Temas em Saúde
Volume 17, Número 2
ISSN 2447-2131
João Pessoa, 2017

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# INFLUENCE OF FOOD INTAKE ON SLEEP IN HUMANS: A NARRATIVE REVIEW[1]

# INFLUÊNCIA DA INGESTÃO ALIMENTAR SOBRE O SONO EM HUMANOS: UMA REVISÃO NARRATIVA

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**ABSTRACT –** The complexity of sleep function and its association with other physiological processes are still not clear in the literature and there is an increased interest in understanding it. Considering the negative consequences caused by the disruption in sleep pattern, strategies which aim to empower sleep quality, such as diet, should be studied and promoted. Until this moment, there is much discussion about the effects caused by a reduction in sleep time on metabolism and food intake, however, there is a lack of studies that have attempted to review the information about the influence of food intake on sleep. Therefore, this review aims to summarize some of the findings relating nutrition strategies and sleep. Results regarding macronutrients suggest that fat-rich diets may reduce sleep time, high-protein meals seem to improve alertness, while carbohydrate intake is associated with improvement in sleepiness. More studies evaluating the types of carbohydrate are necessary, but the literature suggests that the ingestion of high-GI carbohydrate foods is associated with a lower sleep latency. Regarding micronutrients, folate, vitamin B12, B6, D, C, A and E have been associated with sleep parameters. Other foods like banana, walnuts, tart cherry juice, cow's milk, rich-tryptophan and high-carbohydrate foods seem to positively

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[1] This work had financial support of Fundação de Amparo à Pesquisa do Estado de São Paulo – FAPESP (2014/665.000) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES. There is no conflict of interest.
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affect melatonin levels, which may enhance sleep quality. The relationship between diet and sleep is very complex, and further investigations are necessary for its understanding.

**RESUMO** – A complexidade da função do sono e sua associação com outros processos fisiológicos ainda não são claras na literatura, e há um grande interesse em compreendê-la. Considerando as consequências negativas causadas pelos distúrbios no padrão de sono, estratégias que visam otimizar a qualidade do sono, como a alimentação, devem ser mais estudadas e promovidas. Até o momento, há ampla discussão sobre os efeitos causados por uma redução no tempo de sono sobre o metabolismo e ingestão de alimentos, no entanto, há falta de estudos que tentaram avaliar a influência do consumo alimentar sobre o sono. Dito isto, esta revisão tem como objetivo resumir alguns dos achados que relacionam as estratégias nutricionais e sono. Resultados referentes aos macronutrientes sugerem que dietas ricas em gordura podem reduzir o tempo de sono, que refeições ricas em proteínas parecem melhorar o estado de alerta, enquanto que a ingestão de carboidratos parece estar associada ao aumento da sonolência. São necessários mais estudos que avaliem o efeito dos diferentes tipos de carboidratos, mas a literatura sugere que a ingestão de alimentos ricos em carboidratos de alto índice glicêmico está associada à menor latência do sono. Quanto aos micronutrientes, a ingestão de folato, vitamina B12, B6, D, C, A e E foram associados à parâmetros do sono. Outros alimentos como banana, nozes, suco de cereja, leite de vaca, e alimentos ricos em triptofano e em carboidrato parecem aumentar os níveis de melatonina, a qual pode melhorar a qualidade do sono. A relação entre alimentação e sono é muito complexa, e novas pesquisas são necessárias para sua compreensão.

## INTRODUCTION

Sleep is a state inherent to human life and has been attracting the interest from researchers of different areas. The study of sleep is still recent and of complex understanding (PORKKA-HEISKANEN; ZITTING; WIGREN, 2013). Although humans spend on average about a third of their life asleep, the reasons that explain this vital need are still not clear in the literature (PORKKA-HEISKANEN; ZITTING; WIGREN, 2013; COLTEN; ALTEVOGT, 2006).

Sleep is composed of two physiologically different states, the rapid-eye-movement sleep (REM) and non-rapid-eye-movement sleep (NREM), which alternate cyclically during sleep (CARSKADON; DEMENT, 2011). The optimum sleep is characterized by the cyclical variation of the two states, and the sleep-wake cycle is considered a circadian rhythm, or a biological activity rhythm that occurs in a cycle

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of approximately 24 hours (PORKKA-HEISKANEN; ZITTING; WIGREN, 2013). The circadian rhythms are controlled by the central nervous system, under the influence of social and environmental factors (PORKKA-HEISKANEN; ZITTING; WIGREN, 2013; CARSKADON; DEMENT, 2011; GEIB et al., 2003), and variations in age, body and environment temperature, ambient light, available resources (e.g. food), and associated pathologies can directly interfere with its pattern (CARSKADON; DEMENT, 2011) and interfere with the circadian regulation.

Disruption in sleep pattern can lead to metabolic consequences directly related to nutrition issues. It is known that sleep deprivation can lead to an increase in appetite and consequent weight gain (MARKWALD et al., 2013), increased risk of cardiovascular disease (KRONHOLM E et al., 2011), changes in glucose metabolism, with decreased insulin sensitivity and a consequent impaired glucose tolerance, increasing the risk of diabetes mellitus (NEDELTCHEVA; SCHEER, 2014). Furthermore, it can negatively affect attention, memory and decision time (LIM; DINGES, 2010).

Therefore, strategies which aim to empower sleep quality should be further studied and promoted, among them, physical exercise (VEQAR; EJAZHUSSAIN, 2012), medicines (FERRACIOLI-ODA; QAWASMI; BLOCH, 2013), meditation strategies (NAGENDRA; MARUTHAI; KUTTY, 2012), and sleep hygiene practices. Diet has also been pointed out as a possible tool which positively affect sleep (HALSON, 2014; PEUHKURI; SIHVOLA; KORPELA, 2012). There is much discussion about the effects of the sleep deprivation on metabolism; however, there is a lack of studies that have attempted to review the information about the influence of food intake on sleep. This manuscript summarizes some of the findings relating nutrition strategies and sleep.

