-media thickness, mm	13	0.423	0.019	0.423	0.037	0.422	0.018	0.420	0.420	−0.003	0.44
Left carotid intima-media thickness, mm	13	0.424	0.025	0.413	0.030	0.426	0.029	0.413	0.033	0	0.78
Radial artery augmentation index 75 bpm, %	11	−1.5	9.1	0.5	9.8	−8.4	7.8	−10.0	12.0	−10.5	0.04
Carotid-femoral pulse-wave velocity, m/s	13	5.7	0.8	5.7	0.7	5.2	1.8	5.5	1.7	−0.22	.22
Right common carotid artery											
Elastic modulus, mm Hg	13	379	133	341	158	388	143	362	161	+21	0.60
Beta index	13	2.57	0.27	2.56	0.42	4.3	1.5	4.15	2.0	+0.11	0.01
Left common carotid artery											
Elastic modulus, mm Hg	13	388	128	349	204	416	177	383	244	+34	0.42
Beta index	13	2.60	0.30	2.54	0.52	4.6	2.0	4.22	2.44	+1.68	0.008
Laboratory blood testing											
Total cholesterol, md/dL	14	136.7	25.1	135.5	43.0	142	29.2	140.0	25.3	+4.5	0.88
Triglycerides, mg/dL	14	78.9	47.4	60.5	33.0	89.2	51.8	75.5	32.3	+15	0.26
High-density lipoprotein, mg/dL	14	54.5	16.0	57.5	31.0	51.4	12.9	50.5	19.8	−7	0.17

Continued

Table 4. Continued

	n*	Baseline Mean	Baseline (s)†	Baseline Median	Baseline IQR	Postmaintenance Mean	Postmaintenance (s)†	Postmaintenance Median	Postmaintenance IQR	Difference Between Visits‡	*P* Value§
Low-density lipoprotein, mg/dL	14	66.3	23.6	63.0	29.0	72.2	25.7	69.5	30.8	+6.5	0.38
C-reactive protein, mg/dL	14	0.9	1.0	0.3	1.0	0.9	0.7	0.6	1.1	0	0.47
Fasting glucose, mg/dL	14	98.1	9.7	99.5	13.0	96.1	13.8	95.0	12.0	−4.5	0.18
HbA_{1c}, %	14	5.2	0.4	5.2	0.2	5.4	0.4	5.4	0.3	+0.15	0.08
Fitness testing											
VO_2 max, mL/min per kg	13	22.8	6.5	23.3	8.7	25.6	7.8	26.5	6.3	+3.2	0.02
Percent predicted VO_2 max, %	13	59.5	18.8	57.5	20.7	66.8	22.4	71.3	29.3	+13.8	0.01
Maximum heart rate, bpm	13	150	18	147	23	151	16	152	23	+5.5	0.36
Functional movement screening total score	13	15.8	3.1	16.0	3.0	16.6	8.4	19.0	5.0	+5	0.002
Dietary recall											
Total calories, kcal	10	1655	568	1634	977	1729	445	1814	572	+179	0.80
Sodium, mg	10	2935	1168	2741	1613	2522	1057	2245	1792	−496	0.09¶
Potassium, mg	10	1947	1091	1869	1762	2347	830	2098	684	+228	0.07
Saturated fat, g	10	26.6	15.6	28.3	30.0	23.9	11.7	22.6	18.3	−6	0.14#
Physical activity monitoring											
Time in sedentary activity, %	10	71.8	9.7	68.2	13.8	73.6	10.9	76.5	12.6	+8.3	0.88
Time in light activity, %	10	10.1	2.6	10.4	3.4	9.3	2.8	8.6	2.4	−1.8	0.33
Time in moderate activity, %	10	17.0	6.5	19.0	9.3	15.7	7.3	14.9	10.1	−4.1	0.88
Time in vigorous activity, %	10	1.1	0.9	1.4	1.5	1.1	1.5	0.4	1.3	−1.0	0.96
Child Health Questionnaire											
Physical functioning	11	81.5	16.5	87.0	28.9	81.5	27.2	92.6	12.9	+6	0.53
Role/social limitations: emotional	11	81.5	29.3	94.5	22.2	84.8	32.7	100	5.6	+6	0.62
General health perceptions	11	53.5	20.4	49.6	19.9	58.7	12.2	59.2	20.5	+10	0.42

