Weir, Elise and Burns, Paul D and Devenny, Anne and Young, David and Paton, James Y (2017) Cardiopulmonary exercise testing in children with Cystic Fibrosis: one centre’s experience. Archives of Disease in Childhood, 102 (5). pp. 440-444. ISSN 0003-9888, http://dx.doi.org/10.1136/archdischild-2016-310651

This version is available at https://strathprints.strath.ac.uk/58512/

Strathprints is designed to allow users to access the research output of the University of Strathclyde. Unless otherwise explicitly stated on the manuscript, Copyright © and Moral Rights for the papers on this site are retained by the individual authors and/or other copyright owners. Please check the manuscript for details of any other licences that may have been applied. You may not engage in further distribution of the material for any profitmaking activities or any commercial gain. You may freely distribute both the url (https://strathprints.strath.ac.uk/) and the content of this paper for research or private study, educational, or not-for-profit purposes without prior permission or charge.

Any correspondence concerning this service should be sent to the Strathprints administrator: strathprints@strath.ac.uk

The Strathprints institutional repository (https://strathprints.strath.ac.uk) is a digital archive of University of Strathclyde research outputs. It has been developed to disseminate open access research outputs, expose data about those outputs, and enable the management and persistent access to Strathclyde's intellectual output.
Cardiopulmonary exercise testing in children with Cystic Fibrosis: One centre’s experience

Elise Weir¹, Paul D Burns², Anne Devenny¹, Young David³, James Y Paton⁴

¹Department of Respiratory Paediatrics, Royal Hospital for Children, Glasgow, UK
²Department of Respiratory and Sleep Physiology, Royal Hospital for Children, Glasgow, UK
³Department of Mathematics and Statistics, University of Strathclyde, Glasgow, UK
⁴School of Medicine, College of Medical, Veterinary, and Life Sciences University of Glasgow, UK

Corresponding author:
Dr Elise Weir, Department of Respiratory Paediatrics, Royal Hospital for Children, 1345 Govan Road, Glasgow G51 4TF.
elise_yu@doctors.org.uk
Tel 07766313502

Keywords: Cystic fibrosis, cardiopulmonary exercise testing, aerobic fitness, paediatrics, pulmonary function

Word count: 3636
ABSTRACT

Background
Exercise testing is increasingly being used as a prognostic indicator in Cystic Fibrosis (CF) but it is reported to be underutilised in UK CF centres, particularly in children. Here, we evaluated the CPET results of our children with CF at the CF annual review and its possible clinical value.

Method
A pilot observational study comparing CPET results using a cycle ramp test (peak oxygen uptake - VO$_{2peak}$) and pulmonary function (forced expiratory volume in 1 second – FEV$_1$) was performed. Body mass index (BMI) was used as a marker of disease severity. Data were identified from clinical case notes and our CF database.

Results
Thirty-eight children (mean age 11±2.4; range 7-14 years; sex 17M: 21F) completed at least one CPET with 95% achieving technically satisfactory tests allowing measurement of VO$_{2peak}$. Mean VO$_{2peak}$ was 105±18; range 74 - 150% predicted with 8% of children having a reduced VO$_{2peak}$ of < 85% of predicted. Mean FEV$_1$ z-score was -0.77±1.24, range -4.42 – 2.24. We did not demonstrate a significant correlation between VO$_{2peak}$ and FEV$_1$ or BMI (r = 0.25, -0.05). Twenty-eight of 38 children completed a second CPET the following year with 71% showing a decline in VO$_{2peak}$, (mean decline of 8% of predicted value, equivalent to 3.8 ml·kg$^{-1}$·min$^{-1}$).
Conclusion

CPET is feasible with 95 % of children achieving technically satisfactory assessments starting from age 7. In this group of children with relatively mild CF, mean VO₂peak was normal with no significant correlation between VO₂peak and FEV₁ or BMI, as markers of disease severity. The majority of children demonstrated a normal VO₂peak. However, 71 % showed a downward trend on repeat testing 12-18 months later.

