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Lifestyle and attention deficit/hyperactivity disorder | Review

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Abstract: Attention deficit/hyperactivity disorder (ADHD) is a frequent diagnosis in childhood and adolescence and the disorder may also be found in adulthood. The core symptoms of ADHD, inattention, impulsivity and hyperactivity, frequently cause significant impairment in behavioral, social, academic, and occupational functioning. Short-term symptomatic benefits of the commonly used treatments, such as pharmacotherapy and behavior management techniques, have consistently been shown in many individuals with ADHD. However, it is unclear whether or not the currently available treatments improve the outcome in individuals with ADHD over an extended time period, and little is known about long-term safety of the medications administered in ADHD. Extended use of stimulant medication in ADHD from childhood through adolescence is associated with suppression of growth and consequent reduction in adult height with no reduction in symptom severity. Long-term administration of methylphenidate may result in the development of tolerance to the neurotransmitter changes induced by medication, lessening the effectiveness of the drug. These findings regarding the long-term management of ADHD and the failure of a “magic bullet” strategy targeting well-defined biological alterations in ADHD call for alternative research approaches. A wide range of lifestyle factors have been proposed as potential precursors or consequences of ADHD. Various nutrients have been linked to brain development and functioning, and diet may be an important factor in psychiatric disorders including ADHD. The role of vitamins and minerals in the etiology and treatment of ADHD is unclear, and benefits may be confined to individuals with respective deficiencies. The efficacy of polyunsaturated fatty acid supplementation in ADHD seems to be negligible. Clear evidence supporting a role of single nutrients in the etiology and therapy of ADHD has not been produced, and the interrelationship between diet in general and other lifestyle factors may be of greater importance. Emerging evidence suggests that physical activity may be a protective factor in ADHD. While exercise may be a promising alternative or additional treatment option for individuals with ADHD, the currently available studies assessing the impact of physical activity on ADHD symptoms have several limitations. Large-scale, well-designed studies investigating the effects of physical exercise on ADHD should be conducted, since exercise may have additional health benefits regarding cardiovascular function and the prevention of noncommunicable diseases such as diabetes and obesity. The well-established relationship between ADHD and insomnia, and the small but significant association between media use and ADHD-related behaviors call for further investigations. In summary, the interaction of environmental, social and societal factors in ADHD needs to be addressed. The consideration of lifestyles may contribute to a more holistic and interactive understanding of ADHD. Lifestyle research in regard to etiology and treatment appears to be a promising approach to ADHD, and the conducting of such research independent of commercial interests will be a future challenge. Furthermore, lifestyles associated with ADHD should be considered in clinical practice.

Key words: Attention deficit/hyperactivity disorder; lifestyle; food; diet; physical activity; media use; sleep; circadian rhythm; ambient light.

1. Introduction

Attention deficit/hyperactivity disorder (ADHD) has become a common diagnosis in children and adolescents and the disorder may also be found in adults [1]. ADHD has been suggested by some to be a dimensional disorder, with symptoms considered as continuous traits across the general population [2]. A clinical diagnosis of ADHD is made above a certain threshold of symptom severity, in combination with significant dysfunction in daily life [3]. Mainstream treatments used in individuals with ADHD include pharmacotherapy, behavior therapy, and parent management training. These therapies have been shown to yield significant short-term symptom reduction in many individuals with ADHD. Short-term therapeutic effects of medications such as methylphenidate on the symptoms and behavioral problems of affected children and adults have been reported in many randomized controlled trials [4]. However, the extent of their efficacy remains a matter of debate [4,5].

The results of drug trials in ADHD assessing efficacy and safety over short time periods cannot be extrapolated to long-term outcomes. Randomized controlled trials assessing the long-term efficacy of ADHD medications such as psychostimulants and atomoxetine are largely absent [6]. Observational pharmaco-epidemiological studies comparing periods with patients on versus off ADHD medications have suggested potential long-term benefits of treatment [6]. However, it remains unclear whether or not the currently available treatments improve the outcome in individuals with ADHD over an extended time period [6].

