ORIGINAL ARTICLE

Incentive spirometry inspiratory capacity changes and predictors after open heart surgery: a 5-day prospective study

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ABSTRACT

Introduction: Incentive spirometry (IS) is commonly used for increasing postoperative IS inspiratory capacity (ISIC) after open heart surgery (OHS). However, little is known about the serial changes in ISIC and their predictive factors.

Objective: The aim of this study is to identify the postoperative ISIC changes relative to preoperative ISIC after OHS, and determine their predictors, including patient characteristics factors and IS performance parameters such as inspiration volumes (ISv) and frequencies (ISf).

Methods: This is a prospective study with blinding procedures involving 95 OHS patients, aged 52.8±11.5 years, whose ISIC was measured preoperatively (PreopISIC) until fifth postoperative day (POD), while ISv and ISf monitored with an electronic device from POD1-POD4. Regression models were used to identify predictors of POD1 ISIC, POD2-POD5 ISIC increments, and the odds of attaining PreopISIC by POD5.

Results: The ISIC reduced to 41% on POD1, increasing thereafter to 57%, 75%, 91%, and 106% from POD2-POD5 respectively. Higher PreopISIC (B=-0.01) significantly predicted lower POD1 ISIC, and, together with hyperlipedemia (B=11.52), which significantly predicted higher POD1 ISIC, explained 13% of variance. ISv at relative percentages of PreopISIC from POD1-POD4 (B_{POD1}=0.60, B_{POD2}=0.56, B_{POD3}=0.49, B_{POD4}=0.50) significantly predicted ISIC of subsequent PODs with variances at 23%, 24%, 17% and 25% respectively, but no association was elicited for ISf. IS performance findings facilitated proposal of a postoperative IS therapy target guideline. Higher ISv (B=0.05) also increased odds of patients recovering to preoperative ISIC on POD5 while higher PreopISIC (B=-0.002), pain (B=-0.72) and being of Indian race (B=-1.73) decreased its odds.

Conclusion: ISv appears integral to IS therapy efficacy after OHS and the proposed therapy targets need further verification through randomized controlled trials.

KEY WORDS:
Cardiac surgical procedures, coronary artery bypass, spirometry, inspiratory capacity, lung volume measurements

INTRODUCTION

Open heart surgery (OHS) involves median sternotomy and extracorporeal circulation established through cardiopulmonary bypass (CPB).[1] These factors, together with procedures such as topical cooling for myocardial protection and internal mammary artery dissections, predispose OHS patients to postoperative pulmonary complications (PPCs).[1] Additionally, respiratory anomalies that reduce lung volumes, such as monotonous shallow breathing patterns, impaired ventilatory mechanics, reduced lung compliance and impaired gaseous exchange are common causes of atelectasis after OHS.[2-3] Postoperative atelectatic changes are often transient and resolve spontaneously. However they may also progress to PPCs and compromise clinical outcomes in these patients.[5] Apart from increasing propensity towards atelectasis and PPCs, reduced lung volumes also affect expiratory flow rates, making coughing less effective for mucociliary clearance, subjecting patients to pulmonary infections.[1] Spirograph-based evaluation of pulmonary function after OHS indicate marked reduction in lung volumes on the first postoperative day (POD), recovering gradually thereafter. However, these volumes often fail to recover fully to preoperative values by discharge,[6-11] making measures to increase lung volumes an integral part of postoperative care after OHS.[12]

Incentive spirometry (IS), comprising deep inspirations, is a widely used lung expansion therapy (LET) for maintaining alveolar patency and improving pulmonary volumes in postoperative cardiac and thoracic surgical patients.[13,14] However, to date post-OHS lung expansion has not been followed up systematically in the context of objective IS performance evaluation.[15] Although recommendations for IS performance parameters such as inspiration volume and frequency targets are available in most IS prescriptions, their specific roles and association with postoperative changes in IS-based inspiratory capacity (ISIC), in relation to preoperative values, have not been ascertained.[15] ISIC, the maximum volume of air inspired after a normal expiration as measured by volume-oriented incentive spirometers (VIS),[16] reflect lung volumes,[17] and are often used as inspiration volume targets for IS therapy after OHS;[6,16] but the appropriateness of this practice is unclear as there is lack of evidence on postoperative ISIC recovery in context of any IS performance parameters. ISIC has been reported to be only

