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Meta-analysis on shift work and risks of specific obesity types

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Summary

Aims: This systematic review and meta-analysis evaluated the associations between shift work patterns and risks of specific types of obesity.

Methods: PubMed was searched until March 2017 for observational studies that examined the relationships between shift work patterns and obesity. Odds ratio for obesity was extracted using a fixed-effects or random-effects model. Subgroup meta-analyses were carried out for study design, specific obesity types and characteristics of shift work pattern.

Results: A total of 28 studies were included in this meta-analysis. The overall odds ratio of night shift work was 1.23 (95% confidence interval = 1.17–1.29) for risk of obesity/overweight. Cross-sectional studies showed a higher risk of 1.26 than those with the cohort design (risk ratio = 1.10). Shift workers had a higher frequency of developing abdominal obesity (odds ratio = 1.35) than other obesity types. Permanent night workers demonstrated a 29% higher risk than rotating shift workers (odds ratio 1.43 vs. 1.14).

Conclusion: This meta-analysis confirmed the risks of night shift work for the development of overweight and obesity with a potential gradient association suggested, especially for abdominal obesity. Modification of working schedules is recommended, particularly for prolonged permanent night work. More accurate and detailed measurements on shift work patterns should be conducted in future research.

Keywords: Abdominal obesity, meta-analysis, obesity, shift work.

Abbreviations: 95% CI, 95% confidence interval; BMI, body mass index; OR, odds ratio.

Introduction

Shift work schedules are becoming popular among employees because of the high demand for flexibility and productivity in workforces in modern society. Globally, approximately 20% of the overall workforce (1) is engaged in a shift work pattern, which is equivalent to nearly 0.7 billion workers (2). Shift work has recently been identified as an important occupational hazard, with a growing body of evidence showing an association between shift work and adverse health effects such as metabolism abnormalities that include obesity (3–5). Obesity constitutes one of the components of the metabolic syndrome, which is positively associated with the development of several cancers, such as breast cancer (6–10) and cardiovascular diseases (11,12). Overweight and obesity have been regarded as a keynoted health issue with a combined prevalence over 70% in Western populations (13). Although its prevalence is lower at around 18% for Chinese populations (14), it has been rapidly increasing over the past two decades (15).

Several reviews have been conducted to investigate the association between night shift work and obesity. Antunes

et al. summarized the chronobiological aspects of shift work with regard to obesity and identified disruption of circadian rhythms as a critical mechanism underlying the development of obesity (16). This disruption together with sleep deprivation could lead to metabolic disorders (17). A systematic review by Esquirol *et al.* described obesity as one of the negative components of cardiovascular risk factors that were linked to shift work (18). Other systematic reviews have demonstrated that shift work not only had a negative impact on obesity risk (19) but also was strongly associated with weight gain (20). Until now, none of these previous systematic reviews examined the combined risk estimates for the association between shift work and obesity or overweight. Shift work may pose additional risk for abdominal obesity, characterized as a central adipose body shape that may be associated with increased mortality, comparing with other obesity types (21). However, the results from original studies have been inconsistent or lacked statistical power (22–30). There are variations in the characteristics and arrangements of night shift work among different industries and companies, which leads to potential difficulties in the overall risk assessment. A better understanding of the knowledge gaps regarding the associations between specific obesity types and different types of shift work has important implications for guiding occupational health practice and disease prevention. By pooling risk estimates from individual studies, this study aims to address this identified knowledge gap by conducting a systematic review and meta-analysis to summarize the current state of evidence on the associations of different characteristics of shift work with specific obesity types and weight gains.

Methods

Search strategy and inclusion criteria of literature

Two authors (M. S. and L. A. T.) searched the PubMed database and independently reviewed potential studies for inclusion, and any discrepancy encountered was resolved by consensus. 'Shift work' and 'Obesity' and 'Shift work' and 'Overweight' were used as medical subject heading terms. References cited in the targeted articles were also searched manually. Studies that met all of the following criteria were included in this study: (i) reported an association between shift work and the risk of obesity, overweight, body mass index (BMI) change or weight change; (ii) described the definition of obesity, overweight, BMI change or weight change; (iii) assessed shift work exposure with a reliable method; (iv) used observational study designs, including cross-sectional, cohort or case–control study design; (v) provided odds ratios (OR) or risk ratios with 95% confidence intervals (CI) or provided sufficient data to calculate them; and (vi) were studies published in English.

Obesity/overweight in this meta-analysis was defined as BMI $\geq$25 kg/m^2 or abdominal obesity (multiple criteria in ethnic populations). Weight change was defined as body weight having a change of over 5 kg during the period of follow-up.

The following information was extracted from each study: (i) name of the first author; (ii) year of publication; (iii) country of study population; (iv) number of participants; (v) gender and age of the study participants; (vi) study design; (vii) definition and category of shift work; (viii) definition of specific obesity types (i.e. BMI $\geq$25 kg/m^2, BMI $\geq$30 kg/m^2, abdominal obesity and weight gain); (ix) OR or risk ratios with 95% CIs and (x) variables being adjusted in the multiple regression models.

Study quality assessment

The quality of included studies was assessed according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies (31). The STROBE checklist contains 22 items with 34 sub-items for cohort or case–control studies and with 32 sub-items for cross-sectional studies. Using other research that assessed study quality by STROBE statement as referenced (32), we classified the quality of primary studies as 'good (fulfilled $\geq$80% of total items)', 'fair (fulfilled 80–50% of total items)' or 'poor (fulfilled $<$50% of total items)' by the total scores of $\geq$27, 17–27 and $<$17 for cohort or case–control studies or $\geq$26, 16–26 and $<$16 for cross-sectional studies, respectively. There was no significant difference in the scores for quality assessment of each included study between the two reviewers.