Various adverse effects of psychostimulants have been described (e.g. sleep disturbances, growth reduction, cardiovascular problems, loss of appetite), although most are of a transient nature. Short-term use of stimulants appears to be relatively safe, but much less is known about the long-term safety of these drugs [7–10]. If individuals with ADHD require medication over years or even decades, possible adverse effects such as cardiovascular risks across the lifespan should be assessed. The relatively low incidence of such effects in young people is probably not predictive for elderly patients, and the long-term safety of ADHD medications remains an open question [6].

The results of a long-term observational continuation of the randomized controlled Multimodal Treatment Study indicate that children who received stimulant treatment for ADHD into adulthood may show a reduction in height as adults without experiencing any ongoing symptom reduction [11]. While the number of children with ADHD who consistently received treatment into adulthood was relatively small, the individuals who continued to take stimulants showed no benefit in regard to symptom severity compared to those who discontinued the treatment or who never received stimulant medication [11]. However, the average adult height of individuals who continued treatment was more than 2 cm shorter than in those who stopped receiving therapy [11]. Although the effects on height may not affect quality of life, other potential metabolic effects of ADHD medications should be investigated. Given the limited or absent long-term benefits of ADHD medications, the therapeutic value of these drugs may be outweighed by their risks.

Brain dopamine dysfunction in ADHD may explain why stimulant medications, which increase dopamine signaling, are therapeutically beneficial. However, while the acute increases in dopamine induced by stimulant medications have been associated with symptom improvement in ADHD, the chronic effects are less clear. Using positron emission tomography, dopamine transporter availability was measured in the brains of 18 never-medicated adult ADHD subjects before and after 12 months of treatment with methylphenidate and in 11 controls who were also examined at the beginning and end of a 12-month interval but without stimulant medication [12]. Twelve months of methylphenidate treatment increased striatal dopamine transporter availability in ADHD (in the caudate, putamen, and ventral striatum), while no changes in control subjects retested after 12 months were seen [12]. An upregulation of dopamine transporter availability during long-term treatment with methylphenidate may decrease treatment efficacy and exacerbate symptoms when medication is discontinued [12].

In summary, conclusive evidence of long-term benefits of ADHD medications remains elusive. Any claims to the contrary are light on substance and, due to potential vested interests, heavy on salesmanship [6].

2. Lifestyle research in ADHD

As early as the 19th century, a role of social, environmental and lifestyle factors in the etiology and prevention of diseases was proposed by the German pathologist Rudolf Virchow. Virchow focused on the multifactorial causation of illness, emphasizing the etiological involvement of social, psychological and stress factors. In Virchow's view, it is not bacteria, but abnormal stimuli acting on the cells that cause disease

[13]. He was a long-term vigorous opponent of the microbial theory of disease causation, which was supported by the discovery of the bacteriologist and Nobel laureate Robert Koch of the tubercle bacillus as the causative agent in tuberculosis [13]. The success of modern microbiology led to the "magic bullet" concept, i.e. the idea of eliminating specific microbes causing diseases without harming the body. Although Virchow's fierce anti-contagionism may have been an over-reaction to the threat to his theory of socio-medical causation, his commitment to medical, scientific and political reform led to his recognition today as the father of the public health movement. In China, the physician and statesman Sun Yat-sen saw sanitation and personal hygiene as indices of the degree of civilization [14]. Virchow's and Sun's medical and scientific convictions informed their political and social views: both were republicans (as opposed to monarchists) and pointed to the important role of health inequities determined by the social conditions under which people live. They regarded epidemics as disturbances of culture and warning signs regarding the progress of civilizations and states. Sun Yat-sen interpreted the devastating consequences of the bubonic plague in southern China in the 19th century as evidence of the need to topple the incompetent monarchy.

While the death rate from pulmonary tuberculosis is generally accepted as a sensitive index of the social state of a community, we know that this is also true for noncommunicable diseases such as diabetes and obesity [15]. Today, social inequities related to health outcomes, in addition to infection and starvation, concern, among other factors, the quality and composition of diet. While until recently little attention was paid to the properties of food in regard to mental health, a strong link has now been established between quality of diet and the risk of common mental disorders such as depression and anxiety [16,17]. In addition, a growing body of evidence points to beneficial effects of physical activity on mental health [18]. Societal determinants of health should be addressed in order to create (physical and social) environments that are conducive to health.

