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BACK-GROUNDER

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VITAMIN NUTRITION FOR PHYSICALLY ACTIVE PEOPLE

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INTRODUCTION

The Centers for Disease Control and Prevention (CDC), the Surgeon General, the American Heart Association and other leading health authorities have recommended that Americans increase the amount of physical activity they engage in daily.[1-3] Their recommendations are based on accumulating evidence that regular physical activity confers preventive health benefits, which in many cases parallel the benefits of good nutrition in promoting health and reducing risk of chronic diseases. It is becoming clear that physical activity and good nutrition are complementary and perhaps equally important components of a healthy lifestyle. Furthermore, there is a natural synergy between the health benefits of exercise and those of optimal nutrition in reducing risks of cardiovascular disease, hypertension, diabetes and osteoporosis.

Much of the attention in sports nutrition to date has focused on carbohydrate as the major energy-producing macronutrient and on protein for muscle building; however, micronutrients (vitamins and minerals) are also important. Vitamins and minerals play critical roles in the generation of energy in the body, the development of tissues such as muscle and red blood cells, and in reducing the effects of oxidative stress.

This paper reviews both the traditional aspects of the relationship between vitamin nutrition and physical activity — the impact of exercise on vitamin status or requirements; the impact of vitamin status on physical activity; and the value of supplemental intakes of vitamins in physical activity — and the evidence supporting a concordance between vitamin nutrition and physical activity as complementary "pillars" of health promotion and disease prevention.

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PHYSICAL ACTIVITY AND VITAMIN REQUIREMENTS

B Vitamins: Essential Catalysts in Energy Metabolism. The B vitamins are essential for physical activity and exercise because they generally function as part of critical enzymes that are involved with the conversion of carbohydrates, fats and proteins to useful energy. Therefore, requirements for some B vitamins are tied to energy intakes. For example, the Recommended Dietary Allowance (RDA) for niacin is 6.6 mg/1000 calories consumed, the RDA for riboflavin is 0.6 mg/1000 calories consumed, and the RDA for thiamin is 0.5 mg per 1000 calories consumed, but not less than 1.0 mg/day.[4] Similarly, vitamin B_6 requirements are based on estimated protein intakes; the RDA is 1.6 mg/day for women and 2.0 mg/day for men, or approximately 0.016 mg/gram of protein consumed per day. B vitamins are also involved in the synthesis of DNA and RNA and the functioning of the nervous system.

Because of their essential roles in energy generation, nerve function and the formation and maintenance of body support structures (muscle and bone), "it is virtually certain that a deficiency or suboptimal status of any vitamin will, at some point, impair physical performance."[5] This is particularly true if dietary intakes of several vitamins are suboptimal simultaneously. Frank deficiencies of vitamins result in a wide variety of adverse symptoms that would diminish physical performance (Table 1). In addition, there is evidence that more subtle vitamin inadequacies may have an impact. For example, a combined marginal deficiency of thiamin, riboflavin and vitamin B_6 caused a decrease in physical performance within a few weeks.[6,7] Some research has shown that exercise is most likely to affect riboflavin status when a training regimen is unaccustomed or sporadic. Five separate studies have reported that exercise increased riboflavin requirements in untrained women; in contrast, no evidence for an increased requirement was observed in two studies with trained women.[5] It is suggested that perhaps

Table 1

VITAMIN DEFICIENCY SYMPTOMS THAT WOULD ADVERSELY AFFECT PHYSICAL PERFORMANCE[5]

VITAMIN	DEFICIENCY SYMPTOMS
Thiamin	*Muscular weakness, fatigue, altered heart function, depression*
Riboflavin	*Anemia, peripheral neuropathy of the hands and feet*
Niacin	*Weight loss, strength loss, vertigo, mental confusion, decreased ability to concentrate*
Pantothenic acid	*Depression, fatigue, muscular weakness*
Biotin	*Extreme lassitude, muscle pain, anemia*
Pyridoxine (vitamin B_6)	*Depression, peripheral neuritis, ataxia, anemia*
Folic acid	*Anemia*
Vitamin B_{12}	*Anemia, weakness, fatigue, loss of weight, neurological damage*

riboflavin needs are increased at the beginning of an exercise program but that adaptation may occur in trained subjects, allowing them to maintain riboflavin status on intakes approximating the RDA.[5] Whether this will occur for other vitamins is not known.