## METHODS

A review of the literature was conducted for articles published between 1959 and 2016 using as database PubMed, Google Scholar, and Scielo, which examined the relationship between food intake and sleep pattern. The primary search was performed using the following keywords : “nutrition”, “food”, “food restriction”, “diet”, “micronutrients”, “protein”, “carbohydrate”, “fat”, “energy”, “appetite”, “fruit” and “melatonin” combined with the terms “sleep”, “improve sleep”, “sleep duration” and “sleep quality”. Articles in English, Spanish and Portuguese, and conducted only with humans, were considered. In addition to the articles initially identified by the combination of keywords described above, a subsequent search was conducted and relevant references cited in these articles, were also considered, completing the final search, which will be described below.

The search yielded articles which involved sleep mechanisms and influence of dietary intake (energy, macro or micronutrient) on sleep. This category was further divided into studies featuring nutrient or food influence on sleep. In addition, we also present studies which investigated the amount of nutrients and other ingredients (especially melatonin and tryptophan), which may influence sleep.

## RESULTS

Since the 1970's, when the first studies began to investigate the interrelationship between nutrition and sleep, researchers wondered whether the observed associations of eating and sleep would be cause or consequence or if these two behaviors would be regulated by the same physiological mechanism (DANGUIR; NICOLAISIS, 1979). From this point forward, several studies have evaluated the influence of diet on sleep when macronutrients or specific ingredients are manipulated to yield an effect on sleep. Table 1 summarizes studies with humans which investigated the effect of foods and/or nutrients on sleep.

For some of these associations there is not enough evidence in the literature to affirm its positive effect, but some of the foods are commonly recommended and consumed to 'improve sleep' because of beliefs and cultural traditions in different countries (PEUHKURI; SIHVOLA; KORPELA, 2012). Although the association are not always strong, it seems that a poor sleep quality is associated with bad food habits (low consumption of vegetables, high consumption of confectionary, skipping breakfast and eating irregularly) (KATAGIRI, 2014), but to better understand the relationship of these eating habits with sleep, more studies are necessary.

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**Table 1.** Summary of studies evaluating the effects of foods and/or nutrients on sleep.

| Study, year (reference) | Sample characteristics | Study design | Nutrient(s) or food manipulation/investigation | Sleep measurement tools | Implications of the nutrient or food on sleep |
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| Brezinová and Oswald, 1972 (42) | Young and elderly adults, male and female (n=18) | Cross-over experimental | 250 ml of hot milk (with 32g of malt milk) or placebo capsule (claimed by researchers to be a "folk remedy of doubtful efficacy"), consumed right before sleep (2230 hr) for 10 non consecutive nights. | Eletroencephalography | Young volunteers had fewer body movements at the end of the night, while the older individuals had longer sleep time with less wakefulness with the milk |
| Phillips *et al.*, 1975 (28) | Adults, male (n=8) | Cross-over experimental | Four days of intervention, with 2-week of interval. On the first 2 days of both intervention, individuals ate a balanced diet (350g CHO, 140g LIP, 75g PTN), and in the next 2 days half consumed a high-CHO/low-LIP isocaloric diet (600g CHO, 33g LIP, 75g PTN), and half consumed a | Eletroencephalography | After high-CHO individuals presented less SWS sleep. After the ingestion of high or low-CHO diets, there was an increase in REM sleep than in balanced diet. |

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| | | | low-CHO/ high-LIP isocaloric diet (100g CHO of , 255g LIP, 75g PTN). | | |
| Porter and Horne, 1981 (44) | Adults, male (n=6) | Cross-over experimental | Three supplements: high-CHO (130g CHO, 8g PTN, 18g LIP), low CHO (47g CHO, 6g PTN, 21g LIP), zero CHO (only methyl cellulose), consumed 45 min before sleep, for 3 consecutive days, with 2 days of washout. | Eletroencephalography | After high-CHO supplement subjects had a reduction on the duration of the NREM stages and an increase in the REM sleep stage in the first half of the night. |
| Spring *et al.*, 1983 (35) | Adults, male and female (n=184) | Cross-sectional experimental | Four experimental groups, with two isocaloric diets. Two groups received a high PTN meal (57g PTN, 4g LIP and 1g CHO), but one at breakfast and other at lunch; and the two other groups consumed a high CHO diet (57g CHO, 0 PTN, 4g LIP), at breakfast or lunch, for one day. | Sleepiness scale | High CHO intake was related to a subsequent increased sleepiness for female. No difference was observed for men. |

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| Okawa *et al.*, 1990 (51) | Adults (male and female) with sleep-wake rhythm disorders (n=2) | Case study | Daily doses of vitamin B12 (1.5 mg) for a blind girl suffering from a free-running sleep-wake rhythm and for a man suffering from delayed sleep phase syndrome. | Sleep diary | Regarding the girl, sleep-wake rhythm was entrained to the environmental 24-h rhythm 5 days after the supplementation, but reappeared after 2 months without vitamin B12 consumption. In relation to man, his sleep-wake rhythm disorder was improved, although shortly. |
| Mayer *et al.*, 1996 (49) | Adults, male and female (n=20) | Cross-sectional experimental | Two types of vitamin B12: cyano (CB12) or methylcobalamin (MB12), consumed at 0700 hours in one dose of 3mg, for 14 days. | Actigraphy | The activated form (MB12) improved alertness and concentration during the day and reduced sleep time. |
| Driver *et al.*, 1999 (18) | Adults, male (n=7) | Cross-sectional experimental | Evening meal (2010 to 2100 h), varying from high (11.9 ± 0.9 MJ) to average (5.7 + 0.9 MJ) E and a 10-h fast (no evening meal), in one nonconsecutive night each. | Sleep diary and polysomnography | No significant differences in subjective or objective sleep measures. |