What is already known on this topic

- Exercise testing is not widely used in CF centres in the UK.
- VO₂peak and FEV₁ are independent predictors of mortality in Cystic Fibrosis.

What this study adds

- We demonstrate that it is feasible to include a CPET as part of annual review in children from 7 years and upwards.
- CPET provides information additional to pulmonary function tests.
- In milder disease there is no significant correlation between FEV₁ and aerobic capacity.
- Annual review assessments of exercise capacity may identify declining levels of fitness and allow early physiotherapy intervention.
INTRODUCTION

Objective assessment and monitoring of lung health in Cystic Fibrosis (CF) has traditionally relied on radiographic and pulmonary function measures. In CF, pulmonary function, commonly measured as FEV₁, was noted to be a strong prognostic indicator of mortality,[1]. However, with advances in care, abnormal spirometry is becoming a later disease marker with UK registry data showing that median (IQR) % predicted FEV₁ in children > 6 years attending UK paediatric CF centres is 86% predicted (73-97%),[2]. Nixon et al in 1992, Pianosi et al in 2005 and more recently, Hulzebos in 2015, showed that aerobic fitness is an independent predictor of mortality and morbidity in patients with CF,[3,4 5].

The UK CF trust guidelines recommend exercise testing at the CF annual review when clinically indicated,[6]. Additionally, the European Cystic Fibrosis Exercise Working Group recommend that full CPET should be performed routinely in children aged 10 years and over,[7]. However, it has been reported that exercise testing is underused in CF centres in the UK. Of the tests reported to be used, field based walking tests such as the six-minute self-paced walking test (6MWT) and incremental shuttle walk test were most common,[8]. To the best of our knowledge there are no studies assessing the prognostic value of the 6MWT in children with CF. Indeed, there are limited reports on its prognostic value in adults with CF; for example, Martin et al found that a reduced 6 minute walking distance of ≤ 475 m and desaturation to SpO₂ ≤ 90 % during the test were independent predictors of death without transplantation,[9]. An incremental shuttle test is a reproducible and valid
alternative to CPET,[10] but there have been no studies to investigate its prognostic
value in children with CF. The use of other exercise tests in predicting mortality in
children has been investigated. Aurora et al reported that a low minimum oxygen
saturation (Sa,O$_2$min) during a 12-minute walk test was a poor predictor of mortality
in 181 children with severe CF lung disease referred for lung transplantation,[11]. In
contrast, VO$_{2peak}$ during CPET has been shown to predict mortality in children with
CF,[3,4].

VO$_{2peak}$ represents the maximal amount of oxygen that can be delivered by the
cardiovascular system and utilised at the muscles, therefore defines a person’s
functional aerobic capacity,[12]. The correlation between exercise limitation
assessed by VO$_{2peak}$ and lung high resolution computed tomographic (HRCT)
abnormalities has been reported to be stronger than that between spirometry, or
BMI and exercise limitation,[13]. In view of the potential usefulness of measuring
VO$_{2peak}$ as a guide to understanding the causes and extent of any exercise limitation
and for guiding the prescription of individualised exercise programmes,[14], our
centre introduced CPET as a replacement to the 6MWT. This has been offered to all
patients aged over 7 years on a yearly basis at their CF annual review from May
2013. Here, we review our experience of measuring VO$_{2peak}$ using CPET in this
context. We were interested to assess whether in clinical use, there were
correlations with other more commonly used outcome measures such as pulmonary
function test result and/or nutritional status measured as BMI. We also investigated
whether there was a difference in mean VO$_{2peak}$ depending on sex, the presence of at
least one DF508 mutation and a history of intravenous antibiotic treatment in the
preceding year. Finally, we were interested to investigate whether there were
annual changes in aerobic capacity over time.

MATERIALS AND METHODS

Study participants
We retrospectively analysed 18 months of data for each child attending the CF clinic
at the Royal Hospital for Sick Children in Glasgow, who performed CPET between
May 2013 to April 2016. The study cohort comprised of children over 7 years who
regularly attended the CF clinic and who had completed at least one CPET. They all
were clinically stable at the time of testing with disease severities ranging from mild
through to severe. Treatment routines remained unchanged during the study period.