HbA_{1c} indicates hemoglobin A_{1c}; IQR, interquartile range; VO_2 max, maximum oxygen consumption.
*Number of participants with complete data at both baseline and postmaintenance visits.
†Standard deviation.
‡Difference between the median value at postmaintenance and the median value at baseline.
§Paired comparisons between baseline and postmaintenance measurements performed using the Wilcoxon signed-rank test.
¶Median −575.7 mg, *P*=0.046 for those abnormal at baseline (n=6).
#Median −10.1 g, *P*=0.03 for those abnormal at baseline (n=6).

vulnerable population—in this case, pediatric heart transplant recipients—was feasible and if it resulted in good adherence and improved health indices. Our results show that not only does this lifestyle intervention (exercise and nutrition) in pediatric heart transplant recipients delivered via live videoconferencing is feasible, but it also results in excellent adherence and significant improvements of cardiac, vascular, nutritional, and functional health. Furthermore, several of these health indices were sustained after transitioning to a maintenance phase. To our knowledge, no prior studies have focused on incorporating both exercise and live videoconferencing in a vulnerable pediatric population. This work hopefully can assist in shifting our clinical focus from "exercise restrictions to exercise prescriptions."

Our adherence rate of >80% to the intervention is strikingly higher than what has been reported in prior onsite pediatric intervention studies. A recent review by Hampl et al[5] reported adherence rates of <50% for 7 of 8 clinic-based interventions for obese children. Our maintenance adherence rates are even higher (>90% to both exercise and nutrition sessions) and provide evidence for the long-term feasibility of this intervention as a program into home-based preventive care. In our study, parents reported that the ease of scheduling at-home sessions based on their availability allowed for greater attendance and adherence to the intervention. This is further supported by our survey results and that 100% of the parents would like to have continued exercise and diet support from the intervention team in the long run, suggesting the feasibility and acceptability of live video–supervised exercise and nutrition sessions into routine care.

Multiple studies have reported the importance of BMI on morbidity and mortality rates after heart transplantation, with patients on both ends of the BMI spectrum reporting worse outcomes.[28–31] Amarelli et al[31] reported a significant difference according to BMI in post-transplant mortality: 15.3% of patients with BMI <18.5 kg/m^2 died in the first year after transplant, compared with 4.4% of patients with BMI >18.5 kg/m^2. Even though the focus of this intervention has not been not on weight loss or gain, we did see a significant improvement in the BMI percentiles of the 4 overweight/obese and 3 underweight patients in this cohort.[12] Although the 3 underweight patients did not reach normal BMI percentiles after the intervention, the improvement in their BMI might reflect their new focus on healthy nutrition or possibly an increase in muscle mass.

Consistent with prior literature on exercise capacity in pediatric heart transplant recipients, our patients had reduced VO_2 max at baseline compared with published normative data from healthy, nontransplanted individuals.[12,32] Our intervention resulted in significant improvements in VO_2 max and percent predicted VO_2 max, which were sustained after the maintenance phase, suggesting that our intervention has the potential to improve long-term exercise capacity in pediatric heart transplant recipients. The cardiovascular benefits associated with exercise are important; adaptations in the structure, electrical conduction, and function of the heart occur to sustain the increased cardiac output during exercise. Such adaptations include reduced resting and submaximal heart rates, increased stroke volume, improved myocardial contractility, and increased wall thickness of the 4 chambers that contribute to overall greater functional capacity.[33,34] The known benefits of exercise on cardiovascular health and the demonstrated feasibility of this intervention suggest our approach might have important implications for the long-term health and survival of pediatric heart transplant recipients. Moreover, in a cohort of pediatric allogenic hematopoietic stem cell transplant recipients, Vanderkerckhove et al[35] observed a significant correlation between lower exercise capacity, as measured by VO_2 max, and impaired quality of life, specifically in the emotional and social domains. These results suggest that improvements in exercise capacity in pediatric transplant recipients may have benefits not only in cardiovascular health but also on the overall well-being and quality of life of this pediatric patient population, by improving their ability to exercise and participate in group activities with other children that were previously out of reach.

