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The influence of patent foramen ovale on oxygen desaturation in obstructive sleep apnoea

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ABSTRACT: Obstructive sleep apnoea (OSA) is associated with oxygen desaturation to a varying degree. A patent foramen ovale (PFO) may allow interatrial right-to-left shunting. The hypothesis of the current study was that oxygen desaturation will occur more often, in proportion to the frequency of respiratory disturbances, in OSA subjects with PFO than in those without.

In a group of 209 subjects diagnosed with OSA, the proportion of desaturation to respiratory events was calculated as the ratio of oxygen desaturation index (ODI)/apnoea–hypopnoea index (AHI). A total of 15 cases with high proportional desaturation (ODI/AHI $\geqslant$0.66) were individually matched with 15 controls with low proportional desaturation (ODI/AHI $\leqslant$0.33), all without pulmonary disease. PFO was assessed with contrast transoesophageal echocardiography and considered large when $\geqslant$20 bubbles passed over from the right to the left atrium after a single injection.

The prevalence of large PFO was nine out of 15 (60%) in the high proportional desaturation group *versus* two out of 15 (13%) in the low proportional desaturation group. The median number of passing bubbles was positively correlated to minimum oxygen saturation among those with PFO.

In conclusion, oxygen desaturation occurs more often, in proportion to the frequency of respiratory disturbances, in obstructive sleep apnoea subjects with a patent foramen ovale than in those without.

KEYWORDS: Echocardiography, heart septal defects, hypoxia, obstructive sleep apnoea, patent foramen ovale

Obstructive sleep apnoea (OSA) is a common disorder that affects 5–15% of the middle-aged population and has been identified as a risk factor for cardiovascular disease [1–3]. Patent foramen ovale (PFO) is also a common condition, present in 25% of the adult population, which constitutes a risk factor for cryptogenic stroke as well as a potential contributor to hypoxaemia in patients, both with and without pulmonary disease [4–7]. PFO and OSA are often considered to be two separate entities; however, as both have a high prevalence they sometimes co-exist and may influence the pathophysiology of each other. Obstructive apnoea provokes excessive intrathoracic pressure swings that greatly influence central haemodynamics, creating a right-to-left shunt through the PFO, which may cause significant desaturation [8–13]. This may explain why more severe desaturation than predicted from alveolar hypoventilation has been demonstrated in OSA patients [14–16]. The present study hypothesised that desaturation will occur more often proportionally to the frequency of respiratory disturbances in OSA subjects with PFO than in those without.

METHODS

Selection of study population

The study population was selected from a community-based sample described in the Skaraborg sleep study [17]. Briefly, 161 patients with and 183 subjects without hypertension were subjected to polysomnography, without consideration of any clinical symptoms of sleep apnoea. In total, 209 subjects were diagnosed with OSA. The oxygen desaturation index (ODI)/apnoea–hypopnoea index (AHI) ratio was calculated for each of the 209 subjects. They were then ranked in accordance with their ODI/AHI ratios, divided into three groups and those subjects with the lowest and highest ratio ($\leqslant$0.33 and $\geqslant$0.66) were considered for inclusion. The 54 subjects with a ratio $\leqslant$0.33 were defined as low proportional desaturation (PD) and those 57

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subjects with a ratio $\geqslant$0.66, as high PD. Study participants were divided into pairs by contrasting their ratio, and 15 pairs with the highest and the lowest ratio were chosen with the aim of maximising the difference in desaturation between the subjects within each pair in order to test the study hypothesis. The subjects were matched for the presence of hypertension (with or without diabetes), body mass index (within 3 kg·m^{-2}) and age (within 5 yrs). When more than one match was available, the minimum oxygen saturation and the mean overnight oxygen saturation were also considered in a manner that generated maximum difference. When a pair was split due to a participant being excluded or not giving consent, a second best match for the first subject was chosen. Following this procedure, 64 subjects were evaluated for participation before the final 15 matched pairs were finally identified. Exclusions were based on: death (n=2), obstructive pulmonary disease (n=7), other diseases (n=3), or subjects not giving consent (n=22). Characteristics of the subjects are described in table 1. All participants gave written informed consent to participate. The study was approved by the Gothenburg University human research ethics committee.