Statistical analysis

Meta-analysis was performed using STATA 13.0 (StataCorp, College Station, TX, USA) software. We recalculated ORs and the 95% CIs for studies of Marqueze *et al.* (2014) (33), Marqueze *et al.* (2012) (22) and Tada *et al.* (2014) (34) according to the number of cases and controls by univariate logistic regression because these three studies did not provide the corresponding risk estimates. We combined ORs and 95% CIs using a random-effects model if the I^2 index was larger than 50%. Otherwise, the pooled ORs were calculated by a fixed-effects model. Sensitivity analysis was performed to examine potential sources of heterogeneity from several subgroup analyses. Begg's regression asymmetry test was used to detect potential publication bias.

Results

Characteristics of individual studies

A total of 381 articles were retrieved, 362 from the PubMed database and 19 articles that were searched manually. Of these, 311 articles were excluded and regarded as irrelevant after review of the titles and abstracts. Duplicate articles, meeting abstracts, experimental epidemiological studies, reviews and *in vitro* and animal studies were ruled out. Finally, 70 articles were further reviewed and 28 that were published between the years of 1999 and 2016 met the inclusion criteria (Fig. 1).

A summary of the 28 eligible articles is shown in Table 1. Among these studies, 22 were cross-sectional studies and six were cohort studies. No case–control study was identified. Eleven studies (22,27,29,34,38,41,42,44,46,47,51) were conducted on healthcare workers; all but two studies (Poulsen *et al.* (2014) (44) and Gomez-Parra *et al.* (2015) (29)) examined outcomes in nurses and midwives. Another eight studies (23,25,26,36,37,45,48,49) were conducted among manufacturing employees; one Japan study (35) focused on the local government organization, and two Brazil studies (30,33) focused on bus or truck drivers. Six articles (24,28,39,40,43,50) reported results with occupationally mixed populations. Eleven studies (26,27,34,38,40–42,46,47,49,51) focused on female workers, and five (24,25,30,33,36) focused on male participants. Twelve studies included participants of both genders. Nine studies (26,27,34–37,40,46,49) analysed a total of 109,834 East Asian participants, including the populations from Japan, Korea, Malaysia and Taiwan. Overall, 15 articles (>50%) had good quality according to the STROBE statement guidelines, and the remaining 13 studies were all rated as fair quality.

Assessment of shift work exposure and obesity/overweight outcomes with specific criteria

Eleven studies (22,23,25–27,29,33,36,38,41,42) reported the specific time range in the definition of night shift work, and all of the studies covered the time range from 24:00 to 05:00 h aligned with the definition of International Labour

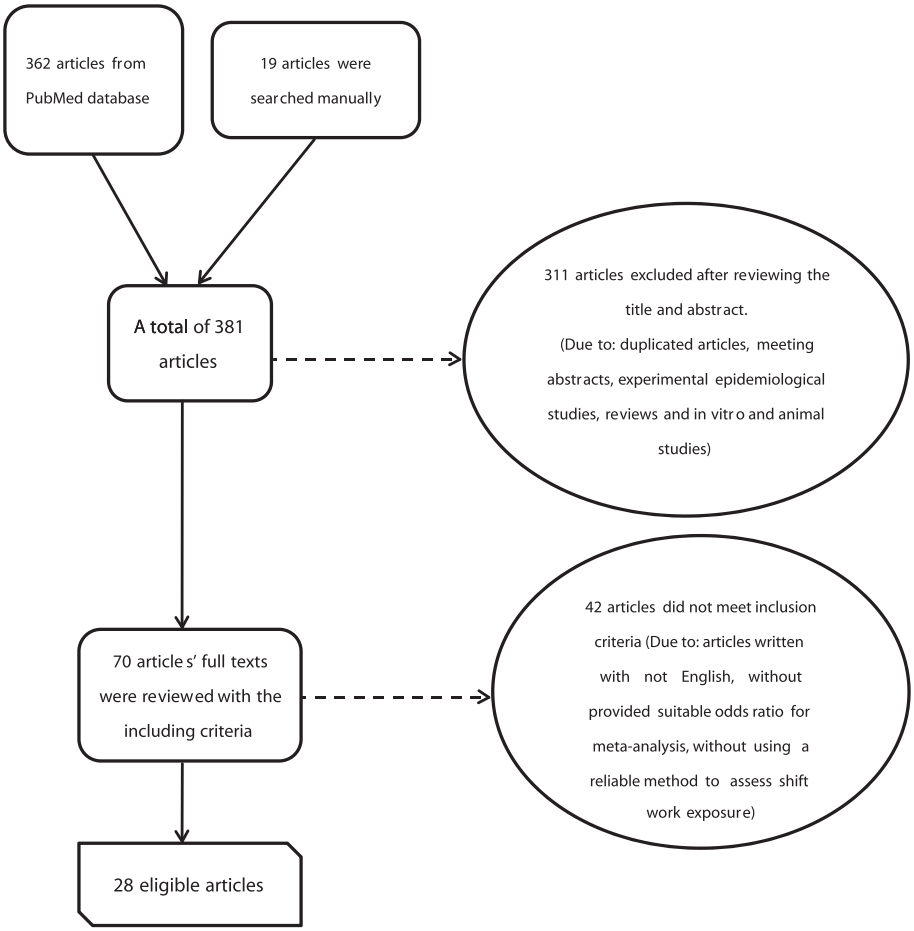

Figure 1 Article selection strategy for the meta-analysis.

