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CLINICAL REVIEW

The influence of bed-sharing on infant physiology, breastfeeding and behaviour: A systematic review

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SUMMARY

This review aimed to better understand the underlying physiology of the risks and benefits of bed-sharing. Eight databases were searched using terms relating to adult–infant/baby, bed-sharing/co-sleeping combined with outcome terms for physiology, sleep, cardiovascular, respiratory, temperature and behaviour. Of 836 papers identified, 59 papers representing 48 cohorts met inclusion criteria. Objective data using various methodologies were available in 27 papers and subjective data in 32 papers. Diverse measures were reported using variable definitions of bed-sharing. Identified physiological and behavioural differences between bed-sharing and cot-sleeping included increased behavioural arousals, warmer in-bed temperatures and increased breastfeeding duration in bedshare infants as well as differences in infant overnight sleep architecture, cardiorespiratory control and cortisol responses to stress.

We concluded that many differences are context-specific, and dependent on the subjective view of the parents and their cultural values. Objective risk arises if the infant is unable to mount an appropriate physiological or behavioural response to their micro-environment. More studies in the bed-sharing setting are needed to identify infant risk, the potential benefits of a safer environment, and how bed-sharing interacts with infant care practices other than sleep.

Introduction

Bed-sharing between infants and parents has been identified in some potentially adverse circumstances as increasing the risk of sudden unexpected death in infancy/sudden infant death syndrome (SUDI/SIDS) [1,2]. However, bed-sharing has also been identified as having a positive role in encouraging breastfeeding and is the norm in many cultures where there is a low rate of SUDI [3]. Prevalence of bed-sharing varies widely among ethnic and social groups but, even in Caucasian societies where bed-sharing is often discouraged, it continues to be a common practice [4,5]. An internet-based infant sleep questionnaire answered by 29,287 parents with children aged up to 36 mo, from New Zealand, Australia, Canada, UK, USA and multiple Asian countries, found 11% of Caucasian parents and 38% of Asian parents reported bed-sharing with their infant at sleep onset [6]. Neither benefits nor risks are fully understood. Parents have identified ease of breastfeeding, having a settled baby, reduced parental tiredness, and a sense of security as bed-sharing benefits [5,7–9], while observational studies have demonstrated increased breastfeeding, increased mother–baby interactions and increased infant arousals [10–13].

In contrast, some studies have identified factors that, when associated with bed-sharing, increase the risk of SUDI/SIDS. These include maternal smoking [2,14–19] alcohol or drug consumption prior to bed-sharing [2,15–17,19], maternal excessive weight [20], overtiredness, household overcrowding, excessive bedding [1], soft bedding [21], bed-sharers other than parents [22], and younger infant age [2,19,20]. A particularly high degree of risk is conferred by unsafe sleep surfaces such as sofas [15] as well as by maternal smoking, parental alcohol and drug consumption [2,15–19]. These interactions help to explain the seemingly ambiguous finding that in some cultures bed-sharing is common but not associated with a

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high rate of SIDS [3,23–25] while in other cultures, particularly where maternal smoking is common, approximately 50% of SUDI are reported to occur while bed-sharing [18]. Carpenter et al. reported an increased risk of bed-sharing in the absence of parental smoking, and alcohol consumption using a reference group of solitary sleepers at very low risk of SIDS and imputed data [26]. These findings were not replicated by Blair et al. [15] using real data and a reference group of solitary sleepers at normal risk.

More recent studies from the UK and New Zealand have demonstrated no statistically significant increased risk of SIDS when bed-sharing in the absence of smoking [15,18] or recent alcohol consumption [15], and an effect in the direction of protection against SIDS for bed-sharing with infants older than three months [15]. Two in-bed sleep devices to enable bed-sharing while providing a separate sleep space for baby, [the wahakura (indigenous flax bassinet) and Pēpi-pod (plastic bassinet)], have been shown as equivalent to stand alone bassinets in terms of exposure to SUDI risk behaviours [27,28].

Several mechanisms for the action of identified risks have been postulated. As early as 1892, Templeman suggested that maternal alcohol consumption may lead to death of the bed-sharing infant by overlaying and consequent accidental asphyxiation [29]. More recent studies propose a similar mechanism based on largely anecdotal evidence [30–32]. Overlaying is difficult to establish from post-mortem findings alone and parental recollection can be unreliable. Postulated mechanisms for the increased risk associated with maternal smoking in pregnancy and subsequent bed-sharing include hyperthermia, rebreathing, and respiratory obstruction. An infant exposed in utero to cigarette smoke may be less responsive to these physiological stressors [33–35].

Most investigation into potential vulnerabilities making an infant more likely to succumb to SUDI has focused on cot-sleeping in a sleep laboratory. However, more recently the influence of infant/adult bed-sharing on infant physiology has been studied. Behavioural studies have explored the possible impact of infant sleep disturbance on infant stress levels. Studies have generally been confined to infants identified at low risk of SUDI.

A recently published narrative review of bedsharing research included studies with participants up to 18 y old and focused on how proximity to the parents influenced children's social, emotional, and physical development [36]. Our systematic review was strictly limited to infants, with a particular focus on in-depth infant physiology particularly, cardio-respiratory, thermoregulatory and arousal responsiveness, extensive coverage of breastfeeding outcomes as well as studies on allergy, infection and cortisol levels and includes recently published behavioural and physiology data from high-risk ethnic minority families [27]; a group rarely studied.

The main aim of this review was to systematically search and synthesise existing literature related to adult–infant bed-sharing and infant physiology, with additional emphases on infant behaviour and breastfeeding outcomes, to provide better understanding of the risks and benefits to the infant.

Methods

A systematic review was conducted in accordance with preferred reporting items for systematic reviews and meta-analyses (PRISMA) [37]. Text words relating to adult–infant/baby, bed-sharing/bedsharing were combined with outcome terms for physiology, sleep, cardiovascular, respiratory, temperature, behaviour, and breastfeeding (see Appendix 1 for search strategy). The following databases were searched for all potentially relevant papers published in any language prior to October 2017: PubMed; SCOPUS; CINAHL; EMBASE; PsychINFO; Web of Science and EBM Reviews including Cochrane.