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| Markus *et al.*, 2005 (36) | Adults (male and female) with (n=14) or without (n=14) sleep complaints | Cross-over experimental | Two milk shakes consumed after isocaloric evening meals (13% PTN, 86% CHO, 1% LIP). The test milk shake contained 20g tryptophan-enriched (4.8 g/100g tryptophan) A-LAC protein and the placebo contained 20g (1.4 g/100g tryptophan) sodium caseinate. | Eletroencephalograp hy | The A-LAC enriched meal increased in 130% the ratio of plasma Tryptophan:LNAA and reduced sleepiness in the morning. No differences were observed between groups. |
| Afaghi *et al.*, 2007 (38) | Adults, male (n=12) | Cross-over experimental | Ingestion of two isocaloric CHO-rich meals (8% PTN, 1.6% LIP, 90.4% CHO) with low (GI=50) or high (GI=109) GI 4 hours before sleep. On another day, the high-GI meal was ingested 1h before bedtime. Each meal was consumed for one day, with one week of interval. | Polysomnography | The high GI meal reduced LAT and improved sleepiness, and the effect in LAT was greater when the ingestion was 4 hours before bedtime when compared with 1 hour before sleep. |

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| Shi *et al*., 2008 (25) | Adults, male and female (n=2828) | Cross-sectional epidemiological | E and MACRO intake (food record –Table of 3 consecutive days). | Sleep diary | Negative association between DUR and LIP intake, and positive correlation of DUR and CHO intake. |
| Weiss *et al.*, 2010 (24) | Adolescents, male and female (n=240) | Cross-sectional epidemiological | E and MACRO intake (24-hour recall of 5 to 7 consecutive days) | Actigraphy | Shorter sleep was correlated with lower CHO intake and with an average daily increase of LIP intake. |
| Grandner *et al.*, 2010 (26) | Adults, postmenopausal women (n=459) | Cross-sectional epidemiological | E, MACRO and MICRO intake (food frequency questionnaire of the last 3 months). | Actigraphy and sleep diary | Negative association between DUR and LIP consumption, specifically with trans-fat, mono, polyunsaturated and saturated fatty acids. Vitamin D intake was positively related with later sleep time. |
| Boelsma *et al.*, 2010 (34) | Adults, men (n=21) | Cross-over experimental | Two liquid breakfasts, with high PTN/low CHO (35% PTN, 35% CHO, 30% LIP) or low PTN/high CHO (10% PTN, 60% | Sleepiness scale | PTN-rich meals resulted in a lower sleepiness after 20 and 240 min of meal consumption in comparison to CHO-rich meals, which |

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| | | | CHO, 30% LIP) for one day each, with one week of washout. | | increased sleepiness after 150 minutes of the meal. |
| Pigeon *et al.*, 2010 (72) | Elderly adults, male and female (n=43) | Cross-over experimental | Ingestion of tart cherry juice (TC) or a placebo beverage two 8-ounce servings/day (one in the morning, 8–10 a.m., and one 1–2 hours before bedtime) for 2 weeks, with 2-week of washout. | Sleep diary | After TC, participants improved all sleep parameters (sleep onset, WASO, DUR, EFIC) compared to pre-treatment, but compared to placebo, there was just a reduction in insomnia severity (WASO). |
| Garrido *et al.*, 2010 (73) | Middle-aged (n=6) and elderly adults (n=6) | Cross-sectional experimental | Ingestion of 200g dessserts twice/day (after lunch and dinner) of 7 different cultivars of whole cherries (*Prunus avium L.*), for 3 days of each cultivar, with 1 week of washout. | Actigraphy | After consumption of all cherry cultivars urinary 6-sulfatoxymelatonin level and the actual sleep time were improved. The other sleep parameters were affected depending on cultivar and age group. |

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| Crispim *et al.*, 2011 (19) | Adults, male and female (n=52) | Cross-sectional observacional | E and MACRO intake, according to the time of consumption (food diary of 3 non-consecutive days) | Polysomnography | Negative relationship between nocturnal LIP intake and the LAT in men; correlation of EFIC, LAT, REM latency, stage 2 sleep, REM sleep, and WASO with percentage of nocturnal LIP intake in women. The percentage of nocturnal E intake was associated EFIC and latency in women. |
| Howatson *et al.*, 2011 (40) | Adults, male and female (n=20) | Cross-over experimental | Two servings (30 min after wakening and 30 min after evening meal) with 30mL of concentrate tart cherry juice (42.6ug, for dose or 85.2ug per day) for seven consecutive days, with 14 days of washout. | Actigraphy and sleep diary | Tart cherry juice elevated total MEL content and improved sleep time and sleep efficiency. |
| Lin *et al.*, 2011 (56) | Adults, male and female (n=24) | Cross-over experimental | Consumption of 2 kiwifruits 1 hour before bedtime, for four weeks, with 3 days of washout for control situation. | Actigraphy and sleep diary | Kiwifruit intake was associated with a decrease in WASO, LAT and sleep quality index, and associated with improving total sleep time and EFIC. |

