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Reference chart of inspiratory muscle strength: a new tool to monitor the effect of pre-operative training

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Abstract

Objectives To develop a reference chart to monitor inspiratory muscle strength during pre-operative inspiratory muscle training for patients at high risk of developing postoperative pulmonary complications awaiting coronary artery bypass graft (CABG) surgery.
Design Secondary data analysis using patients from the intervention arm of a randomised clinical trial.
Setting University medical centre.
Participants Patients at high risk of developing postoperative pulmonary complications awaiting CABG surgery.
Interventions Patients performed inspiratory muscle training seven times per week for at least 2 weeks before surgery.
Main outcome measures Maximal inspiratory muscle strength.
Results A new reference chart was produced using a non-linear time trend model with a normal error structure.
Conclusions The chart is a novel tool for monitoring the progress of inspiratory muscle training for physiotherapy practice. Wider use of this chart is recommended.

Keywords: Randomised controlled trial; CABG; Pre-operative inspiratory muscle training; Postoperative pulmonary complications

Introduction

Pre-operative inspiratory muscle training (IMT) has positive effects for patients at high risk of developing postoperative pulmonary complications (PPCs) awaiting coronary artery bypass graft (CABG) surgery. In particular, IMT has been found to reduce the incidence of PPCs and length of hospital stay [1–4]. Hulzebos *et al.* provided a recent overview of the effectiveness of pre-operative IMT [5].

Maximal inspiratory muscle strength ($P_{i\text{–}max}$, cmH_2O) is a widely used, clinically relevant indicator of respiratory fitness. IMT before surgery can increase $P_{i\text{–}max}$, and thus improve the pre-operative respiratory condition of patients.

A present, no tools exist to monitor $P_{i\text{–}max}$ over time for patients awaiting CABG surgery. Such a tool would be useful to determine IMT performance prior to surgery. A pre-operative screening tool could assist the clinician in evaluating whether the patient has advanced sufficiently to be considered fit for surgery. Also, the tool could be used to show patients the effects of training in terms of increased inspiratory muscle strength. Visual feedback on progress could enhance patient motivation, and thus enhance training adherence and success.

The aim of this study was to develop a reference chart to monitor $P_{i\text{–}max}$ during pre-operative IMT for patients at high risk of developing PPCs awaiting CABG surgery.

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[1] co-author Lindeman died some months ago, so this is a publication post-mortem. I suggest to make the reader aware of this.

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Methods

Design

This study analysed data collected in a randomised clinical trial at the Department of Cardiothoracic Surgery, University Medical Centre Utrecht, Utrecht, The Netherlands [1]. In total, 279 patients were eligible for randomisation and were assigned to either the intervention group (IMT, $n = 140$) or the control group (usual care, $n = 139$). The main results of the trial have been reported elsewhere [1]. The present study used data from a subset of the intervention group.

Intervention

The intervention group received pre-operative exercises, namely IMT, incentive spirometry, education in active cycle of breathing techniques and forced expiration techniques. Patients performed IMT seven times per week for at least 2 weeks before surgery [6]. Each session consisted of 20 minutes of IMT, which was performed six times per week without supervision, and once a week with supervision by a physical therapist, who measured P_{i-max} and endurance of the inspiratory muscles after each week of training.

P_{i-max} at residual volume was measured with a hand-held pressure gauge (Micro Medical MPM; PT Medical, Leek, The Netherlands). All measurements were taken by the same physical therapist. The inspiratory load of the threshold IMT (http://www.respironics.com/) is calibrated in cmH_2O and can be increased by removing the mouthpiece and tightening the spring. The patients started breathing at an inspiratory resistance equal to 30% of baseline P_{i-max} for 20 minutes. Resistance was increased incrementally based on the rate of perceived exertion scored on the Borg scale [7]. If the rate of perceived exertion was less than 5, the resistance of the inspiratory threshold trainer was increased incrementally by 5%. Additional detail on the measurement procedure can be found elsewhere [1].