From 1690 total publications, 854 duplicates were removed (see Fig. 1). Titles and abstracts of the remaining 836 papers were screened for eligibility. One paper was removed as it could not readily be translated. All other papers were in English. The inclusion criteria were: study population and exposure where infants were aged less than two years old and were bed-sharing with an adult family member, or caregiver of the child; the study was prospective in design, and included a control/comparison group or within-study post-hoc analyses of bed-sharing/non-bed-sharing relating to an outcome of interest. The outcomes of interest were sleep architecture, arousal from sleep, sleep position, cardiovascular, respiratory, temperature/thermoregulation, infant behaviour and breastfeeding. Retrospective, risk factor and epidemiological descriptive studies were excluded, as were guidelines, letters, comments, recommendations, conference abstracts, fact sheets and studies with outcomes not relevant to the review. Studies reporting kangaroo care, twins sleeping together, or sofa sleeping as the exposure of interest were also excluded. Papers not meeting inclusion criteria were excluded (721), leaving 115 papers for detailed review.

Full-text versions of the 115 articles were sourced and assessed for final inclusion by three members of the research team (MP, SB, BG). Three independent reviewers (AP, PB, DE) assessed the quality of each article using the Lewis, Olds, Williams (LOW) critical appraisal tool [38], which assesses the presence or absence of nine methodological criteria suitable for observational studies of exposures or interventions, or cross-sectional studies included in systematic evidence reviews. The studies were assessed only on the information provided in the manuscripts. Possible responses to each item were yes, no, or cannot determine. We grouped 'no' and 'cannot determine' into 'unclear risk of bias'. Discrepancies were resolved through consultation with the other authors (SB, BG).

Results

Fifty-nine papers representing 48 different cohorts were included in the review. Half (31 papers) described cohort studies, 19 case–control, seven cross-sectional surveys, one a mixed methods study and one a randomised control trial (RCT), although a small number of mother/baby pairs (n = 64) were studied in the RCT. Papers originated from 15 countries: USA (19 papers), UK (14), The Netherlands (five), New Zealand (four), Brazil (three), two papers from each of Australia, Germany and Russia, one paper from each of Barbados, China, Ireland, Japan, Sweden, Switzerland and Thailand, and one internet-based study that included five predominantly-Caucasian countries and 12 predominantly-Asian countries. Papers were published between 1994 and 2017. Participant numbers ranged from ten to 29,287 with a median of 196. Two-thirds of the papers (40/59) reported data from infants aged six months or younger. The rest reported on infants aged up to one year (12 papers) and up to two years (seven).

Objective data were reported in 27 papers, collected from physiological, video, actigraphy, or biochemical monitoring in the home (20 papers) or in the sleep laboratory (seven). All studies recruited healthy infants, except one which recruited 'fussy infants' [39].

Of papers reporting overnight objective data, three compared routine bed-sharers with routine cot-sleepers sleeping in their usual location on the study night [13,40,41]. Nine were of cross-over design. In these latter papers routine bed-sharers and routine solitary sleepers (slept in adult bed with the mother <1 night/wk) were monitored – after random allocation of the order of sleep location – during one night bed-sharing and one night solitary sleeping [11,12,42–47]. Another compared triadic with dyadic bed-sharing [48]. A further study randomised babies to sleep location from birth [49] and another reported analysis of

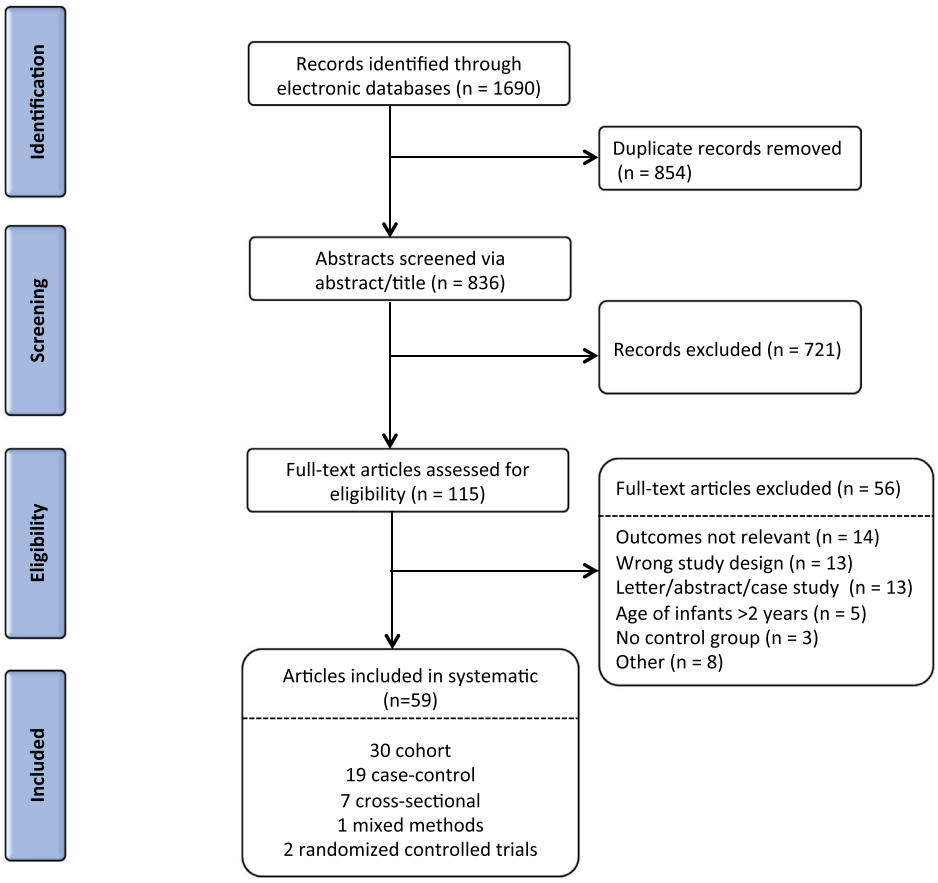

Fig. 1. Search strategy flow chart.

actual sleep location on a single night after randomising babies to receive a wahakura or conventional bassinet [27]. All studies, except the latter, had an adaptation night before data were collected. Another four papers reported on longitudinal physiological or video data [50–53]. Others related biochemical measures of cortisol reactivity [54–57], melatonin rhythms [58] and nicotine exposure [59] to sleep location.

The remaining 32 papers reported data from surveys or interviews. These comprised longitudinal interviews (12 papers), cross-sectional interviews (eight), longitudinal surveys (seven), cross-sectional surveys (four) or review of medical records (one).

Appendices 2–7 present the 59 papers included in this review, grouped into themes according to reported outcomes: Sleep; Temperature; Cardiorespiratory; Breastfeeding; Behaviour; Other. Other includes allergy, infection, cotinine and cortisol reactivity. Some papers appear under more than one theme, reflecting the diverse outcomes reported. Within each table, papers are listed chronologically, with a summary of the important aspects of each.

