FEASIBILITY OF MUSCLE ACTIVITY ASSESSMENT WITH SURFACE ELECTROMYOGRAPHY DURING BED CYCLING EXERCISE IN INTENSIVE CARE UNIT PATIENTS

JUULTJE SOMMERS, MSC, PT,[1] MICHELLE VAN DEN BOORN, MSC,[2] RAOUL H.H. ENGELBERT, PROF, PT,[1,3] FRANS NOLLET, MD,[1] MARIKE VAN DER SCHAAF, PHD, PT,[1,3] and JANNEKE HORN, PHD, MD[2]

[1] Department of Rehabilitation Medicine, Amsterdam Movement Sciences, Amsterdam UMC, University of Amsterdam, Meibergdreef 9, P.O. Box 22660, 1100DD, Amsterdam, The Netherlands

[2] Department of Intensive Care, Amsterdam UMC, University of Amsterdam, Amsterdam, The Netherlands

[3] ACHIEVE–Centre of Applied Research, Faculty of Health, Amsterdam University of Applied Sciences, Amsterdam, The Netherlands

Accepted 26 August 2018

ABSTRACT: *Introduction:* Intensive care unit (ICU) patients often develop weakness. Rehabilitation is initiated early to prevent physical deterioration, but knowledge of optimal training schedules is lacking. A reliable method to assess muscle activity during exercise is needed. In this study we explored the feasibility of electrical activity measurement by surface electromyography (sEMG) during bed cycling in ICU patients. *Methods:* SEMG was performed in 9 ICU patients and 6 healthy controls. A standardized 1-minute incremental resistance bedside cycle ergometer protocol was used. *Results:* The median cycle time was 5.3 minutes in patients and 12.0 minutes in controls. The maximum sEMG increased in both groups; the minimal sEMG activity remained the same in patients, whereas an increase in the control group was found. *Discussion*: sEMG is feasible and can detect muscle activity during bed cycling in ICU patients. It may be a useful monitoring tool. Repeated measurements could possibly provide information on the effects of training.

Muscle Nerve **58**:688–693, 2018

In critically ill patients who are admitted to the intensive care unit (ICU), muscle weakness often develops, which is referred to as ICU-acquired weakness (ICU-AW).[1] Limiting bed rest and inactivity in early rehabilitation has a positive effect on muscle strength, walking ability, and functional outcome.[2,3] However, the optimal frequency, intensity, and type of exercise for ICU patients is unknown.[3,4]

To achieve training effects on muscle strength and cardiorespiratory fitness, the training load should be sufficient, but not excessive, for the cardiac, respiratory, and musculoskeletal systems. Monitoring of these systems during exercise is required to investigate and document the training intensity.[5] Therefore, a tool to assess muscle activity during exercise would be helpful to identify the optimal level of exercise intensity for an individual. Such information would allow the development of a personalized training schedule. Surface electromyography (sEMG) monitoring of muscle activity has been described in healthy volunteers to assess muscle activity and fatigue during exercise.[6–9] sEMG detects the electrical activity of the motor units that are involved in muscle contractions and can be considered a surrogate measure of the effort of the muscles. sEMG has been used for diaphragm monitoring in (mechanically ventilated) pre-term infants,[10,11] but monitoring of leg muscles during bed cycling in patients in the ICU is new and could provide useful information.

The aim of this pilot study was to determine whether sEMG is a feasible method for muscle monitoring during bed cycling in ICU patients.

METHODS

Between January 2015 and March 2016, we conducted a prospective pilot study in the ICU of the Academic Medical Center, Amsterdam, The Netherlands, a 34-bed, mixed medical–surgical ICU and medium care unit. The study was approved by the medical ethics review committee (NL50006.018.14), and informed consent from each study subject was obtained.