Training duration was bounded by the period between the date at baseline and the date of surgery. The date of surgery was determined in advance at baseline, and did not depend on the condition or IMT of the patient.

Participants

Patients scheduled for elective CABG surgery who were able to provide informed consent were eligible for inclusion in the main study. A pulmonary risk score was calculated for each patient based on age, productive cough, diabetes mellitus, smoking history, chronic obstructive pulmonary disease (COPD), body mass index and pulmonary function tests. Only patients with an elevated risk score were eligible for inclusion in the present study. The inclusion criteria were very similar to those described by Agostini *et al.* [8], but ordinate grades 2, 3 and 4 alone were used in the present study [5,9]. Exclusion criteria were: surgery scheduled within 2 weeks of initial contact; history of cerebrovascular accident; use of immunosuppressive medication in 30 days preceding surgery; and presence of a neuromuscular disorder, cardiovascular instability or an aneurysm.

The duration of training varied between 1 and 10 weeks, but only data observed between Weeks 1 to 8 were analysed. The data set for analysis contains 413 weekly P_{i-max} measurements from 89 patients (out of 140 randomised to IMT) for whom we had at least two preoperative inspiratory muscle function measurements.

Data analysis

The statistical model describes the variation of P_{i-max} as a normal distribution where the mean and spread vary with training week (i.e. weeks since baseline). GAMLSS 4.1-5 in R Version 2.15.0 (R Foundation for Statistical Computing, Vienna, Austria) was used to obtain estimates of the mean and standard deviation (SD) that are smooth functions of training week [10]. The degrees of freedom of the smoothers were determined by the Worm plot [11] and by Q-statistics [12].

Results

Preliminary analysis

At baseline, the mean age of the 89 selected patients (70 males, 19 females) was 66.2 (SD 9.0) years. Mean body mass index was 28.7 (SD 6.3) kg/m^2, mean forced expiratory volume in 1 second (FEV_1) was 84 (SD 20)% predicted [20], mean forced vital capacity (FVC) was 91 (SD 17)% predicted, mean FEV_1/FVC was 95 (SD 15)%, mean P_{i-max} was 83 (SD 29) cmH_2O and mean P_{m-peak}/P_{i-max} was 43 (SD 20)%, where P_{m-peak} is maximal peak pressure. In terms of New York Heart Association class, five patients were Class I, 16 patients were Class II, 66 patients were Class III and two patients were Class IV.

Reference values and chart

Fig. 1 shows the reference chart developed for clinical use. It portrays the distribution of P_{i-max} as a function of training week. The distribution is described by centile lines at −2 SD, −1 SD, 0 SD, +1 SD and +2SD, corresponding to 2%, 16%, 50%, 84% and 98% of the reference population, respectively.

All centiles rise with training duration. Training during the first few weeks leads to the greatest gains in inspiratory muscle strength. The effect of IMT tapers off after approximately 5 to 6 weeks. Interestingly, patients with lower scores at Week 0 have steeper curves, so the gain in inspiratory muscle strength in patients that start off in the lower centiles is generally larger. Overall, the increase in inspiratory muscle strength from Week 0 to Week 6 is approximately 1 SD. Table 1 shows the corresponding reference data.