Most physically active people consume enough food to fulfill both their energy and micronutrient needs, but there are some cases where this may not be the case. Physically active people who also restrict calories are likely to have inadequate intakes of several vitamins. Athletes who restrict their food intake to maintain low body weight, as is often the case among those involved in gymnastics, dancing, diving, figure skating and college wrestling, may be at risk for inadequate vitamin intakes. Even recreational exercisers who diet for weight control may be at risk. For example, the combination of dieting plus moderate exercise — 2 1/2 hours a week of aerobics — was shown to increase the requirement for riboflavin.[8]

Exercise and Oxidative Stress. Performance of strenuous physical activity can increase oxygen consumption by 10 to 15-fold over rest. This in turn produces oxidative stress through the generation of free radicals and increased lipid peroxidation in skeletal muscle cells.[9-12] Exercise can also generate free radicals by other means, including increased production of epinephrine and other catecholamines that can produce oxygen radicals by autoxidation; production of lactic acid that can convert a weakly damaging radical (superoxide) into a strongly damaging one (hydroxyl); and the immune response to muscle damage as a consequence of overexertion, which can lead to lipid peroxidation of membranes and an increase in macrophages and white blood cells in damaged muscle.[11]

In general, there is evidence that strenuous exercise can increase lipid peroxidation, as measured by biochemical markers of free radical production. In particular, certain byproducts of lipid peroxidation are detectable in the blood (plasma MDA or malondialdehyde and conjugated dienes) and in the breath (expired pentane); however, these measurements have been criticized as being imprecise. Evidence for increased oxidative stress is also suggested by the fact that regular physical training appears to enhance antioxidant status, as measured by elevated levels of vitamin E and antioxidant enzymes in highly trained runners.[11]

Antioxidant Defenses. The body's antioxidant defense system minimizes the damage caused by free radicals. This defense system includes the antioxidant enzymes superoxide dismutase (containing zinc, copper and magnesium) and glutathione peroxidase (containing selenium), the antioxidant vitamins E and C, and carotenoids such as beta carotene. Physical training has been shown to augment antioxidant enzyme defenses and reduce lipid peroxidation, but the degree to which this adaptation occurs is not yet known. Weekend athletes who tend to overexert themselves on an irregular basis may not have the augmented defense system produced through continual training and therefore may be more susceptible to oxidative stress.[11]

Vitamin E is the most important fat-soluble antioxidant in the body, protecting cell membranes from oxidative free radical attack. Vitamin C is an effective water-soluble antioxidant, found in the fluid compartments within and between cells. In addition to being an antioxidant itself, vitamin C has the ability to regenerate vitamin E.

Vitamin E has been shown to reduce the oxidative stress that accompanies or follows exercise. The increases in biochemical markers of free radical damage observed with exercise are reduced by vitamin E supplements.[13-15] Plasma MDA and expired pentane were also reduced by a combination antioxidant supplement containing vitamin E, vitamin C and beta carotene.[16] However, the clinical significance of reducing oxidative stress in exercise is yet to be determined.

Antioxidants in Attenuation of Muscle Damage. The free radicals generated during exercise appear to play a key role in exercise-induced muscle injury, particularly in irregular exercise since antioxidant adaptations are inadequate. Damage to the muscle is reflected by microscopic tears in the muscle and leakage of enzymes from the muscle cells into the plasma. It results from the "eccentric" or "negative" component of exercise, which involves the muscle lengthening while it produces force. This is a natural component of all forms of exercise, but some activities such as bench stepping, downhill skiing and downhill running have a higher eccentric proportion than others. Muscle injury that occurs during these activities can result in impairment in muscle function and delayed onset muscle soreness.[17]

Most exercise results in some skeletal muscle damage, but unaccustomed exercise can cause extensive damage. Researchers theorize that if free radical injury is an important factor in the etiology of exercise-induced muscle damage, then increasing the antioxidant defense system by increasing intake of vitamin E and/or C should attenuate the muscle injury and subsequent effects, particularly in infrequent exercisers.[18]