Anthropometry
Before CPET, height was recorded without shoes to the nearest 0.1 cm using a fixed
stadiometer (Holtan Limited UK).[15]. Weight was measured with minimal clothing
to the nearest 0.1 kg (Seca 704).

Pulmonary function testing
Before CPET, spirometry and lung volumes were measured using a Jaeger
Masterscreen Body Plethysmograph (Jaeger V5.4, Germany). All pulmonary function
measurements were carried out by an experienced physiologist according to
American Thoracic Society (ATS)/European Respiratory Society (ERS)
standards,[16,17,18].
Cardiopulmonary Exercise Testing

A symptom limited CPET was performed using an electronically-braked cycle ergometer (Ergoline, Netherlands) with an incremental ramp protocol. Before each test, the metabolic cart (Jaeger, CPX, Germany) was calibrated following the manufacturer’s protocol using gases of known concentration, and an automatic volume calibration was performed on the turbine volume transducer. We used a Godfrey exercise protocol,[19] modified by our centre to minimise large increments in work load. The bicycle ramp ranged between 6.5 – 25 Watts·min⁻¹ with fixed increments of 6.5, 7.5, 8.5, 10, 12, 15, 20 and 25 Watts·min⁻¹. The ramp was increased every 10 s to minimise load perception for the patient. To achieve an optimal test duration of 8-12 min, the child’s predicted power output based on weight,[20] was divided by 10 to give the rate of ramp increase. Patients received verbal encouragement to achieve as near to a maximal test as possible. The test was stopped once the cadence could not be maintained > 60 rpm and the patient could not be verbally encouraged to do so. VO₂peak, peak oxygen pulse (VO₂/HRpeak) and peak ventilation (VEpeak) were averaged over the last 30 s of the test. The gas exchange threshold was non-invasively identified using a combination of the ‘V slope’ method and ventilatory equivalents.[12].

We considered a CPET technically satisfactory if one of the following 3 criteria were achieved at the end of the test: (1) HRpeak within 15 bpm of predicted maximum based on age; (2) respiratory exchange ratio (RER) > 1.1; or (3) plateau in VO₂.
Consent

This study was a retrospective review of results from our standard clinical practice. As such, we did not seek informed consent for review of the data. All patient data were anonymised.

Statistical Analysis

Demographic data (age, sex, genotype and intravenous antibiotic use) were retrieved from case notes and our CF database and were expressed as means and standard deviations. FEV$_1$ was expressed in absolute terms and as z-scores using all age reference ranges,[21]. Static lung volumes were expressed in absolute values and as z-scores using UK derived paediatric reference ranges,[22]. VO$_{2peak}$ was expressed in L·min$^{-1}$, ml·kg$^{-1}$·min$^{-1}$ and as percent predicted using a paediatric reference range,[20].

The relation between disease severity and VO$_{2peak}$ was assessed in two ways. We assessed the relation between VO$_{2peak}$ and body mass index (BMI) since it is well recognized that poor nutritional status has a negative impact on pulmonary disease,[23,24]. We also examined whether there was a correlation between VO$_{2peak}$ and intravenous antibiotic use in the preceding year. We included children treated both for CF exacerbations as well as those receiving routine treatment as part of their CF management.

Relationships between VO$_{2peak}$ with FEV$_1$, BMI z-score and age were studied using Pearson’s Correlation Coefficient. Differences between mean VO$_{2peak}$ with sex and
intravenous antibiotic use were studied using a Two-sample T-Test. A one-way
ANOVA was conducted to compare the effect of genotype (DF508 homozygous,
DF508 heterozygous and ‘other’ genotypes) on VO\textsubscript{2peak}.