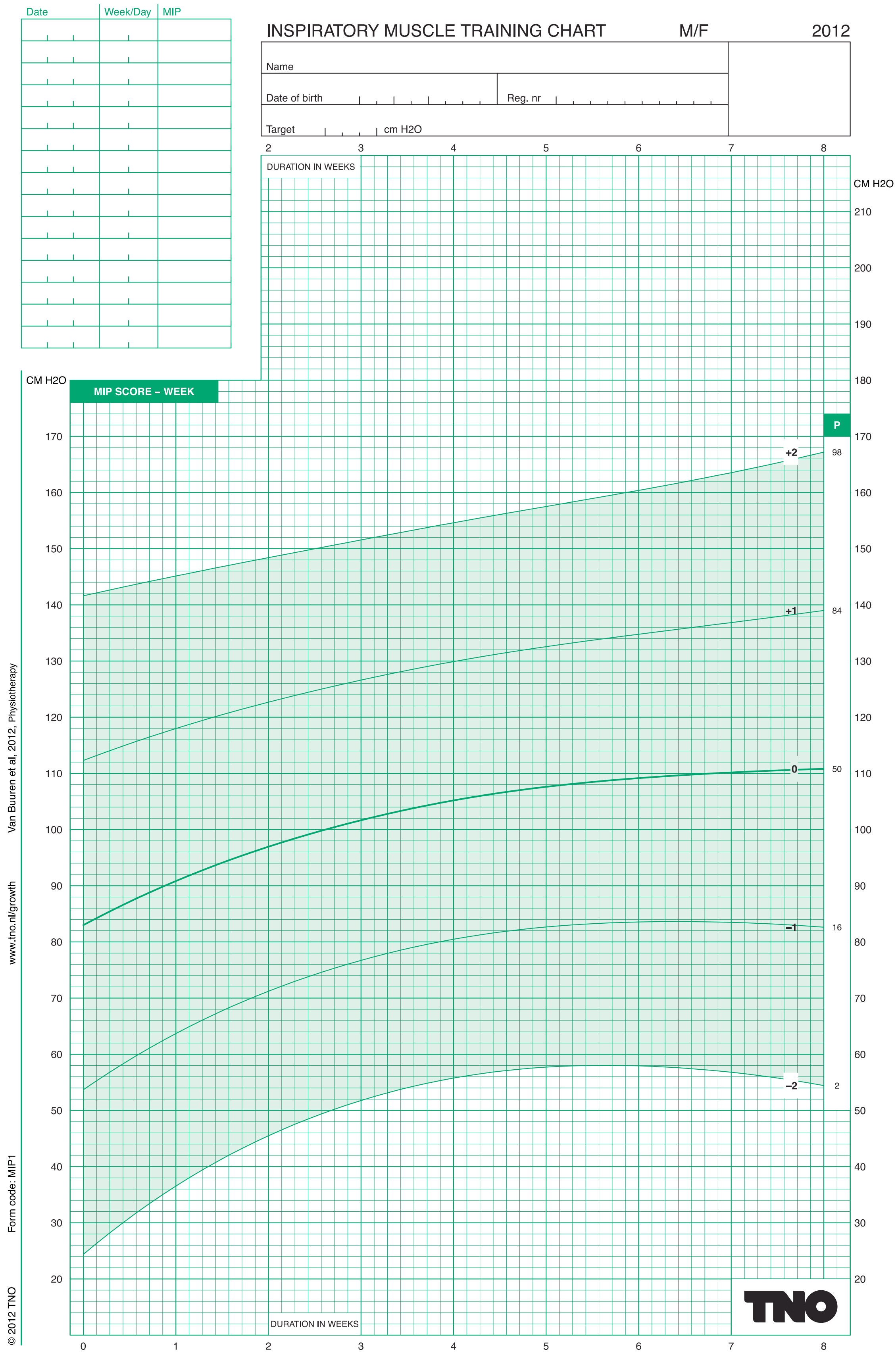

Fig. 1. Reference chart: distribution of maximal inspiratory muscle strength since commencement of inspiratory muscle training.

Table 1
Weekly reference values for maximal inspiratory muscle training (cmH_2O) since commencement of inspiratory muscle training.

Week	Mean	SD
0	83.0	29.3
1	90.8	27.2
2	97.0	25.7
3	101.7	25.0
4	105.2	24.7
5	107.6	25.0
6	109.2	25.6
7	110.2	26.7
8	110.8	28.2

SD, standard deviation.

