

The effect of diet components on the level of cortisol

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Abstract The way and the quality of nutrition are important factors that can have influence on behavior of both the health and well-being. Proper diet helps to maintain homeostasis in the body. Changes in lifestyle lead to increase the degree of food processing and hence reduce the nutritional value of available products. This forces the use of technological amendments in nourishment, i.e., fortification and formation of diet supplements. Modified food can complement diet in necessary nutrients. Environmental factors like activity can cause adaptation changes in endocrine system of every human. Cortisol is a corticosteroid, in which influence is varied depending on its concentration. Through its multipronged action, it mobilizes organism to fight stress, by ensuring a stable level of glucose, stimulating tissue's regeneration and inhibiting inflammation processes. Factors like stressful work, personal problems, intensive trainings can lead to long-term sustained, excessive concentration of this hormone, affecting formation of metabolic disorders such as insulin resistance, increased blood pressure, abnormal bone regeneration and collagen synthesis or calcium deficiency in the organism. Diet supplementation is currently extensively used by both healthy and unwell people, in different age, but most commonly refers to physically active people. Lots of widely available dietary supplements contain nutrients which regulate steroid hormones homeostasis. Elaboration of optimal diet is one of the agents determining well-being, health and success. In this paper, we review the current knowledge on the effect of dietary components on level of cortisol.

Keywords Cortisol · Nutrition · Supplementation · Sports · Hormonal balance

Introduction

Cortisol (hydrocortisone) is in human body the prevailing hormone from glucocorticoids group. By multidirectional acting within the physiological processes, it prepares body to physical and mental stress. It affects the metabolism of proteins, carbohydrates and fats and also participates in the regulation of water and electrolyte balance, blood pressure, body temperature, mineralization of the bones and the immune response. Additionally, it acts on mood and behavior, appetite and pain perception [1, 2].

Cortisol mobilizes organism to fight stress, by affecting functioning of many organs and systems. It regulates the usage of diet nutrients through increasing gluconeogenesis and increasing lipolysis in adipose tissue. In addition, it increases protein synthesis in the liver and restricts their formation in muscles and skin cells. Furthermore, it increases retention of water and sodium, controls production of adrenaline in adrenal medulla, inhibits inflammatory processes and also affects the psyche, often provoking euphoria or depression [3].

The aim of the study is to present the current scientific views on the role of dietary components and way of nourishment on production of cortisol in the body of physically active person.

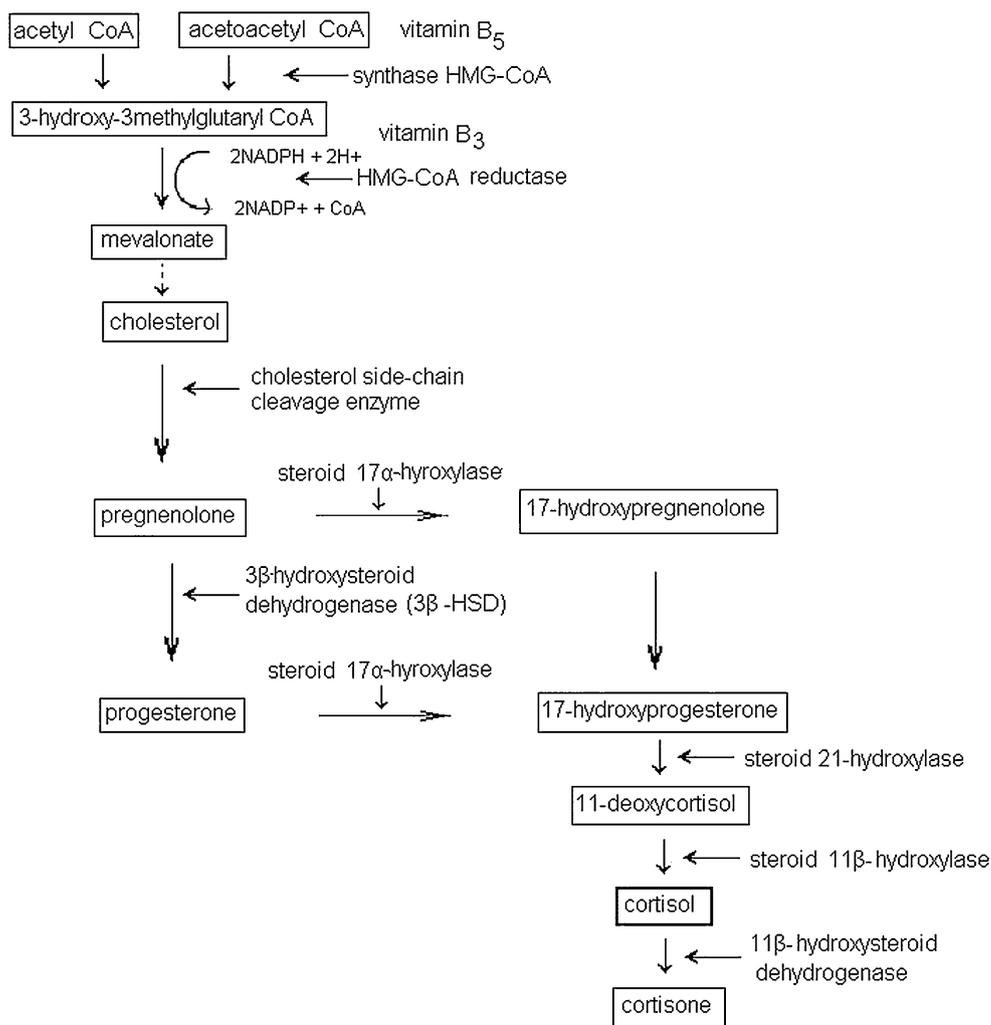
Dietary components and metabolism of cortisol