Polysomnography

The in-home, full-night polysomnography recording used a computerised recording system (Embla A10©; Embla, Reykjavik, Iceland), which consisted of the following: 1) sleep monitoring through three-channel electro-encephalography, two-channel electro-oculography, and one-channel submental electromyography; 2) bilateral tibial electromyography and a body-position detector; 3) two-lead ECG; and 4) respiration monitoring through an oro-nasal thermistor as well as nasal pressure sensor for apnoea–hypopnoea detection. Piezo crystal effort belts were used for thoracic–abdominal movement detection and a pulse oximeter (Embla Oximeter-XN; Embla) was applied. The sensors were applied and the equipment calibrated at the primary care centre by a certified sleep technician or specially trained local staff. Data were subsequently scored, based on 30-s epochs according to the Rechtschaffen and Kales criteria [18]. An overall sleep stage report and accurate measures of respiratory events during the sleeping period were generated. Respiratory events were scored in accordance with guidelines for measurements in clinical research [19]. Obstructive apnoea (hypopnoea) was defined as a flat ($\geqslant$40% reduction of) nasal pressure signal accompanied by respiratory effort movements for $\geqslant$10 s and desaturation $\geqslant$3% from the immediately preceding baseline, or arousal. The definition of both apnoea and hypopnoea included the same requirement of $\geqslant$3% desaturation and/or arousal. The AHI was calculated to define the number of episodes of apnoea and hypopnoea per hour of sleep. OSA was defined as AHI $\geqslant$10 obtained through sleep recording with a total sleep time of $\geqslant$4 h. The ODI was defined as the number of episodes per hour of sleep with a reduction in saturation of $\geqslant$4% from baseline, and $\geqslant$10 s.

TABLE 1 Characteristics of matched groups

	High PD#	Low PD¶	p-value+
Subjects n	15	15	
Age yrs	60.3±5.2	61.0±5.8	NS
Male	12 (80.0)	8 (53.3)	0.13
BMI kg·m^{-2}	29.6±3.8	29.8±3.7	NS
Hypertension	8 (53.3)	8 (53.3)	NS
SBP mmHg	141±16	141±18	NS
DBP mmHg	81±10	80±8	NS
Diabetes	2 (13.3)	2 (13.3)	NS
Smoking	1 (6.7)	2 (13.3)	NS
ESS	6.3±3.5	6.7±3.4	NS

Data are presented as n, n (%) or mean±SD, unless otherwise stated. PD: proportional desaturation; BMI: body mass index; SBP: systolic blood pressure; DBP: diastolic blood pressure; ESS: Epworth Sleepiness scale; NS: nonsignificant. #: oxygen desaturation index (ODI)/apnoea–hypopnoea index (AHI) $\geqslant$0.66; ¶: ODI/AHI $\leqslant$0.33. All p-values are given unless p>0.2.

Daytime sleepiness was assessed with the Epworth Sleepiness Scale, an eight-item self-administered questionnaire used for rating the likelihood of dozing in eight daily situations on a scale of 0–3. The final score ranged from 0 (no daytime sleepiness) to 24 (maximum daytime sleepiness) [20].

Spirometry

Standard dynamic spirometry (Spirotrac; Vitalograph, Ennis, Ireland) was performed on the same day as the transoesophageal echocardiography (TE) examination in all subjects. Values were calculated as percentages of predicted values [21, 22]. Daytime percutaneous oxygen saturation was measured with the Ohmeda Biox 3740 (Ohmeda, Louisville, CO, USA).