Adult ICU patients mechanically ventilated for > 48 hours who could cycle were eligible for the study. To enable active bed cycling, a muscle strength score ≥ 3 on the Medical Research Council (MRC) scale for the legs (hip flexion, knee extension, and dorsal flexion of the feet) was required. Exclusion criteria were contraindications to perform physical exercise according to the safety criteria of the Evidence Statement for Physiotherapy in the ICU,[4] a score of < 3 (as measured using the Short 5-item Questionnaire [S5Q]) for inability to follow instructions,[12–14] and insufficient knowledge of Dutch. The control group consisted of healthy subjects.

Measurements. The patients and controls were tested once. They were placed in the semi-recumbent position in bed with both legs placed in a motorized cycling exercise device (MOTOmed letto2; RECK-Technik, Betzenweiler, Germany). The cycling protocol started with 1 minute of passive, unloaded cycling at 20 revolutions per minute (RPM). Next, active cycling started, in which the resistance was gradually increased according to the fixed levels of resistance (steps) of the bed cycle. The capacity of the bed cycle consisted of

Additional supporting information may be found in the online version of this article.

Abbreviations: APACHE, Acute Physiology and Chronic Health Evaluation; DEMMI, De Morton Mobility Index; HR, heart rate; ICU, intensive care unit; ICU-AW, ICU-acquired weakness; MRC, Medical Research Council; RMS, root mean square; RPE, rating of perceived exertion; RPM, revolutions per minute; sEMG, surface electromyography; S5Q, Short 5-item Questionnaire; $sEMG_{max}$, maximum sEMG; $sEMG_{min}$, minimum sEMG; ΔsEMG, change of sEMG; MDF, median frequency; MFCV, muscle fiber conduction velocity

Conflicts of Interest: None of the authors have any conflict of interest to disclose.

Correspondence: J. Sommers; e-mail: j.sommers@amc.nl

Published online 30 August 2018 in Wiley Online Library (wileyonlinelibrary.com). DOI 10.1002/mus.26330

20 increasing levels of resistance with the lowest resistance at 0 (step 0). Resistance was increased at 1 step per minute in the patient group and 2 steps per minute in the control group, leading to a total protocol duration of 22 minutes and 12 minutes, respectively. The bed cycle provided detailed data of the maximal workload (watts), duration of cycling (minutes), and RPM. When RPM was reduced to <10, the cycling was stopped. Throughout the exercise test, hemodynamic parameters (heart rate [HR] and mean arterial pressure) and respiratory parameters (oxygen saturation and respiratory frequency) of the patients were collected to assess safety. When the HR was >80% of the maximum predicted HR (using the Fox formula), or the patient's safety was threatened in any other way, the cycling was stopped.[2,4,15]

The Borg Rating of Perceived Exertion (RPE) scale (range 6–20 points)[16,17] was used directly after the exercise. The Borg RPE scale is a reliable and valid measurement to assess exertion perceived by patients during and after exercise,[18] with higher scores indicating higher perceived exertion.[17] Furthermore, the patients and controls were asked whether they experienced muscle fatigue (yes/no) in the legs. The sEMG (microvolts) recordings were performed using the Dipha-16 device (Inbiolab BV, Groningen, The Netherlands). Four electrodes (H59P Cloth Electrode; Kendall) were placed on the muscle rectus femoris in both legs (refer to Fig. S1 in Supplementary Material online). Without analog filtering, the sEMG data were digitized and sent wirelessly to the Dipha-16 system connected to a laptop with a Polybench (Applied Biosignals, Weener, Germany) application.

The following data were obtained from the patients' medical records: age; gender; reason for ICU admission; disease severity according to the Acute Physiology and Chronic Health Evaluation (APACHE) II[19]; duration of mechanical ventilation and ICU stay at moment of testing; muscle strength (MRC sum score); and the level of mobility (on the testing day), as assessed by the De Morton Mobility Index (DEMMI).[20,21] The APACHE score measures the severity of illness on ICU admission, with a range of 0–71. A higher score corresponds to more severe disease and a higher risk of death. The MRC sum score for the assessment of ICU-AW was defined as a score obtained from bilateral testing of 6 muscle groups (shoulder abduction, elbow flexion, wrist extension, hip flexion, knee extension, and ankle dorsiflexion).[22,23] This leads to a range for the MRC sum score of 0–60 points.[24] The DEMMI scale measures the full range of mobility within the ICF activity domain.[20,21] It consists of 15 hierarchical mobility items (3 beds, 3 chairs, 4 static balances, 2 walking and 3 dynamic balance items). The score range is 0–100, where 0 represents poor mobility and 100 indicates high levels of independent mobility. From the control group, we obtained data on age, gender, Borg RPE scale, and muscle fatigue.