Table 1 Summary of main characteristics of included studies

Author (year)	Population (location)	Age	Definition of shift work (data sources)	Definition of outcomes	RR or OR (95% CI)	Adjusted variables	Study quality
Cohort study							
Lee GJ, *et al.* (2016) (27)	Nurses, 934 women at baseline (Korea)	N/A (5 years of retrospective longitudinal study)	Rotating shift work: three-shift rotating, system that included day shifts (07:00–15:00 h), evening shifts (15:00–22:00 h) and night shifts (22:00–7:00 h); night shifts were usually followed by a day off (factory schedule)	WC ≥80 cm for abdominal obesity	For 20–29 years old: 3.21 (1.29–7.98) For 30–39 years old: 1.46 (0.78–2.74)	Work schedule, follow-up period and exercise	Good (27/34)
Itani O, *et al.* (2011) (35)	Local government organization employees, 21,693 men/1,050 women (Japan)	N/A (7 years of follow-up)	Rotating shift work: a night shift every 3/4/5/6/8 days (self-administrated questionnaire)	BMI ≥25 kg/m^2	For men: 1.06 (0.97–1.17) For women: 1.55 (0.80–3.00)	Age, eating habits, alcohol consumption, smoking habit, exercise habit, mental complaints, hyptertension, hyperglycaemia, hypertriglyceridaemia and hypo-HDL cholesterolaemia	Good (29/34)
De Bacquer D, *et al.* (2009) (24)	Mixed occupation, 1,529 men (Belgium)	40 years at baseline (6.6 years of follow-up)	Rotating shift work: no specific definition (self-administrated questionnaire)	WC ≥94 cm for abdominal obesity	1.12 (0.88–1.42)	Age, WC, diastolic blood pressure and HDL cholesterol at initial examination	Good (28/34)
Suwazono Y, *et al.* (2008) (36)	Steel company employees, 7,254 men (Japan)	37.0 ± 9.4 (14 years of follow-up)	The shifts were scheduled on a four-team/three-shift plan and clockwise rotation (5-day shifts, two rest days, five evening shifts, one rest day, five night shifts and two rest days). The day, evening and night shifts started at 07:00, 15:00 and 23:00 h, respectively (factory schedule)	5%, 7.5% or 10% increase in BMI	For 5% increase: 1.14 (1.06–1.23) For 7.5% increase: 1.13 (1.03–1.24) For 10% increase: 1.13 (1.00–1.28)	BMI, age, drinking habits, smoking habits and habitual exercise	Good (28/34)
Watari M, *et al.* (2006) (37)	Telecommunications company workers, 19,894 men/5,418 women (Japan)	N/A (5 years of follow-up)	Shift work (self-administrated questionnaire)	BMI ≥26.4 kg/m^2 (combined to BMI ≥25 kg/m^2 group in further analysis)	For men: 0.77 (0.53–1.12) For women: 0.89 (0.56–1.42)	Age, working conditions and lifestyle	Fair (20/34)
Niedhammer I, *et al.* (1996) (38)	Nurses, 469 men (France)	30 years at baseline (10 years of follow-up)	Shift work: including alternate work on successive morning, evening and night shift, that is, 06:00–14:00 or 13:00–21:00 or 20:00–06:00 h and permanent night shift from 20:00 to 06:00 h (self-administrated questionnaire)	Weight gain >5 kg	For 1980–1985: 0.9 (0.4–3.6) For 1985–1990: 1.9 (1.0–3.6)	Age, number of children, smoking and activities	Good (28/34)
Cross-sectional study							
Barbadoro P, *et al.* (2016) (39)	Mixed occupation, 22,937 men/13,877 women (Italy)	N/A	Shift work (self-administrated questionnaire)	BMI ≥30 kg/m^2	1.06 (0.94–1.20)	Workers gender, age class, family BMI, category level of leisure time physical activity, dietary habits,	Fair (22/32)

(*Continues*)

Table 1 (Continued)

Author (year)	Population (location)	Age	Definition of shift work (data sources)	Definition of outcomes	RR or OR (95% CI)	Adjusted variables	Study quality
						presence of chronic conditions, working hours per week, type of working contract, being occupied in shift-work, level of occupational physical activity and occupational classification of jobs	
Neil-Sztramko SE, *et al.* (2016) (28)	Mixed occupation, 2,304 men/2,019 women (Canada)	36.5	Regular and rotating night shift (self-administrated questionnaire)	BMI ≥30 kg/m^2 WHR ≥0.85 or WC ≥88 cm in women or WHR ≥0.9 or WC ≥102 cm in men for abdominal obesity	For BMI ≥30 kg/m^2: 1.39 (1.09–1.53) For high-risk WHR: 1.37 (1.18–1.60) For high-risk WC: 1.31 (1.14–1.51)	Age, gender and children in the household	Fair (24/32)
Yoon CG, *et al.* (2016) (40)	Mixed occupation, 42,234 women (Korea)	N/A	Night shift work (self-administrated questionnaire)	BMI ≥25 kg/m^2	For manual worker: 1.06 (0.98–1.15) For non-manual worker: 1.20 (1.01–1.42)	Age, marital status, education level and household income, smoking history, alcohol intake, physical activity and sleep duration	Fair (22/32)
Pepłońska B, *et al.* (2015) (41)	Nurses and midwives, 724 men (Poland)	48.3 ± 5.2	Rotating night shift work: fast rotating 12:00 h long duties between 19:00 and 07:00 h, followed by a day off (structured questionnaire)	BMI 25–29.9 kg/m^2 BMI ≥30 kg/m^2 Abdominal obesity: WHR >0.85	For BMI 25–29.9 kg/m^2: 1.2 (0.8–1.7) For BMI ≥30 kg/m^2: 1.5 (1.0–2.3) Abdominal obesity: 1.3 (0.9–1.8)	Age, smoking, marital status, body silhouette at age 20 and current menopausal hormone replacement therapy use	Good (27/32)
Ramin C, *et al.* (2015) (42)	Nurses, 54,724 women (USA)	54.9 ± 4.4	Every night shift work: 23:00–07:00 h (self-administrated questionnaire)	BMI ≥30 kg/m^2	1.37 (1.31–1.43)	Age, education level of the nurse's spouse/partner, primary night only, primary rotating with night shift work age (20–25, 26–35, 36–45 and 46+), physical activity and chronotype	Good (27/32)
Givens ML, *et al.* (2015) (43)	Mixed occupation, 718 men/875 women (USA)	N/A	Night shift, rotating shift or other alternate shift (self-administrated questionnaire)	BMI ≥25 kg/m^2	2.07 (1.31–3.28)	Age, race/ethnicity, gender and educational attainment	Fair (24/32)
Gomez-Parra M, *et al.* (2015) (29)	Healthcare setting employees, 160 men/ 40 women (Columbia)	35.1 ± 9.1	Rotating shift, daytime (07:00–19:00 h) and night time (19:00–07:00 h) followed by either 36 or 60 h off (self-administrated questionnaire)	BMI 25–29.9 kg/m^2 BMI ≥30 kg/m^2 WC ≥88 cm in women or ≥100 cm in men for abdominal obesity	For BMI 25–29.9 kg/m^2: 0.81 (0.31–1.71) For BMI ≥30 kg/m^2: 1.49 (0.44–5.02) For abdominal obesity: 0.80 (0.57–1.11)	Gender, age, work, related stress, current smoking status, occupation, educational level and years working in shifts	Fair (22/34)
Balieiro LCT, *et al.* (2014) (30)	Bus company drivers, 150 men (Brazil)	44.0 ± 8.5	Night shift work (self-administrated questionnaire)	BMI ≥25 kg/m^2 BMI ≥30 kg/m^2 WC 94 ≥cm for abdominal obesity	For BMI ≥25 kg/m^2: 2.94 (1.14–7.66) For BMI ≥30 kg/m^2: 1.47 (0.72–2.99)	Age	Fair (17/32)