In a double-blind, placebo-controlled trial, the effects of vitamin E on exercise-induced oxidative stress were examined in young (22-29 year old) and older (55-74 years old) men who exercised by running downhill. A supplement containing 800 IU of vitamin E was given each day for 48 days. The vitamin E treatment showed minimal effects on the responses of the young subjects, but had a substantial effect on the responses of the older men, presumably by restoring the ability of the immune cells to invade the damaged muscle and stimulate repair.[15] In another placebo-controlled trial, 3000 mg vitamin C was given for three days prior to and four days after an exercise of the calf muscles that was designed to induce delayed onset muscle soreness. Less soreness was experienced by those taking vitamin C than those taking the placebo.[19]

Muscle damage from eccentric exercise not only results in increased release of muscle enzyme and disruption of muscle fiber ultrastructure, but also the loss of contractile performance. Recovery of contractile function after exercise was reported to be greater in subjects given 400 mg of vitamin C 21 days before and seven days after exercise, compared to a group receiving a placebo and to a group receiving 400 IU per day of vitamin E.[17]

These studies suggest that vitamin E supplementation reduces the biochemical markers of oxidative stress and muscle damage, and that vitamin C will alleviate muscle soreness and enhance return of muscle function following eccentric exercise. Since the studies in general had small sample sizes, further studies are needed to confirm the role of antioxidants in exercise-induced muscle damage and to determine whether there is a net benefit from antioxidant vitamin supplementation.[20]

Vitamin Supplements and Physical Performance. It is well accepted that a balanced, adequate diet is necessary for effective performance and that nutrient deficiencies will impair performance; hence, multivitamin/mineral supplements are considered appropriate to help replenish nutrient deficits that are not or cannot be met through the diet. A more popular question about supplemental vitamins and minerals is whether higher-than-dietary intakes confer additional benefits for athletic or work performance in well-nourished subjects. In general, the data do not support this notion.

Thiamin, vitamin B_6 and vitamin B_{12} are necessary for optimum neurological function, and in one study, supplemental thiamin and vitamins B_6 and B_{12} given for eight weeks improved firing accuracy in experienced marksmen, a task considered to reflect complicated interactions of various brain areas.[21] However, a single study cannot be considered definitive evidence of a significant impact on human performance.

Despite the fairly consistent evidence that vitamin E mitigates oxidative damage to muscles, no significant effect of vitamin E supplementation on human performance has been observed.[5,9,22,23] One possible exception is the observation that supplementation with 300-1200 IU a day of vitamin E improved VO2 max in mountain climbers at high altitudes.[9,24] The improved performance at high altitudes could be a result of the vitamin's antioxidant activity and/or could reflect the reduction in blood viscosity resulting from reduced leukocyte count following vitamin E supplementation.[24]

In contrast, approximately 20 reports have indicated some benefit from vitamin C supplementation on physical performance; however, since about the same number of studies found no effect, any conclusion is equivocal.[5] The differences in results may be related to the initial vitamin C status of the subjects, which is often not reported. Subjects with low initial status might be more apt to improve than subjects with adequate status. Exercise, however, does in some manner affect the metabolism of vitamin C (increases or decreases in blood, decreases in urine, decreases in tissues such as adrenals and brain, decreased post-exercise cortisol). One review of the vitamin C literature concluded that "persons involved in strenuous physical activity on a regular basis may be advised to consume vitamin C at levels approximating those reported to produce tissue saturation (100 to 200 mg/day)."[5]

Anemia can occur with prolonged exercise due to increased losses of iron in the sweat and urine and increased gastrointestinal blood loss.[25] In consequence, there is some increase in both iron deficiency and iron deficiency anemia in athletes. This is of particular concern for women, who are more subject to iron deficiencies because of lower dietary intakes as well as loss of iron through the menses. If iron deficiency is determined by laboratory testing of blood samples, iron supplements may be recommended. Iron supplements generally increase iron status in iron-deficient women athletes, as indicated by plasma ferritin, when given at levels of 50 mg/day or more.[25] Intake of such large doses might cause gastric distress, interfere with the absorption of zinc, and would be contradicted in persons with hemochromatosis. An alternative and safer method of improving iron status would be to consume 50-100 mg of vitamin C with each meal, either as part of the diet or as a supplement, to improve iron absorption.[26,27]