We used a paired T-test to check for statistically significant differences between
initial and consecutive CPET parameters of aerobic fitness. This included absolute
VO\textsubscript{2peak} (L·min\textsuperscript{-1}), relative VO\textsubscript{2peak} (ml·kg\textsuperscript{-1}·min\textsuperscript{-1}), VO\textsubscript{2peak} % predicted and finally
VO\textsubscript{2peak} allometrically scaled (ml·kg\textsuperscript{2/3}·min\textsuperscript{-1}).

**RESULTS**

**Genotype.**

Nineteen children with DF508 homozygous, 16 children DF508 heterozygous and 3
children with ‘other’ genotypes.

**Pulmonary function & anthropometry.**

Anthropometry and pulmonary function are summarised in tables 1 & 2. We
analysed results from 38 children (17 male and 21 female). Seven children had an
FEV\textsubscript{1} consistently below the lower limit of normal,[22].

**Table 1**

**Table 2**
CPET parameters are summarised in table 3. We were able to perform technically satisfactory assessments on 36/38 (95%) of children. In 2 young children (both 7 years old) the CPET was technically unsatisfactory due to poor cooperation and effort. Aerobic capacity in children with CF was within a range consistent with a normal, healthy population (VO$_{2peak}$ of ≥ 85% predicted,[25]). Only 5 children (13%) had VO$_{2peak}$ of < 85% predicted. Two children desaturated to SpO$_2$ < 95% at peak exercise. No ECG arrhythmias were detected in any of the patients.

Table 3

Using Pearson’s Correlation Coefficient, we found no significant correlation between VO$_{2peak}$ and FEV$_1$ (r = 0.25, p=0.13), VO$_{2peak}$ and age (r = -0.24, p=0.15) or between VO$_{2peak}$ and BMI z-score (r = -0.05, p=0.77). Using a Two-sample T-Test, we found no significant differences in mean VO$_{2peak}$ between males (107.9±19.1) vs females (107.1±17.0), p=0.90. Fourteen of 38 child received intravenous antibiotic treatment in the preceding year. We found no significant differences in mean VO$_{2peak}$ if the child had received intravenous antibiotics (103.0±18.5) vs no intravenous antibiotics (110.1±17.1), p=0.23. Nineteen children were DF508 homozygous, 16 were DF508 heterozygous and 3 had ‘other’ genotypes. We found no significant effect of genotype on VO$_{2peak}$ (p=0.24).

Figure 1. Change in VO$_{2peak}$ % predicted in 28 children with CF measured between 12-18 months apart.
Consecutive annual CPET data were available for 28/38 (74%) children (Figure 1). These were performed up to 18 months after the initial CPET due to timings of the CF annual review appointment. Ten children did not perform a repeat CPET: 3 transitioned to adult services; 4 did not attend their annual review appointment; 1 had a CF exacerbation at the time of annual review; 1 had an unsatisfactory test due to submaximal patient effort and there was insufficient staffing for 1 patient.

VO\textsubscript{2peak} decreased in 71% of the subjects. The mean change in VO\textsubscript{2peak} parameters are shown in table 4. Overall, there was no significant difference in mean change of absolute VO\textsubscript{2peak} (p > 0.05). However, there was a statistically significant decline in VO\textsubscript{2peak} when it was related to body weight, or to % predicted VO\textsubscript{2peak} (which includes sex and body weight in the predicting equation) or when using allometrical scaling (ml·kg\textsuperscript{-2/3}·min\textsuperscript{-1}), p= 0.001, 0.003 and 0.03 respectively. The mean decline relative to body weight was 3.8 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}equivalent to an 8% from baseline value. An 8% change is greater than the normal coefficient of variation reported in the literature for VO\textsubscript{2peak} (4.8%) when looking at biological quality control,[26] although the normal variability for young CF patients is likely to be greater.[27].
DISCUSSION

We found that the majority of our CF patients had normal BMI and pulmonary function in keeping with data in the UK CF registry,[2]. In this relatively mild group of children with CF, the majority of our VO$_{2peak}$ results were also normal suggesting that we have an aerobically fit group of children. This may partly reflect our Centre’s focus on promoting a healthy diet, regular physical activity and physiotherapy in our CF patients.