No distinct etiology, pathophysiology or biomarker has been revealed in ADHD [19]. The search for an essential neurobiological substrate in the central nervous system, as has been found in Parkinson's disease, with its characteristic degeneration of the nigrostriatal system and the dopamine loss in the striatum, has so far been unsuccessful in ADHD. This failure of a "magic bullet" strategy targeting well-defined biological alterations in ADHD calls for alternative research approaches. As a consequence, a wide range of lifestyle and environmental factors have been proposed as relevant research topics in ADHD.

The question of whether children with and without ADHD differ from one another in regard to the overall number of healthy lifestyle behaviors has been examined [20]. The children's parents completed a lifestyle questionnaire assessing seven domains, including intake of water and sweetened beverages, use of multivitamins, screen time, reading, physical activity, and sleep. A reduced lifestyle index score formed from these domains was associated with teacher-rated inattention and hyperactivity, and children with ADHD were almost twice as likely to engage in a reduced number of healthy behaviors [20]. Another study examined the association of health behaviors (diet quality, physical activity, and sedentary behaviors) with ADHD symptomatology in children with ADHD throughout adolescence [21]. The number of primary diagnoses of attention deficit disorder, hyperactivity disorder, hyperkinetic syndrome, or hyperkinetic conduct disorder was significantly lower in students with better quality of diet, higher levels of physical activity, and those who spent less time playing computer and video games [21]. Furthermore, children with ADHD symptoms have been reported to show more unhealthy lifestyle behaviors, such as external eating (combined with screen time or other sedentary behaviors) and bedtime eating [22]. These behaviors may be associated with an increased risk of obesity. In adults, an association was found between current symptoms of ADHD and self-reported unhealthy lifestyles and poor diets with high consumption of sugar [23].

3. Food and diet

Various nutrients have been linked to brain development and functioning, and diet may be an important factor in psychiatric disorders including ADHD. Dietary improvement may therefore be able to assist in the prevention and therapy of ADHD. Dietary compounds suggested to be involved in the etiology or to have therapeutic efficacy in ADHD include polyunsaturated fatty acids (PUFAs) and micronutrients such as vitamins (for review see [24–26]). Artificial food additives have also been suggested to be of etiological relevance, and the therapeutic potential of elimination diets has been examined. The effect sizes reported for artificial food color elimination do not provide convincing evidence of therapeutic efficacy [27]. However, medium to large effect sizes for the few-foods diet suggest that it might

offer treatment options in children too young for or not responding to medication [27].

Omega-3 PUFAs exert important effects on brain morphology and function [28], and reduced blood omega-3 PUFA levels found in individuals with ADHD suggest therapeutic efficacy of these substances [26,29,30]. In a systematic review of meta-analyses of double-blind placebo-controlled trials, the reported effect sizes for PUFA supplementation were small in regard to parent and teacher ratings [27]. A recent randomized placebo-controlled trial evaluated the efficacy of omega-3 PUFAs in children and adolescents with ADHD [31]. Randomly assigned participants received either supplements containing docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) or placebo for three months. Psychoactive or omega-3-containing treatments were not administered during the study period. The total reduction in the ADHD Rating Scale version 4 score was significantly greater in the placebo group than in the DHA-EPA group. In summary, this study did not show any beneficial effect of omega-3 supplementation in ADHD. In addition, when previously pooled data [32,33] were updated with the results of this study, no overall effect of DHA-EPA on ADHD could be found [31]. These findings do not suggest PUFAs to be a useful therapeutic approach in ADHD.

Various vitamins and minerals have been suggested to be involved in the pathogenesis of ADHD, and their supplementation may therefore have therapeutic benefits. While several pathophysiological mechanisms have been proposed to explain the relationship between vitamins and minerals and ADHD, it is unclear whether respective deficiencies play a role in the etiology of ADHD and whether supplementation has therapeutic efficacy [34–37].