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around 27% of preoperative values on POD1 after OHS, progressively increasing to around 57% by POD5,[18] but the influence of IS inspirations and frequencies on these changes was not investigated in this study. While pain has been identified as a risk factor for pulmonary dysfunction[19] and found to be associated with lower POD1 ISIC volumes[18] after OHS, its prediction assessment in this context has not been conducted. Prediction assessment of other risk factors which have been similarly linked, such as advanced age, cardiopulmonary bypass (CPB) time,[20] gender, body mass index (BMI),[21] smoking status,[22] and predictive inspiratory capacity (PIC),[23] too have not been investigated. Thus, the objectives of this research were to explore ISIC changes relative to preoperative values from the first to fifth day after OHS and determine if factors such as preoperative ISIC, age, gender, sex, race, body mass index, comorbidities, smoking status and cardiopulmonary bypass time, were predictive of ISIC on POD1 and its recovery to preoperative volumes on POD5. This study also sought to examine if postoperative pain scores and IS performance parameters, namely inspiration volumes (ISv) and frequencies (ISf), had any association with postoperative ISIC from POD2 to POD5.

MATERIALS AND METHODS

Study design, venue and subject recruitment

Ethical approval was obtained to conduct this prospective study at a tertiary level hospital in Malaysia. Data collection was done in the cardiothoracic surgical wards where OHS patients routinely undergo postoperative IS therapy. Patients aged 18 years and above, planned for elective OHS and gave their informed consent to participate, were recruited during a 22- month period from August 2016 to June 2018. Those with any clinically evident or apparent pulmonary disease or dysfunction evidenced by chest radiographs and auscultations, cognitive dysfunction, visual impairment, hearing loss or any condition which prevented them from performing IS procedures correctly, were excluded. In concordance with fast-track OHS, stable patients were usually extubated within 15 hours post-surgery; thus, to standardise the postoperative data collection period, those exceeding this timeframe were excluded. Two cardiothoracic medical personnel, who were blinded to the study objectives and design, were tasked with study sample recruitment.

G*Power® version 3[24] for multiple linear regressions with medium effect size *(f)* of 0.15, α-level: 0.05 and power (1-β): 0.80 for nine potential predictors of POD 1 ISIC estimated a minimum requirement of 114 patients. This was increased to 141 to account for possible sample size reduction of 25% as experienced by Harton et al.[16] As a blinding strategy, any information on possible associations of IS performance with postoperative ISIC outcomes was concealed from participants, study staff and data analyst.

Working definition of IS variables

Several terms and working definitions for key ISIC, IS inspiration and frequency variables investigated in this study were constructed as follows:

– ISIC – highest of three VIS-based volumes inspired during baseline evaluation which reflected lung volume and was used as IS therapy volume target for a specific postoperative day. ISIC in this study was expressed as:
  a. PreopISIC – ISIC obtained preoperatively [in absolute values (ml)].
  b. POD*i* ISIC– ISIC obtained in absolute values (ml) on each postoperative day investigated before commencement of IS therapy and expressed as a percentage of Preop ISIC.

  Where '*i*' denotes a specific POD

– IS performance parameters
  a. ISf – frequency of IS inspirations
     – POD*i* ISf – frequency of VIS inspirations performed each POD.
  b. ISv – mean volume of air inhaled per IS inspiration derived as a function of ISf of a specific POD
  – POD*i* ISv - mean volume of air in absolute values (ml) inhaled during IS therapy on a specific POD expressed as a percentage of Preop ISIC.
    Where '*i*' denotes a specific POD

Data collection procedures

Data was collected for both pre- and postoperative periods. Postoperative IS performance was monitored using a newly-developed and validated multi sensor IS data collection device (ISDCD)[25] and data on key variables were obtained from several sources; patient baseline characteristics were retrieved from patient records, PIC values from nomograms accompanying the VIS, Preop ISIC and POD*i* ISIC were obtained from direct measurements during baseline IS inspiratory capacity evaluation; while data on IS performance, namely ISf and ISv, was downloaded from the ISDCD memory card after POD5.

Three nurses and two physiotherapists who were routinely involved in administering IS therapy to OHS patients were tasked with data collection. They were trained by the researchers in data collection methods prior to the study and refresher training was conducted periodically to address any arising issues. An IS procedure protocol based on available guidelines[26] was used to standardise instructions to patients on IS techniques and evaluation of PreopISIC and postoperative ISIC.