Transoesophageal contrast echocardiography

From March to December 2003, one person (M. Johansson) performed all examinations. Subjects were instructed and trained to perform the Valsalva manoeuvre with $\geqslant$40 mmHg for 8 s. The achieved pressure was shown to the subject using a manometer. Multiplane TE was performed (Acuson Sequoia256 (Siemens, Munich, Germany) or General Electric Vivid 7 (General Electric, Fairfield, CT, USA) after mild sedation with midazolam and local pharyngeal anaesthesia (lidocaine). Colour Doppler with reduced pulse repetition frequency to ~40 cm·s^{-1} and repeated contrast injections were used to detect PFO. A gelatin-based plasma expander (3.5% polygelin; Aventis Pharma, Frankfurt am Main, Germany) and a small amount of air (5–10% mixture) was agitated between two syringes mounted on a three-way stop-cock immediately before a bolus injection *via* a 20-gauge venous cannula [23]. All 2-mL injections were administered antecubitally while 10-mL injections were administered *via* the foot vein, followed by a bolus injection of 5–10 mL saline. Contrast injections were given according to a standardised protocol that included injections during relaxed breathing in the supine and left lateral cubitus position and multiple provocations such as the Valsalva manoeuvre, coughing and bed tilt [24, 25]. In order to reduce preload, nitroglycerin (0.8 mg) was sprayed lingually during 10° foot-down bed tilt, and contrast was injected antecubitally during relaxed breathing and Valsalva. Antecubital injections were made a few seconds after start of the Valsalva manoeuvre with the aim of maintaining strain for ~10 s and making the septum primum bulge over towards the left atrium, at the same moment as the region in the right

atrium adjacent to the fossa ovalis was filling with contrast [26]. When this failed, the timing of Valsalva *versus* contrast injection was adjusted and the procedure repeated. Foot vein injections were made a few seconds before the start of the Valsalva manoeuvre.

PFO analysis

The TE evaluation was performed off-line from Super-VHS video and blinded to the polysomnography results and patient group allocation. A PFO was defined as a minimum of three bubbles in the left atrium adjacent to the septum within three heartbeats from contrast filling of the right atrium [25]. The number of bubbles passing into the left atrium was estimated. A large PFO was defined as a minimum of 20 accumulated bubbles passing over after a single injection [5]. PFO analysis was made independently by two persons (M. Johansson and P. Eriksson) during 2003 and 2004. Disparities were settled by consensus with a third observer.

Transthoracic echocardiography

Standard echo-Doppler examinations were performed in all subjects. Left ventricular mass was calculated according to the corrected formula of the American Society of Echocardiography and indexed for body surface area. The longitudinal, myocardial, peak systolic and early diastolic velocities were assessed in the base of the left ventricular lateral wall and in the base of the right ventricular wall with spectral, pulsed-wave tissue Doppler. The left ventricular ejection fraction was visually estimated. The systolic maximum tricuspid regurgitation gradient was assessed with and/or without signal amplification with agitated polygelin as echo contrast. Right atrial pressure was quantified on the basis of the respiratory variations of the inferior vena cava width and the right ventricular systolic pressure was calculated as the sum of the right atrial pressure and tricuspid regurgitation gradient. The left and right atrial area was measured in apical four-chamber view in end systole.

Statistical analysis

A minimum of 60% PFO prevalence in high PD subjects and a maximum of 15% in low PD subjects was hypothesised, and it was calculated that a sample of 15 pairs would give 80% power to detect any difference with a level of significance of $p<0.05$. McNemar's two-tailed test was used for paired proportions. For comparison of the prevalence between groups, Fischer's two-tailed exact test was used; for quantitative parameters, an unpaired t-test was used and for correlation Pearson's test was used. A p-value <0.05 was considered statistically significant. All values are given as means$\pm$SD, unless otherwise stated.

RESULTS

All 30 subjects completed contrast TE with 12–20 injections each. A PFO was found in 14 (47%) subjects and was classified as small in three and large in 11 subjects. The PFO subjects received 17.6 ± 1.6 and the non-PFO subjects received 18.4 ± 2.2 injections. A large PFO was found in nine out of the 15 (60%) high PD cases but only in two out of the 15 (13%) low PD controls ($p=0.02$), as shown in figure 1. Furthermore, the PFOs were found in individuals with a large range of AHI values as shown in figure 2. The paired distribution showed a higher prevalence of large PFOs in high PD cases than in low PD controls. There were eight pairs in which only the high PD case had a large PFO, one pair in which both had a PFO, five pairs in which no large PFO was found, while in one pair only the low PD control had a large PFO ($p<0.04$). The paired distribution regarding all-size PFO did not reach a statistically significant difference ($p=0.07$). The predictive value of the ODI/AHI ratio for PFO detection was calculated. A high ratio (≥0.66) had a sensitivity of 82% and a positive predictive value of 60%. A low ratio (≤0.33) had a specificity of 68% and a negative predictive value of 87%. The spirometry and polysomnography data for the groups are shown in table 2. As expected, the ODI is higher in high PD cases than in low PD controls, but the significant difference is not explained by AHI. In fact, the AHI was not significantly different between groups. No significant difference in AHI, apnoea index or apnoea duration was found regarding the presence or absence of a large PFO. However, the ODI/AHI ratio in large PFO subjects was twice that found in subjects without a large PFO. The ODI/AHI ratio, but not the minimum oxygen saturation and ODI *per se*, was fairly well correlated to a large PFO ($r=0.55$,