Properly composed diet provides all the nutrients derived from plants and animal products. Cholesterol is a fat-like

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Fig. 1 Endogenous synthesis and metabolism of cortisol. Own elaboration based on [1–8]



substance which occurs in animal fats and is also continuously produced in the human body. Endogenous synthesis of cholesterol starts with the condensation of three molecules of acetyl CoA. The further course of the reaction is dependent on the presence of a number of enzymes and of vitamin B3 inheritance. As a result of a triple enzymatic hydroxylation of cholesterol arises cortisol (Fig. 1), which is released into the blood by passive diffusion process [1–8].

Figure 1 shows the synthesis and metabolism of cortisol including the effect of B vitamins (B3 and B5).

Metabolism of cortisol takes place mainly in the liver, where by means of reductases it is converted to tetrahydro-metabolites (THMs), which are then excreted in urine. The hormone may undergo changes in the organism before it reaches the receptors in the target cells under microsomal 11 β -hydroxysteroid dehydrogenase which reversibly deactivates it to cortisone [2, 7].

Factors regulating production and secretion of cortisol

Cortisol secretion is controlled by circadian rhythm, the negative external stimuli and feedback regulation, as confirmed by studies conducted by Bornstein et al. [6].

Under the influence of circadian and stress factors, hypothalamus releases corticotropin-releasing hormone (CRH) and vasopressin (ADH, antidiuretic hormone). Arising hormones stimulate the anterior pituitary gland to produce adrenocorticotropic hormone (ACTH). ACTH affects expression of StAR protein which transports cholesterol across the mitochondrial membrane and allows the process of cortisol formation in the adrenal cortex [2].

Transport of cortisol takes place in biologically inactive conjunctions with transcortin (90 %) and albumin (7 %). In target cells, it affects the transcription of DNA. In

conducted studies, it was found that cortisol can also influence functioning of body, using non-genomic mechanisms [1–3].

The body's response to cortisol depends on its concentration and the concentration of the receptor that is affected by the state of development, timing of cell cycle and endocrine disorders [1–3].

Functions of cortisol in human body

Endocrine functions are dependent on environmental factors, including the manner and quality of diet as well as physical activity.

A number of dietary and endogenous factors affect on maintaining an appropriate level of glucose in human blood. Cortisol acts on glucose amount by activating hepatic glycogen stores, reducing the oxidation of glucose, stimulation of lipolysis and intensification of gluconeogenesis from amino acid severity. Persisting high levels of this hormone contributes to the development of insulin resistance, dyslipidemia, hypertension and obesity. Mobilization of glucose reserves is particularly important in case of rapid stress situations like endurance training due to prolonged effort [2, 7–9].