(*Continues*)

Table 1 (Continued)

Author (year)	Population (location)	Age	Definition of shift work (data sources)	Definition of outcomes	RR or OR (95% CI)	Adjusted variables	Study quality
					Abdominal obesity: 2.82 (1.20–6.69)		
Poulsen K, *et al.* (2014) (44)	Healthcare workers, 186 men/7,119 women (Denmark)		Shift work: evening/night shift (questionnaire)	BMI ≥30 kg/m^2	1.50 (1.25–1.80)	Demography, health, work and lifestyle variables (including physical activities)	Good (26/32)
Marqueze EC, *et al.* (2014) (33)	Truck drivers, 57 men (Brazil)	39.8 ± 6.6	Irregular shift work: 20:30–08:00 h, combined with work at morning or afternoon (self-administrated questionnaire)	BMI ≥25 kg/m^2	2.88 (0.94–8.75) *	None	Good (29/32)
Tada Y, *et al.* (2014) (34)	Nurses, 2,758 women (Japan)	41.1 ± 11.1	Rotating shift work: no specific definition (self-administrated questionnaire)	BMI ≥25 kg/m^2	1.55 (1.22–1.97) *	None	Good (27/32)
Pepłońska B, *et al.* (2014) (45)	Blue collar in industrial enterprises, 369 men/236 women (Poland)	47.1	Night shift work (self-administrated questionnaire)	BMI 25–29.9 kg/m^2 BMI ≥30 kg/m^2	For male, BMI 25–29.9 kg/m^2: 1.18 (0.57–2.47) For BMI ≥30 kg/m^2: 0.86 (0.38–1.95) For female, BMI 25–29.9 kg/m^2: 1.49 (0.56–3.97) For BMI ≥30 kg/m^2: 0.82 (0.23–2.92)	Age, marital status and education	Fair (20/32)
Kim MJ, *et al.* (2013) (46)	Nurses, 5,149 women (Korea)	33.2 ± 8.6	Shift work: answered 'yes' to the question 'Do you currently work in shifts?' (online-based questionnaire)	BMI ≥25 kg/m^2	Night shift work 6.83–38.00 years versus 0.08–3.08 years: 1.37 (0.91–2.09); 3.08–6.75 years versus 0.08–3.08 years: 1.21 (0.84–1.74)	Age, current smoking status, regular drinking habit, breakfast skipping, regular exercise, marital status, family income, education, sleep problem and self-perceived health status	Good (27/32)
Marqueze EC, *et al.* (2012) (22)	Nurses, 73 men/475 women (Brazil)	34.8 ± 9.5	Night shift: to work between 19:00 and 07:00 h; the working system was referenced to 12 h on duty per 36 h off (self-administrated questionnaire)	BMI ≥25 kg/m^2	0.98 (0.67–1.46) *	None	Good (26/32)
Macagnan J, *et al.* (2012) (23)	Poultry processing plant workers, 35% men/65% females (Brazil)	30.5 ± 8.7	Permanent night work: 18:00–05:00 h (factory schedule)	BMI ≥25 kg/m^2; WC ≥88 cm in women or ≥102 cm in men for abdominal obesity	For BMI ≥25 kg/m^2: 1.27 (1.00–1.61) For abdominal obesity: 1.45 (1.10–1.92)	Socio-demographics, parental overweight status, behavioural characteristics (leisure physical activity and number of meals/day) and sleep characteristics, including hours of sleep	Good (29/32)
Zhao I, *et al.* (2012) (47)		43.4 ± 9.6		BMI 25–29.9 kg/m^2 or BMI ≥30 kg/m^2	For BMI 25–29.9 kg/m^2: 1.013 (1.003–1.023)	Diet quality, physical activity and smoking and alcohol consumption,	Fair (23/34)

(*Continues*)

Table 1 (Continued)