Data and Statistical Analysis. Patients' characteristics and continuous variables are described using descriptive statistics and are presented as mean and standard deviation, or, in the case of a skewed distribution, as median and interquartile range (25th–75th percentile, IQR). Normality was checked using the Kolmogorov–Smirnov test. Categorical variables are expressed as proportion with percent.

The sEMG signals were transformed using root-mean-square (RMS) analysis, and the curves were analyzed offline in MATLAB (MATrix LABoratory, The Mathworks, Natick, Massachusetts).

Stable signals were selected from at least 10 cycling cycles immediately after an increase of resistance. The maximum sEMG ($sEMG_{max}$) and minimum sEMG ($sEMG_{min}$) were determined using a peak detection (high and low) algorithm in MATLAB. If peak detection identified 2 consecutive peaks or troughs, only the first peak or trough was used for analysis.[11] From the selected 10 cycling cycles, the mean was calculated and used for group analysis.[11]

Three parameters, $sEMG_{max}$, $sEMG_{min}$, and change in sEMG (ΔsEMG), were analyzed for each step.[7,11] The peaks ($sEMG_{max}$) represent the number of motor units recruited during muscle contraction, and the troughs ($sEMG_{min}$) represent the number of motor units still active during relaxation of the muscle within each revolution cycle (see Fig. S2 in Supplementary Material online). By subtracting the troughs from the peaks, the ΔsEMG was calculated. $P < 0.05$ for overall difference between groups (ICU patients and controls) was considered significant using the linear mixed model.

RESULTS

Nine patients and 6 healthy volunteers were included in this pilot study. The reason for ICU admission were medical (4 patients), planned (3 patients), and unplanned surgical (2 patients). Further characteristics are presented in Table 1. The patients had decreased levels of physical function.

The patients cycled for a shorter duration than the healthy controls (see Table 2). The increases in resistance and maximal workload were lower. During

Table 1. Patients' characteristics at the moment of testing.*

	ICU patients (*n* = 9)	Healthy persons (*n* = 6)
Age, in years	70 (53–77)	59 (47–63)
Gender, women (*n*)	3	3
ICU stay to inclusion, in days	45 (14–59)	—
Patients with mechanical ventilation during measurement (*n*)	4	—
Mechanical ventilation, in days	18 (6–40)	—
APACHE II score	17.5 (14–21)	—
MRC sum score	42 (37–43)	60 (60–60)
DEMMI	24 (18–32)	100 (100–100)

IQR, interquartile range; ICU, intensive care unit; APACHE, Acute Physiology and Chronic Health Evaluation score; MRC, Medical Research Council scale; DEMMI, De Morton Mobility Index.

*Data presented as median (interquartile range), unless noted otherwise.

Table 2. Results of bed cycling.*

	ICU patients (n = 9)	Healthy persons (n = 6)
Duration of the test (min:s)	5:3 (4:6–8:2)	12:0 (12:0–12:0)
Maximal workload (W)	3 (2.5–5)	34.5 (32.5–54.5)
RPM	33.5 (26–38.3)	60 (53.3–73.8)
Maximum steps	4 (4–5)	20 (20–20)
Borg score	13 (12–15)	13 (9–13)
Reason to stop (n)		
Muscle fatigue	7	
Dyspnea	1	
Other	1	6 (end of program)

ICU, intensive care unit; RPM, revolutions per minute.