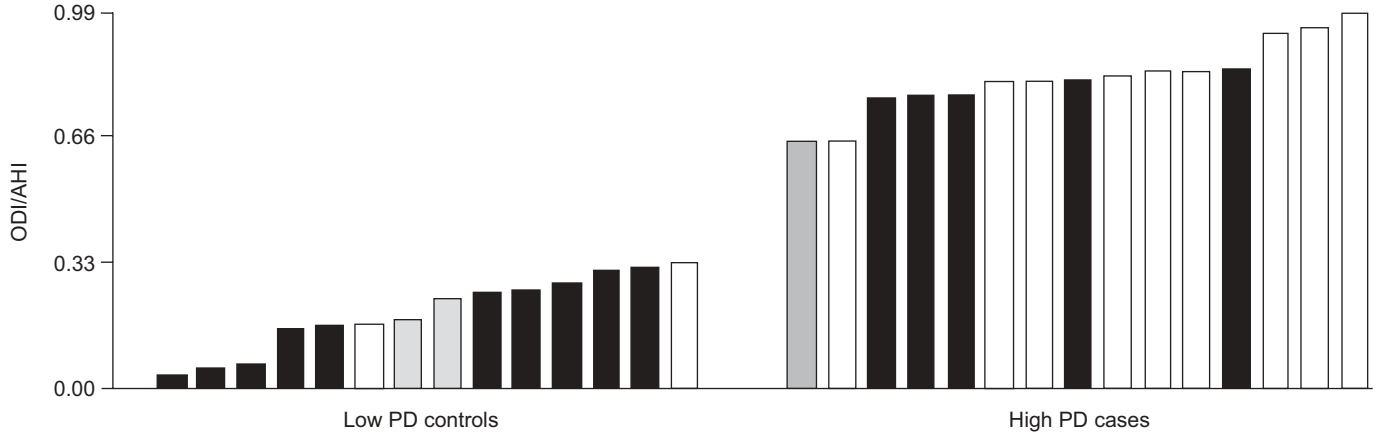

FIGURE 1. Distribution of subjects with a patent foramen ovale (PFO) according to oxygen desaturation index (ODI)/apnoea–hypopnoea index (AHI) ratio. One subject without PFO had ODI/AHI=0. □: subjects with large PFO; ▒: subjects with small PFO; ■: subjects without PFO. Low proportional desaturation (PD) ODI/AHI ≤0.33; high PD: ODI/AHI ≥0.66;

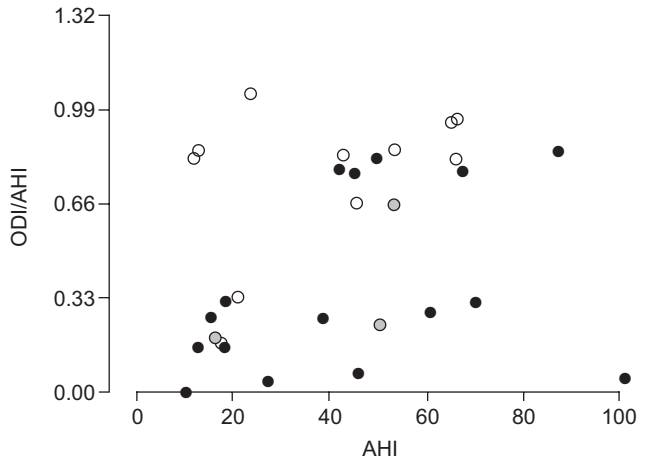

FIGURE 2. Correlation of oxygen desaturation index (ODI)/apnoea–hypopnoea index (AHI) ratio and AHI among subjects with (large (○) or small (●)) and without (●) a patent foramen ovale (PFO). It was more likely that a subject in the upper part of the graph would have a PFO than a subject in the lower part, irrespective of AHI value.