Author (year)	Population (location)	Age	Definition of shift work (data sources)	Definition of outcomes	RR or OR (95% CI)	Adjusted variables	Study quality
	Nurses and midwives, 2,086 women (Australia)		Rotating shift work and night shift work: no specific definition (online-based questionnaire)		For BMI ≥30 kg/m^2: 1.020 (1.007–1.033)	general physical and mental health, menopausal status and current work pattern	
Bushnell PT, *et al.* (2010) (48)	Manufacture employees, 18,163 men/8,279 women (multiple countries)	42.6 ± 10.7	Permanent night work and rotating shift work: no specific definition (online-based questionnaire)	BMI ≥30 kg/m^2	Using 8-h-day workers as reference For permanent night work 8 h: 1.26 (1.14–1.40); 10 h: 1.38 (1.09–1.75); 12 h: 1.01 (0.77–1.31) For rotating shift work 8 h: 0.98 (0.91–1.06) 10 h: 0.97 (0.81–1.16) 12 h: 1.11 (1.02–1.20)	Occupational group, age, gender, job tenure and marital/living status	Fair (21/32)
Chen JD, *et al.* (2010) (26)	Semiconductor-manufacturing employees, 1,838 women (Taiwan)	33.6 ± 7.1	Permanent night work: 19:00–07:00 h (factory schedule)	BMI ≥25 kg/m^2 WC ≥80 cm for abdominal obesity	For BMI ≥25 kg/m^2: 2.7 (1.6–4.5) For abdominal obesity: 2.9 (1.7–5.1)	Age, smoking, drinking, education level and duration of employment	Fair (23/32)
Chee HL, *et al.* (2004) (49)	Electronics assembly factories workers, 1,612 women (Malaysia)	30.1 ± 8.1	Rotating shift, could be three 8-h shifts (morning, afternoon or night) or two 12-h shifts (day and night) (self-administrated questionnaire)	BMI ≥25 kg/m^2	1.6 (1.28–2.06)	Age group, ethnic, marital status, education, income, staying in hostel and exercise	Fair (21/32)
Karlsson B, *et al.* (2003) (25)	Paper and pulp manufacturing workers, 1,324 men (Sweden)	44	Rotating shift work, and night shift between 22:00 and 6:00 h or between 18:00 and 06:00 h (self-administrated questionnaire)	WHR >0.9 for abdominal obesity	1.19 (0.92–1.56)	Age, socioeconomic factors, physical activity, current smoking, social support and job strain	Good (26/32)
Karlsson B, *et al.* (2001) (50)	Mixed occupation, 12,996 men/14,489 women (Sweden)	N/A	Shift work: by asking 'do you have shift work, or do you work during weekends?' (self-administrated questionnaire)	BMI ≥30 kg/m^2	For men: 1.44 (1.27–1.64) For women: 1.39 (1.25–1.55)	Age and socioeconomic factors	Good (28/32)
Kivimäki M, *et al.* (2001) (51)	Nurses, 689 women (Finnish)	41.6 ± 9.6	Shift work: permanent night work or two-shift/three-shift work for rotating shift work (self-administrated questionnaire)	BMI ≥25 kg/m^2	1.54 (1.06–2.25)	Age	Fair (24/32)
Niedhammer I, *et al.* (1996) (38)	Nurses, 469 women (France)	30 years in 1980; 35 years in 1985; 40 years in 1990	Shift work: including alternate work on successive morning, evening and night shift, that is, 06:00–14:00 or 13:00–21:00 or 20:00 to 06:00 h and permanent night shift from 20:00 to 06:00 h (self-administrated questionnaire)	Overweight (BMI ≥26.9 kg/m^2) prevalence (combined to BMI ≥25 kg/m^2 group in further analysis)	1980: 3.3 (1.3–8.2) 1985: 1.4 (0.6–3.2) 1990: 1.4 (0.6–3.5)	Age, number of children, smoking and activities	Good (28/34)

*Study did not provide odds ratios in the original article.

BMI, body mass index; CI, confidence interval; HDL, high-density lipoprotein; OR, odds ratio; RR, risk ratio; WC, waist circumference; WHR, waist/hip ratio.

Organization for night shift work (52). Six of the 11 studies reported a significant risk of obesity/overweight, ranging from 1.13 (36) to 1.9 (26). The remaining 17 studies did not provide a specific time definition for night shift work.

Ten studies (24,25,27,29,34–36,41,45,49) found an increased risk of obesity from rotating shift work; three studies (23,26,48) reported an increased risk from permanent night work, but only one study (33) reported an increased risk from irregular shift work. Moreover, Bushnell *et al.* (2010) (48) revealed an association between obesity (BMI ≥30 kg/m^2) and both rotating shift work and permanent night work, indicating that night shift work with 10 h per day had the highest risk of obesity (OR = 1.38, 95%CI: 1.09–1.75). The rest of the included studies did not report the relationship between different types of shift work and the risk of obesity/overweight.

Multiple diagnostic criteria were used among the included studies, and several studies reported associations according to more than one type of obesity. Overall, there were 14 studies (22,23,26,30,33–35,37,38,40,43,46,47,49,51) reporting OR on the risk for BMI ≥25 kg/m^2. Another 11 studies (28–30,39,41,42,44,45,47,48,50) reported OR on the risk for BMI ≥30 kg/m^2. Nine studies (27–30,41,42,44,48,50) reported OR for abdominal obesity. Two studies (36,38) reported OR for weight/BMI increase. Except for the study of Pepłońska *et al.* (2014) (45), all studies that defined BMI ≥30 kg/m^2 as obesity showed a significantly excess risk of obesity between 2% and 194% among shift workers.

Pooled risk estimates between night shift work and obesity/overweight risk

The pooled OR was 1.23 (95% CI: 1.17–1.29, $p_{\text{heterogeneity}}$ < 0.001, I^2 = 90.7%) for the association between shift work and obesity/overweight (Fig. 2). The combined OR of cross-sectional studies was higher (1.26, 95% CI: 1.19–1.33, $p_{\text{heterogeneity}} < 0.001$, I^2 = 91.7%) than that for cohort studies (1.10, 95% CI: 0.99–1.21, $p_{\text{heterogeneity}}$ = 0.088, I^2 = 47.9%). Results from Begg's regression asymmetry test showed no evidence of publication bias (P = 0.371).

Pooled risk estimates in subgroup analyses by characteristics of studies

To assess the association between shift work and obesity/overweight and potential issues of heterogeneity, subgroup analyses were performed for (i) criteria of obesity/overweight; (ii) definition and types of shift work; (iii) gender or type of study population; (iv) measurements on shift work patterns; and (v) adjustment for confounding factors (Table 2). The pooled effect was the highest for examining the association with abdominal obesity (OR = 1.35, 95% CI: 1.13–1.61, $p_{\text{heterogeneity}}$ = 0.002, I^2 = 67.0%) comparing with BMI ≥30 kg/m^2 and weight/BMI gain, but the pooled OR for BMI ≥25 kg/m^2 showed a similar risk (OR = 1.32, 95% CI: 1.15–1.51, $p_{\text{heterogeneity}} < 0.001$, I^2 = 72.9%). The pooled OR for 'weight/BMI gain' was 1.13 (95% CI: 1.08–1.19, $p_{\text{heterogeneity}}$ = 0.975, I^2 = 0.0%).