We found no significant correlation between FEV$_1$ and VO$_{2peak}$. This could be explained by the relatively small sample size and the majority having normal lung function and aerobic capacity. However, it is also recognized that FEV$_1$ has to be significantly reduced to affect exercise capacity,[28].Previously, FEV$_1$ has been shown to correlate with VO$_{2peak}$ in children,[29]. McBride et al investigated 64 children with CF aged 8-11 years and found a statistically significant but weak correlation between FEV$_1$ % predicted and VO$_{2peak}$ % predicted with an R$^2$ value of 0.14. The most likely explanation for the differences observed in our study is a combination of a larger sample with a wider range of lung function and fitness. However, the low R$^2$ in the study by McBride and the absence of any correlation in our data suggest there is not a strong relationship between FEV$_1$ and VO$_{2peak}$. As only 7 of our patients had an FEV$_1$ below the lower limit of normal, it is perhaps not surprising that we did not see a relationship in a relatively mildly affected population,[30]. However, there is also a debate about the factors which limit aerobic function in CF with both suggestions of central such as impaired stroke
volume,[31] and/or peripheral mechanisms such as impaired muscle metabolism being involved, apart from changes in lung function[32].

In our mild to moderate CF children, the majority did not demonstrate any evidence of ventilation limitation at maximal exercise, as would be expected in healthy children. There are varying reports in the literature on the aerobic fitness of CF children. Nixon et al were one of the first groups to investigate VO\textsubscript{2peak} and its prognostic value. Their group included 40 adults and 68 children and adolescents. They found a range of lung function impairment with 65 % of their study population having an FEV\textsubscript{1} of < 65 % predicted. They found generally a low aerobic capacity with a mean VO\textsubscript{2peak} of 70 % predicted (35 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}),[3]. More recently, Hulzebos et al investigated 127 adolescents with CF with a mean FEV\textsubscript{1} of 77.7±15.6 % predicted and a VO\textsubscript{2peak/kg} 93.3±17.9 % predicted,[5].

Pianosi et al exclusively investigated children with CF and reported an initial VO\textsubscript{2peak} of 41.2 ml·kg\textsuperscript{-1}·min\textsuperscript{-1},[4]. This would be classed as ‘fair’ aerobic fitness according to published reference values for children and adolescents,[28]. More recent studies have included control groups and showed that CF children and adolescents had a significantly reduced VO\textsubscript{2peak} when compared to healthy children. For example, Bongers et al found their CF group of 22 children was within the normal range although the values for VO\textsubscript{2peak} were significantly lower than the controls,[33]. Saynor et al also found a reduced aerobic capacity (mean VO\textsubscript{2peak} 36.3 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}) in subjects with CF compared to controls,[34].
Other studies have reported that nutritional status affects exercise capacity,[35,36]
but since very few of the children in our study had either an abnormal BMI or an
abnormal VO_{2peak} ≤ 84 % predicted (range 64 – 84),[25] we were unable to
demonstrate a significant a correlation. On reviewing the 3 children with an
abnormal VO_{2peak}, all had normal BMI z-scores -0.57, 1.13, 1.83. One child with a BMI
z-score of 1.83 (98th percentile) and VO_{2peak} 74 % predicted, had poor exercise
activity. His low VO_{2peak} may be a reflection of deconditioning as well as high fat
rather than muscle mass.