Definition of bed-sharing

Bed-sharing was defined as infant/adult sleep on a same sleep surface. The review included papers that used the terms "bed-sharing" or "co-sleeping" as there is not universal agreement on these definitions. If the outcomes in a paper were not related to sharing a same sleep surface this was identified in the review. Out of the 59 papers included in this review, 17 (29%) provided a detailed definition of routine bed-sharing/co-sleeping, including terms relating to frequency (such as "usually", "regularly", "every night", or "at least 5 nights per week") combined with a term relating to duration of bed-sharing (such as "all night", "most of the night", "whole night", "at least four hours", "whole or part of the night", "main night time sleep" or "some of sleep") [4,11,13,27,40,41,43,48,58–66]. One paper provided subcategories of bed-sharing: *habitual* (infant sleeps in parents' bed all night every night); *combination* (infant sleeps in more than one place, but sleeps in parents' bed for at least part of night on at least two nights per week); *occasional* (infant sleeps in parents' bed once a week or less); and *non-bed-sharing* (infant never slept with parent(s) in an adult bed) [65]. Fifteen papers (25%) provided little detail relating to the definition of bed-sharing, either in terms of frequency or duration [6,39,42,49–52,55,56,67–73]. The remaining 27 papers (42%) reported a moderate amount of information relating to frequency (such as "usually", "more than two nights per week", "at least once per week" or "regularly"), but no reference to duration. Tables S1–6 summarise the data on bed-sharing definition for each paper.

Quality assessment of papers

Methodological quality of papers included for relevant outcomes ranged from four [39,46,58,70,73–75] to nine points [13,40,41] with a mean of six. A maximum of nine points was only possible if studies included a control group, otherwise the maximum score was seven as scored in eight studies [6,54,61–63,76–79]. All studies had a clear focus and the majority (86%) recruited subjects in an acceptable way. The main methodological problems were not taking into consideration confounding factors and numbers deemed inadequate or unable to ascertain in 36 (61%), the latter due to many not reporting sample size calculations. Criteria for scoring adequate power was either the reporting of a sample size calculation related to the

outcome of interest or a cohort study >1000 subjects. Seventeen articles (29%) included a control group and just eight scored a positive response to representativeness of sample/sufficient numbers [12,13,40–42,48,49,53]. Four papers included a stable baseline period reflective of their experimental design [44,45,64,80]. The results of the papers were subjectively rated as 'believable' in the majority, with four scoring no/unable to ascertain due to small numbers, claims not consistent with study design or uncertain validity of the outcome measure [58,67,75,81]. Results are summarised in Fig. 2.

Overnight infant sleep

Of the 59 included papers, 19 reported outcomes related to sleep of bed-sharing infants (Table S1). Methods of data capture varied and included surveys, sleep diaries, video recordings, actigraphy, and polysomnography. Several different cultures were represented across the studies. Unsurprisingly, mixed results were found regarding the relationship between bed-sharing and sleep parameters. Compared to solitary sleeping, bed-sharing was associated with a significantly shorter total sleep time in infants [6,61,68,75,82], no difference [13,49,58,70], and increased total sleep time in specific sleep stages [11,39].

In a small study investigating the development of circadian rhythms, no differences in the timing and magnitude of sleep–wake rhythms (using actigraphs) or melatonin levels, were identified, although bed-sharing infants had more robust rhythms [58]. Arousal deficiency has been suggested as a contributory factor in some cases of SIDS. More frequent transient sleep arousals or sleep awakenings have been significantly associated with bed-sharing in many papers [6,40,43,74–76,80,82,83] but not all [39,68], and have been shown to occur more often in bed-sharing babies who breastfeed compared to those who bottle-feed [48].

In the 1990s, electroencephalography (EEG) recordings of infants at the peak age for SIDS (11–15 wk) demonstrated increased stage 1 and 2 sleep and reduced stage 3 and 4 sleep in healthy, routinely bed-sharing infants, compared to routinely solitary-sleeping infants [11]. One study reported more 'active sleep' in bed-sharers measured by actigraphy, but this method has not been validated [67].

Temperature

Six studies reported on infant temperature or the thermal environment [40,46,51–53,73] (Table S2). Four of these collected temperature data from overnight monitoring of healthy term infants [40,46,51,53]. Another collected overnight temperature data from preterm infants at 44–45 wk post-conception age in their usual place of sleep [52], and one [73] reported interview data from mothers of 4 wk old infants. Studies reported on a range of measures including overnight infant rectal temperature [40,51,53], shin [40], axillary [46], and insulated abdominal skin temperature [52], as well as room temperature [40,46,52], and thermal insulation of bedding and clothing [40,53,73].

The studies consistently showed a difference in thermal environment when infants shared the adult bed compared to solitary sleeping. One study reported an overall mean increase in rectal temperature of 0.1 °C between two and eight hours after sleep onset [53], while another reported that an increase of 0.1 °C did not occur until eight hours after sleep onset [40]. A small sample of Asian babies had a significantly smaller drop in rectal temperature with sleep onset during bed-sharing compared to solitary-sleeping, maintained throughout overnight sleep [51]. Bed-sharing was associated with significantly increased axillary temperature in both routine bed-sharers and routine solitary-sleepers. This occurred in non-rapid eye movement (NREM/non-REM) sleep only and was associated with increased transient, movement-associated arousals [46].

Shin temperature was 0.8 °C higher in bed-sharing babies, compared to cot-sleepers, two hours after sleep onset and continued to increase overnight. This resulted in a smaller overnight rectal-shin temperature difference (indicator of thermal comfort [84]) for bed-sharing infants compared to cot-sleepers [40], indicating bed-sharing babies were in a thermolytic state while cot-sleepers were in a thermogenic state.

Two studies calculated the insulation of bedding over bed-sharing infants to be significantly greater than that over cot-sleepers, while insulation due to clothing was similar [40,73]. A third found a small non-significant difference in the tog value of clothing and bedding combined [53].

Thomas and Burr measured insulated abdominal skin temperature as an indicator of circadian cycle acrophase [52]. Preterm infants at 44–46 wk post-conceptual age who slept in the same room and/or same bed as their parents showed different temperature circadian rhythms to infants who slept in a separate room, their temperature acrophase peaking in daytime. The authors suggested this represented the beginning of entrainment to the social day–night pattern.