Studies that specifically defined 'night work' as having a working time between 24:00 and 05:00 h showed a higher OR (1.32, 95% CI: 1.18–1.48, $p_{\text{heterogeneity}} < 0.001$, I^2 = 74.3%) than those with a broad definition of 'shift work' (1.17, 95%CI: 1.12–1.23, $p_{\text{heterogeneity}} < 0.001$, I^2 = 88.3%) in which day shift workers might be involved. However, there was marginally significant evidence of a different exposure effect between 'night work' and a broad definition of 'shift work', after using ratio of relative risks (53) to measure interaction (ratio of relative risk 1.127, 95% CI: 0.997–1.274). Although only one study measured irregular night shift type, three studies revealed that permanent night workers showed higher risk than those rotating shift workers from 10 studies (OR = 1.43, 95% CI: 1.19–1.71, $p_{\text{heterogeneity}} < 0.001$, I^2 = 70.8% vs. OR = 1.14, 95% CI: 1.05–1.23, $p_{\text{heterogeneity}}$ = 0.003, I^2 = 67.5%).

For different regions of study population, Asian workers showed a similar risk of obesity/overweight (OR = 1.29, 95% CI: 1.14–1.46, $p_{\text{heterogeneity}} < 0.001$, I^2 = 81.5%) compared with workers from other regions (OR = 1.23, 95% CI: 1.17–1.29, $p_{\text{heterogeneity}} < 0.001$, I^2 = 91.6%). Similar risk estimates were also demonstrated for different genders (Table 2). Considering the data collection methods, studies that assessed shift work exposure according to a factory schedule showed a higher OR of 1.62 (95% CI: 1.24–2.11, $p_{\text{heterogeneity}} < 0.001$, I^2 = 82.0%) compared with those that used self-administrated or online-based questionnaires to assess the exposure of shift work. Workers who were employed mainly in manufacturing industries showed a higher risk for obesity/overweight (OR = 1.30, 95% CI: 1.16–1.46, $p_{\text{heterogeneity}} < 0.001$, I^2 = 78.2%).

Summary of dose–response relationship between night shift work and obesity/overweight risk

Four of the included studies reported a dose–response relationship between night shift work exposure and risk of obesity/overweight (Table 3). Ramin *et al.* (42) surveyed over 50,000 American female nurses and found an increasing trend towards obesity (BMI ≥30 kg/m^2) risk as the number of night shifts per month increased, with the highest OR at 3.42 (95% CI: 1.95–6.03). Among Korean nurses, Kim *et al.* (46) reported that shift workers with the longest duration of shift work (years of shift work, 6.83–38.00 years) had 1.37 times higher (95% CI: 0.91–2.09) risk of overweight (BMI ≥25 kg/m^2) than those with the shortest duration of shift work (years of shift work, 0.08–3.00 years). Marqueze *et al.* (2012) estimated that each year of night shift work might cause an average BMI increase of 0.24 kg/m^2 for nurses (22). Pepłońska *et al.* (41) reported

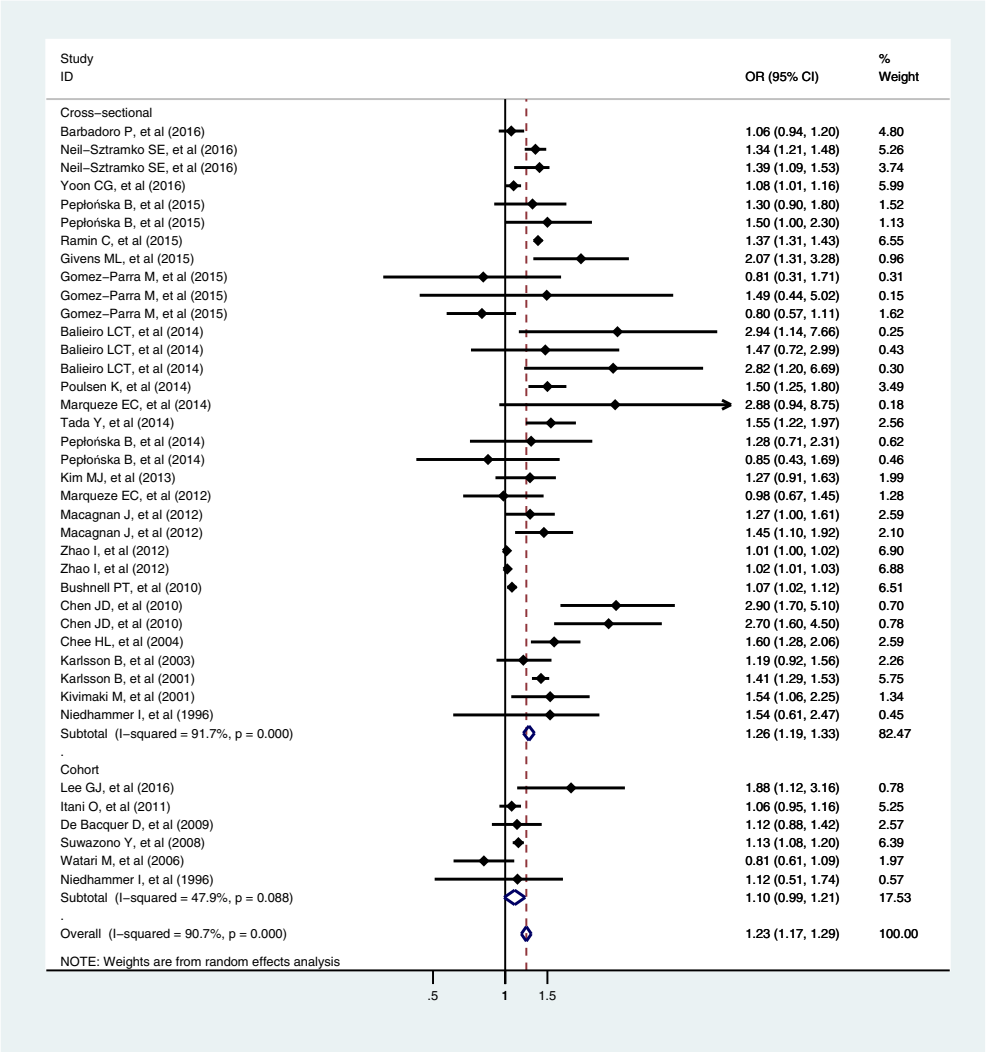

Figure 2 Pooled effects estimation for shift work and obesity/overweight by cohort/cross-sectional studies. CI, confidence interval; OR, odds ratio. [Colour figure can be viewed at wileyonlinelibrary.com]

a dose–response relationship between shift work exposure and being obese could be observed from the density (nights per month), duration (years) and cumulative exposure to night work, although the relationship did not achieve statistically significance.