Furthermore, cortisol affects the appetite [7]. De Sa et al. demonstrated that oral administration on this substance amplified startle responsiveness during presentation of pictures of food with high glycemic index. There was not such an effect in case of normal and pleasant non-food images [10]. It was shown that injection of ghrelin, the hormone that stimulates hunger, increases levels of cortisol, ACTH and growth hormone but does not affect leptin [11].

In physiological concentrations, cortisol stimulates the synthesis of collagen. However, increasing its amount in blood stream, caused by mental stress or too intense physical effort, leads to a number of modifications within the structure of osteoblast and concentrations of chemical substances involved in process of bone remodeling. These changes bring disturbances in bone mineralization and inhibition of collagen synthesis. In addition, an excess of cortisol impairs the active transport of calcium ions across cell membranes and reduces its absorption in gastrointestinal tract, leading to calciuria [5].

Cortisol enhances sensitivity of tissues of blood vessels and heart to noradrenaline, vasopressin and angiotensin II, resulting in increased blood pressure. In addition, it affects the water and electrolyte balance, increasing retention of water and sodium [3, 7, 9]. Cortisol also acts on thermal regulation of body, to prevent overheating of organism [7].

Hydrocortisone affects the immune system, showing anti-inflammatory and immunosuppressive effects

by reducing secretion of proinflammatory cytokines, by decreasing migration of white blood cells to sites of inflammation and by inducing cell apoptosis. This stimulates the body's defensive responses to injuries, including those occurring during training and sport starts [9, 12, 13].

Cortisol influences neuronal plasticity and neurodegenerative processes by acting on neurons and glial cells within the central nervous system. In addition, it modifies mood and behavior, as well as perception of pain, which is particularly important in mobilizing player in time of starts [7].

Cortisol, which is called hormone of fight with stress, prepares athlete to increase effort. However, its excess leads to catabolic reactions, negatively affecting the organism. The concentration of cortisol, as a catabolic hormone, stays in dynamic equilibrium with anabolic hormones. It has been shown that high levels of cortisol (C) inhibit synthesis of testosterone (T) in body, contributing to disorders in quantity ratio of these hormones. Estimated C/T is an indicator that reveals the exhaustion and overtraining of athlete [8, 14].

The impact of training and competitions on cortisol level

Several studies demonstrate relationship between the subjectively perceived stress and changes within the endocrine system of an athlete as substantial increase in level of cortisol and adrenaline and a less pronounced increase in level of testosterone [14, 15]. Determination of cortisol and testosterone allows the assessment of prestart stress [14]. It has been shown that in athletes with higher motivation and orientation on the success, levels of these hormones were higher than those of other players. They also generally achieve better results [14].

In response to a long-lasting endurance effort, especially under conditions of low temperature and at high altitudes, an increase in cortisol level is observed [16–18]. In addition, on level of this hormone are affecting emotional factors associated with start in competition and the extreme burden and psychological exhaustion [18, 19]. It has been shown that people who experience mental depletion experience limited activity of pituitary gland and sympathetic nervous system [19].

The increase in cortisol level after exercise depends on degree of fitness of an athlete, on cultivated discipline and on volume and quality of training [20–22]. It has been demonstrated that cooling the body after training with cold water affects lowering of post-training cortisol levels as compared to the control group [22].

Effect of nutritional components of diet on level of cortisol in blood

The way of nourishment as well as nutrients in diet and physical activity has a decisive impact on proper functioning of body, including balance within the endocrine system.

Properly balanced diet with optional supplementation is one of the important factors determining the high physical and mental capacity of organism. Elderly people, athletes and heavy workload people often use nutritional supplementation, which makes it possible to increase efficiency and durability as well as accelerate healing process [23, 24].

These groups are particularly exposed to abnormal secretion, metabolism and transport of hormones, including cortisol. Long-term sustained high levels of cortisol in the blood are disadvantageous. This fact points to desirability of enriching daily diet with supplements, which can help to stabilize hormones.

It was shown that in stressful situations appetite for sweet and fat meals rises, probably because of their high rewarding character [25]. Consumption of meals induces increase in cortisol level. This response is strongly marked in men than in women. Influence of kind of macronutrients in taken food on cortisol concentration was investigated in many researches, but the results are not clear [26–29].