p=0.02). The median number of bubbles passing into the left atrium after an injection was significantly correlated among all 30 subjects with nocturnal minimum oxygen saturation (r=0.36, p=0.05) and among the 14 subjects with a PFO (r=0.62, p=0.02). However, age, body mass index, hypertension, diabetes and blood pressure did not differ in accordance with the PFO diagnosis. The measured echo parameters did not differ between groups, as shown in table 3. The characteristics of patients with high PD are shown in table 4; patients with a high PD without a PFO had significantly more hypopnoeas that those with PFO.

DISCUSSION

To the best of the current authors' knowledge, this is the first study demonstrating an association between nocturnal desaturations in OSA and the existence of PFO. In order to discriminate between desaturation caused by veno-arterial admixture and desaturation caused by apnoea–hypopnoea-related interruption in alveolar ventilation, the ODI/AHI ratio was calculated for each OSA subject. This ratio is a novel construction that consists of two well-defined parameters with the same denomination: number per hour of sleep. The ODI and AHI values were fairly well correlated with each other among those 209 OSA subjects from whom the 30 study subjects were selected (r=0.8, p<0.01). Also in the literature, ODI is generally considered to be positively correlated with AHI in OSA subjects [27]. Due to this correlation, the ODI/AHI ratio was considered to be a factor that roughly corrects the desaturation frequency for the apnoea–hypopnoea frequency and that its variation reveals that factors other than ventilation could be involved. Although the correlation is good in a group of OSA subjects, large variations are actually found when AHI and ODI are compared between individual subjects [27]. In the whole group of 209 subjects with OSA, the AHI values were generally higher than the ODI values, with a mean difference of 15.8 and a considerable scatter (SD 13.7). According to the present hypothesis, a subject with an ODI of 16 and AHI of 20 (ODI/AHI 0.8) would be more likely to have a PFO than a subject with an ODI of 10 and an AHI of 40 (ODI/AHI 0.25),

TABLE 2 Spirometry and polysomnography data in the matched groups and in subjects with *versus* without large patent foramen ovale (PFO)

	PD		p-value#	Large PFO		p-value#
	High	Low		Yes	No	
Subjects n	15	15		11	19	
VC % pred	87.9±12.1	85.5±17.4	NS	90.0±13.5	84.8±15.5	NS
FEV1 % pred	97.1±15.9	86.7±17.7	0.10	97.3±19.0	88.8±16.0	0.20
PEF % pred	92 .2±18.5	77.2±12.4	0.02	93.0 ±20.0	79.9±13.8	0.07
OS % daytime	95.4±2.1	96.0±2.0	NS	95.4±2.3	95.9±1.9	NS
OS mean % sleep	93.0±1.7	95.2±1.7	0.02	93.3±1.8	94.5±2.0	0.09
OS min % sleep	75.4±7.5	84.7±2.9	<0.001	78.3±6.7	81.1±7.6	0.18
Desat 10 %	10.1±11.0	0.0±0.0	0.003	9.0±12.9	2.8±5.4	0.15
ODI n·h^{-1}	40.5±18.4	6.5±6.2	<0.001	31.5±22.3	18.9±20.9	0.14
AHI n·h^{-1}	48.9 ±20.8	34.9±26.1	0.12	38.8±22.0	43.7±25.90	NS
ODI/AHI	0.83±0.10	0.19±0.11	<0.001	0.75±0.27	0.37±0.30	0.001
AI n·h^{-1}	26.7±20.7	9.9±16.6	0.021	23.6±21.9	15.2±19.2	NS
Apnoea duration s	25.0±9.1	16.8±8.0	0.014	23.3±12.6	19.5±6.9	NS
HI n·h^{-1}	21.9±13.1	25.0±14.9	NS	14.7±7.2	28.5±14.4	0.007
Hypopnoea duration s	28.3±8.4	23.6±3.6	0.06	26.9±7.9	25.4±6.2	NS

Data are presented as n or mean±SD, unless otherwise stated. PD: proportional desaturation; VC: vital capacity; % pred: % predicted; FEV1: forced expiratory volume in one second; PEF: peak expiratory flow. OS: oxygen saturation percutaneously measured; Desat 10: episodes per hour of sleep with desaturation >10%; ODI: oxygen desaturation index; AHI: apnoea–hypopnoea index; AI: apnoea index (number of apnoeic episodes per hour of sleep); HI: hypopnoea index (number of episodes of hypopnoea per hour of sleep); NS: nonsignificant. All p-values are given unless p<0.2.