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| Santana *et al*., 2012 (20) | Obese elderly, male and female (n=58) | Cross-sectional observacional | E, MACRO and MICRO intake of one habitual day (Usual Dietary Recall) | Sleep diary | Negative association between DUR and monounsaturated fatty acids (only in men), PTN, cholesterol dietary intake and daily E intake. |
| Lindseth *et al*., 2013 (33) | Adults, male and female (n=44) | Cross-over experimental | Four types of diets: PTN-rich (56% PTN, 22% CHO, 22% LIP), CHO-rich (56% CHO, 22% PTN, 22% LIP), LIP-rich (56% LIP, 22% CHO, and 22% PTN), or a control diet (50% CHO, 35% LIP, 15% PTN) for four consecutive days each, with a 2-week interval. | Actigraphy | After a PTN-rich diet the number of wake episodes during sleep was reduced. There was a reduction in LAT after the consumption of a CHO-rich diet. |
| Grandner *et al*., 2013 (52) | Adults, male and female (n=5587) | Cross-sectional epidemiological | E, MACRO and MICRO, antioxidant intake (24-hour recall) | Sleep diary | Normal DUR (7-8 hours) was associated with the greatest food variety. Very short (<5h) and long (≥9h) sleepers had the lowest total energy intake, and short (5–6h) sleepers the highest. Very short sleepers had the lowest PTN and CHO intake. There was association of DUR and |

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| | | | | | vitamin C, theobromine, lutein + zeaxanthin, choline, lycopene, selenium, alcohol and dodecanoic acid consumption. |
| Garrido *et al*., 2013 (74) | Young, middle and elderly adults, male and female (n=30) | Cross-over experimental | Ingestion of Jerte Valley cherry–JVC (18.85 g of pitted, freeze-dried cherries of 4 cultivars, equivalent to 141g fresh cherries) or placebo, twice/day (lunch and dinner desserts). | Actigraphy | After JVC, EFIC, LAT, number of awakening, total nocturnal activity, assumed sleep, actual sleep time and immobility were improved, as well as urinary 6-sulfatoxymelatonin. Better results were obtained with advancing age. |
| Yoneyama *et al*., 2014 (47) | Adults, male and female (n=1848) | Cross-sectional epidemiological | E, MACRO and MICRO intake (diet history questionnaire of the past month) | Subjective questionnaire (Pittsburgh Sleep Quality Index) | A high GI CHO-diet was associated with a better quality of sleep. |
| Grandner *et al*., 2014 (63) | Adults, male and female (n=4548) | Cross-sectional epidemiological | E, MACRO and MICRO and antioxidant intake (24-hour recall) | Sleep diary | Difficulty falling asleep had a negative correlation with alpha-carotene, selenium, dodecanoic acid, calcium, and positively associated with hexadecanoic acid. Difficulty in |

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| | | | | | maintaining sleep was positively correlated with salt use and negatively with<br><br>butanoic acid, carbohydrate, dodecanoic acid, vitamin D, and lycopene. |
| Hansen *et al.*, 2014 (62) | Adults, male, forensic patients (n=95) | Cross-sectional experimental | Fish group (FG) received 300g of Atlantic salmon (13.5 FAT, 20.3g PTN, 5 µg Vitamin D, 1.6 g of EPA+DHA per 100g), 3 times/week, and the Control group (C) received an alternative meal (chicken, pork, or beef) with the same nutritional value as their habitual diet, 3 times/week during 6 months. | Actigraphy and sleep diary | LAT increased from pre to post-test in C. Vitamin D status (VDS) was closer to optimal level in FG. VDS was negatively correlated with actual wake time and positively with EFIC during pre-test. In post-test, there was a positive association of VDS with daily functioning and sleep quality. |
| Killer *et al.*, 2015 (22) | Highly-trained cyclists, male (n=13) | Cross-over experimental | High CHO (24g before, 60g during, 30g after and 14g of CHO + 17g PTN in recovery of training session) or moderate (CON: 2g before, 20g during, 10g after | Actigraphy | Lower sleep time in High CHO than CON throughout intensified training. |

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| | | | and 1g cellulose in recovery of training session) CHO manipulation for 9 days, separated by 10-day washout period. There was a consequent increase in energy and protein intake in High CHO. | | |
| Rodrigues, 2015 (46) | Adult paralympic athletes, male and female (n=18) | Cross-sectional observational | E, MACRO and MICRO intake, GI (24-hour recall) | Qualidade subjetiva de sono e a sonolência | Daily CHO intake was negatively associated with subjective sleep quality and positively correlated with EFIC |
| Daniel, 2016 (21) | Adult athletes, male (n=9) | Cross-over experimental | CHO-rich evening meals (dinner and evening snack) with high or low GI consumed in a night before a basketball game, for two consecutive days (in a competition). Evaluation of the daily E and MACRO intake. | Sleep diary and actigraphy | No difference on sleep parameters between the two GI conditions. Correlation between daily E intake and WASO, and a negative association with EFIC and DUR. In the high GI condition, there was a negative correlation between daily PTN intake and positive correlation of CHO intake with daytime sleepiness before sleep and |

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| | | | | | after waking up. In low GI condition, the daily CHO intake was negatively correlated with EFIC and MEL secretion before sleep, and positively correlated with WASO and sleepiness after dinner. |
| Cao et al., 2016 (29) | Adults, male and female (n=1474) | Longitudinal observational | Meal, E, MACRO and MICRO intake (3-day weighed food records), analyzed at 2 moments (baseline-2002 and follow-up-2007). | Sleep diary | Positive association between dinner fat intake and short DUR at baseline; negative association of fat intake in breakfast at baseline and daily sleepiness at follow-up. |

E= energy; MACRO=macronutrient; MICRO=micronutrient; CHO=carbohydrate; PTN=protein; LIP=lipid; DUR=sleep duration; LAT=sleep latency; EFIC=sleep efficiency; MEL=melatonin; WASO=Wake after sleep onset; SWS=slow-wave sleep; REM=rapid-eye-movement; LNAA= Large neutral amino acids; OSA= obstructive sleep apnea; GI=glycemic index.

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## Energy Intake

A literature review (PEUHKURI; SIHVOLA; KORPELA, 2012) suggests that energy restriction can reduce melatonin secretion. The relationship between this hormone and sleep is described below, but it is possible to infer that melatonin is able to increase sleep propensity (CAJOCHEN; KRÄUCHI; WIRZ-JUSTICE, 2003; SOUZA NETO; CASTRO, 2008), so its reduction can negatively interfere on sleep.