Rather than investigating the effects of single nutrients on ADHD symptoms, several studies have examined the role of dietary patterns and whole diets. A case-control study identified dietary and nutrient patterns using food-frequency questionnaires in children and adolescents with ADHD and matched controls [38]. A fish/white meat dietary pattern was shown to be inversely related to ADHD. An inverse relationship was also observed for a mineral/protein nutrient pattern rich in zinc, protein and other minerals [38]. Another case-control study examined the relationship between a Mediterranean diet and ADHD [39]. In children and adolescents with newly diagnosed ADHD and matched controls, food consumption and nutrient intake were measured using a food-frequency questionnaire. An increased prevalence of ADHD diagnosis was associated with low adherence to a Mediterranean diet, i.e. (1) low consumption of fruit, vegetables, pasta, rice, and fish, (2) high consumption of sugar, candy, and soft drinks, and (3) an increase in the frequency of skipping breakfast and eating at fast-food restaurants [39]. The case-control designs used in the above studies allow no conclusions regarding the causal relationship between dietary pattern and ADHD. Another study supporting the importance of dietary pattern in ADHD found a positive correlation between intake of processed meat and salty snacks and hyperactivity, while hyperactivity was negatively correlated with the consumption of vegetables, coarse cereals, aquatic foods, beef, mutton, and milk [40]. The effectiveness of overall dietary interventions in ADHD should be investigated using randomized controlled trials [41].

In summary, evidence in support of an etiological role of nutritional deficiencies (vitamins, minerals, and PUFAs) or nutritional surpluses (e.g. artificial food additives) is sparse. While a role of single nutrients in the etiology and therapy of ADHD appears questionable and may be confined to subgroups of patients presenting with respective deficiencies, the relationship between ADHD and diet in general or other lifestyle factors may be of greater importance.

4. Physical activity

Emerging evidence suggests that physical activity may be a protective factor in ADHD. However, major limitations of the available studies assessing the impact of physical activity on ADHD symptoms have been small sample size, lack of randomization, and the retrospective nature of the studies [42].

The effect of physical activity during late adolescence on ADHD symptoms in early adulthood was investigated [43]. The study was conducted in 232 monozygotic twin pairs. Parents rated their children's ADHD symptoms at baseline and follow-up, and the participants' weekly energy expenditure was assessed using self-reports at baseline of frequency, intensity and duration of physical activity [43]. The results showed that greater weekly energy expenditure in adolescence was significantly associated with reduced ADHD symptom levels in early adulthood, even when controlling for unmeasured confounding (all genetic and shared environmental factors shared within monozygotic twin pairs), and ADHD symptoms and body-mass-index at baseline. Similar results were observed for the two ADHD sub-components hyperactivity/impulsivity and inattention

[43]. In summary, physical activity in adolescence was inversely associated with ADHD symptoms and might therefore decrease ADHD symptoms in early adulthood.

In a systematic review and meta-analysis, evidence for the effectiveness of exercise interventions on ADHD-related symptoms in children and adolescents was examined [44]. The meta-analysis of randomized controlled trials suggests that short-term aerobic exercise (over 6–10 weeks) had a moderate to large effect on core symptoms such as attention, hyperactivity and impulsivity, as well as related symptoms, including anxiety, executive function and social disorders, in children with ADHD. However, the effects of yoga exercise were less clear [44,45]. The small number of studies and the heterogeneity of their outcome measures should be considered.

Another review summarized the evidence for management of ADHD with long term aerobic physical activity, based on the findings from widely varying studies, research designs and outcome measures [46]. Studies comparing chronic aerobic physical activity to at least one control group were included. Preliminary evidence suggests that physical activity can be beneficial for ADHD symptoms, executive function, and motor abilities. This supports the use of physical activity as an adjunctive treatment for ADHD, but present evidence is insufficient to recommend physical activity as a monotherapy [46].

A systematic review of 30 short-term and long-term studies supported the clinical benefits of physical activity on behavioral, cognitive and physical symptoms in individuals with ADHD [47]. Adverse effects of physical exercise were not reported in any study. A recent systematic review concluded that physical activity of 20–30 min (intensity 40–75%) produces positive acute effects on processing speed, working memory, planning and problem solving in young individuals with ADHD, while data on the effects on behavior are contradictory [48]. Longer term physical activity (≥30 min/d, ≥40% intensity, ≥3 d/week, ≥5 weeks) improved attention, inhibition, emotional control, behavior, and motor control [48].