Discussion

Our systematic review and meta-analysis are the first to quantitatively combine the risk estimates of night shift work on the risk of specific and different types of obesity/overweight from individual studies. We showed that night shift work increases the risk of obesity/overweight by 23%, and the excess risk with abdominal obesity was even higher at 35%. There is evidence of an exposure–response relationship between the intensity of night shift work (i.e. years of exposure and number of night shifts per month) and obesity/overweight risk. However, it was not possible to quantify this because of the limited number of studies and small variety of intensity descriptions, which highlights the need for such dose-dependent relationships in the future research.

Abdominal obesity is characterized by body shape alteration and visceral fat accumulation, which are commonly associated with abnormal metabolic profiles, such as increased insulin resistance and dyslipidaemias (54). Circadian disruption is a consequence of exposure to light at night, which may induce the suppression of melatonin. This is thought to be an important mechanism underlying metabolic abnormalities in night shift workers. Melatonin plays a key role in synchronizing central and peripheral circadian rhythms and regulates the secretion of hormones such as cortisol, insulin (55) and leptin (56). Such misalignments may lead to a disturbance of body homeostasis and produce

Table 2 Pooled effect estimation by subgroups with different characteristics

	N^1	Pooled OR (95%CI)^2	I^2 (%)
Criteria of obesity			
BMI ≥25 kg/m^2	14	1.32 (1.15, 1.51)	72.9
BMI 25–29.9 kg/m^2	3	1.01 (1.00,1.02)	0.0
BMI ≥30 kg/m^2	11	1.25 (1.11, 1.41)	95.9
Abdominal obesity	9	1.35 (1.13, 1.61)	67.0
Weight/BMI gain	2	1.13 (1.08, 1.19)	0.0
Methods for shift work assessment			
Self-administrated questionnaire	29	1.27 (1.17, 1.37)	73.0
Online-based questionnaire	4	1.02 (1.01, 1.04)	58.6
Factory schedule	6	1.62 (1.24, 2.11)	82.0
Definition of night shift work			
Clear definition	17	1.32 (1.18, 1.48)	74.3
Unspecific definition	22	1.17 (1.12, 1.23)	88.3
Adjustment for multiple variables			
With	35	1.21 (1.16, 1.28)	91.3
Without	4	1.42 (1.07, 1.87)	47.6
With eating habits and physical activity	8	1.02 (1.00, 1.05)	56.3
Target population			
Asian	10	1.29 (1.14, 1.46)	81.5
Others	29	1.23 (1.17, 1.29)	91.6
Gender			
Mixed	12	1.23 (1.10, 1.38)	77.2
Male	12	1.19 (1.06, 1.34)	64.5
Female	20	1.25 (1.17, 1.34)	93.2
Shift type			
Ambiguous/mixed type	20	1.27 (1.14, 1.41)	94.0
Rotating shift	15	1.14 (1.05, 1.23)	67.5
Permanent night shift	7	1.43 (1.19, 1.71)	70.8
Irregular night shift	1	2.88 (0.94, 1.52)	N/A
Occupations			
Mixed or other occupations	13	1.24 (1.11, 1.39)	80.2
Healthcare employees	16	1.20 (1.12, 1.28)	93.3
Manufacture employees	10	1.30 (1.16, 1.46)	78.2

[1]number of risk estimates included for pooled effect estimation.
[2]pooled OR (95%CI), calculated by fixed-effect model if I^2 is less than 50%; otherwise, random effect model was applied.
BMI, body mass index; CI, confidence interval; OR, odds ratio.

abnormal metabolic profiles. Circadian disruption has been considered one of the key potential mechanisms in the aetiology of obesity occurring with night shift work. Night shift workers are more prone to abdominal obesity accompanied by metabolic disorder, referred to as 'metabolically obese', which might be associated with a higher risk of cardiovascular disease (57).

Original studies investigating the association between obesity/overweight and night shift work covering the period between 24:00 and 05:00 h (52) showed a pooled estimate OR of 1.32. This reinforces the hazardous consequence of night working hours. Permanent night shifts showed a higher risk of obesity/overweight than rotating shifts in this meta-analysis. The reason for this might be that permanent night workers are much more frequently exposed to light at night than rotating shift workers. Moreover, it is difficult to adapt to new sleep patterns. For example, even after a prolonged exposure, only a minority of night workers (<3%) showed a full adaption of their circadian rhythm to nocturnal activity (58). In addition, as permanent night shift workers have to sleep during daytime hours, their sleep is more likely to be interrupted by environmental factors (59), yielding shorter sleeping times and accumulated chronic sleep debt in shift workers (60). Conversely, rotating shift workers with continuous adaptation of their circadian systems did not show a higher risk of obesity/overweight than those working permanent shifts. Sleep deprivation is another remarkable mechanism by which body weight is increased among shift workers by altering metabolic profile (61,62).