Driver et al. (1999) observed that the intake of different amounts of energy (see Table 1) did not alter sleep; however, other study (CRISPIM et al., 2011) noted that nocturnal energy intake had a positive correlation with sleep latency (time that the individual takes to fall asleep after going to bed) and negative association with sleep efficiency, suggesting that the higher energy intake close to sleep time, the worse was sleep quality. Total daily energy intake has also been negatively correlated to total sleep time (SANTANA et al., 2012).

A study with athletes' found a correlation between daily energy intake and wake after sleep onset (WASO) and a negative association with sleep efficiency and sleep duration (DANIEL, 2016). Killer et al. (2015) conducted another study with athletes and observed that the increased carbohydrate intake resulted in a reduced total sleep time. However, it is emphasized that these findings can be related not only to the intake of carbohydrate-rich drinks, but also by the increase in energy and protein intake, considering that the authors did not adjust the energy consumption in the control group (not isocaloric conditions) (KILLER et al., 2015).

Studies that evaluate the influence of different energy intakes on sleep parameters in human are scarce. Further research, with controlled and balanced macronutrients intake, is necessary for the understanding of this relationship.

## Macronutrients

The association between dietary intake and sleep generated an interest in understanding which was the best meal composition and moment of ingestion to induce a greater influence on sleep (GARCÍA-GARCÍA; DRUCKER-COLÍN, 2001). Since then, research has emerged on specific manipulation of macronutrients, which evaluated the effect of consumption of meals rich in carbohydrate, protein or lipid on the duration and quality of sleep.

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**Fat**

The ingestion of fat-rich diets has been associated with shorter sleep time, either in adolescents (WEISS et al., 2010), adults (SHI et al., 2008), elderly (SANTANA et al., 2012), and specific groups, such as postmenopausal women (GRANDNER et al., 2010). Considering that the contemporary society is increasingly reducing sleep time, sleep deprivation is a factor, which, although often overlooked, could be directly involved in the worldwide obesity epidemic (SPIEGEL et al., 2009).

Furthermore, the timing of intake seems to matter. When fat-rich meals are consumed close to the time of sleep there is a negative correlation with sleep efficiency and REM sleep, while a positive association with sleep latency, REM sleep latency, N2 sleep, and WASO (CRISPIM et al., 2011). In contrast, Phillips et al. (1975) observed that individuals who consumed a fat-rich and low-carbohydrate diet improved REM sleep in comparison to a balanced diet. According to the authors, a hypothesis to explain this result is that an increase in fat consumption could improve the amount of plasma free fatty acids, increasing the availability of plasma tryptophan, which could influence on REM sleep (PHILLIPS et al., 1975).

Santana et al. (2012) observed that the ingestion of dietary cholesterol was correlated to a shorter sleep time. The authors also noted a negative correlation between sleep duration and the intake of monounsaturated fatty acids, although only in men (SANTANA et al., 2012). Sleep duration was also negatively associated with fat consumption in postmenopausal women, specifically with trans-fat, mono, polyunsaturated and saturated fatty acids intake (GRANDNER et al., 2010), and positively associated with dinner fat intake in health adults (CAO et al., 2016).

Although the physiological explanation for these associations are still unclear, two possible hypothesis are that polyunsaturated fatty acids are important for the production of prostaglandin $D_2$ (LINDSETH; MURRAY; HELLAND, 2015), which is directly involved in sleep regulation (HUANG; URADE; HAYAISHI, 2007; URADE; HAYAISHI, 2011), or that fat consumption alters circadian regulation, reducing induction of proteins involved in suprachiasmatic clock and the response to light (CAO et al., 2016).

**Protein**

A reduced number of arousals during sleep was observed after a protein-rich diet (LINDSETH; LINDSETH; THOMPSON, 2013), and the ingestion of protein-rich meals has also been associated with improved alertness (BOELSMA et al., 2010) and reduction of sleepiness (SPRING et al., 1983), in comparison to carbohydrate rich meals. A study

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that controlled the glycemic index (GI) of carbohydrate-rich evening meals showed that in the high GI condition, there was a negative correlation between daily protein intake and daytime sleepiness, both before sleep and after waking up (DANIEL, 2016). This result suggests that the timing of nutrient consumption is important to be considered when manipulating the diet in other to avoid (e.g. when aiming to improve sleep) or stimulate (e.g. in case of nocturnal workers) alertness.

Aiming to assess the effect of different meals on sleep, Markus et al. (2005) tested if the ingestion of two evening meals rich in α-lactalbumin and enriched with tryptophan could influence alertness and cognitive performance after sleep. The authors noted that the test meal increased the ratio of plasma Tryptophan:LNAA (Large Neutral Amino Acid) and significantly reduced sleepiness in the morning, in comparison to control meals (MARKUS et al., 2005).

Tryptophan is an essential amino acid which effects on sleep have been associated with its role as a substrate to serotonin and melatonin synthesis (LINDSETH; MURRAY; HELLAND, 2015), so its amount may play an important role in protein manipulations. High-protein diets or meals offers a greater amount of amino acids, especially LNAA (tyrosine, valine, isoleucine and leucine), compromising the tryptophan transport through the blood-brain barrier, as those amino acids compete for the same transporters. When an amino acids-rich meal is consumed, the plasma ratio of Tryptophan:LNAA is reduced, decreasing the uptake of tryptophan and consequently the production of serotonin and melatonin (WURTMAN et al., 2003). In an opposite situation, with high plasma ratio of Tryptophan:LNAA, the available tryptophan crosses the blood-brain barrier and is converted into serotonin, and subsequently into melatonin. Therefore, diets high in this amino acid seem to increase the secretion of melatonin (WURTMAN et al., 2003; AFAGHI; O'CONNOR; CHOW, 2007), and are related to better sleep quality (FERRACIOLI-ODA; QAWASMI; BLOCH, 2013; BRZEZINSKI et al., 2005; HOWATSON et al., 2011).