*Data presented as median (interquartile range), unless noted otherwise.

the exercise test, there were no changes in the hemodynamic and respiratory safety parameters monitored. Therefore, cycling was never stopped due to safety reasons. All controls completed the 12-minute program with 20 steps of increasing resistance.

Surface Electromyography. At the start of cycling, during the passive period, sEMG activity was able to be recorded. Evaluation of sEMG during active cycling showed an increase in ΔsEMG in the ICU and control groups. This reflected primarily an increase in $sEMG_{max}$. The trough values ($sEMG_{min}$) showed no change in the patient group but an increase in the control group (Fig. 1.).

The overall difference between the peaks ($sEMG_{max}$) of the ICU and control groups was not significant (0.27 μV [95% confidence interval –4.41 to 4.96]; P = 0.9). For trough ($sEMG_{min}$), a statistically significant difference of 1.8 μV (95% confidence interval 0.05 to 3.53) was found (P = 0.047).

DISCUSSION

In this pilot study we have shown that muscle activity from the rectus femoris can be monitored during bed cycling by sEMG in ICU patients. With increasing resistance, a clear increase in muscle activity was observed. These findings indicate that sEMG is feasible and may be useful to monitor muscle activity in ICU patients during exercise. In addition, during passive cycling, limited muscle activity was detected.

Recording of sEMG for the assessment of muscle activity during cycling in healthy persons has already been described.[6–9] In these populations, the method was found to be a useful tool to investigate muscle fatigue. sEMG during cycling was also used in patients with chronic low back pain or cerebral palsy to detect muscle activation and fatigue.[25,26] Because all these studies were performed on normal training bikes instead of cycles used at the bedside, we decided to explore our method in healthy subjects to compare and validate our method of cycling in the ICU.

The methods used to analyze the results of sEMG recordings during cycling differ substantially in the literature.[6,7] Martin-Valdez *et al.* and Macdonald *et al.* used the median frequency (MDF), muscle fiber conduction velocity (MFCV), and amplitude (RMS) to investigate muscle fatigue.[6,7] Both studies recommended the use of RMS amplitude as the most suitable and sensitive variable to observe muscle activity during incremental exercise and fatigue.[6,7] In our pilot study, we evaluated the amplitude (in the RMS signal) found in 10 subsequent rotations directly after each increase in resistance. This straightforward method was also used to assess diaphragm weakness at our hospital.[11]

We also found sEMG activity in both groups during the passive period of cycling. This indicates that motor units were already activated in this phase. These results seem to support the observations by Kayambu *et al.* of the benefits of passive cycling in ICU populations. In those studies, they found that passive cycling reduced muscle wasting and prevented muscle atrophy, improved muscle strength and physical function, and reduced length of hospital stay in medical and surgical ICU populations.[2,27–29]

In most ICU patients, termination of bed cycling was caused by patients reporting muscle fatigue in the legs. None of the controls stopped for this reason. We also evaluated general exertion using the Borg RPE scale immediately after the exercise.[16,17,30] Both ICU patients and controls reported a Borg RPE score of 13 defined as "somewhat hard," indicating that there was no difference in perceived exertion.[16,17]

Limitations. Our study has some limitations that need to be acknowledged. Due to the strict inclusion criteria we used, our study population was small and training was done at a rather late phase of the ICU admission. Another limitation of our study was the software of the bedside cycle ergometer used. The increased power during the test could not be set on a fixed wattage per minute. The software selected its own increase in resistance based on the RPM and