We observed a significant improvement in endothelial function after the intervention. Studies in obese pediatric (nontransplant) patients have shown similar results following an exercise and diet lifestyle intervention.[36] However, data from the adult heart transplant literature are inconsistent: in a study following 16 adult heart transplant recipients at least 1 year after transplant, neither high-intensity interval training nor continued moderate training improved endothelial function, but this program did not include additional diet training.[37] Our intervention is the first, to our knowledge, to evaluate the impact of both an exercise and diet intervention on endothelial function in pediatric heart transplant recipients and to demonstrate an improvement. However, the improvement in endothelial function observed after intervention was not sustained after maintenance, after decreasing the frequency of live video–supervised exercise sessions to $\times 1$/week. Although patients reported exercising at least twice weekly on their own, we do not have data to confirm the accuracy of their self-reporting. It is conceivable that self-directed exercise sessions may not have been as demanding or as long as the live video–supervised sessions. Nevertheless, this was a study to test the feasibility of a live video–supervised exercise and diet intervention in this population and to evaluate its impact on the cardiovascular health and to explore a maintenance phase. Future research should investigate how to structure the maintenance phase best to maintain gained benefits in improved endothelial function.

Recently, a retrospective, single-center study reported that pediatric heart transplant recipients who are malnourished are at higher risk of postoperative complications and mortality, highlighting the need for an effective intervention to address inadequate and/or unhealthy nutrition in this high-risk patient population.[38] In our study, participants consumed a significantly lower amount of saturated fat daily after the intervention, suggesting that a weekly live video nutrition session based on the Dietary Approaches to Stop Hypertension protocol is a feasible and effective way to improve adherence to the nutrition guidelines for pediatric heart transplant recipients. Although this improvement was not sustained after maintenance in the entire cohort, it was sustained in patients with elevated saturated fat intake at baseline. Of note, the decrease in daily sodium intake reached significance after maintenance in patients with elevated sodium intake at baseline. These findings suggest that patients may benefit from longer-term nutrition interventions, as diet-related behaviors may take longer to change, especially in patients with unhealthy diets at baseline.

We also evaluated quality of life in this cohort. Our baseline results were similar to prior studies. Cousino et al[39] reported in their study that one third of pediatric heart transplant patients presented with significant psychosocial risk factors per parent report. In another study by Uzark et al,[40] parental and patient reports both indicated that pediatric heart transplant recipients had diminished physical and psychosocial quality of life compared with normal controls, particularly in emotional and social function. In our study, quality of life as reported through the Child Health Questionnaire did not significantly improve after intervention, suggesting the possible need for other psychosocial support for this patient population. It is encouraging that long-term engagement with a live video–supervised exercise and diet intervention to elevate exercise capacity in this patient population could result in significant improvements in quality of life, as patients are able to increase their exercise ability, range of movements, and participate in activities with other children that were previously out of reach.

As there was a range of duration (time spent) in the intervention (number of weeks), we considered that those engaging in the intervention for additional weeks might have better outcomes. However, using the Spearman correlation test, none of our outcome variables correlated with the number of weeks in the intervention. These findings suggest that the duration of the intervention can be as short at 12 weeks to see the desired outcomes. Even though we did not plan to include this in the scope of this article, we also reported some of our observations in the socioeconomic status of the patients and parents and how it might have affected participant engagement in the study.