Overnight infant cardiorespiratory measures

Five papers [41,42,45,47,75] reported on data related to cardiorespiratory factors (Table S3). Four studies were of case control design. Data were collected from overnight infant monitoring in the home or sleep laboratory. These studies reported on measures including oxygen saturation [41,42], carbon dioxide (CO_2) in the air around the infant's face [41], heart rate [41,42,47], apnea, and periodic breathing [41,45] in relation to sleep state [45,47]. All included overnight video monitoring. The fifth study was a cross-sectional survey where mothers were interviewed about infant care and sleep, including about noisy breathing during sleep [75].

Oxygen desaturation, apnea and heart rate. In one study, desaturation events, where oxygen saturation dropped to less than 90%, were twice as common during bed-sharing as cot-sleeping but when warmer in-bed temperatures were taken into account this reduced to a one-and-a-half-fold difference [41]. Another study showed an increased frequency of central apnea and periodic breathing during bed-sharing. The greatest difference was between routine bed-sharers on their bed-sharing night compared to routine solitary-sleepers on their solitary-sleep night [45]. Central apnea during bed-sharing was associated with the increase in frequency of non-REM stage 1 and 2 and REM sleep [45].

Characteristics of desaturation events were not different between bed-sharing and cot-sleeping infants [41,42], and neither were the mean apnea duration and maximum apnea duration measured in another study [45]. Apneas longer than 15 s were rare [41,45], as were desaturation events less than 80% [41].

Over three-quarters of desaturation events in bed-sharing and cot-sleeping infants were preceded by a central apnea of five to ten seconds and were not associated with bradycardia [41]. Desaturation events were not associated with times when the level of CO_2 in the air at the infant's face was greater than 3% [41], nor with the infant's mouth and nose being covered [42]. There was no consistent impact on oxygen saturation or heart rate even during prolonged airways covering [42].

Irrespective of routine sleep condition, heart rate was higher on the bed-sharing night in all sleep stages, and associated with increased axillary temperature. Heart rate variability was lower on the bed-sharing night in stage 1 and 2 and REM sleep [47].

Carbon dioxide measured in the air around the infant's face. Eighty rebreathing events, due to an increase in CO_2 in the air surrounding the infant's face [41], were recorded from 22 bed-

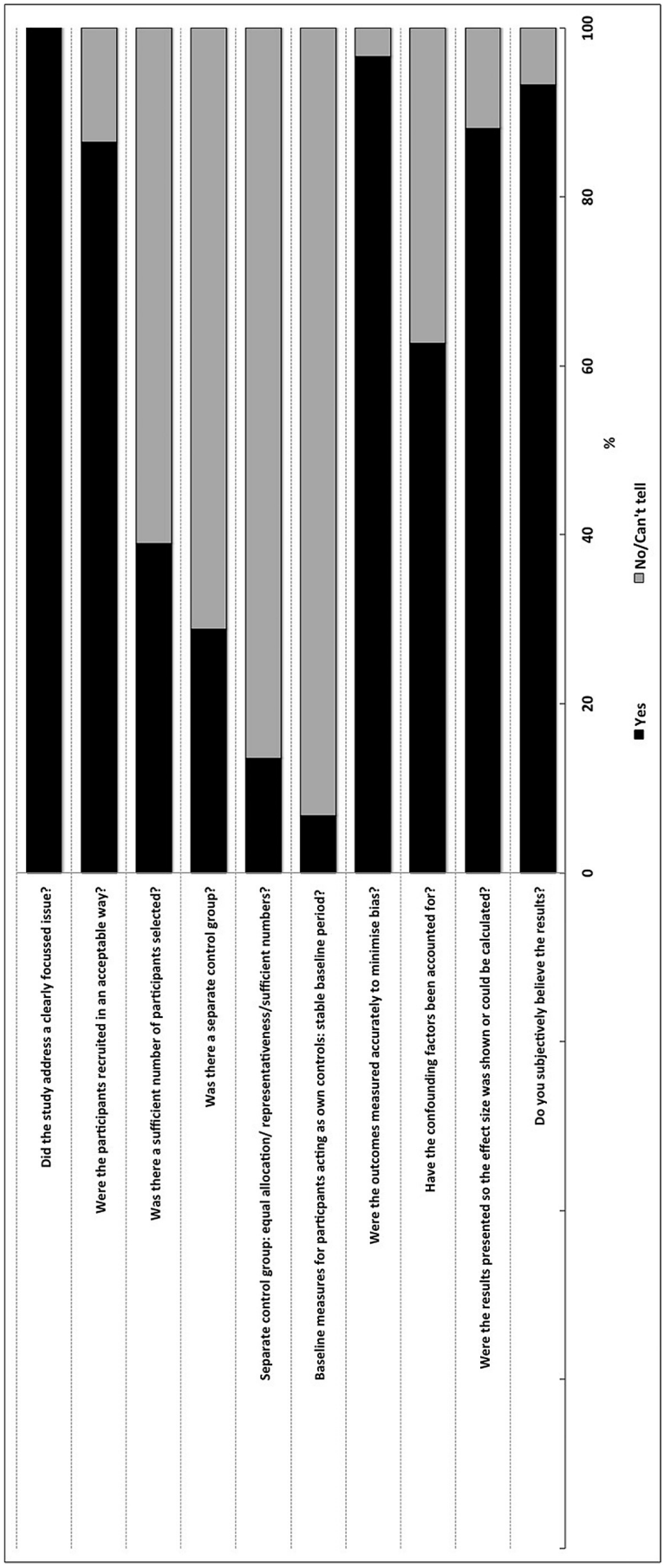

Fig. 2. Summary of the quality assessment of all included studies using questions from the LOW critical appraisal tool [38].

sharing infants and one cot-sleeping infant with 70% of these events associated with head covering. Mean oxygen saturation was maintained at 97.6% during rebreathing events [41]. Cumulative duration of rebreathing per night ranged from 3 to 154 min. The median of the average CO_2 at the infant's face during rebreathing events was 2.5%, with a maximum of 4% CO_2 [41].

More bed-sharing infants than cot-sleepers were exposed to rebreathing, with one infant in each group exposed to greater than 4% CO_2. The face of the cot-sleeper was covered by a muslin wrap leading to CO_2 greater than 4% for 13 min [41].

From a survey of 112 parents where 26% bed-shared with their infant, mothers reported more noisy infant breathing and infants scored higher on sleep disordered breathing and parasomnia scores during bed-sharing compared to solitary sleep [75]. The cross-sectional study design means we do not know if infants were brought into bed because of breathing difficulties.