PreopISIC was evaluated the day before scheduled surgery using Spiro-ball 4000ml capacity VIS (Leventon, S.A.U.) to a volume target set to PIC values obtained from nomograms accompanying each VIS. POD1 ISIC was evaluated 2 hours after extubation while ISIC from POD2 to POD5 was assessed between 8-10am. These were used as volume targets for each corresponding POD. Severity of pain using Numerical Rating Scale (NRS) scores were also assessed during these baseline inspiratory maneuvers as pain evaluation during specific movements after cardiac surgery better reflects the possibility of it being a hindering factor to performance of that activity.[27] Six ISDCDs were labelled from 'A' to 'F' and each subject received one with a Spiro-ball attached, for IS therapy from POD1 to POD4. The Spiro-ball was detached from the ISDCD on POD5 and given to the patient for continuation of therapy till discharge while the ISDCD was sent to the researchers for data extraction and recalibration, after which it was returned to the study site.

Postoperative IS therapy
IS therapy commenced soon after POD1 ISIC evaluation and patients were instructed to inspire at least ten times to target volumes or beyond every hour while awake, aiming for 100 inspirations each postoperative day, in accordance with the IS protocol routinely used in this hospital setting. Postoperative physiotherapy sessions comprising active cycle of breathing techniques, progressive mobilising exercises and ambulation were also initiated and continued till discharge.

Analysis of Data
SPSS version 22 software (SPSS Inc., Chicago, IL, USA) was used for data analysis. Shapiro-Wilk normality test, z-scores and quantile-quantile (Q-Q) plots were used to assess data distribution[28] and data was found to be within normal distribution. Mean scores and standard deviations were used to describe normally distributed data, and parametric tests (i.e. paired t-test, independent t-test, one-way repeated ANOVA with Greenhouse-Geisser correction and Pearson Correlation Coefficient) with significance level set at $\alpha = 0.05$ were used to analyse significance of mean differences or associations between parameters.

Regression models were used to study predictors at three stages: multiple linear regression analyses for POD1 ISIC outcomes and daily ISIC achievements from POD2 – POD5, and multiple logistic regression for odds of attaining PreopISIC on POD5. Simple linear and logistic regressions were used for these respective models to first identify significant contribution of independent variables to the regression models. P-value <0.15 was used at this stage to increase probability of retaining significant independent variables[29] as potential predictors for multiple regression analyses. Once potential predictors for these three models were identified, they were entered hierarchically as independent variables to the respective regression model, based on the strength of R^2.[28,29] Independent variables which had collinearity tolerance > 0.1 with variance inflation factor (VIF) < 10, and contributed to significant R^2 increases of a significant regression model ($p < 0.05$), were accepted as predictors for the respective model.

RESULTS

Sample Characteristics
146 patients were recruited but 51 patients were excluded due to several clinical and technical issues (extubation after 15 hours [n=5], postoperative bleeding [n=2], ventilatory insufficiency requiring reintubation [n=3], postoperative arrhythmias [n=7], postoperative renal dysfunction requiring dialysis [n=3], incomplete demographic and patient characteristic data [n=14], missing preoperative inspiratory capacity volumes [n=17]). The final sample size comprised 95 patients with baseline characteristics presented in Table I.

ISIC changes from preoperative values to POD5
PreopISIC for the whole cohort (N=95) was significantly lower than PIC volumes at 87 ± 25% of PIC. ISIC of the study sample reduced to 41±18% on POD1 but showed increments from POD2 and recovered fully to PreopISIC values on POD5 with volumes on POD2, 3, 4 and 5 being significantly higher than their preceding PODs ($F_{2.53,237.84}$=229.70,p=0.00). However, despite this increasing trend, ISIC remained significantly lower than PreopISIC from POD1 to POD4 ($p \leq 0.004$, r: 0.29-0.96). Postoperative ISIC of around 56% (n=53) of the study cohort returned to preoperative volumes by POD4 and were categorized as 'achievers' subgroup (n_a) while the rest (n=42), had significantly lower than PreopISIC on POD5 and were classified as 'non-achievers' (n_{na}). Table II presents ISIC volumes from POD1 to POD5 with 95% confidence interval (CI) for the study cohort and subgroups.