Limitations

An important limitation of our study is that we did not have a control or comparison group and used patient baseline data as their own controls. Also, selection bias may have influenced our findings, as participants who were willing to participate in our study may have been more motivated to exercise and improve their diet compared with the overall pediatric heart transplant population. We approached 45 patients for enrollment in the study, and 5 of these patients declined. The median age of these 5 patients was 12 years (IQR, 10–15 years), and they were at a median of 7.7 years (IQR, 0.83–12 years) after transplant. They resided at a median of 71 miles (IQR, 33–88 miles) from our center. The remaining 26 of 45 patients we approached expressed interest but could not enroll in the study, citing scheduling the 3 study visits as a barrier. We acknowledge that some incentives of the study (ie, tablet and exercise equipment) may have influenced enrollment of participants who otherwise would not have participated in the study. However, these incentives were unlikely to influence the adherence rate, as incentives were given at the beginning of the study regardless of subsequent participation in study visit testing or scheduled exercise or nutrition sessions. Parental influence was critical in each participant's overall engagement with the study. Patients whose parents were more involved in scheduling and who were present for exercise and nutrition sessions were more likely to have consistent participation, although we did not collect this data quantitatively. However, we observed that the 2 patients from single head-of-household families had the lowest adherence rates in both the intervention and maintenance phases.

The increasing trend for more sedentary time seems counterintuitive despite significant changes in exercise testing results, vascular profiles, and functional movement scoring. It is important to recognize that this information is based on blocks of 1-week data before intervention, after intervention, and after maintenance periods and thus does not represent the physical activity of the patients throughout the entire 24- to 32-week-long participation. Additionally, even though we do not have data to support this, it is conceivable that patients might have been more eager in the first week of participation versus the last week and wanted to "impress" the investigators by moving more than usual.

Additionally, we were limited in evaluating the effects of the maintenance phase, as data on patients' self-directed exercise were self-reported and may be susceptible to recall or reporting biases. As such, we cannot conclusively state that patients exercised an additional $\times 2$/week on their own. This may have impacted the final measures of cardiac, vascular, and functional health and may explain why improvements achieved during the intervention phase were not sustained during the maintenance phase. Future research should consider incorporating more frequent supervised exercise sessions during the maintenance phase and/or more frequent monitoring of self-directed exercise by the intervention team.

Our maintenance results show that significant changes in height (median, +2.35 inches; P=0.002), BMI percentile (median, −37%; P=0.006), AIx75 bpm (median, −10.5%; P=0.04), VO_2 max (median, +3.2 mL/kg per minute; P=0.02), percent predicted VO_2 max (median, +13.8%; P=0.01), and FMS total score (median, +5; P=0.002) were sustained even after reducing the number of supervised exercised sessions from ×3/week to ×1/week. Although patients reported exercising at least twice weekly on their own, we do not know the accuracy of the self-report. At first, changes in improvements in endothelial function did not appear to be sustained after maintenance in the reducing supervised exercise sessions to ×1/week in our overall patient cohort.

We performed post hoc subgroup analyses of vascular measures after intervention and after maintenance for patients with abnormal values at baseline. As these subgroups were determined by baseline cutoffs, this type of analysis is subject to type 1 error because of regression to the mean. We were also not statistically powered to analyze these small groups. However, these cutoffs were based on objective normative values published previously or per laboratory standards. Finally, it is also important to note that the success we observed in this population could be isolated to this population and needs to be demonstrated in other pediatric populations.

Conclusions

In pediatric heart transplant recipients, a live video–supervised exercise and diet intervention is feasible and results in excellent adherence. In this intervention, several cardiac, vascular, nutritional, and functional health indices improved over 12 to 16 weeks, and several improvements were sustained following a maintenance phase. However, long-term maintenance of these benefits may require more frequent communication and supervision by the intervention team. Survey results support that the intervention has changed the outlook on exercise and nutrition for many of these patients and their families, both of whom would like to continue to work with the team. Integrating this telehealth program into a clinical setting has potential to improve long-term outcomes in this high-risk patient population.

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Disclosures

None.

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