The feasibility and impact of a 10-week after-school exercise program for children with ADHD and/or disruptive behavior disorders living in an urban poor community were assessed in Chicago [49]. The participants were randomized to an exercise program or a comparable but sedentary attention control program. Both cognitive and behavioral outcomes were collected pre-/posttest. This study trial demonstrated that, with proper training and support, after-school physical activity programs can be implemented for children with behavioral disorders in a high poverty community [49]. Children in both groups improved on clinically relevant outcomes, with few differences between groups [49]. Future studies using larger samples are needed in order to examine the effectiveness of such exercise programs.

5. Media use

Over recent decades, children's use of electronic media, including internet, television, social networks and video games, has changed significantly and has increased to several hours per day [50]. Entertainment media have become more fast-paced, arousing and violent. This change has a significant impact on the development and daily activities of children, with an increase in the use of visual compared to auditory communication, a displacement of activities believed to stimulate cognitive abilities more than screen entertainment media, and a change from free play in groups to solitary web-based media use ("screen culture"). High-risk youths may spend an increased time in front of screens, with daily screen time of about seven hours per day in youths attending a psychiatric clinic [51]. In particular, it has been contended that ADHD-related behaviors may be influenced by the use of media entertainment [52]. In addition, overuse and lack of control of electronic media have led to research on ''internet addiction'' [53]. The findings of various studies suggest that psychiatric disorders, and ADHD in particular, are associated with overuse [52,54]. Children with ADHD may be particularly vulnerable to overuse of media entertainment including computer games, which operate in short segments, demand relatively little attention and offer immediate rewards. While a strong case for a connection between ADHD and both internet and off-line video gaming has been made [52], the causal relationship of this correlation needs to be investigated in future studies.

A meta-analysis, including 45 empirical studies investigating the relationship between ADHD-related behaviors and the use of screen entertainment media in children and adolescents, was conducted [55]. The results of this analysis indicated a small but significant association of media use with increased symptoms of ADHD [55]. Whether the strength of this association is influenced by media content (fast-paced, violent), media type (television, video games), or type of ADHD-related behavior (inattention, impulsivity, hyperactivity) should be examined. A better understanding of the relationship between ADHD and media use, particularly in regard to

causality, individual susceptibility, and the underlying mechanisms, is needed in order to develop prevention and intervention strategies.

6. Sleep, circadian rhythm, and ambient light

Sleep problems are common in ADHD and may exacerbate the expression of daytime symptoms [56]. The assessment of the cross-sectional relationship between ADHD and insomnia in adulthood shows a prevalence of insomnia in adults with ADHD ranging from 43–80%, which is higher than in the general population (31–56%) [57]. Longitudinal evidence for a link between childhood-onset ADHD and insomnia later in life is mixed [57]. In randomized, placebo-controlled trials, insomnia is reported significantly more often in the treatment arm than in the placebo arm [57]. Current overall ADHD symptom severity in adults, especially the severity of hyperactivity, was shown to be associated with the current presence and persistent history of sleep problems [58]. ADHD symptom severity was also associated with an extreme evening chronotype, but not with short sleep [58]. In a general population study, the relationship between ADHD symptom severity, insomnia symptoms, and sleep duration in adults was examined [59]. Clinically significant ADHD symptoms as well as inattention and hyperactivity symptom dimensions were consistently associated with insomnia symptoms and altered sleep duration [59]. A meta-analysis of sleep studies in adults with ADHD was recently conducted [60]. Adults with ADHD differed significantly in seven of nine subjective parameters when compared to adults without ADHD, while no significant differences were detected for polysomnographic parameters [60]. Future research should investigate if and to what extent sleep-related complaints are underpinned by objective sleep alterations.

In order to investigate an association between sleep schedules, sleep-related problems and ADHD symptoms, a cross-sectional study comprising a large sample of 15,291 preschoolers was conducted in China [61]. Logistic regression analysis, after adjusting for TV viewing duration, outdoor activities, and socio-demographic characteristics, showed that delayed bedtime was significantly associated with a risk of high levels of ADHD symptoms. Longer time falling asleep, no naps and frequent sleep-related problems were also significantly associated with an increased risk of high levels of ADHD symptoms, while longer sleep duration (>8.5 h) was associated with a decreased risk of high levels of ADHD symptoms [61]. These findings indicate a role of sleep schedules and sleep-related problems in ADHD in preschoolers, and suggest that regular sleep habits might attenuate ADHD symptoms.