Example

Fig. 2 illustrates the growth curves of three typical patients. Patient A had a low IMT value of 38 cmH_2O at baseline, improved rapidly during the first few weeks and subsequently plateaued until Week 8. IMT was clearly beneficial for this patient. Patient B had a high IMT value at baseline and remained more or less at that level. For this patient, IMT did not have much effect and one could question the need for IMT. Finally, Patient C had a low IMT value at baseline, and hardly improved over time. In principle, IMT could be beneficial for this patient, but the chart reveals a lack of progress. It is not known if there was a particular reason for the lack of progress (e.g. patient did not train, medical cause), but this pattern should alarm the therapist. Most patients in the study database had results similar to those of Patient A.

Application in clinical practice

There are various ways to use this chart, and possibilities are discussed below.

The simplest method is to set a threshold, an absolute value of inspiratory muscle strength beyond which the risk of PPCs is considered acceptable. A widely used threshold for inspiratory muscle weakness is $P_{i\text{–}max}$ <60 cmH_2O [13]. For weak patients, the therapist can indicate this threshold as a horizontal line on the chart. Once the patient achieves the threshold, IMT can continue with the aim of maintaining the effect of treatment.

Obviously, the therapist has the freedom to set alternative thresholds. The threshold could be based on known risk factors for PPCs for the patient. A risk stratification model [1] could be used to estimate PPC risk based on age, cough, diabetes, smoking history, COPD and body mass index. For example, in a strategy that aims to achieve a minimum PPC risk, it is sensible to opt for a higher threshold for diabetic patients.

An alternative is to set an individual goal, based on the patient's baseline $P_{i\text{–}max}$, under the assumption that any increase in inspiratory muscle strength is beneficial for the patient. The therapist can set the therapeutic goal for a period of, say, 4 weeks by visually extrapolating the plotted value parallel to the centile curves until Week 4. For example, the target for a patient with a baseline $P_{i\text{–}max}$ of 50 cmH_2O could be set to 75 cmH_2O at 4 weeks, whereas the target for a patient with a baseline $P_{i\text{–}max}$ of 120 cmH_2O could be set to, say, 138 cmH_2O at 4 weeks. The target is marked on the chart. Over the next 3 weeks, the therapist and patient evaluate progress on a weekly basis relative to the specified target. If the target is not reached within 4 weeks, additional training may help to achieve the goal. Generally speaking, improvement beyond Week 6 is small [1]. Therapy failure can be identified fairly early, when no progress is seen during the initial monitoring weeks [6,14]. In these cases, therapy may have to be adjusted up until progress becomes obvious, a strategy known as 'titration' [15].

Discussion

This novel reference chart shows how inspiratory muscle strength changes as a result of IMT in patients awaiting CABG surgery. Some patients benefit more from training than others. Patients with the weakest inspiratory muscles at baseline are likely to gain the greatest benefit, as the potential for improvement is greater. For example, a patient that develops exactly along the −2 SD line would increase from $83 - 2 \times 29.3 = 24$ cmH_2O at Week 0 to $109.2 - 2 \times 25.6 = 58$ cmH_2O at Week 6; an increase of 34 cmH_2O. The relevant numbers in this calculation are taken from Table 1. In contrast, a patient that develops along the +2 SD line would increase from $83 + 2 \times 29.3 = 142$ cmH_2O to $109.2 + 2 \times 25.6$ cmH_2O; an increase of 18 cmH_2O. Thus, the benefit of training in terms of cmH_2O gain is approximately twice as large for the weaker patient. Also, as PPC risk changes more rapidly at the lower end of the $P_{i\text{–}max}$ scale, an increase from 40 cmH_2O to 70 cmH_2O reduces PPC risk more than an equivalent increase from, say, 120 cmH_2O to 150 cmH_2O.

In practice, inspiratory muscle strength measures may not be taken at intervals of exactly 1 week. This does not present additional problems for the chart, as weeks on the chart are subdivided into 7 days, so progress can be monitored on a daily basis.

Patients may achieve higher $P_{i\text{–}max}$ values solely because they learn the measurement procedure executed by the physiotherapist. If this is the case, the validity of the earlier measurements may be affected, as part of the gain may be ascribed to learning instead of physiology. Although learning effects cannot be ruled out, these would also be present in new patients. As the reference chart uses actual measured data, validity issues are unlikely to affect the usefulness of the chart for clinical practice.