Breastfeeding

Breastfeeding was the most commonly reported outcome related to bed-sharing (Table S4). In total, 26 papers from 10 different countries reported on breastfeeding. There were 18 cohort studies [27,50,55,60–62,65,69,71,74,76–78,85–89], two case control studies [12,13], two cross-sectional studies [83,90], one randomised controlled trial [49], one mixed methods [72], one longitudinal survey [4] and one longitudinal interview study [79]. Methods of collecting breastfeeding and bed-sharing data included objective overnight video [12,13,27,49,50], and self-reported data from surveys and sleep diaries, some of which included age of breastfeeding cessation. Breastfeeding was inconsistently defined, including “any”, “ever”, “full” and “exclusive”. In some studies it was not defined at all.

Nineteen papers reported breastfeeding to an older age among bed-sharing infants [4,55,60–62,65,69,71,72,74,76–79,83,85,86,88,89] while three did not find this association [27,87,90]. The remaining four papers reported more breastfeeding attempts [12,13,49,50] and longer duration [12,50] of overnight breastfeeding as observed on overnight video. Infants in the early postnatal period in hospital randomly allocated to bed-sharing or a side-car crib exhibited more feeding effort and feeding attempts compared with infants allocated a stand-alone cot [49]. Using maternal sleep logs and interviews, Blair and Ball reported on 1356 infants from two UK studies showing that bed-sharing was strongly related to breastfeeding, with 46% of bed-sharing infants still breastfeeding at three to four months, twice as many as among solitary sleeping infants (23%) ($p = 0.0001$) [86]. In another paper, habitual bed-sharing infants breastfed for more weeks, than inconsistent bed-sharers and non-bed-sharing infants [89].

Exclusive and any breastfeeding were associated with bed-sharing on discharge [88], and at various points after discharge [4,27,55,60,62,65,74,79,83,86]. Older infant age at breastfeeding cessation was also associated with bed-sharing [4,65,71,77,79,88,89]. Ball examined night-time care-giving practices of 253 families during their infants' first four months using sleep logs and interviews [65]. The rates of breastfeeding declined more slowly in bed-sharers (46% at 16 wk) compared to non-bed-sharers (27% at 16 wk).

Overnight video studies reported increased breastfeeding attempts [12,49,50], increased length of breastfeeding [12,50], and increased frequency of successful breastfeeds [49,50].

Several studies investigated factors that may modify the apparent relationship between bed-sharing and breastfeeding: maternal anxiety and depression [61,69], ethnicity [78], socioeconomic status [72], breastfeeding beyond four weeks, and bed-sharing pattern (early, late, constant) [60]. Three papers reported no significant relationship between bed-sharing and breastfeeding [27,87,90], possibly related to the characteristics of the participants.

Behaviour

Aspects of parent and infant behaviours were reported in 13 papers [13,27,42,44,48,53,66,67,74,76,81,83,90] from eight countries: Thailand, Russia, Sweden, and Japan (one paper), New Zealand, The Netherlands, USA (two), UK (three), using video recordings [13,27,42,44,48] or self-report [53,66,67,74,76,81,83,90] (Table S5). The papers included case control studies reporting objective data from overnight video (five papers), cross-sectional studies (three), and cohort studies (five) reporting subjective data from questionnaires, sleep diaries, or interviews or from video.

Sleep position was the most commonly studied behaviour. Prone sleep was rarely reported. Bed-sharing infants were significantly more likely to be placed to sleep laterally [13,42–44,48,83,90] compared to non-bed-sharing infants, although this was not the case in one study [53] nor was sleep position different between bed-sharers and infants in a wahakura [27]. In two studies supine was the most common position during bed-sharing [44,67].

The direction faced by side-sleeping infants was rarely reported. One paper [44] identified bed-sharing infants (whether lateral or supine) mostly slept facing their mothers, less than 30 cm apart [44] and in another mothers who breastfed and bed-shared mainly slept facing their infant, and infants mainly slept facing their mothers [48]. In home studies infants more often slept laterally compared with laboratory-based studies where bed-sharing infants more often slept supine [48].

Head covering events were reported as significantly more common during bed-sharing compared to cot-sleeping in two studies [13,42]. All instances were initiated and most (70%) terminated by maternal movements [13,42]. Bed-sharing infants were checked three times more often by parents [13].

Video studies [13,43,48] and parent-reported data [83] identified that bed-sharing infants woke more frequently, often associated with breastfeeding, and were less likely to use a pacifier [83]. Studies report variable impacts of bed-sharing on infant temperament such as more negative mood and less persistence at activities [81], but no impact on duration of crying/fussy behavior [67], and more separation distress, dysregulation and negative mood, and poorer manageability [74]. In the latter study it was suggested that bed-sharing was a response to infant behavior rather than the behavior being caused by bed-sharing.

After establishing bed-sharing behaviour at two months using questionnaires, Mileva-Seitz assessed infant attachment at 14 mo using a validated tool and found bed-sharing was associated with more secure attachment than solitary sleep [66].

Another study found that ethnicity influenced perceptions about whether or not waking was problematic, and that Turkish, Moroccan or Caribbean mothers were more influenced by cultural values about bed-sharing than were Dutch mothers whose bed-sharing practices were more reactive [76].

Other – allergy (asthma/wheezing), infection, cotinine, cortisol

Asthma/wheezing, infection. Two large-population-based, prospective, cohort studies, from Brazil [63] and the Netherlands [91], administered parental questionnaires about bed-sharing and infant infections [63] and later childhood respiratory illness [91] (Table S6).

No association was shown between bed-sharing in infancy and subsequent wheezing or asthma [91] nor a higher risk of hospitalisation for pneumonia, provided the infant was breastfed. Breastfeeding gave nearly twice the protection of non-breastfeeding [63]. There was no significant association between bed-sharing and hospitalisation for diarrhoea after allowing for confounders [63].

Smoking/cotinine. A UK study [59] involving 104 infants, aged 10–12 wk where 70% parents smoked and 11% bed-shared found that bed-sharing compared to solitary-sleeping increased infant smoke exposure as measured by infant urinary cotinine (Table S6).

Cortisol. Three studies reported cortisol reactivity [54–56]. Participants were recruited from larger prospective longitudinal studies in the Netherlands [55,56] and the USA [54] (Table S6). Maternal infant-sleep-diary reports were matched with cortisol reactivity to a mild physical stressor (bathing session) at five weeks of age, and to a mild pain stressor (vaccination) at two months [56]. Bed-sharing was related to a lower cortisol response to the mild stressor at five weeks. No effects of bed-sharing were found on the cortisol response to the stressor at two months age [56]. Bed-sharing/room sharing was associated with an increased cortisol response to inoculations at six and 12 mo independent of more frequent night waking [54]. A fourth study reported that increased maternal emotional availability at bedtime and more maternal responses to infant distress, but less co-sleeping were linked to healthier cortisol patterning [57].