By comparing the effect of different diets on the amount of LNAA in plasma, Berry et al. (1991) reported that carbohydrate-rich meals reduced LNAA levels in plasma by 18%, while protein-rich meals increased LNAA concentration in plasma by 24%. In order to test whether this change in LNAA plasma levels also affected tryptophan plasma levels, Wurtman et al. (2003) observed that a carbohydrate-rich breakfast increased the tryptophan:LNAA plasma ratio after 80 minutes of the intake, while a protein-rich meal decreased the ratio of tryptophan:LNAA.

In the 1970's some researches associated sleep and cow milk (BREZINOVÁ; OSWALD, 1972) because of its content of tryptophan and melatonin (ASHER et al.,

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2015). In a study in which individuals consumed a hot malt-milk drink or a placebo capsule before sleep, the authors observed that after the milk ingestion the young volunteers had fewer body movements at the end of the night, while the older ones had longer sleep time with less wakefulness, compared with control nights (BREZINOVÁ; OSWALD, 1972).

**Carbohydrate**

Carbohydrate manipulation as a strategy for promoting sleep has been studied since the early 1980's, when Porter and Horne (1981) controlled the amount of carbohydrate of meals offered before sleep and analyzed its effects on sleep architecture. After the ingestion of a carbohydrate-rich meal subjects had a reduction on duration of the NREM stages and an increase in the REM stage in the first half of the night, meaning a change in the duration of the sleep phases (PORTER; HORNE, 1981). Other study (KRAUCHI et al., 2002) affirmed that this type of meal and the time that of ingestion (morning or evening) could directly influence the circadian cycle by modifying the pattern of heart rate and body temperature (KRAUCHI et al., 2002). The distribution of sleep stages was also altered by the consumption of carbohydrate-rich and low-lipid meals, with reduction in the NREM sleep and increase in the REM sleep (PHILLIPS et al., 1975).

In a retrospective study, Weiss et al. (2010) observed that a lower carbohydrate intake was associated with shorter sleep. The authors suggested that teenagers who slept less increased their intake of high fat foods, which could consequently reduce the proportion of carbohydrate intake (WEISS et al., 2010). This same negative relationship between carbohydrate and sleep time was also observed in a study in which athletes received a greater amount of carbohydrate before, during and after an intense cycling exercise session (KILLER et al., 2015). The authors suggested that the carbohydrate-supplemented athletes required shorter sleep time for recovery after intense exercise (KILLER et al., 2015). Rodrigues (2015) points out that the daily intake of carbohydrate was negatively associated with subjective sleep quality and positively correlated with sleep efficiency in para-athletes.

High-carbohydrate foods can also be positively associated with alertness. Some studies indicated that a higher intake of this macronutrient is related to a subsequent increased sleepiness in adults (BOELSMA et al., 2010; SPRING et al., 1983). In relation to different types of carbohydrate, a study showed that subjects presented more sleepiness after consuming a meal with high GI, in comparison a with low GI meal (AFAGHI; O'CONNOR; CHOW, 2007).

In order to better investigate the role of the GI of carbohydrate-rich foods in sleep, Afaghi et al. (2007) offered carbohydrate-rich meals with low or high GI four hours before sleep, and high GI meals were also consumed one hour before bedtime. It was observed that the high GI meal reduced volunteer's sleep latency, while this effect was greater when the ingestion was four hours before bedtime when compared with intake one hour before sleep (AFAGHI; O'CONNOR; CHOW, 2007). A similar investigation was conducted with athletes during a competition period. Daniel (2016) analyzed if the GI (high or low) of high-carbohydrate evening meals could influence sleep. No difference on sleep parameters was observed between the two GI conditions; however, daily carbohydrate ingestion was correlated with an increased daytime sleepiness before sleep and after awaking, and with a lower subjective sleep quality when high GI evening meals were consumed (DANIEL, 2016). Otherwise, with the ingestion of low GI evening meals, the daily carbohydrate intake was correlated with a worse sleep quality (lower sleep efficiency, higher WASO and lower melatonin secretion before sleep time) and with a greater sleepiness after dinner (DANIEL, 2016). The results suggest that more than the type (GI) of carbohydrate consumed before sleep, the nutrient intake throughout the day seems to exert a greater influence on sleep parameters (DANIEL, 2016).

It is expected that a carbohydrate-rich meals, especially those composed of high GI foods, will promote an increase in the proportion of tryptophan:BCAA (Branched Chain Amino Acids), through improved BCAA muscle uptake, resulting from an increase in insulin secretion in response to the ingested meal (WURTMAN et al., 2003). Studies have shown that high GI carbohydrate-diets are associated with a better quality of sleep (YONEYAMA et al., 2014). Although positive effects of this manipulation on sleep have been demonstrated, a retrospective study found an increase in sleep latency related with high GI dinner consumed by Paralympic athletes in a pre-competition period, suggesting a negative effect on sleep (RODRIGUES, 2015). Otherwise, Afaghi et al. (2007) noted a reduction in sleep latency after high GI carbohydrate-meals.

Although the literature suggests that carbohydrate intake could be associated with improvement in sleepiness, and with lower sleep latency, more studies are necessary to understand this association.

## Micronutrients

Some vitamins and minerals have also been investigated regarding their effects on sleep. The mechanisms involved to explain the associations between micronutrients and sleep are not yet completely understood; therefore more studies are necessary.