Environmental Hazards with Exercise. Although the health benefits of exercise are undisputed, there are some concomitant potential risks, some of which are mitigated by adequate vitamin nutrition. Since respiration increases markedly with exercise, the intake of air in physically active people is much higher than for sedentary people. Most exercise is outdoors, increasing exposure to air pollutants, excessive heat or cold, and ultraviolet light radiation. Ozone and nitrogen dioxide are potent oxidants that can damage the lungs, contribute to chronic obstructive disease and emphysema, and may trigger asthmatic attacks. Numerous studies show that ozone and nitrogen dioxide exposure in exercising normal or asthmatic adults causes a transient increase in both nasal airway constriction and in responsiveness to inhaled bronchoconstrictors.[28] In animals, both vitamin E and vitamin C protect against ozone and nitrogen dioxide toxicity.[29] Similarly, vitamin C has been shown to attenuate certain adverse effects of NO_2 in exercising humans. In humans, a positive correlation was found between plasma vitamin E levels and lung function in non-smokers.[30]

A role for vitamin C in alleviating heat stress during exercise in a hot environment has been suggested, and in fact, vitamin C supplements are given regularly to coal miners in South Africa. The practice is based on several studies conducted in South African mine workers during the 1970s which found that supplementation with either 250 or 500 mg of vitamin C per day improved a 10-day heat acclimation process, reduced rectal temperatures and reduced total sweat output.[31,32] However, similar results have not been found in better-nourished populations than the South African miners.[11,33] Additionally, significant losses of vitamin C in sweat have not been substantiated, and one early study failed to find any effect of 500 mg of supplemental vitamin C per day on pulse rate at rest and during exercise, rectal temperatures, or the occurrence of heat exhaustion.[34]

Exposure to ultraviolet (UV) light causes more rapid aging of the skin and increased rates of skin cancer and cataracts. These effects are at least partially mediated by the ability of ultraviolet light to cause oxidative damage by stimulating the formation of singlet oxygen, which, while not a free radical itself, is a very reactive form of oxygen and an important source of oxidative damage in people exposed to sunlight. Beta carotene is one of the most potent known "quenchers" of singlet oxygen. Exposure to UV light reduces plasma beta carotene and suppresses the immune response. Administration of beta carotene will enhance the immune response in exposed individuals; in animal models it inhibits skin cancer induced by ultraviolet radiation.[35] Vitamin E also helps protect against UV-induced immune suppression in the skin.[36] Either oral or topical administration of vitamins E and C will inhibit the reddening of the skin associated with sunburn.[37]

COMPLEMENTARY ROLES OF NUTRITION AND PHYSICAL ACTIVITY

Reducing Cardiovascular Disease Risk. Regular exercise even at relatively moderate levels will decrease the risk of coronary heart disease, hypertension and stroke and is a recommended part of a healthy lifestyle. The cardioprotective effects of exercise could be the result of better weight control; improved glucose tolerance and insulin metabolism; reduced blood pressure; better clearance of circulating triglycerides; improved lipid and lipoprotein metabolism; improvements in coagulation and hemostatic factors; and better cardiac performance due to an enhanced ability to increase stroke volume.[38] Ensuring adequate dietary intake of vitamins that have been shown to reduce the risk of CVD can augment and complement these beneficial effects of exercise. Just as oxidative stress can play a role in muscle injury, oxidative stress also is a critical part of the etiology of atherosclerosis.[39] Oxidation of low density lipoprotein (LDL) is thought to be a critical step in the development of atherosclerosis, the basis for CVD. Vitamin E is effective in preventing this oxidation.[40]

In the last few years a great deal of epidemiological evidence has suggested that intakes of vitamin E over 100 IU per day reduce the risk of coronary heart disease (Table 2).[41-48] This effect is seen primarily from supplement use, although in one recent study the association between vitamin E and reduced risk of death from coronary heart disease was most striking in the subgroup of women who did not take supplements, but who had high dietary intakes of vitamin E.[47] A recent clinical trial showed that supplementation with 800 IU vitamin E for approximately 18 months reduced the risk of non-fatal myocardial infarction by 77% in patients with atherosclerosis of the coronary arteries.[48] There are also some reports suggesting that higher intakes of vitamin C are associated with a lower risk of CVD.[49]