Whilst the majority of our patients had normal CPET results, 71 % demonstrated a
decline in VO_{2peak} on repeat testing 12-18 months later. There is little reported data
about what constitutes a significant decline in VO_{2peak} in CF patients. There are a
number of cross sectional and longitudinal studies investigating the trend in VO_{2peak}
in healthy children. In a review by Krahenbuhl et al, mean values of VO_{2peak} relative
to body weight from several longitudinal and cross sectional studies were plotted
against age in males and females to investigate the relationship over the age range
6-16 years,[37]. They found that males had an unchanged VO_{2peak} corrected for body
weight over time, whereas females showed a decline from 52.0 ml·kg^{-1}·min^{-1} to 40.5
ml·kg^{-1}·min^{-1}. However, it is recognized that correcting VO_{2peak} for body mass has
limitations and does not normalize the data,[38,39]. Ratio scaling of VO_{2peak} by body
mass (as opposed to fat free mass) penalizes females and those that are heavier than
their aged match peers and it has been reported that allometric scaling of VO_{2peak} is a
more reliable method to interpret changes in VO_{2peak},[40]. The Amsterdam Growth
and Health Longitudinal Study recently published data on changes in aerobic fitness
for approximately 650 adolescents over a 25 year period. VO\textsubscript{2peak} was presented in absolute values, relative to body weight and allometrically scaled. They found that from 12-17 years in both males and females, there was a downward trend in VO\textsubscript{2peak} relative to body weight. However, when allometrically scaled, VO\textsubscript{2peak} in males did not decrease whereas females did demonstrate a decline,[41]. In our data, aerobic fitness declined significantly, irrespective of whether it was related to body weight, or to sex and body weight using the predicted values or using allometric scaling (table 4), although the deterioration was least using allometric scaling.

Pianosi et al looked at annual CPET over a 5 year period in CF children and found that VO\textsubscript{2peak} decreased in 70\% of the subjects with a mean annual decline of 2.1 ml·kg\textsuperscript{-1}·min\textsuperscript{-1},[4]. These results show similarity to our results, albeit over a much shorter period. We can only speculate on the reasons for the decline in some children. Although changes in lung function itself may not have caused changes in aerobic fitness, acute exacerbations as well as disease progression may have resulted in these patients participating in less physical activity with a consequent reduction in fitness. In others, the increase fitness may represent the effects of interventions such as planned exercise prescription.

Pianosi also showed that initial VO\textsubscript{2peak} did not affect the rate of decline and this highlights that longitudinal assessments of aerobic capacity are important,[4]. Further work will be required to investigate the place of repeated CPET tests in assessing exercise capacity in CF patients over time. Identifying a downward trend in a child’s exercise capacity may allow early physiotherapy intervention and
encouragement to increase physical activity to prevent ongoing decline in exercise capacity. Regardless of the definition of a ‘clinically significant decline’ in VO\textsubscript{2peak}, we consider any fall in exercise capacity to be important as small declines in VO\textsubscript{2peak} may cumulatively result in a clinically significant reduction in aerobic capacity. Pianosi at al showed that patients with VO\textsubscript{2peak} < 32 ml·kg\textsuperscript{-1}·min\textsuperscript{-1} exhibited a dramatic increase in mortality,[4]. This may highlight those who would benefit from additional encouragement to increase their physical activity and prevent de-conditioning.

We had previously used the 6 Minute Walk Test (6MWT) to assess exercise performance at annual review but in the light of the evidence about VO\textsubscript{2peak} as a strong predictor of mortality, we replaced the 6MWT with CPET. Whilst the initial cost for CPET equipment is significant, the cost for consumables is minimal and our respiratory laboratory already had dedicated time allocated for the assessments. Performing an annual CPET in place of 6MWT added minimal time to the CF annual review visit. We found that it was feasible to include CPET as part of the annual review. Ninety-five % of our children achieved technically satisfactory assessments starting from an age of 7 years. In our centre, children under 7 years of age are not routinely offered CPET or field exercise test due to difficulties in performing them in this age group. However, we would attempt CPET if clinically indicated and at the discretion of the referring clinician. For the duration of this study, no children under 7 years of age were referred for exercise testing. Whilst we have demonstrated that CPET is a feasible and achievable investigation in children 7 years and older at the CF annual review, it is a technically demanding assessment and can only be performed in a centre with the necessary equipment and appropriately trained staff.
Although we have no formal feedback, the majority of our patients and their parents have engaged well with the introduction of CPET at annual reviews. The children reported that they enjoy the challenge of CPET. Importantly, our respiratory physiotherapists have found CPET clinically beneficial in identifying those children needing more specific exercise advice, particularly for children with stable lung function but declining VO$_{2peak}$. Of the 5 patients who had an abnormal VO$_{2peak}$ $\leq$ 84 % predicted, none had reduced lung function. Whilst our centre encourages all our patients to undergo regular physical activity, the declines in VO$_{2peak}$ highlighted the need for additional physiotherapy intervention to increase their physical activity and prevent ongoing decline. This emphasizes the value of using CPET as an assessment tool to guide counseling about exercise and the prescription and monitoring of exercise programmes,[42].