The purpose of this reference chart is to monitor IMT in patients awaiting CABG surgery. Healthy populations are likely to have better inspiratory muscle strength, so the distribution portrayed in the chart is not applicable. However, the chart may work in a similar way to monitor the progress of

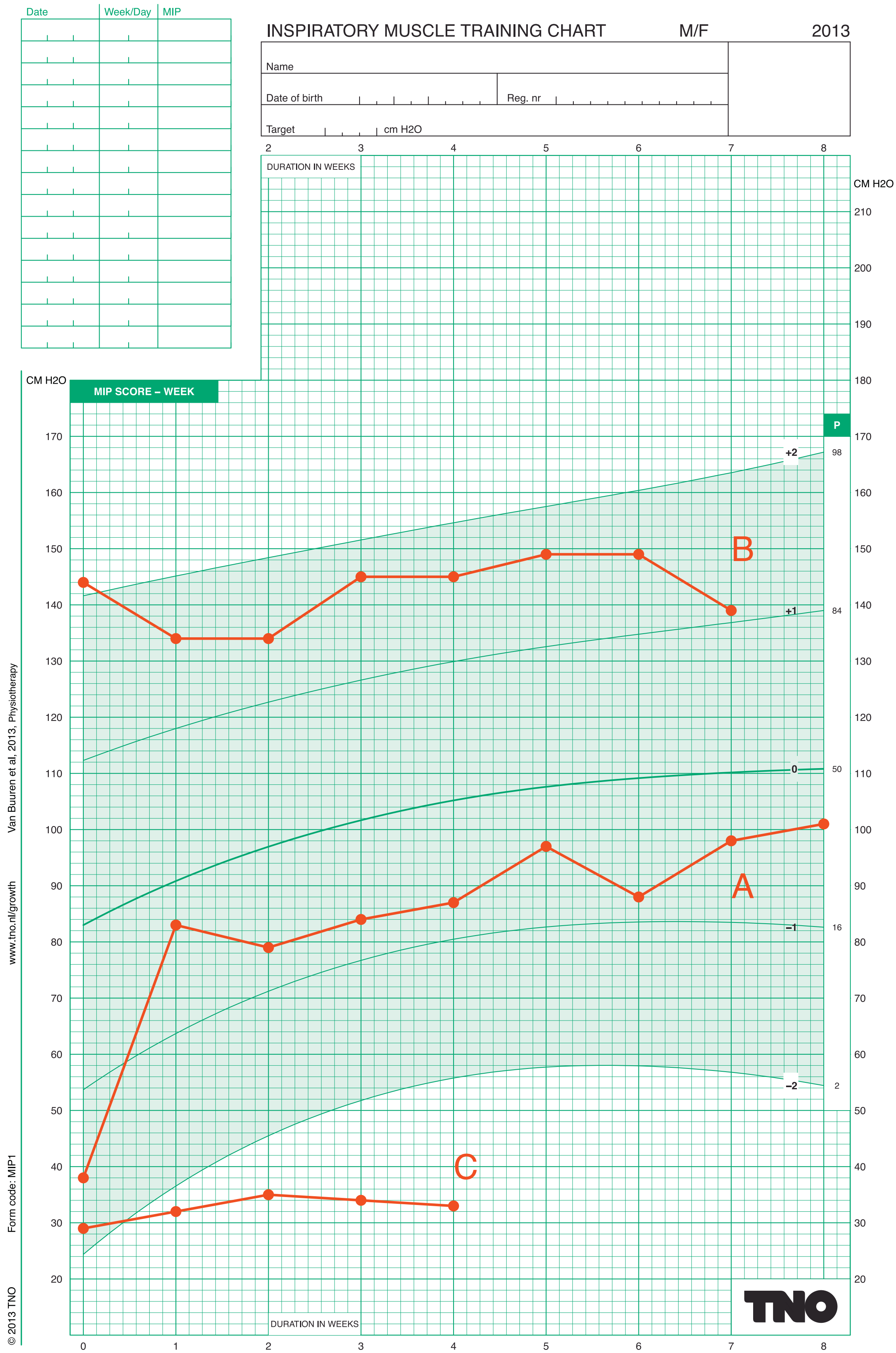

Fig. 2. Trajectories of three patients plotted on to the reference chart.

training in other patient groups. Independent studies would be needed to validate alternative uses.