Relatively new research has related intakes of folate, vitamin B_6 and vitamin B_{12} to risk of CVD. Scientists have found that the risk of CVD is directly related to the level of homocysteine, an amino acid, in the plasma and that higher levels of these three vitamins will lower the level of homocysteine. Elevated homocysteine is a risk factor completely independent of cholesterol levels and most other accepted risk factors.[50-52] Most Americans are not consuming these vitamins at levels considered desirable to limit homocysteine, which potentially may offset the benefits of other lifestyle changes they are making.[53]

Table 2

STUDIES OF VITAMIN E AND REDUCED RISK OF HEART DISEASE[41-48]		
Stampfer *et al.* 1993	87,245 female nurses	40% reduced risk of CHD in women taking 100 IU or more/day for at least 2 years
Rimm *et al.* 1993	39,100 male health professionals	45% reduced risk of CHD in men taking 100-249 IU/day for at least 2 years
Losonczy *et al.* 1994	10,249 elderly	58% reduced risk of CHD
Meyer *et al.*1994	2,226 Canadian men	40% reduced risk of first IHD event in supplement users
Hodis *et al.* 1995	162 men	Lower progression rate after PTCA in supplement users (100 IU/day)
Knekt *et al.* 1994	5,133 Finnish men and women	45% reduced rate of CHD in those with higher intakes of vitamins C and E from fruits and vegetables
Kushi *et al.* 1996	34,486 postmenopausal women	58% reduced risk for coronary heart disease death among women with dietary vitamin E intakes of (8 IU or more/d); 47% reduced risk among women with combined diet & supplement intakes of 8 IU or more
Stephens *et al.* 1996	2,002 patients with coronary atherosclerosis	77% reduction in heart attacks in patients treated with either 800 IU or 400 IU of vitamin E daily versus placebo group

IHD = ischemic heart disease CHD = coronary heart disease PTCA = angioplasty

Effects on Immune Function. Frequent reports of increased susceptibility to infectious diseases among highly trained competitive athletes suggest that high intensity exercise may suppress the immune system.[54,55] The levels of cortisol and catecholamines are increased during exercise. These hormones are immune-suppressive and could partially account for the decreased immunity. Specific aspects of the immune system are affected by a single session of intense exercise: for example, natural killer cell activity is reduced, and the number of specialized immune cells called CD4+ cells decreases. On the other hand, studies in mice suggest that moderate exercise may enhance the immune system, and the effect of moderate exercise on human immune function has yet to be elucidated.

Vitamins E, C, A, B_6 and beta carotene all play critical roles in the immune system, and elevated intakes particularly of vitamins E, C and beta carotene have been shown to enhance immune function. Runners taking daily supplements of 600 mg vitamin C had fewer and less severe respiratory infections following a marathon than runners on a placebo.[56] Whether other vitamins would help prevent the increase in infectious disease accompanying and following intense exercise is not known.

Maintaining Bone Health. One of the benefits of weight-bearing exercise is a reduced risk of osteoporosis, a chronic loss of bone which can lead to life-threatening bone fractures. Nutrition also is an important factor in slowing the progression of this disease. It is generally agreed that preventive measures should start as early as possible since after menopause bone loss is more difficult to reverse. In addition to calcium, the nutrients that play an essential role in the growth and maintenance of bones are vitamins D, C, and K. Therefore, a diet that provides recommended levels of these vitamins and minerals can complement the benefits of exercise in promoting bone health.

Management of Diabetes. Numerous epidemiological studies have shown a protective effect of a physically active lifestyle on the development and management of non-insulin dependent diabetes mellitus (NIDDM).[2] Some of the recent evidence suggests a dose-response relationship. For example, women in the Nurses' Health Study who exercised five times a week had a lower risk of NIDDM than those who exercised vigorously at least once a week.[57] Similar patterns were found in a five-year prospective study of male physicians.[58] The protective effect of exercise is believed to be mediated through improved sensitivity to insulin and an increased rate of glucose disposal, decreased deposition of total body fat or intra-abdominal fat, and improvements of other risk factors for atherosclerosis which may decrease the risk of certain complications of diabetes.