The mechanisms modulating sleep alterations associated with ADHD in adulthood are poorly understood. Genetic and non-shared environmental influences may play a role. Media use might be one factor linking altered sleep to ADHD. The exposure to artificial light exerts a marked suppressive effect on melatonin levels and shortens the body's internal representation of night duration [62]. The chronic exposure to electrical lighting in the late evening has been shown to disrupt melatonin signaling and could thereby impact sleep and related physiological measures [62]. In this context, the use of electronic devices shortly before bedtime may have a negative impact on sleep, possibly mediated by the short wavelength-enriched light emitted. For example, people reading a light-emitting eBook before bedtime as compared to a printed book showed reduced evening sleepiness, needed more time to fall asleep, and had reduced melatonin secretion, later timing of their circadian clock, and reduced next-morning alertness [63].

Individuals with ADHD have a high prevalence of obesity. In order to investigate whether circadian rhythm disruption is a mechanism linking ADHD symptoms to obesity, ADHD symptoms and two manifestations of circadian rhythm disruption, i.e. sleep problems and an unstable eating pattern (skipping breakfast and binge eating later during the day) were assessed in adult ADHD patients, participants with obesity, and controls [64]. Participants with obesity showed a higher prevalence of ADHD symptoms and short sleep on free days as compared to controls, but a lower prevalence of ADHD symptoms, short sleep on free days, and an unstable eating pattern as compared to ADHD patients [64]. Participants with obesity had a similar pattern of an unstable eating when compared to controls. In addition, mediation analyses showed that both sleep duration and an unstable eating pattern mediated the association between ADHD symptoms and body mass index [64]. These findings support the hypothesis that circadian rhythm disruption is a mechanism linking ADHD symptoms to obesity.

In summary, the associations between ADHD symptom severity and insomnia symptoms [59] suggest that sleep disturbances require attention in clinical practice.

7. Conclusion

Whether or not the currently available therapies improve the outcome in individuals with ADHD over an extended time period is unclear, and little is known regarding the long-term safety of the medications used in ADHD. Extended administration of stimulant medication in ADHD from childhood through adolescence is associated with suppression of adult height without a reduction in symptom severity. These findings in respect of the long-term management of ADHD and the failure of a "magic bullet" strategy targeting distinct biological changes in ADHD call for alternative research strategies.

Lifestyle factors, such as diet, exercise, media use, and sleep habits, may be precursors or consequences of ADHD. Current evidence suggests that individuals with ADHD may benefit from improved lifestyle choices. The role of single nutrients, such as PUFAs, minerals and vitamins, in the etiology and treatment of ADHD is unclear and may be confined to individuals with respective deficiencies. Experimental long-term investigation of different diets would be challenging if not impossible for logistical reasons. Moreover, the interrelationship between the entire diet and other lifestyle factors may be of greater importance. The well-established relationship between ADHD and insomnia, and the small associations of media use with ADHD-related behaviors call for further investigations.

Emerging evidence suggests that physical activity may be a protective factor for ADHD and that exercise may be a promising alternative or additional treatment option. However, the currently available studies assessing the impact of physical activity on ADHD symptoms have several limitations. Large-scale, well-designed studies should investigate the effects of exercise on ADHD, and an examination of the most effective type of exercise should be undertaken. Exercise programs can be easily implemented, are relatively inexpensive, and can be combined with other treatments. Physical activity has additional benefits for cardiovascular health, the prevention of noncommunicable diseases such as diabetes and obesity, and the improvement of psychological well-being, including the reduction of the risk for anxiety and mood disorders [65]. The feasibility of school-related exercise programs for children with behavioral disorders has been demonstrated, and such programs may provide good value for societal investment [49].

The identification of health-related lifestyle risk factors, such as quality of diet, physical and sedentary activities, use of media, and sleep habits, appears to be important in individuals with ADHD, since interventions in these areas may improve behavioral, cognitive and physical symptoms of ADHD. Health promotion programs aiming to improve children's diets and promote more active lifestyles may also reduce the public health burden of ADHD [21]. In summary, lifestyle research appears to be a promising approach and may provide a more holistic and interactive understanding of ADHD. Furthermore, lifestyles associated with ADHD should be given greater emphasis in clinical practice.

Declaration of interests

The author declares no competing interests.

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