Discussion

Adult–infant bed-sharing is a polarising issue. Bed-sharing is often a valued cultural practice, part of a broader approach to parenting. It can also be a response to an unsettled infant, and decisions about it may be made under stressful circumstances. Health professionals have an important role in providing up-to-date evidence about advantages and risks to facilitate parental decisions. This knowledge may reduce anxiety for those who choose to bed-share, and decrease use of alternate strategies that might put the infant at increased risk, such as sleeping on a sofa with an infant [15].

This systematic review yielded 59 papers, representing 48 different cohorts. There was consistency of results across some studies, but the methodologies and definitions of bed-sharing were not consistent enough to combine any outcomes in a meta-analysis. One recommendation from this study is for better definitions of bed-sharing. For example, when investigating the impact of bed-sharing on physiology, a longer duration (as suggested by Burnham [58]) could be appropriate i.e., infant–mother bed-sharing for at least 4 h per night on at least five nights per week from birth to at least one month old.

Approximately half of the 59 studies collected data objectively and the other half subjectively. In the majority, bed-sharing variables were primary outcomes, but to ensure comprehensive reporting, data on bed-sharing were extracted from studies where this was not the prime focus. Some findings were derived from small numbers of participants who were part of a larger study.

Impact of study design

Overnight monitoring studies provided the most consistent definitions of bed-sharing in both laboratory and home, and those studies were the most comprehensive, reporting on a range of objective measures. Those of crossover design studied infants in both habitual location and a novel sleep arrangement. Studies that observed infants in their usual sleep location were open to more confounding (partly controlled for through analysis) e.g., infant age and season of study.

Self-reported data are arguably less reliable, and also influenced by cultural attitudes [61,76,92]. Where data were collected via maternal reporting [6,68,74,75,82], bed-sharing was associated with a significantly shorter total infant sleep time, but overnight monitoring showed either no difference [13,49,58,70] or increased total sleep time in specific sleep stages [11,39], compared to solitary-sleeping infants. Increased waking was problematic for some mothers [75] but not others [61]. There was only one paper that randomised infants to bed-sharing or another sleep location [49]. There are limited possibilities for further studies using this design, as parents often have strong views about infant sleep location.

Micro-environment and context

The bed-sharing micro-environment includes factors such as the adult bed, the number of people in the bed (adults and/or siblings), mother–infant proximity and interactions, and the thermal insulation and mobility of adult bedding. This systematic review shows that different sensory and physical micro-environments for cot-sleeping and bed-sharing lead to measurable physiological and behavioural differences, including differences in sleep architecture, infant arousals, infant overnight temperature control, cardiorespiratory responses, breastfeeding duration, sleep position, mother–infant interactions, and physiological responses to mild stress. It is not possible to determine definitively whether the physiological differences were clinically significant as apnea and oxygen desaturation occur in normal infants and definitions of what constitutes pathology in infants are not clear [93]. Values have not usually been presented in the research studies reviewed as indices of events per hour in each sleep state and so data cannot easily be compared with data derived from clinically directed infant polysomnography. However the fact that associations are in expected directions suggests that these changes represent normal homeostatic mechanisms in these infants.

Many differences are context-specific. Thus risk and benefit may sit more appropriately on a continuum as suggested by McKenna and McDade [94], dependent on the subjective view of the parents, and influenced by cultural values. Objective risk to an infant arises only if the infant is unable to mount an appropriate physiological or behavioural response to its micro-environment. In this scenario aspects of the bed-sharing environment may be seen as exogenous stressors and while physiological differences in low SUDI risk infants were small compared to solitary sleeping infants, these might be exacerbated in vulnerable infants during bed-sharing thus providing a mechanism for increased risk in hazardous circumstances [13] in line with the triple risk hypothesis related to SUDI [33].

Potential benefits

Breastfeeding and sleep position

Considerable evidence supports a significant positive relationship between bed-sharing and breastfeeding. The benefits include increased frequency of successful breastfeeds, increased attempts at breastfeeding, and longer total breastfeeding time during a given night, as well as later age of breastfeeding cessation. Mothers who strongly intend to breastfeed are more likely to bed-share and to breastfeed for longer [4]. Mothers report that close proximity facilitates breastfeeding [95]. Three papers reported no relationship between bed-sharing and breastfeeding [27,87,90]. This may have been related to different bed-sharing drivers within the specific populations. One study included Thai mothers for whom bed-sharing was the cultural norm, not necessarily associated with breastfeeding [90]. A USA study found that bed-sharing was associated with single marital status and moving accommodation since the birth of the infant, but not with breast-feeding [87]. The final study included a small number of bed-sharing infants and others sleeping in an in-bed device. SUDI risk factors were common in this group [27]. The relationship between bed-sharing and breastfeeding is complex. One study demonstrated the influences of maternal mood, socioeconomic status, ethnicity, parental stress, and parental depressive scores. Despite the increased risk of SUDI associated

with bed-sharing in some situations, it is clear that many mothers adopt bed-sharing for breastfeeding, despite no public education campaigns promoting bed-sharing for this purpose [4]. The interdependent relationship between bed-sharing and breastfeeding has led McKenna and Gettler to suggest the term “breastsleeping” to emphasise this relationship [96].

Without guidelines on “safe” bed-sharing for breastfeeding, families may engage in higher risk behaviours, such as feeding and sleeping on a sofa [15]. There is a need to develop broader guidelines. In-bed sleep devices have been promoted as a means of maintaining mother–baby proximity while providing a separate sleep place for the infant, particularly for infants identified at increased risk of SUDI. A New Zealand study showed that use of a culturally-derived in-bed device, the wahakura, was associated with increased full breastfeeding at 6 mo, compared to bassinet sleeping [27].

Sleep position during bed-sharing – side [13,27,42,48], supine [43,44], commonly facing the mother, and in close proximity – likely facilitates breastfeeding and mother–infant interactions. It is not clear if side-sleeping during bed-sharing poses the same risk as it does during cot-sleeping, when the infant may roll to prone. Disappointingly few studies reported on the infant's orientation in relation to the mother, although this is important to understand the infant's micro-environment. The impact of the mother's presence is also not clear, although the possibility of rolling to prone may be reduced by the positioning of the mother relative to the infant [48,97].