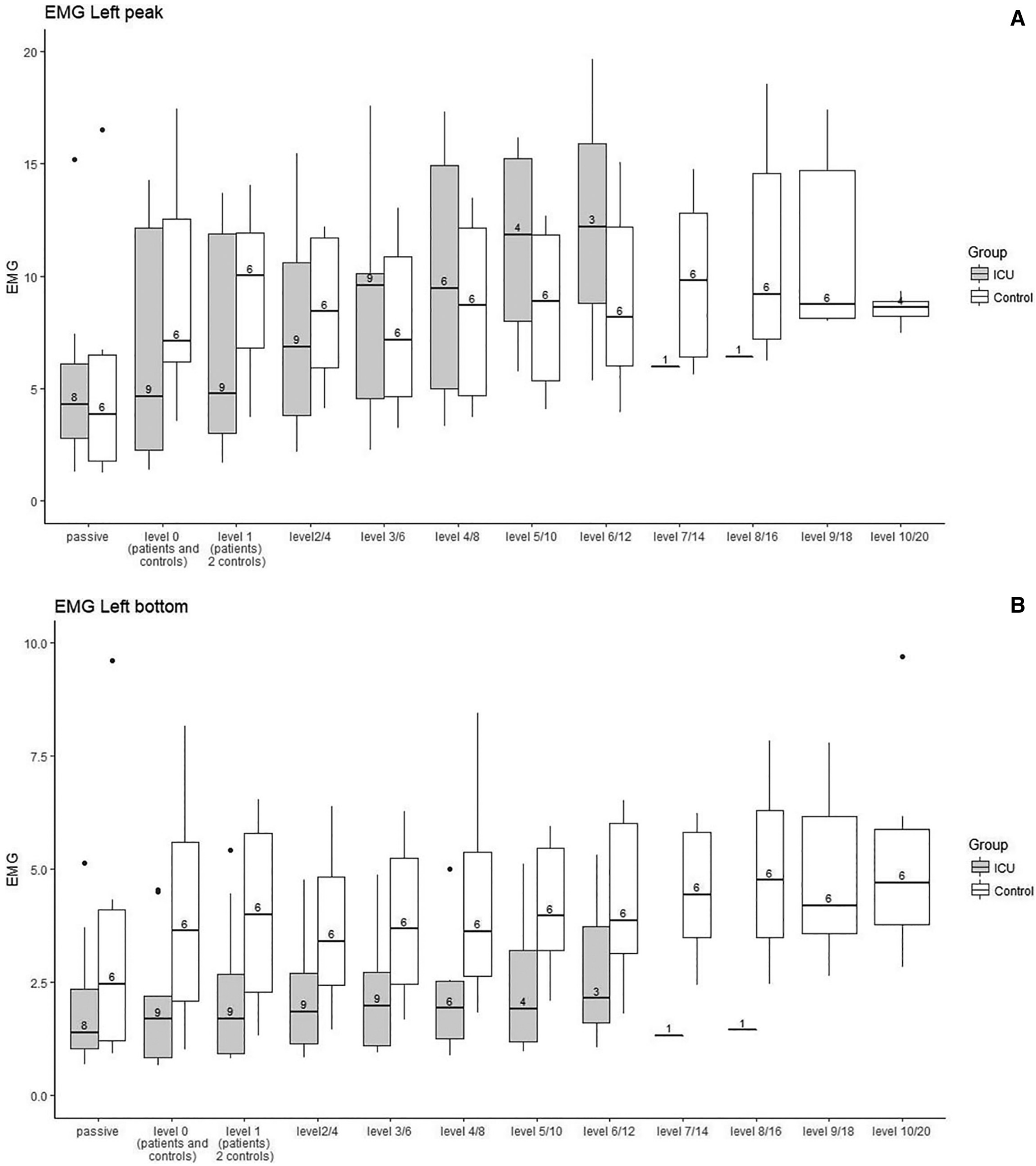

FIGURE 1. (A) Peak values ($sEMG_{max}$) from patients in the ICU and controls. Numbers of participants are given on boxplot (EMG expressed in microvolts). Peak values of the left quadriceps are shown. **(B)** Trough values ($sEMG_{min}$) for patients in the ICU and controls. Numbers of participants given on boxplot (EMG expressed in microvolts). Trough values of the left quadriceps are shown. **(C)** Delta values ($\Delta sEMG$) from patients in the ICU and controls. Numbers of participants are given on boxplot (EMG expressed in microvolts). Delta values of the left quadriceps are shown.

steps algorithm of the bed cycle. Nevertheless, the bed cycle was preferred because it has been recommended and widely used in ICU patients for practical and safety reasons.[2] The program of the bed cycle provided detailed data of the wattage and number of RPMs after completion of the exercise. By following a strict protocol, we could increase the steps in a similar manner.