The content and type of carbohydrates in diet have a significant affect on endocrine system of active person. It was observed that the level of cortisol increases, by counter-regulatory way, in response to hypoglycemia. Therefore, it is important for athletes to refill carbs before, during and after training [30]. It has been demonstrated that supplementation with 7 % solutions of sugars during endurance training causes lowering of post-exercise concentration of hydrocortisone in blood while the consumption of liquids containing up to 1.5 % carbohydrate or maltodextrin solutions (8 %) during training don't affect level of this hormone [31, 32].

The impact of around training protein or branched-chain amino acid (BCAA) supplementation as well as their connections with carbohydrates is not clear and requires testing on large groups of athletes of various disciplines [32–38]. In case of supplementation of certain amino acids such as tryptophan, which is a precursor of serotonin, may lead to a reduction in cortisol level increase, inducted by exercise [39]. Around training administration of glutamine and arginine does not change the concentration of cortisol [32, 38, 40].

Further nutrients, which may affect the levels of cortisol, are phospholipids: phosphatidylserine and phosphatidic acid. It has been shown that supplementation of their complex in a dose of 400 mg/day for 6 weeks resulted in

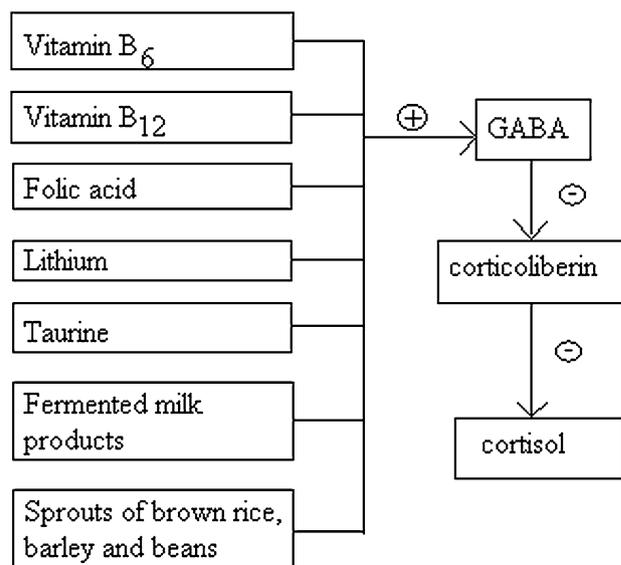


Fig. 2 Effect of food nutrients on concentration of γ -aminobutyric acid (GABA) and associated with its level of cortisol. Own elaboration based on the literature [44–50]

reducing secretion of cortisol, caused by exercise, but a dose of 200 mg did not give a similar effect [41, 42]. Natural source of phosphatidylserine is egg yolk and of serine is protein-rich products. Serine is an endogenous amino acid and can be synthesized by organism from other amino acids. This is another reason why to maintain sufficient amounts of protein in diet of an athlete is very important [43].

A chemical compound that affects the hormonal control of cortisol is γ -aminobutyric acid (GABA). GABA reduces the secretion of corticoliberin (corticotropin-releasing hormone, CRH), which triggers a series of consecutive hormonal changes, leading to secretion of cortisol by the adrenal cortex [44, 45]. Natural sources of this substance can be fermented milk products, sprouts of brown rice, barley and beans [46, 47]. On market of dietary supplements, there are available formulations that increase the level of GABA, as well as chemically prepared γ -aminobutyric acid. However, there is evidence that use of supplements containing GABA induces side effects which haven't been observed when using a natural product [46].

Trace elements, i.e., lithium, vitamin B₆, vitamin B₁₂ and folic acid, affect on acceleration of the activity of the GABAergic system [48, 49]. Ability to stimulate the GABA receptor has the amino acid taurine [50]. GABA is produced from the amino acid glutamine in the presence of endogenous vitamin B₆ [51].

Figure 2 shows the effect of nutrients and food products on GABA and cortisol concentrations.

For many years, very popular are yoga classes. It is philosophical system of India, whose practice involves, among others, exercises, meditation or working with breath. A significant impact of yoga session on increasing concentration of GABA in brain was found [52].