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ISSN 2447-2131
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B vitamins have been related to sleep, especially vitamin B6 (PARTINEN; WESTERMARCK; ATROSHI, 2014), B12 (MAYER; KRÖGER; MEIER-EWERT, 1996) and folic acid (KELLY, 1998). The therapeutic benefit of vitamin B12 on sleep has been highlighted by its positive influence on the endogenous sleep-wake cycle in circadian rhythm (OKAWA et al., 1990), by influencing melatonin secretion (MAYER; KRÖGER; MEIER-EWERT, 1996). Its activated form (methylcobalamin) seems to exert more influence on sleep than its cyanocobalamin form, and the consumption of 3 mg/day in the morning improved sleep, alertness and concentration during the day (MAYER; KRÖGER; MEIER-EWERT, 1996).

Folate, or folic acid deficiency, has been associated to insomnia, restless leg syndrome, and with very short (<5 hours of sleep) sleep duration (GRANDNER et al., 2013). Considering that its metabolism is related with vitamin B12's and that both vitamins play important functions in central nervous system regulation (CHANARIN et al., 1989), the combination of folate-B12 has been suggested as interesting in the treatment of sleep disorders (PARTINEN; WESTERMARCK; ATROSHI, 2014).

The folate content has been pointed out as one possible explanation for the positive influence of kiwifruit intake on sleep quality. Kiwifruit is rich in a variety of micronutrients, especially folate (MARTIN et al., 2010), contributing to the daily recommended intake to be achieved (SKINNER et al., 2011). Kiwifruit can have 36µg of folate (9% of the dietary requirements for men and women >13 years) in 100g of fruit (about 1.5 medium kiwifruit), and the seeds contain about 15% more folate than the pulp (MARTIN et al., 2010). By investigating its influence on sleep parameters, Lin et al. (2011) noted that kiwifruit intake was significantly associated with reduced WASO, sleep onset latency and sleep quality index, improving sleep quality. Other possible explanation to kiwifruit influence on sleep is that its content of serotonin and antioxidants, specially vitamin C and E (LIN et al., 2011), which are known to be positively associated with improvement in sleep disorders (SALES et al., 2013).

Vitamins C, A and E have an important role as nutrients with antioxidants functions. Obstructive Sleep Apnea Syndrome (OSA) has been associated with decreased levels of vitamin A, vitamin E (BARCELÓ et al., 2006) and vitamin C (SALES et al., 2013). Sales et al. (2013) (p.453) suggested that "an imbalance between antioxidants and pro-oxidants may contribute to neuropsychological alterations in OSA patients".

Another vitamin that has been studied is vitamin D, which activated form in human body is 1,25-dihydroxyvitamin D, or calcitriol (PARTINEN; WESTERMARCK; ATROSHI, 2014). The intake of this vitamin was negatively related with sleep maintenance (GRANDNER et al., 2013) and positively with bedtime (more vitamin D, later time to sleep) (GRANDNER et al., 2010). Vitamin D was also negatively related with daytime sleepiness (McCARTY et al., 2012), depressive disorders (MILANESCHI et al., 2013) and regulation of serotonin synthesis (PATRICK; AMES, 2014), all factors which could influence sleep.

A study that evaluated the effects of fatty fish consumption on sleep parameters attributed the positive effect of experimental group to vitamin D (HANSEN et al., 2014). The authors observed that individuals improved their daily functioning and sleep quality after fatty fish consumption, as well as they had higher vitamin D levels compared with control group (HANSEN et al., 2014). The literature is scarce and there is no information on the ideal daily intake to promote positive effects on sleep, but it seems that a low intake of vitamin D could impair sleep quality.

A study with a large sample found associations between several micronutrients and sleep parameters (GRANDNER et al., 2014). The authors found that difficulty in falling asleep was negatively associated with alpha-carotene, selenium and calcium ingestion (GRANDNER et al., 2014). Low daily intake of vitamin D and lycopene were correlated with greater difficulty in maintaining asleep, while calcium and vitamin C ingestion were negatively associated with non-restorative sleep (GRANDNER et al., 2014). Despite these data, more studies are necessary to understand the influence of specific micronutrients on sleep.

**Melatonin-rich foods**

Melatonin is the main hormone secreted by the pineal gland, an endocrine organ located between the cerebral hemispheres (CLAUSTRAT; BRUN; CHAZOT, 2005). It is a compound synthesized from circulating tryptophan, converted in serotonin, which is subsequently turned into melatonin (CLAUSTRAT; BRUN; CHAZOT, 2005) being its converting enzymes dependent of the circadian rhythm and controlled by the pineal gland (BERNARD et al., 1999). One of the factors that interfere on melatonin secretion is the light (DAWSON; ENCEL, 1993). A clear/dark information is transmitted by retina via retinohypothalamic tract to suprachiasmatic nucleus, and a cascade of reactions is activated until the information reaches the pineal gland, interfering on melatonin secretion (WEINERT, 2000).

Literature reviews have indicated that melatonin is able to increase sleep propensity (CAJOCHEN; KRÄUCHI; WIRZ-JUSTICE, 2003; SOUZA NETO; CASTRO, 2008; DAWSON; ENCEL, 1993). Its peak secretion starts in the early evening (WEINERT, 2000), and is related to a reduction in body temperature and increased sleepiness, resulting in what is called as "window of opportunity" for the onset of sleep (DAWSON; ENCEL, 1993). Studies have also shown that endogenous melatonin plays the function of promoting sleep onset and is involved in its maintenance, and suggest that melatonin is directly related to sleep regulation, but not to circadian clock modulation (GANDHI et al., 2015). Considering its effect of inducing sleep, the exogenous administration of melatonin via food or drugs has been studied in humans. Attempts to enhance its synthesis through food are based on the manipulation of tryptophan intake (HALSON, 2014) or consumption of melatonin-rich foods.