Employees in the manufacturing industry showed a relatively higher risk of obesity/overweight in our study, but the reason for this remains to be elucidated. Interestingly, Bushnell *et al*. (2010) found that shift workers with different average working hours showed varying degrees of obesity (BMI ≥30 kg/m^2) risk (48). They further pointed out that the highest risks were among workers on 10-h permanent night shifts or 12-h rotating shifts compared with other night shift work schedules (48). The workers who had long working hours, whether involved in a shift work schedule or not, exhibited an increased risk of type 2 diabetes mellitus or obesity (63,64). Moreover, the risk for night shift workers whose work demands a heavy workload, which is common among manufacturing employees with a 10- or 12-h shift, could be related to the high energy as they needed extra calories to maintain their performance during the night-time shift (65). This is despite no significant difference in the total daily energy intake between the night shift workers and daytime workers being observed (65). Night-time eating behaviour has been shown to be associated with increased risks of metabolic disorders, weight gain and breast cancer (66–68). However, to our knowledge, none of the previous studies investigated the effect of night eating behaviour on the aetiology of obesity among night shift workers, which deserves further exploration in future studies.

Merits and limitations

This systematic review has merits and some novel findings that have never been reported previously, and publication bias was not significant. However, several limitations should be noted. Firstly, our study found a high degree of heterogeneity. Attempts were made to identify the origins of this heterogeneity. Although most studies had adjusted for several confounding factors, including age and other demographic factors, as well as smoking and drinking habits, the factors in regression models were varied and considered inadequate for the studies involving obese outcomes that constitute a potential source of heterogeneity. Among 28 studies that provided multiple adjusted ORs, only six (23,35,37,39,46,47) took full consideration of eating habits and physical activities with lower pooled OR, indicating

Table 3 Summary of dose–response relationship between night shift work and obesity/overweight risk from included studies

Author (year)	Low exposure to night shift work OR (95% CI)	Medium exposure to night shift work OR (95% CI)	High exposure to night shift work OR (95% CI)
Pepłońska B, *et al.* (2015) (41)	**Frequency of night shift work, 2–7 nights/months** For BMI 25–29.9 kg/m^2: 1.2 (0.8–1.7) For BMI ≥30 kg/m^2: 1.4 (0.9–2.1) For abdominal obesity: 1.1 (0.8–1.7)		**Frequency of night shift work, ≥8 nights/month** For BMI 25–29.9 kg/m^2: 2.0 (0.8–4.7) For BMI ≥30 kg/m^2: 3.9 (1.5–9.9) For abdominal obesity: 2.4 (1.2–4.9)
Ramin C, *et al.* (2015) (42)	**Duration of night shift work, ≤10 years** Reference group: 1.0 **1–2 nights/month vs 0 nights/month** For BMI ≥30 kg/m^2: 1.13 (0.70–1.83)	**Duration of night shift work, 10–20 years** For BMI 25–29.9 kg/m^2: 1.1 (0.7–1.7) For BMI ≥30 kg/m^2: 1.2 (0.7–2.2) For abdominal obesity: 1.3 (0.8–2.1) **3–4 nights/month vs 0 nights/month** For BMI ≥30 kg/m^2:1.38 (0.85–2.22) … **16–20 nights/month vs 0 nights/month** For BMI ≥30 kg/m^2: 2.28 (1.39–3.75)	**Duration of night shift work, >20 years** BMI 25–29.9 kg/m^2: 1.1 (0.8–1.7) BMI ≥30 kg/m^2: 1.5 (0.9–2.6) Abdominal obesity: 1.0 (0.7–1.) **21+ nights/month vs 0 nights/month** For BMI ≥30 kg/m^2: 3.42 (1.95–6.03) (*p-trend* < 0.0001)
Kim MJ, *et al.* (2013) (46)	**Tertile 1 (0.08–3.00 years of shift work)** Reference group: 1.0	**Tertile 2 (3.08–6.75 years of shift work)** For BMI ≥25 kg/m^2:1.21 (0.84–1.74)	**Tertile 3 (6.83–38.00 years of shift work)** For BMI ≥25 kg/m^2: 1.37 (0.91–2.09)
Marqueze EC, *et al.* (2012) (22)		**Duration of work on night shift (years)** For weight gain: β = 0.24 kg/m^2 (0.12–0.37)	

BMI, body mass index; CI, confidence interval; OR, odds ratio.

that lifestyle factors need to be fully considered in future studies to produce more accurate risk estimates for night shift work.

Secondly, the lack of a consistent definition of night shift work is a concern in our meta-analysis, which may lead to a dilution of effects. Because more than half of the studies used vague definitions of shift work, a degree of misclassification of night shift work exposure might have occurred. Moreover, multiple diagnosis criteria of obesity/overweight (e.g. BMI and abdominal obesity) were adopted in the original studies, which contribute to the high heterogeneity of our pooled estimate. This heterogeneity remained in some subgroups analyses using similar diagnosis criteria of obesity/overweight, indicating other potential sources of heterogeneity, such as study design. BMI or waist circumference could not fully represent the metabolic abnormalities and the increase of adipose tissue in the human body (69). Accordingly, greater consideration of metabolic disturbance in individuals with obesity is needed in future studies of night shift workers.

The overall pooled association between night shift work and weight gain may be underestimated in the cross-sectional study design as a result of a potential healthy worker survival effect that makes the remained employees healthier than those who quit shift work (70). However, our study actually found a higher risk on subgroup analysis of cross-sectional studies than that of cohort studies. A precise description of the definition of night shift work, especially the exposure assessment on the time range of night shift should be provided. Because cross-sectional studies cannot determine cause and effect, large-scale prospective cohort studies with a long period of follow-up and better assessment of both exposure and obesity/overweight outcomes, such as measurement of body adipose tissue, are needed in future studies.

Conclusion

This meta-analysis demonstrated that night shift work was associated with an increased risk of obesity/overweight, particularly abdominal obesity, and the risk was more prominent among long-term night shift workers. A positive gradient was suggested for the relation between obesity/overweight and the increasing exposure frequency and intensity of night shift work. Modification of working schedules to avoid prolonged exposure to long-term night shift work might be an efficient administrative control to reduce the risk of obesity. Large-scale prospective cohort studies with more accurate measurements of night shift work and obesity are needed for future research.

Conflict of interest statement

All authors declare no conflict of interest.

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