In conclusion, our pilot study has shown that sEMG is feasible and may be a useful monitoring tool to detect muscle activity during bed cycling in ICU patients. This investigation is a first step toward

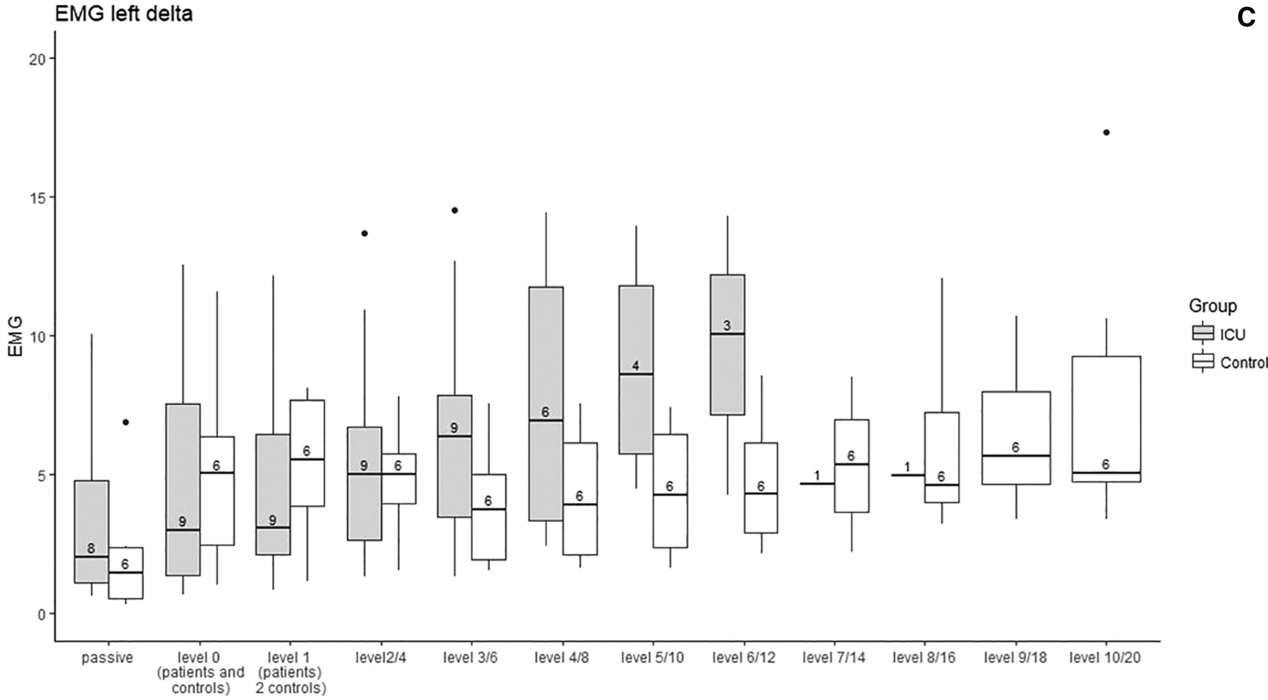

FIGURE 1C Continues

bedside monitoring of muscle exercise and fatigue in ICU patients during bed cycling. With multiple measurements in single patients over a longer period of time, more knowledge can be achieved on fatigue and training effects. Ideally, in such future projects, sEMG monitoring should be combined with oxygen uptake and heart rate measurements during incremental bed cycle exercises. Such studies could help to determine the optimal dose and timing of exercise for individual patients.

The authors thank J.M. Binnekade, E. Witteveen, J. Jurgens, G.J. Glas, and A.S. van Bergen for their assistance.

Ethical Publication Statement: We (the authors) confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

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