Recent studies have linked elevated blood glucose levels with increased oxidative stress in both humans and animals with diabetes.[59] It has been suggested that a free radical process involving peroxidation of lipids in cell membranes may be involved in the altered glucose metabolism associated with diabetes.[60] Vitamin E has been shown to inhibit protein glycosylation in diabetic patients,[61] and preliminary evidence suggests that it may also improve insulin action,[62,63] normalize platelet activity,[64] help protect blood vessel walls,[65] reduce lipid peroxidation products in the blood and improve the lipid profile.[66]

Vitamin C has also shown benefits in NIDDM patients, including a decline in fasting plasma insulin, LDL-cholesterol and triglycerides, as well as improvements in glucose metabolism.[67-68] Although there is much to be learned about the effects of micronutrients and exercise in the management and prevention of diabetes, current science is at least suggestive of both independent and synergistic benefits.

SUMMARY

The relationship between vitamin nutrition and exercise/physical activity is multi-faceted, complex, and not completely understood. Both physical activity and optimal vitamin nutrition confer health benefits, and these effects are in many cases complementary. It is well accepted that adequate nutritional status is associated with better physical performance and that vitamin deficiencies can impair performance. Whether vitamin needs are increased by exercise is less clear. There are some data to suggest that physical activity may alter status of some B vitamins as well as vitamin C, but whether these alterations increase requirements is not known definitively.

Data to support a role for vitamin supplements at levels above optimal dietary levels are generally lacking, if the goal is to improve physical performance. However, a reasonable case may be made for vitamin/mineral supplementation that corrects suboptimal intakes or supports targeted health goals of physical activity—for example, calcium supplementation plus exercise to preserve bone health, or vitamin E supplementation plus exercise to promote cardiovascular health. More subtle relationships, such as may exist among exercise, vitamin nutrition and immune function, or exercise, vitamin nutrition and diabetes, present new opportunities for continued nutrition and physical activity research.

VNIS COMMENTARY: NUTRITION AND EXERCISE STATUS OF AMERICANS

Exercise and physical activity practices in America, like nutrition practices in America, span a widely varied landscape. On the positive side, membership in health, racquet and sports clubs has grown steadily over the past two years, as has the number of people in the 34-55 year age group who report themselves as frequent exercisers.[69-70] A recent survey from the National Sporting Goods Association found that current participation in common physical activities is widespread:[71]

Walking (for exercise)	*70.8 million Americans*
Swimming	*60.3 million*
Bicycling	*49.8 million*
Running	*20.6 million*
Step aerobics	*11.5 million*

On the other hand, such regular physical activity is typical of only about a third of the population. In response to a 1991 survey, 58% of adults reported that they exercised sporadically or not at all, and more recently, it has been estimated that between 24 and 30 percent of U.S. adults engage in no leisure time physical activity.[72,73] Sedentary lifestyles have been linked to the prevalence of obesity and overweight in the US as well as to cardiovascular disease, diabetes, osteoporosis and some cancers; indeed, sedentary people have a 20-100 percent increase in risk of early death compared with those who are most active.[1,74,75] One study estimated a health care cost savings potential of $5.6 billion annually if just 10% of adults began a regular walking program.[76]

Statistics like these, coupled with evidence of real health gains to be accrued from regular activity, have provided the impetus for a new national physical activity initiative. There is clearly a trend to integrate public education and understanding about physical activity with that of improved nutrition, as evidenced by the inclusion of recommendations for physical activity in the most recent edition of the Dietary Guidelines for Americans.[77] Although some progress has been made in changing America's nutrition habits, health and nutrition educators are well aware that men and women generally need to double their intake of fruits and vegetables; that women are getting only about half the calcium they need; that folic acid intakes fall far below the amount recommended by the Public Health Service; that Americans of all ages generally exceed the "use sparingly" guideline for intake of fats, oils and sweets.

Heightened focus on physical activity as a national priority provides an excellent opportunity for health and nutrition educators and communicators to join exercise physiologists and other sports professionals in providing the public with an integrated perspective about these two critical, complementary "pillars" of good health. It is reasonable to hope that those who are motivated to make positive changes in one arena (i.e., increasing exercise/activity or improving nutrition habits) can also be motivated to make complementary changes in the other.

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