ISf, ISv and NRS pain scores from POD1 to POD4
ISf was significantly lower than the recommended 100 inspiration on all PODs investigated for the whole cohort (POD1=38, POD2=65, POD3=52, POD4=41; $p < 0.002$, r: 0.31-0.89). Their distributions were also widely varied with performances that peaked mostly at daytime and there was no association between daily ISf and subsequent ISIC for all PODs ($p > 0.07$, $r < 0.19$). ISv increased progressively from POD1 to POD4 and was significantly higher than ISIC on POD1 and lower than ISIC on POD4. Positive correlations were elicited between POD 1, 2, 3 and 4 ISv with POD2, 3, 4 and 5 ISIC respectively (Table III). Pain scores ranged from NRS 5 on POD1 to NRS 1 on POD5 and no association was elicited between pain and IS performance parameters ISf and ISv on all PODs (ISf: $p > 0.19$, $r < 0.123$; ISv: $p > 0.18$, $r < 0.02$). As for association between NRS scores of a specific postoperative day and their subsequent ISIC, significant correlation was noted only between POD2 NRS and POD3 ISIC ($p = 0.03$, $r = -0.22$).

Comparison of baseline characteristics, IS volume changes, IS performance and pain scores between subgroups
There were two significant differences in baseline characteristics between subgroups; n_{na} subgroup had higher number of Indian patients (p=0.03, r=0.32) while n_a had lower PreopISIC (t=-5.46, p=0.00, r=0.38). PreopISIC of n_a was also significantly lower than PIC (t=-6.89, p=0.00, r=0.69) but no significant difference was observed for n_{na} in this aspect. Both subgroups showed marked ISIC reductions on POD1 followed by increments on subsequent postoperative days. ISIC volumes of n_a returned to PreopISIC values on POD4 while that of n_{na} remained significantly lower than their preoperative volumes on POD5. Both subgroups had significantly higher ISIC on POD2, 3, 4 and 5 as compared to that of POD1, 2, 3 and 4 respectively (n_a : $F_{2.35,122.09}$=145.38, p=0.00; n_{na}: $F_{3.05,124.86}$=121.87,p=0.00). As for pain and IS performance, NRS scores were significantly higher in the n_{na} subgroup (t=-2.953, p=0.004, r=0.29) while ISf was higher in the n_a subgroup (t=2.068, p=0.041, r=0.21) on POD2.

Predictive factors for postoperative ISIC
Simple linear and logistic regression analyses identified potential predictors for postoperative ISIC for the three stages: (i) POD1 ISIC outcomes, (ii) ISIC achievements from POD2 – POD5 and (iii) odds of attaining PreopISIC on POD5 (Table IV). There were three potential predictors for stage one, two for each postoperative day in stage two and ten for stage three which had p-value less than 0.15 and these were used to construct multiple regression models. Inclusion and elimination of these potential predictors were based on their significance of R^2 contribution to the models, collinearity tolerance and VIF. The selected predictors from multiple regression analysis for each stage is shown in Table V.

Table I: Baseline characteristics of study sample

Baseline characteristics		Study sample (N=95)
Age (years)		52.8±11.5
Gender [n (%)]	Male	88 (92.6)
	Female	7 (7.4)
Race [n (%)]	Malay	40 (42.1)
	Chinese	36 (37.9)
	Indian	18 (18.9)
	Others	1 (1.1)
Body mass index		25.8±4.2
Past medical history [n (%)]	Diabetes	41 (43.2)
	Hypertension	71 (74.7)
	Hyperlipidemia	18 (18.9)
	Myocardial infarction	11 (11.6)
	Others	20 (21)
‡Smoking history [n (%)]	Non-smoker	38 (40)
	Smoker	3 (3.2)
	Ex-smoker	54(56.8)
Ejection fraction (%)		52.7±11.9
Type of surgery [n (%)]	Coronary artery bypass	87 (91.6)
	Valve replacement	7 (7.4)
	Atrial septal defect repair	1 (1)
Bypass time (minutes)		140.2±42.2
PreopISIC (ml)		2286±706
PIC (ml)		2621±248

‡Smoking history categorized as per protocol practiced in study setting: Non-Smoker - never smoked any tobacco products; Smoker - smoking at time of admission or had smoked in the two months prior to admission; Ex-smoker: stopped smoking at least two months before admission.