**Study limitations**

This was a retrospective review and we had no control group, relying instead on published normal data. We recognise that our numbers were small, only 74 % completed a second CPET during the study period, and our patients were only followed up for one year. We continue to collect data as longer follow up will give a more informative assessment of extent and value of changes in aerobic capacity. In this case, the predicted values for VO$_{2peak}$ are based on a limited number of North American children. Future research should focus on providing suitable reference data for UK children. In the context of our paediatric clinical population, it was not feasible to perform a supramaximal test on each patient to verify a ‘true’ VO$_{2peak}$ as demonstrated by a plateau in VO$_2$. Our use of secondary criteria of HR$_{peak}$ and RER
may therefore underestimate the ‘true’ VO$_{2\text{peak}}$ [43]. We also did not routinely take
body fat measurements but recognise that this may affect the VO$_{2\text{peak}}$ % predicted
which uses body weight in the predictive equation. Finally, we had no standardised
recording of physical activity levels of the children in the 12-18 month interval
between the first and second tests which might have been informative in assessing
the effect of regular activity and/or exercise on aerobic capacity.

CONCLUSION

CPET is feasible as a test of aerobic function at the CF annual review. It offers
additional prognostic information to routine pulmonary function tests and allows
identification of de-conditioned patients who may need to increase their physical
activity. In our population with relatively mild CF, most children had normal VO$_{2\text{peak}}$
when compared with reference data. However, a large majority showed significant
declines in VO$_{2\text{peak}}$ the following year highlighting the importance of serial aerobic
fitness measurements to help identify patients who may benefit from additional
physiotherapy support and intervention.

Acknowledgements

We would like to thank all the patients who performed PFT’s and CPET during the
study period and our physiotherapy team who contribute to maintaining aerobic
fitness in our children with CF.
Contributorship.

AD instigated, designed and supervised the study. EW and PB contributed to the design of the study, collected the data and analysed results with DY. EW and PB wrote the article. JYP reviewed and commented on the article.

Funding

No funding was obtained for this study.

Competing interests

None declared
2 UK Cystic Fibrosis Registry 2014 Annual Data Report. Published August 2015
28 Cooper BC, Storer TW. Exercise testing and interpretation. Cambridge University Press 2001
### Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>mean</th>
<th>SD</th>
<th>Min, max Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>11.0</td>
<td>2.39</td>
<td>7.3, 15.7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>145.3</td>
<td>16.48</td>
<td>115, 180.8</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>39.2</td>
<td>13.18</td>
<td>20.2, 69.5</td>
</tr>
<tr>
<td>BMI z-score</td>
<td>0.1</td>
<td>1.00</td>
<td>-2.2, 2.5</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>mean</th>
<th>SD</th>
<th>Min, max Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV&lt;sub&gt;1&lt;/sub&gt; (L)</td>
<td>2.07</td>
<td>0.75</td>
<td>0.98, 4.06</td>
</tr>
<tr>
<td>FEV&lt;sub&gt;1&lt;/sub&gt; z-score</td>
<td>-0.77</td>
<td>1.24</td>
<td>-4.42, 2.24</td>
</tr>
<tr>
<td>FEV&lt;sub&gt;1&lt;/sub&gt;/FVC (%)</td>
<td>81</td>
<td>8</td>
<td>57, 96</td>
</tr>
<tr>
<td>FEV&lt;sub&gt;1&lt;/sub&gt;/FVC (%) z-score</td>
<td>-0.99</td>
<td>1.24</td>
<td>-3.64, 1.55</td>
</tr>
<tr>
<td>TLC (L)</td>
<td>3.67</td>
<td>1.15</td>
<td>2.04, 7.01</td>
</tr>
<tr>
<td>TLC z-score</td>
<td>0.70</td>
<td>1.04</td>
<td>-1.08, 3.17</td>
</tr>
<tr>
<td>RV (L)</td>
<td>1.07</td>
<td>0.49</td>
<td>0.58, 2.58</td>
</tr>
<tr>
<td>RV z-score</td>
<td>0.59</td>
<td>1.75</td>
<td>-1.48, 6.61</td>
</tr>
</tbody>
</table>