Prone sleep, while rare, has been observed, with infant on mother's chest [97]. It is not clear if this poses the same risk as prone cot-sleeping. Further to this, campaigns to discourage prone positioning would likely have less impact among bed-sharers, due to their infrequent prone sleep. This potentially explains the subsequent proportional rise of SIDS during bed-sharing. There are few observational studies of the impact of bed-sharing with other adults or siblings [48,97]. In one study, the mother most commonly slept between the father or siblings and the infant, maintaining the close mother–infant proximity. Other bed-sharers could distract the attention of the mother and bed size may be a consideration [97]. However, most research on infant sleep position in relation to SUDI has been on cot-sleeping infants. Given the different micro-environment during bed-sharing, research on the impact of sleep position, and the presence of bed partners, is warranted.

Arousals

Maternal-reported data and overnight studies show increased frequency of transient sleep arousals or awakenings significantly associated with bed-sharing [6,40,43,46,74–76,80,82,83]. A growing body of knowledge links sleep disruption to a range of impairments in children and adults. However, waking to feed is a feature of newborn life and breastfeeding infants tend to wake more frequently than bottle-fed infants [48]. Bed-sharing infants have more frequent but shorter arousals than cot-sleepers [13]. Parental views on whether this constitutes a sleep problem vary widely. This has not been well addressed in the literature. Studies show that infant sleep disturbance adversely influences parental mood and parenting emotional engagement at bedtime and that emotional engagement, in turn, influences infant sleep [98]. If infants feel more secure they are more likely to sleep [98]. Increased maternal responses to infant stress are also linked to healthier cortisol patterning [57]. Some evidence indicates that bed-sharing is associated with more secure attachment [66]. One study, however, suggests longer bed-sharing is associated with a less healthy cortisol pattern [57]. We suggest more research is necessary on the impact of bed-sharing on infant security/attachment and infant sleep, and that researchers include more diverse populations as most studies have included mainly Caucasian populations.

Sleep architecture

Bed-sharing infants experience less quiet sleep [11] and arouse more frequently despite being in a warmer environment [40,46]. This finding seems inconsistent with the increase in auditory arousal threshold shown in cot-sleeping infants in higher ambient temperatures [99]. This again suggests that extrapolating findings from cot-sleeping to bed-sharing infants may be inappropriate, as each environment has unique sensory and behavioural characteristics. The interactions of a bed-sharing mother and baby may represent a more complex dynamic than that observed in solitary infant sleep. Decreased quiet sleep and increased arousability have been suggested as protective of SIDS [43]. The bed-sharing mother–baby dyad is also characterised by increased sleep synchrony. The implications of this are not clear. Sleeping close to adults (same room or same bed) can influence infant circadian rhythms and peak temperature acrophase, suggestive of entrainment to the social day–night pattern [52]. This requires further study.

Stress responses

Mother–infant proximity (room-sharing or bed-sharing), particularly in the early months, may influence the hypothalamic–pituitary axis development, and modulate the stress response as measured by cortisol reactivity [54–56]. More research in this area is needed.

Mother–infant proximity during bed-sharing has also been the focus of investigations into allergy development and transmission of infection. Studies to date do not suggest bed-sharing increases development of childhood respiratory allergic responses or facilitates transmission of infections when the baby is also breastfed. This latter finding from Brazil, was particularly important, as bed-sharing is common (46%).

Potentially hazardous conditions during bed-sharing

Evidence suggests that the bed-sharing infant's safety is reliant on both mother and infant being responsive to subtle cues during the night. This may explain the increased risk when a mother's responses are impaired by alcohol or overtiredness, or when the infant is impaired through infection or exposure to smoking in-utero.

Bed-sharing is a more dynamic environment than sleeping in a cot. The mobility of bedding during adult movement exposes the infant to the risk of head covering. This is associated with increased rebreathing of air with higher levels of CO_2 and lower levels of oxygen. It also potentially reduces the infant's ability to lose heat.

Head covering

Head covering is identified as increasing the risk of SUDI and occurs more frequently during bed-sharing [41,42]. Most case–control studies have only collected data on head covering at the end of the final sleep which may be under-reported by parents as one study showed head covering and uncovering occurred during the night with few infants' heads covered at final waking [97].

Rebreathing was markedly more common among bed-sharing infants (55%) compared to cot-sleeping infants (2%) [41]. Oxygen desaturation was not associated with these rebreathe events, and infant responses included increased ventilation, or removing themselves from the rebreathe situation, sometimes prompting maternal action. Head covering events did not all result in accumulation of CO_2. This may have been due to air channels between the bedding and the infant's face, unable to be identified from the videoed evidence [100]. Infants often remained head covered for extended periods of time (up to 59 min) and maintained oxygen saturation. It is suggested that normal homeostatic respiratory responses to the rebreathe environment protected these infants. Mothers also spontaneously removed bedding during head

covering events, indicating the importance of a responsive mother during bed-sharing [97]. An infant or mother with impaired arousal mechanisms may not be able to respond appropriately.

Infant temperature

Bed-sharing and cot-sleeping infants tend to experience different thermal environments. Peripheral temperatures were higher in bed-sharing infants [40], likely due to more thermal insulation from adult bedding [40,73] and reduced ability to lose heat from infant skin surfaces in contact with the mother [101]. Peripheral temperatures reflect the vasodilatory response to maintain core temperature in a warmer thermal environment. This increased peripheral temperature indicates that bed-sharing infants are likely in a thermolytic state to maintain core temperature [40]. Overnight temperature recordings identify increased rectal temperature with waking [102]. It may be that warmer temperatures during bed-sharing reflect the increased waking and feeding episodes with a further contribution from greater bedding insulation. The evidence suggests reducing adult bedding when bed-sharing, along with having face and hands exposed to enable effective heat loss, could reduce the infant thermoregulatory challenge. There is potential for more research in this area.

Later maturation of sleep temperature pattern is reported in groups at increased risk of SIDS, such as prone-sleeping or bottle-fed infants. Sharing a bed with an adult, and being of Asian ethnicity, are also associated with later development of an adult temperature pattern [51,103]. This can be influenced by minor illness: a smaller drop in rectal temperature at sleep onset occurs in the prodromal stage of infection [104]. The evidence suggests infants at low risk of SUDI are likely to maintain normal rectal temperature, but a combination of risk factors such as infection or in-utero smoke exposure may lead to an inadequate response and contribute to hyperthermia during bed-sharing.