Table II: Pre- and postoperative ISIC with 95% CI for whole cohort and subgroups

PreopISIC (ml)	N 2286 (2142,2429)	n_a 1955 (1877,2034)	n_{na} 2702 (2438,2967)
Postoperative ISIC(as % of PreopISIC)			
POD1 ISIC	41(37,44)	47(41,52)	33(29,37)
POD2 ISIC	57(53,61)	65(59,70)	46(41,51)
POD3 ISIC	75(71,80)	87(81,92)	61(55,66)
POD4 ISIC	91(85,97)	104‡ (96,113)	74(68,80)
POD5 ISIC	106‡(99,112)	124(116,132)	83(78,88)

n_a, 'achievers' subgroup; n_{na}, 'non-achievers' subgroup; ISIC, incentive spirometry inspiratory capacity; PreopISIC, preoperative incentive spirometry inspiratory capacity; POD, postoperative day; CI, confidence interval.
‡ Return of ISIC volume to PreopISIC volumes.

Table III: Postoperative ISv, comparison and correlation for whole cohort (N = 95)

Postoperative ISv (as % of Preop ISIC)

POD	ISv
1	48 ±16
2	59 ± 20
3	74 ±25
4	83 ±32

Paired t-test: PODi ISv with corresponding PODi ISIC

POD	t	p-value	r
1	3.989	<0.001*	0.38
2	1.278	0.20	0.13
3	-0.329	0.74	0.03
4	-2.174	0.032*	0.22

Pearson correlation coefficient: Between PODi ISv of each POD and subsequent PODi ISIC

POD	r	p-value
1-2	0.48	<0.001*
2-3	0.493	<0.001*
3-4	0.406	<0.001*
4-5	0.496	<0.001*

ISv, incentive spirometry inspiration volume; POD*i, i*th postoperative day; ISIC, incentive spirometry inspiratory capacity; N, whole cohort of 95.
* Correlation and comparison (2-tailed) significant at $p < 0.05$.

Table IV: Simple linear regression of (i) POD1 ISIC and (ii) ISIC from POD2-POD5, and simple logistic regression of (iii) PreopISIC attainment on POD5

Potential Predictors		R	R^2	p-value
i. POD1 ISIC				
Gender		0.01	0.00	0.93
Smoking history	Smoker	0.14	0.02	0.18
	Non-smoker	0.01	0.00	0.92
	Ex-smoker	0.06	0.00	0.57
Ejection fraction		0.01	0.00	0.91
Comorbidity	Diabetes	0.06	0.00	0.59
	HPT	0.10	0.01	0.31
	HLD	0.27	0.07	0.01*
	MI	0.04	0.00	0.69
Race	Malay	0.06	0.00	0.54
	Chinese	0.09	0.01	0.39
	Indian	0.06	0.00	0.59
Age		0.15	0.02	0.14*
BMI		0.06	0.00	0.54
Bypass time		0.06	0.00	0.55
PreopISIC		0.28	0.08	0.01*
ii. ISIC from POD2 - POD5				
POD2	POD1 ISv	0.48	0.23	<0.001*
	POD1 ISf	0.086	0.007	0.41
	POD1 NRS	-0.155	0.024	0.14*
POD3	POD2 ISv	0.493	0.243	<0.001*
	POD2 ISf	0.07	0.005	0.50
	POD2 NRS	-0.222	0.049	0.031*
POD4	POD3 ISv	0.406	0.165	<0.001*
	POD3 ISf	0.017	0.000	0.87
	POD3 NRS	-0.162	0.026	0.118*
POD5	POD4 ISv	0.496	0.246	0.000*
	POD4 ISf	0.054	0.003	0.607
	POD4 NRS	0.224	0.05	0.029*
Potential Predictors		**R^2_N**	**p-value**	
iii. PreopISIC attainment on POD5				
Gender		0.7	0.48	
Smoking status	Non-smoker	1.2	0.35	
	Ex-smoker	3.6	0.11*	
Ejection fraction		3.4	0.13*	
Comorbidity	Diabetes	0.9	0.44	
	HPT	3.6	0.11*	
	HLD	0.0	0.89	
	MI	0.0	0.94	
Race	Malay	0.0	0.9	
	Chinese	3.9	0.10*	
	Indian	6.3	0.04*	
Age		5.1	0.06*	
BMI		1.3	0.35	
Bypass time		0.2	0.73	
PreopISIC		37.6	0.00*	
POD1 ISIC		21.6	0.00*	
§ Mean ISv		32.8	0.00*	
Mean pain		11.2	0.01*	

POD, postoperative day; PreopISIC, preoperative incentive spirometry inspiratory capacity; BMI, body mass index; ISICrel, relative incentive spirometry inspiratory capacity; ISv, incentive spirometry inspiration volume; ISf, incentive spirometry frequency; NRS, numerical rating scale; R^2_N, Nagelkerke R^2.
* Univariate analysis significant at $p < 0.15$; § Mean of ISv from POD1 to POD4.