Conclusion

This paper introduced a reference chart to monitor the gain in P_{i-max} as a result of IMT. Application and evaluation of the chart in clinical settings is recommended. The tool is designed to be easy to use, to enable therapeutic goal setting, and to enhance patient motivation and adherence.

Ethical approval: University Medical Centre Utrecht, Utrecht, The Netherlands.

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Conflict of interest: None declared.

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References

[1] Hulzebos EH, Helders PJ, Favie NJ, De Bie RA, Brutel de la Riviere A, Van Meeteren NL. Preoperative intensive inspiratory muscle training to prevent postoperative pulmonary complications in high-risk patients undergoing CABG surgery: a randomized clinical trial. JAMA 2006;296:1851–7.

[2] Hulzebos EHJ, van Meeteren NLU, van den Buijs BJ, de Bie RA, Brutel de la Rivière A, Helders PJM. Feasibility of preoperative inspiratory muscle training in patients undergoing coronary artery bypass surgery with a high risk of postoperative pulmonary complications: a randomized controlled pilot study. Clin Rehabil 2006;20:949–59.

[3] Hulzebos EHJ, Helders PJM, Favié NJ, de Bie RA, Brutel de la Rivière A, van Meeteren NLU. Fewer lung complications following inspiratory muscle training in patients undergoing coronary bypass surgery: a randomized trial. Ned Tijdschr Geneeskd 2007;151:2505–11.

[4] Dronkers J, Veldman A, Hoberg E, van der Waal C, van Meeteren N. Prevention of pulmonary complications after upper abdominal surgery by preoperative intensive inspiratory muscle training: a randomized controlled pilot study. Clin Rehabil 2008;22:134–42.

[5] Hulzebos EH, Smit Y, Helders PP, van Meeteren NL. Preoperative physical therapy for elective cardiac surgery patients. Cochrane Database Syst Rev 2012;11:CD010118.

[6] Savci S, Degirmenci B, Saglam M, Arikan H, Inal-Ince D, Turan HN, *et al.* Short-term effects of inspiratory muscle training in coronary artery bypass graft surgery: a randomized controlled trial. Scand Cardiovasc J 2011;45:286–93.

[7] Borg GAV. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 1982;14:377–81.

[8] Agostini P, Naidu B, Cieslik H, Rathinam S, Bishay E, Kalkat MS, *et al.* Comparison of recognition tools for postoperative pulmonary complications following thoracotomy. Physiotherapy 2011;97:278–83.

[9] Kroenke K, Lawrence VA, Theroux JF, Tuley MR. Operative risk in patients with severe obstructive pulmonary disease. Arch Intern Med 1992;152:967–71.

[10] Stasinopoulos DM, Rigby RA. Generalized additive models for location scale and shape (GAMLSS) in R. J Stat Softw 2007;23:1–46.

[11] van Buuren S, Fredriks AM. Worm plot: a simple diagnostic device for modelling growth reference curves. Stat Med 2001;20:1259–77.

[12] Royston P, Wright EM. Goodness-of-fit statistics for age-specific reference intervals. Stat Med 2000;19:2943–62.

[13] Gosselink R, De Vos J, van den Heuvel SP, Segers J, Decramer M, Kwakkel G. Impact of inspiratory muscle training in patients with COPD: what is the evidence? Eur Respir J 2011;37:416–25.

[14] Sheel AW. Respiratory muscle training in healthy individuals. Sports Med 2002;32:567–81.

[15] Glaziou P, Irwig L, Mant D. Monitoring in chronic disease: a rational approach. Br Med J 2005;330:644–8.