One of the fruits that has been most studied as a strategy to improve sleep is tart cherry. In addition to its antioxidant effects (KELLEY, 2013), its great melatonin content (BURKHARDT et al., 2001) has called attention of researchers. Pigeon et al. (2010) tested this fruit's possible effect on sleep and the authors verified that adults with moderate to severe insomnia who consumed tart cherry juice in the morning and at night showed reduction in WASO and in the Insomnia Severity Index (ISI). In comparison to the placebo group, no other sleep parameters changed, so the authors concluded that the drink played a modest influence of sleep (PIGEON et al., 2010). Aiming to verify if the cherry tart drink intake increased the endogenous melatonin levels, and if different types of cherry juice could differently affect sleep, Garrido et al. (2010) evaluated subjects that consumed cherry from different cultivars for two consecutive days. The results showed that all the seven tested cultivars led to significantly improved sleep time and urinary 6-sulfatoxymelatonin (aMT6-s) in the morning, both in middle-aged and in elderly volunteers (GARRIDO et al., 2010). Other studies have also found that tart cherry juice improved sleep time, emphasizing its usefulness in sleep disorders treatment (HOWATSON et al., 2011; GARRIDO et al., 2013). Only few studies described the exact amounts of cherry or melatonin concentration utilized. For instance, in a study in which volunteers consumed two servings of 30mL of concentrate juice (42,6ug/dose), it represented approximately 100 tart cherries each (HOWATSON et al., 2011).

Another fruit that has interested the melatonin experts is banana. Since the 1950's, researchers observed that banana was rich in serotonin (UDENFRIEND; LOVENBERG; SJOERDSM, 1959), which is subsequently converted into melatonin (CLAUSTRAT; BRUN; CHAZOT, 2005). Unfriend et al. (1959) observed that the major serotonin content of bananas (no variety described) was in the shell (50 to 150ug/g), while the pulp contained about one third (45ug/g) of the total amount. The authors also evaluated the effect of the ripening on the fruit, and observed that serotonin amount increased with the fruit ripening and that this increase is greater in the peel (inside or outside) (UDENFRIEND; LOVENBERG; SJOERDSM, 1959). Since then, other studies investigated the effect of ripening on the serotonin content in banana. The French plantain variety had its serotonin amount increased during ripening, which subsequently decreased from over ripening (FOY; PARRATT, 1960), while the ripening of the Musa *cavendishii* variety has a decreased serotonin concentration in the pulp and increased in the peel (VETTORAZZI, 1974). The Musa *acuminata* or M. *balbisiana* (prata banana) variety showed a gradual decrease in its serotonin concentrations after fourteen days of storage (ADÃO; GLÓRIA, 2005).

Although their knowledge on banana's serotonin and melatonin content, researchers wondered if the melatonin provided by the fruit could really promote an increase in serum melatonin. Sae-Teaw et al. (2013) evaluated the effect of the consumption of two peeled bananas in serum melatonin. The study showed that banana consumption could significantly increase melatonin serum concentration after 120 minutes, with a fourfold rise (SAE-TEA et al., 2013). Authors also observed that the consumption of orange and pineapple juice extracted from 1kg of the fruit, with one washout week between them, also increased melatonin concentration after 120 minutes of consumption (SAE-TEA et al., 2013).

Cow's milk is a beverage that is rich in tryptophan (BREZINOVÁ; OSWALD, 1972), and is also a melatonin source (ASHER et al., 2015; JOUAN et al., 2006; MILAGRES et al., 2014). The amount of melatonin found in bovine milk can vary according to the time that milk was milked or if the animal was exposed to light (ASHER et al., 2015). Melatonin concentration in the milk collected by day (1230 hours) was of approximately 5.4±0.3pg/ml, whereas the milk collected in the evening (0430 hours), without light, has 30.7±1.8pg/ml. When milk was milked at night, but in the presence of light, the melatonin concentration dropped to 17.8±0.3 pg/ml (ASHER et al., 2015).

Other fruits and vegetables, like tomatoes (UDENFRIEND; LOVENBERG; SJOERDSMA, 1959; VAN TASSEL et al., 2001), red plum, avocado (UDENFRIEND; LOVENBERG; SJOERDSM, 1959), olive oil (DE LA PUERTA et al., 2007) and grapes (MURCH et al., 2010; BOCCALANDRO et al., 2011) have also been pointed out like melatonin rich foods, but more researches are necessary to confirm if their melatonin content is also noted in individuals serum. The literature also indicates that carbohydrates-rich meals, especially with high GI, may increase the secretion of melatonin and consequently improve the quality of sleep (AFAGHI; O'CONNOR; CHOW, 2007).

## CONCLUSION

Table 2 summarizes the main highlights presented in this study, which are evidenced in the literature. It is known that the relationship between diet and sleep is very complex, and little is known about the interrelationship of these two parameters. Therefore, further investigations aiming to better understand the association of specific meals composition, timing of intake and amount of food are necessary to understand food influence on sleep.

**Table 2.** Main highlights related to the association of diet and sleep.

| SUMMARY |
| --- |
| • Nocturnal or daily energy intake seems to be negatively associated with sleep efficiency and sleep duration;<br>• High-protein meals seems to improve alertness;<br>• Carbohydrate intake is associated with improvement in sleepiness, and some studies suggest that the ingestion of high-GI carbohydrate foods is associated with a lower sleep latency;<br>• Some micronutrients, like folate, vitamin B12, B6, D, C, A and E have been associated with sleep parameters, and other nutrients like alpha carotene, selenium, calcium and lycopene need to be more investigated;<br>• Tart cherry juice, banana, walnuts, cow's milk, rich-tryptophan foods and high-carbohydrate foods are related with improved melatonin levels, which could enhance sleep quality. |

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Volume 17, Número 2
ISSN 2447-2131
João Pessoa, 2017

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