G*Power® post-hoc analysis performed with two predictors as observed in regression model (i) (Table 6), indicated this study achieved power of 0.92 (R^2=0.13; f^2=0.15; α=0.05; N=95).

DISCUSSION

This study explored and described ISIC changes and its associated factors following device-based objective monitoring of IS performance in the early period after OHS. Marked deficits in ISIC on POD1 and gradual improvements observed on subsequent PODs thereafter were consistent with trends reported in previous studies using both IS[18] and spirometric evaluations.[6-11] As ISIC have been found to be reliable indicators of pulmonary volumes,[30,31] keeping track of these volumes is recommended as a useful method of monitoring pulmonary function.[32] Hence, ISIC that show decreases on progressive PODs may indicate deteriorating pulmonary status which could alert healthcare personnel

Table V: Selected predictors from multiple regression of (i) POD1 ISIC (ii) ISIC from POD2-POD5 and (iii) PreopISIC achievement on POD5

	Predictor	R	p-value	R^2	R^2_{model}	B (seB)	95%CIB
(i) POD1 ISIC	PreopISIC	0.28	0.01*	0.08	0.13	-0.01 (0.00)	(-0.01,-0.00)
	HLD	0.27	0.01*	0.07		11.52 (4.17)	(3.24, 19.79)
(ii) POD2 ISIC	POD1 ISv	0.48	<0.001*	0.23	0.23	0.60 (0.11)	(0.38,0.83)
POD3 ISIC	POD2 ISv	0.49	<0.001*	0.24	0.24	0.56 (0.10)	(0.36,0.76)
POD4 ISIC	POD3 ISv	0.41	<0.001*	0.17	0.17	0.49 (0.11)	(0.26,0.71)
POD5 ISIC	POD4 ISv	0.50	<0.001*	0.25	0.25	0.50 (0.09)	(0.32,0.67)
(iii) PreopISIC attainment on POD5							
	Predictors	B (S.E)	Exp (B) CI95%	R^2_N	Accuracy (%)	Hosmer and Lemeshow χ^2	
	Preop	-0.002*(0.001)	0.998 (0.996,0.999)	0.59	81.1	14.18 (p = 0.07)	
	§Mean ISv	0.05*(0.02)	1.05 (1.01,1.09)				
	Mean Pain	-0.72*(0.34)	0.49 (0.25,0.94)				
	Indian	-1.73*(0.73)	0.18 (0.04,0.75)				
	Constant	4.35(2.30)					

POD, postoperative day; ISIC, incentive spirometry inspiratory capacity; PreopISIC, preoperative incentive spirometry inspiratory capacity; ISv, incentive spirometry inspiration volume; ISf, incentive spirometry frequency; NRS, numerical rating scale; R^2, predictive strength (%); CI, confidence interval; R^2_N, Nagelkerke R^2.
§ Mean of total ISv from POD1 to POD4.

into remedial action. As for the study cohort, none developed any clinical evidence of PPCs throughout the duration of the study

IS compliance was evident only for ISv on POD1 to POD3, with patients inspiring to ISIC volumes on POD2 to POD3 and significantly higher than ISIC on POD1. A possible reason for a higher POD1 ISv could be because of the timing when evaluation of POD1 ISIC was done. Apart from establishing baseline ISIC volumes for each POD, these evaluations were also used to determine ISv targets. It is possible that at the time of POD1 ISIC evaluation, done two hours after extubation procedures, patients may be experiencing discomfort or fatigue that may have hindered their inspiratory efforts during the evaluation process. This may have improved as the day progressed resulting in ISv that was higher than ISIC on POD1. As such, there is a need to be cognisant such issues and re-evaluate ISIC later in the day to re-establish ISv targets, especially on POD1, so that patients' IS inspiratory efforts can be optimised. In contrast, ISv on POD4 was significantly lower than its corresponding ISIC. Although ISIC on POD4 was already at 91% of PreopISIC, IS inspirations performed at a lower relative volume still contributed significantly to full ISIC recovery on POD5, highlighting the need for continuing IS therapy until the return of postoperative ISIC to preoperative values.