TABLE 3 Echocardiography data in the matched groups and in subjects with *versus* without large patent foramen ovale (PFO)

	PD		p-value#	Large PFO		p-value#
	High	Low		Yes	No	
Subjects n	15	15		11	19	
LVMI g·m^{-2}	123±26	122±28	NS	117±26	126±28	NS
LVEF %	58±3	58±4	NS	59±3	59±4	NS
S_m cm·s^{-1}	13.2±4.0	12.9±2.6	NS	12.8±2.9	13.5±4.1	NS
E_m cm·s^{-1}	12.6±2.9	12.3±2.2	NS	12.3±2.9	12.6±2.4	NS
E/E_m	5.7±1.3	6.0±1.4	NS	5.9±1.2	5.8±1.4	NS
$S_{m,RV}$	18.6±6.0	18.0±5.1	NS	19.3±5.3	17.8±4.8	NS
$E_{m,RV}$	16.9±6.8	16.7±3.8	NS	16.6±8.0	17.0±3.5	NS
E_{RV}/$E_{m.RV}$	3.3±1.1	3.1±0.7	NS	3.2±1.1	3.2±0.8	NS
RAP mmHg	6.0±2.1	5.0±0	0.08	5.5±1.5	5.5±1.6	NS
RVSP mmHg	27.8±6.5	26.8±3.3	NS	27.3±7.2	27.3±3.6	NS
LA area	20.4±4.6	21.5±4.3	NS	19.4±4.0	21.8±4.5	NS
RA area	16.9±3.6	16.2±2.7	NS	16.5±3.1	16.5±3.2	NS

Data are presented as n or mean±SD, unless otherwise stated. PD: proportional desaturation; LVMI: left ventricular mass index; LVEF: left ventricular ejection fraction; S_m: peak systolic velocity of the left ventricular myocardium; E_m:early diastolic left ventricular myocardial relaxation velocity; E/E_m: ratio between early diastolic transmitral inflow velocity and E_m; $S_{m,RV}$: peak systolic velocity of the right ventricular myocardium; $E_{m_{RV}}$: early diastolic right ventricular myocardial relaxation velocity; E_{RV}: early diastolic transtricuspid inflow velocity; RAP: right atrial pressure; RVSP: right ventricular systolic pressure; LA: left atrial; RA: right atrial; NS: nonsignificant. All p-values are given unless $p<0.2$.

TABLE 4 Characteristics of high proportional desaturation (PD) cases according to presence of a large patent foramen ovale (PFO)

Large PFO	Yes	No	p-value#
Subjects n	9	6	
ODI/AHI	0.86±0.11	0.78±0.07	0.08
AHI n	43±22	58±17.0	0.18
HI n	14.0±7.7	34±10.3	0.003
AI n	28.6±21.4	23.8±21.3	NS
Hypopnoea min·h^{-1}	5.8±2.4	14.8±5.1	0.006
Apnoea min·h^{-1}	14.0±12.9	9.2±8.9	NS

Data are presented as n or mean±SD, unless otherwise stated. ODI: oxygen desaturation index; AHI: apnoea–hypopnoea index; HI: hypopnoea index (number of episodes of hypopnoea per hour of sleep); AI: apnoea index (number of apnoeic episodes per hour of sleep); NS: nonsignificant. All p-values are given unless $p<0.2$.