### Table 3

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Min, Max Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximal Exercise parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute VO&lt;sub&gt;2peak&lt;/sub&gt; (L·min&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>1.58</td>
<td>0.52</td>
<td>0.88, 3.01</td>
</tr>
<tr>
<td>Relative VO&lt;sub&gt;2peak&lt;/sub&gt; (ml·kg&lt;sup&gt;-1&lt;/sup&gt;·min&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>42.0</td>
<td>7.7</td>
<td>29.2, 62.3</td>
</tr>
<tr>
<td>VO&lt;sub&gt;2peak&lt;/sub&gt; (% predicted)</td>
<td>105</td>
<td>18</td>
<td>74, 150</td>
</tr>
<tr>
<td>VE max (L·min&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>64</td>
<td>24</td>
<td>28, 137</td>
</tr>
<tr>
<td>Breathing reserve (%)</td>
<td>19</td>
<td>20</td>
<td>-36, 54</td>
</tr>
<tr>
<td>Heart Rate max (Beats·min&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>188</td>
<td>10</td>
<td>160, 208</td>
</tr>
<tr>
<td>Oxygen Pulse max (ml·beat&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>8.6</td>
<td>2.8</td>
<td>4.0, 16.0</td>
</tr>
<tr>
<td>End test SpO&lt;sub&gt;2&lt;/sub&gt; (%)</td>
<td>97</td>
<td>2</td>
<td>89, 100</td>
</tr>
<tr>
<td>Peak power Output (Watt)</td>
<td>97</td>
<td>42</td>
<td>41, 212</td>
</tr>
<tr>
<td>Relative Peak power output Watt·kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>2.5</td>
<td>0.6</td>
<td>1.6, 3.8</td>
</tr>
</tbody>
</table>

| **Submaximal Exercise**                |      |     |                |
| VO<sub>2</sub> at GET (ml·min<sup>-1</sup>) | 826  | 215 | 415, 1455      |
| GET (% of VO<sub>2peak</sub>)          | 53   | 7   | 38, 70         |
| VO<sub>2</sub>/Work Rate (ml·watt<sup>-1</sup>·min<sup>-1</sup>) | 10.6 | 0.9 | 9.1, 12.3      |
| VE/VCO<sub>2</sub> Slope               | 30.9 | 3.8 | 22.4, 44.0     |

*GET - Gas exchange Threshold*
<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean$_{1\text{st CPET}}$</th>
<th>Mean$_{2\text{nd CPET}}$</th>
<th>Absolute Difference</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO$_{2\text{peak}}$ (L·min$^{-1}$)</td>
<td>1525 ± 480</td>
<td>1539 ± 420</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>VO$_{2\text{peak}}$ Relative to bodyweight (ml·kg$^{-1}$·min$^{-1}$)</td>
<td>42.7 ± 7.0</td>
<td>38.9 ± 8.2</td>
<td>-3.8</td>
<td>-9</td>
</tr>
<tr>
<td>VO$_{2\text{peak}}$ % Predicted (includes sex and body weight)</td>
<td>107 ± 17</td>
<td>99 ± 17</td>
<td>-8</td>
<td>-8</td>
</tr>
<tr>
<td>VO$_{2\text{peak}}$ Allometrically scaled (ml·kg$^{-2/3}$·min$^{-1}$)</td>
<td>137 ± 22</td>
<td>130 ± 22</td>
<td>-7</td>
<td>-6</td>
</tr>
</tbody>
</table>