Notably, ISv values were within limits of their corresponding ISIC from POD2 to POD4, implying that IS therapy providers need to be mindful of ISIC changes occurring after OHS to ensure that ISv targets given to patients are within the context of ISIC on each postoperative day. Hence, baseline evaluation of ISIC to establish volume targets is essential before increases in inspiratory volumes are contemplated in the postoperative period. Although maximal volumes are needed for effective lung expansion maneuvers and using IS therapy to achieve this is generally presumed safe,[14] a case of pneumothorax resulting from inappropriately high IS inspiration volumes, has been reported.[33] Conversely, this practice will also ensure that ISv targets that are lower than ISIC are not prescribed as this may not result in significant lung volume increases in this clinical population which is especially susceptible to PPCs. Study findings suggest that ISv plays a vital role in the efficacy of IS therapy as an LET modality as ISv (POD1 to POD4) were sole predictors of ISIC from POD2 to POD5 respectively and mean ISv was the only predictor that increased the odds of postoperative ISIC recovery to preoperative values on POD5. Additionally, the lack of association between ISf and ISIC volumes of subsequent PODs infers that effectiveness of IS therapy may be reliant primarily on ISv alone. As such, it is imperative that IS therapy patients are monitored for their adherence to recommended inspiration volumes in an attempt to optimize their postoperative lung expansion.

PreopISIC significantly predicted POD1 ISIC with negative B-value indicating an inverse relationship between these two variables. The reason for this is unclear and warrants further investigation as patients with higher Preop ISIC also had less likelihood of recovering ISIC to preoperative volumes on POD5, as indicated by its negative odds ratio on POD5 ISIC achievement. This was reflected in the n_{na} subgroup, which had significantly higher PreopISIC but experienced a greater reduction in POD1 ISIC which failed to recover to preoperative volumes by POD5 ISIC. Hence, clinicians need to be mindful that although patients may have higher PreopISIC at the outset, they may not recover their ISIC volumes fully on POD5, and if discharged by then, may need to be followed up on their ISIC recovery. Additionally, in the context of preoperative inspiratory capacity, dissonance between PreopISIC and nomogram-based PIC values suggests that the latter may not be appropriate as reference values for Malaysian patients. PIC values are derived from mainly Caucasian populations,[34] hence, ISIC evaluation using VIS to establish preoperative inspiratory capacity may be a better option for the Malaysian population.

Although higher PreopISIC was associated with lower POD1ISIC, patients with HLD, on the other hand, retained higher ISIC volumes on POD1. One possible explanation could be the effect of statin therapy, which is commonly used for lipid-lowering in HLD patients.[35] Cardiac surgery procedures such as CPB can trigger systemic inflammatory responses[36] which are often associated with various anomalies in gaseous exchange that reduces pulmonary function.[2,3] Statins have been found to have potent anti-inflammatory effects[37] and the ability to attenuate decline in lung function,[37] factors which may have led to better preservation of ISIC on POD1. However, as the use of statins and their subsequent effects were not assessed in this study, further investigation is required to affirm these possibilities. Unlike PreopISIC, HLD did not emerge as a predictor for achieving PreopISIC on POD5, suggesting that its possible effects in conserving lung volumes may be confined to the intraoperative or early postoperative period; a finding that needs to be explored further.

In contrast with a previous finding where POD1 pain score was associated with IS inspired volume on POD1,[18] no association was found between pain and inspired volumes on any corresponding postoperative day, which suggests that pain did not interfere with this study sample's ability to inspire to target IS inspiratory volumes in the postoperative period. However, an inverse relationship was elicited between POD2 NRS scores and POD3 ISIC. POD2 was also the only postoperative day where NRS scores was significantly higher and inspiration frequency (ISf), significantly lower for the n_{na} subgroup as compared to the n_a subgroup. This implies that while pain may not have impeded IS inspiratory volumes, it may have interfered with some patients' ability to perform activities such as sitting up and mobilising to access their VIS, as reflected by their significantly lower POD2 ISf. Pain may also have impeded early mobilisation and physical activities, components of early postoperative care strongly encouraged after OHS to improve postoperative lung volumes.[38] However, as the mobility status of patients was not assessed in this study, it is not possible to make definite inferences on these aspects. As NRS scores also appeared to decrease the odds of patients' ISIC returning to preoperative values by POD5, this perspective warrants more research to determine the need for further optimisation of pain management in some patients, especially on POD2 when ambulation and active mobilisation efforts are usually commenced.