Potential for hypoxia and exposure to maternal smoking

During bed-sharing the mobility of over-bedding due to the presence of adults has the potential to contribute to increased head covering and desaturation events, while maternal proximity may expose the infant to maternal expired air. Desaturation events, where oxygen saturation (SaO_2) dropped below 90%, were twice as common in bed-sharing infants compared to cot-sleepers. This was mainly associated with the increased in-bed temperature and thus increased central apnea in the bed-sharing infants. In both groups, desaturation was not associated with bradycardia, and decreases to below 80% were rare [41]. The impact of increased desaturation events related to central apnea and periodic breathing in normal infants is not clear but neither central apnea nor periodic breathing are observed more frequently in future SIDS victims [105]. Animal studies show that repeated hypoxic events blunt arousal responses [106]. Frequent desaturations in vulnerable infants could be a contributory factor for SIDS risk associated with bed-sharing. Reducing the bed-sharing thermal environment may reduce these mild hypoxic events.

Infant–parent proximity leads to infant exposure to maternal expired air containing elevated CO_2 which may maintain a stimulus to infant breathing [107], but may be problematic if the mother is currently a smoker. A UK study [59] that included small numbers of bed-sharing infants demonstrated increased urinary cotinine of bed-sharers compared to cot-sleepers when one parent was a smoker. Further research in this area would be valuable in understanding the mechanism of this risk.

Night waking

Infants wake more frequently during bed-sharing. This is often linked to increased breast-feeding. Parent and research reports are varied as to whether or not this is problematic. Different approaches may be related to the infant's age. Newborns wake regularly during the night to feed [108]. As infants grow older, maternal tolerance of night waking may reduce [61]. Mosko et al. demonstrated that mothers of three-month-old infants had similar total sleep duration on bed-share and separate-sleeping nights [109]. However, bed-sharing has been criticised for over-involving parents and contributing to the infant sleep interruption. Bed-sharing was associated with more waking in nine-month-old infants, who exhibited more dysregulation and separation distress. It was not possible to identify whether bed-sharing was a direct cause of sleep disruption or if parents were bed-sharing to cope with a poorly-sleeping infant [74]. The biological drive to wake to breastfeed compared to sleep disruption experienced in different contexts requires greater investigation.

Implications

Given the large number of families that bed-share for some time on a regular basis [4] despite widespread advice in some countries not to bed-share, it is important to understand what motivates families to engage in this sleep arrangement. There is considerable research focused on the potential risks to the infant but some of this is extrapolated from a solitary sleep environment and not derived from research during bed-sharing. More understanding of the benefits and ways to provide a safe environment may be advantageous for families, but a clear understanding of the factors that create a hazardous environment is also needed to reduce unsafe bed-sharing. Ways of modifying bed-sharing, such as clip-on cots [49] or in-bed infant sleep devices [27,28] may provide effective alternatives in otherwise hazardous situations.

Future studies, with a clear definition of bed-sharing, are needed to collect objective data. Published physiological studies present consistent results from the hospital, home-like sleep laboratory and home settings. They identify measurable differences compared to solitary sleeping infants, suggesting different normative measures exist in the bed-share environment. These studies are predominantly describing low SUDI-risk infants which leaves us hypothesising about high-risk infant responses as, ethically, it is difficult to research this group. Investigations of bed-sharing among low-risk infants help to characterise bed-sharing as a beneficial activity. For those who have risk factors but still intend to bed-share, strategies are needed to provide options. Our recommendations for research build on these concepts.

Limitations

Included studies differed widely in regard to study design and outcomes, thus no meta-analysis was possible and a narrative synthesis of results was deemed appropriate as was also identified by Mileva-Seitz et al. [36] in their review. The lack of control groups in most studies and inadequacy of sample size led to further limitations in the evaluation of the quality of reviewed studies. However, studies involving overnight assessments and intense measurements make it difficult to study large numbers. The formal quality assessment conducted was limited by no validated tool being available for the study designs included. All well-validated quality assessment tools are intended to assess randomised controlled trials. To minimise publication bias, attempts were made to contact authors where information was missing or study overlap was unclear.

Conclusion

Bed-sharing studies report diverse measures and use variable definitions of the frequency and duration of bed-sharing. This

makes comparisons difficult. While the risks of bed-sharing are quantifiable, it is more challenging to quantify the benefits. Extrapolation of results from infants sleeping in a cot or bassinet does not take into account the dynamic environment of bed-sharing nor the presence of the mother or caregiver, and thus cannot be assumed to accurately represent the experience of the infant during bed-sharing. More studies in the bed-sharing environment are needed to differentiate between the experiences of lower and higher risk infants, although the latter poses many challenges.

Practice points

1. Bed-sharing is associated with increased breastfeeding and mother–baby interactions.
2. The increased head covering and the warmer environment during bed-sharing lead to protective physiological responses from the infant. Vulnerable infants may not respond effectively.
3. Keeping infant heads clear of over-bedding should reduce the incidence of rebreathing and expose the face for cooling. Reducing the thickness of adult over-bedding could reduce the need for infants to lose heat.
4. The importance of an unimpaired mother and a responsive healthy infant is emphasised.
5. Bed-sharing following maternal smoking in pregnancy or when alcohol or drugs have been consumed on the bed-sharing night could influence the ability of the mother or infant to respond and should be avoided completely as should bed-sharing on unsafe sleep surfaces such as sofas.

Research agenda

1. Efforts to address the risks of SUDI associated with bed-sharing must recognise the differences in infant sleep environments, and that some differences are beneficial.
2. Clear definitions of bed-sharing need to be used in research. Room sharing with the infant in a separate bassinet/cot should not be included as bed-sharing.
3. Research is needed into bed-sharing practices in cultures where bed-sharing is common and SUDI risk is low.
4. Future studies could explore the impact of the thermal environment.
5. Innovative protocols are needed for studying physiological responses of infants at high SUDI risk, due to the acknowledged risks of bed-sharing for these infants.
6. Further exploration of the benefits of bed-sharing in the absence of hazardous environments would be helpful to support those who wish to bed-share.
7. Further study of in-bed and clip-on devices is needed as alternatives to bed-sharing for infants at increased risk.

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Contributors' statements

Professor Sally Baddock participated in the design and coordination of the study, conception of data analysis, led the drafting of the manuscript, and approved the final manuscript as submitted.

Dr Melissa Purnell participated in design and coordination of the study, conception of data analysis, helped draft the manuscript, and approved the final manuscript as submitted.

Professors Elder and Blair and Dr Pease completed quality assessment of papers and approved the final manuscript as submitted.

Research Associate Professor Galland participated in the conception and design of the study, helped edit the manuscript, and approved the final manuscript as submitted.

Clinical trials registration

This is not registered as a clinical trial.

Conflicts of interest

The authors do not have any conflicts of interest to disclose.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.smrv.2018.10.007.

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