Dietary supplements

Influence of ascorbic acid on level of cortisol has been widely investigated. In vitro researches demonstrated no influence of vitamin C on cortisol synthesis induced by ACTH [53]. Brody et al. [54] showed that taking 3000 mg of vitamin C per day leads to faster cortisol recovery after response to acute psychological stress, but it doesn't decrease overall concentration of this hormone. Numerous studies indicate that supplementation with high doses of ascorbic acid (1000–1500 mg/day) during the period preceding start of athletes in endurance disciplines hampered the growth of levels of cortisol. In addition, it contributed to reduction in muscle pain and improved efficiency of regenerative processes. A similar effect was observed when supplementation with high doses of vitamins B1, B2 and niacin, which are involved in metabolism and production of cortisol [55, 56]. Efforts were also made to link cortisol levels with vitamin D, but the views of scientists are controversial [57, 58].

Physical exercise as a stress factor increases secretion of cortisol. In studies of Golf et al., it was demonstrated that this process can be limited by supplementation of athletes' diet with magnesium. After completion of the 14-day cycle of supplementation with 15 mol of magnesium was recorded lack of exercise-induced increase in cortisol level [59]. Action of magnesium is explained by its inhibitory activity on NMDA (*N*-metil-D-aspartate) receptor, which leads to reduction in adrenocorticotropin secretion by anterior pituitary and to inhibition of cortisol synthesis at the stage of conversion of cholesterol to pregnenolone [60]. However, not all studies confirm this effect. Cinar et al. showed that the combination of magnesium supplementation (10 mg/kg b.w.) with physical activity caused increase in cortisol concentrations. In people who only trained or were only receiving magnesium, such body's response was not found [61]. The impact of magnesium supplementation on cortisol levels in athletes is not clear and needs further investigation.

Another bioelement that affects hormonal balance is boron. In clinical study by Naghii et al. [62], it has been found that a daily morning use of preparation containing 11.6 mg of boron, just after 1 week, results in increase in cortisol and free testosterone, dihydrotestosterone and vitamin D while decreasing estradiol levels.

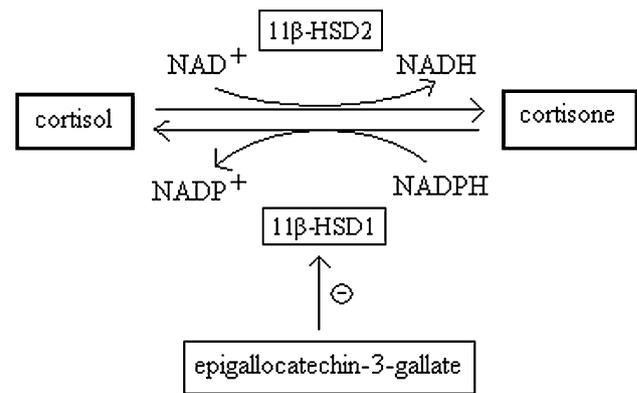


Fig. 3 Effect of epigallocatechin-3-gallate, on balance between levels of cortisol and cortisone. Own elaboration based on [69, 70]

Supplement manufacturers often advertise preparations containing omega-3 and vitamin E, as lowering levels of cortisol, but scientific studies are not unequivocal [63–66].

It was shown that 3-week supplementation of fish oil, containing eicosapentaenoic (60 mg/day) and docosahexaenoic acid (252 mg/day), reduces basal level of cortisol and subjective feeling of stress [67].

Another group of supplements widely promoted by shops with supplements with healthy food is formulations containing plant extracts. One of the plants that is commonly associated with limitation of effects of stress is lemon balm. Its positive impact on stress has been widely proved; however, discussion is whether one of the mechanisms of this action decreases level of cortisol by active compounds contained in the plant [68]. Impact of components of green tea on plasma cortisol concentration was confirmed. It was found that an epigallocatechin-3-gallate inhibits activity of 11β-hydroxysteroid dehydrogenase type 1 (11β-HSD1), which participates in conversion of cortisone to cortisol [69, 70]. Figure 3 shows effect of epigallocatechin-3-gallate on balance between levels of cortisol and cortisone.