even though the OSA is more severe in this latter subject. As shown in table 2, pulmonary function was significantly better in high PD cases than in low PD controls, supporting the hypothesis that other factors besides respiratory factors are involved. Moreover, the variation in ODI/AHI ratio between groups was not explained by the AHI. However, the power of the ODI/AHI ratio to predict shunt-related desaturation is limited. The magnitude of desaturation from an interatrial shunt will depend on the size of the PFO and the interatrial pressure relation. The potential opening diameter of the PFO ranges ⩾1–19 mm [4]. Since the number of bubbles passing through is only a rough estimate of the diameter during balloon sizing, and no catheterisation was performed, the exact maximum opening diameter is not known [28]. The interatrial pressure relationship will depend on the degree of right-heart loading during obstructive apnoea but also on concomitant left-heart condition [23]. Shunt diagnosis was only performed with the subjects awake, for which reason the actual degree of shunting during sleep is unknown. In order to overcome this weakness the frequency of moderate desaturation (>4%) rather than maximum desaturation was focused upon. BEELKE *et al*. [29] found right-to-left shunting in nine out of 10 PFO subjects during obstructive apnoea lasting longer than 17 s but not during hypopnoea. That study exclusively included OSA subjects with apnoea–hypopnoea and concomitant 4% desaturation, which would correspond to the high PD cases in the present study. One of the two low PD controls with PFO in the present study had only hypopnoeic and no apnoeic events, while the other had only three episodes of apnoea per hour of sleep. The current results are in contrast, in part, to the study of SHANOUDY *et al*. [12], which showed a generally increased prevalence of PFO in OSA, but did not consider the degree of desaturation in relation to apnoeic events. The present study showed a low prevalence of only 13% in the low PD group. It also seems logical that PFO is not a cause of upper airway obstruction, but its valve-like function permits unidirectional right-to-left shunting during right-heart loading, such as that occurring during obstructive apnoea [8, 9, 29]. The analysis of PFO is not always distinct. There was disagreement in the analysis of one large PFO and three small PFOs; however, they were all solved through consensus. This is in concordance with CABANES *et al*. [25] who found considerable variation in small-PFO analysis with only a few bubbles passing to the left atrium. However, the clinical significance of these small shunts is probably very limited [5]. In the current study, the PFO channel was visualised in nine subjects, all with large PFO, whereas in the other subjects, the exact location of the passage could not be visualised. Another route of contrast passage could hypothetically be intrapulmonary shunts, but this is probably not the case as contrast appeared in the left atrium adjacent to the septum within three heartbeats from contrast filling of the right atrium. The current sampling and classification procedure may have been skewed towards high AHI values in this population, as the definition of respiratory events was based on nasal pressure cannula recording. Moreover, obstructive events were also scored when respiratory events included arousal but not necessarily desaturation. This practice may also have elevated the AHI value in patients with minor desaturation but frequent arousal responses. Apnoea duration and the relationship between episodes of apnoea and hypopnoea may also have introduced a confounding influence. In calculating ODI/AHI, apnoeas and hypopnoeas were counted together, although shunting seems only to occur during apnoeas [29]. The high PD cases without PFO had significantly more hypopnoeas than those with PFO (table 4). Frequent hypopnoeas in OSA subjects have been associated with reduced hypoxic ventilatory drive [30]. This may cause a high ODI/AHI ratio because of reduced ventilation between

events and relatively low respiratory event scoring, as the baseline respiratory flow is also reduced.

The present study supports the hypothesis that interatrial shunting gives a substantial increase in the number of desaturations in OSA subjects with PFO. Moreover, this may be the mechanism that explains the increased risk of stroke that is seen in OSA [31]. If this link could be established, percutaneous closure of a PFO may be a potential treatment option in the future [32]. A strength of the present study is that it was based on a cross-sectional population sample randomly selected for polysomnography without prior knowledge of sleep disturbances. Subjects diagnosed with OSA were considered for inclusion on the basis of their ODI/AHI ratio and with obstructive pulmonary disease as the only exclusion criterion. Although the study group was small, the findings may therefore be regarded as reasonably applicable to a general population of OSA patients with healthy lungs.

In summary, oxygen desaturation occurs more often in proportion to the frequency of respiratory disturbances in obstructive sleep apnoea subjects with a patent foramen ovale than in those without. The oxygen desaturation index/apnoea–hypopnoea index ratio might be a clinically useful screening tool, which is able to select obstructive sleep apnoea subjects with a high likelihood of a patent foramen ovale.

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