Patients of Indian ethnicity also had lower odds of regaining PreopISIC on POD5. This highlights possible racial variations in the postoperative ISIC recovery process of OHS patients. The reasons for racial disparities in outcomes after OHS is not well defined but numerous influencing factors ranging from a wide spectrum of factors which may include physiological, psychosocial and behavioral aspects, have been suggested in the literature.[39] Hence, given the multi ethnicity of the local population, further exploration in this direction may provide valuable insights into this perspective.

Proposal for IS therapy targets from POD1 to POD4

Findings on significant associations of ISv with postoperative ISIC outcomes paves the way for proposal of an evidence-based IS inspiratory volume targets guideline from POD1 to POD4. Since no association was found for ISf, the frequency obtained in this study was set as minimum targets. Whether using frequencies less than this, while maintaining ISv at the recommended magnitude, would effectuate significant increases in postoperative ISIC needs to be further ascertained. As distribution of inspirations was mostly during the day, this was included as a recommendation.

The proposal for inspiratory volume and frequency targets (range as defined in the CI) from POD1 to POD4, based on findings from the whole study cohort (N) in Table III, is presented below:

- POD1
  - IS volume target: 48% (45,52)95%CI PreopISIC
  - IS frequency target: 38 (31,44)95% CI or more during daytime
- POD2
  - IS volume target: 59% (55,63)95%CI PreopISIC
  - IS frequency target: 65 (52,78)95%CI or more during daytime
- POD3
  - IS volume target: 74% (69,80)95%CI PreopISIC
  - IS frequency target: 52 (41,63)95%CI or more during daytime
- POD4
  - IS volume target: 83% (77,90)95%CI PreopISIC
  - IS frequency target: 41 (32,50)95%CI or more during daytime

In this study, the ISDCD was used as a research tool to collect comprehensive IS data to explore the relationships between various parameters. As the magnitude of inspiratory volumes done at certain frequencies emerged as key predictors of ISIC increases, cost-effective technology solutions providing necessary inspiratory volume and frequency information that can be integrated with present-day VIS models which do not have this capability, needs to be considered. Until such devices are available, a viable option would be through concerted effort of ward personnel like physiotherapists, doctors and nurses to perform baseline ISIC each POD to set IS volume targets, and ensuring required minimum inspirations at this volume (and beyond, as tolerated) for each specific POD, under direct supervision. IS performance charts to document such information can be developed and implemented, with patients also encouraged to complement supervised sessions with independent inspirations ad *libitum*. Patients with IS inspiratory volumes within limits defined in this study, or higher, may be expected to regain Preop ISIC volumes by POD5, but those with lower values may require further monitoring. Also, deterioration in inspiratory volumes on progressive PODs, despite such measures, may signal declining pulmonary status warranting further investigation, given that study findings indicate an upward trend in these volumes from POD1 to POD5.

STRENGTHS AND LIMITATIONS

Post-hoc analysis indicated this study achieved power of 0.92 while blinding procedures and objective data collection using

a validated device contributed rigor to its findings. There were several limitations though: the extent of other respiratory therapy patients received, which may have impacted outcomes, could not be ascertained as it was not monitored and was based on the attending physiotherapist's clinical judgment. Also, non-probability sampling from a single center with patients of distinct characteristics may not be wholly representative of disparate OHS populations. Follow-up period, too, was restricted to five days to standardize the evaluation period; evidently, some patients may take longer to recover, so, extending the timeline further may elucidate their actual recovery to preoperative ISIC.

CONCLUSION

This study draws attention to the serial changes that occur in ISIC after OHS. It also illuminates the role and significance of IS inspiratory volumes on the efficacy of IS as an LET modality to effectuate increases in postoperative ISIC. Systematic and objective evaluation of IS performance facilitated formulation of recommendations for inspiration volume and frequency therapy targets. However these proposals need further optimisation through randomised controlled trials. Our findings also suggest that the probability of regaining preoperative ISIC volumes by POD5 were influenced by patients' PreopISIC values, inspiratory volumes during IS therapy and pain scores from POD1 to POD4, and being of Indian race; factors which are incidentally the same ones which significantly differentiated the nna from na subgroup.

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CONFLICT OF INTEREST

The authors have no financial disclosures or conflicts of interest to declare. No additional data are available.

ETHICAL APPROVAL

Medical Research & Ethics Committee, Ministry of Health Malaysia, Study ID: NMRR-11-898-9888.

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