In a study conducted by Arent et al., it has been shown that consumption of black tea extract, enriched with theaflavin, can reduce cortisol discharge caused by stress connected with training in interval system [71]. Drinking strong infusions of turquoise oolong tea can result in a significant decrease in cortisol levels [72]. Similar effects have infusions of green coffee [73]. In contrast to the green, black coffee stimulates secretion of hydrocortisone. Studies of Gavrieli et al. [74] on cortisol levels in men who drank decaffeinated and caffeine-containing coffee showed that for the impact on level of this hormone is responsible caffeine. In addition, it was noted that included caffeine in coffee inhibits evening decrease in cortisol levels. This effect is more pronounced in younger group (15–40 years) than in older (41–70 years), regardless of gender [73–75].

Consumption of caffeine before a workout leads to a dose-dependent increase in both cortisol (*K*) and testosterone (*T*) concentrations. Supplementation with caffeine before workout can improve the *T/K* ratio, regardless of the duration of the night's rest [76–80].

The studies concerning consumption of drinks containing carbohydrates and caffeine during workout have shown that the highest increase in cortisol levels were achieved in the group that supplemented caffeine without carbohydrates [81, 82].

Mechanism of action of caffeine on concentration of this glucocorticoid is not entirely understood. There are reports indicating stimulating effect of caffeine on gene encoding 11 β -HSD2 [83]. It is also suggested that caffeine stimulates production of cortisol by adrenal glands through a direct effect on expression of StAR protein, as well as hereditary epigenetic mechanisms [75]. Some of the researchers suggest that the mechanism of caffeine effect on cortisol levels can be sex-dependent. In men, a central nervous system activity is observed, and in the case of women, additional peripheral reactions occur [77].

It was demonstrated that chronic inflammatory and immune diseases lead to resistance to anti-inflammatory action of glucocorticosteroids including cortisol [84]. Ruijters et al. showed that food-derived bioactives, because of their antioxidant activity, can protect positive functions of cortisol on inflammation process. Among the components with the biggest protective activity, there was curcumin, resveratrol, chrysin, genistein, 7-mono-*O*-(β -hydroxyethyl)-rutoside and theophylline [85].

Another substance of plant origin, which may affect the level of cortisol, is betaine (trimethylglycine). It has been demonstrated that supplementation of betaine resulted in a significant decrease in amount of this hormone in organism of trained men relative to control group. Further increase in the amount of growth hormone and IGF-1 was found, indicating improved anabolic profile of patients [78].

Miyake et al. showed that supplementation with L-ornithine decreases serum cortisol level and cortisol/DHEA ratio. It also reduces anger and improves quality of sleep, which can find application in relieving sleep disorders and fatigue [86].

In recent publications appear reports about active substances contained in golden root (*Rhodiola rosea*), which may affect glucocorticoid receptors. Their action can have an impact on reducing the discharge of cortisol in a group of physically active people [79–81]. It has been shown that a 4-week supplementation with a standardized extract from roots of *Eurycoma longifolia* (“Malaysian ginseng”) influences favorably on hormonal profile of respondents of both sexes. A reduction in cortisol levels by 16 % and increased level of testosterone by 37 % was noted. Authors suggest that the observed improvement may support sports performance [82, 83].

It was shown that intake of enzyme-treated asparagus extract prevents the growth of baseline cortisol level. It also raises sleep quality [87].

Among supplements advertised as increasing muscle mass and strength are formulations comprising active ingredients of plant, i.e., methyl-oxy-isoflavone, ecdysterone and sulfo-polysaccharide. Effect of the above-mentioned compounds on hormonal profile, muscle strength and lean body mass was not confirmed [88].

Conclusions

Nowadays, all people are under great pressure to achieve better results at work, sport and personal life. Mental stress in combination with physical stress contributes to formation of adverse changes in hormonal balance. Excessive levels of cortisol, which is known as the “stress hormone,” leads to negative changes in body functioning. Endocrine imbalance can be reduced using a suitable way and quality of nutrition.

Demand for various nutrients is varied and dependent on gender, age, kind of work and lifestyle. The variety of produced food allows use of a varied diet, taking into account individual needs and preferences of a person.

To achieve professional and personal success, it is very important to preserve adequate nourishment. Edibles, including supplementation, have now become the subject of aggressive advertising campaigns. The necessity of consuming dietary supplements by athletes should be considered.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Compliance with ethics requirements The manuscript does not contain clinical studies or patient data.

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