# Mild hyperbaric oxygen: mechanisms and effects

# 轻度高压氧：机制和效果

Adequate oxygen supply by exposure to mild hyperbaric oxygen at appropriately high atmospheric pressure (1266–1317 hPa) and increased oxygen concentration (35–40% oxygen) has a possibility of improving the oxidative metabolism in cells and tissues without barotrauma and excessive production of reactive oxygen species. Therefore, metabolic syndrome and lifestyle-related diseases, including type 2 diabetes and hypertension, in rats were inhibited and/or improved by exposure to mild hyperbaric oxygen. It accelerated the growth-induced increase in oxidative capacity of the skeletal muscle in rats and inhibited the age-related decrease in oxidative capacity of the skeletal muscle in mice. A decrease in dopaminergic neurons in the substantia nigra of mice with Parkinson’s disease was inhibited by exposure to mild hyperbaric oxygen. This review describes the beneficial effects of exposure to mild hyperbaric oxygen on some metabolic diseases and their perspectives.

通过在适当的高气压（1266-1317hPa）下暴露于轻度高压氧和增加氧气浓度（35-40%氧气）来提供足够的氧气，有可能改善细胞和组织的氧化代谢，而不会造成气压伤和活性氧的过量产生。因此，通过暴露于轻度高压氧，可以抑制和/或改善大鼠的代谢综合征和生活方式相关疾病，包括2型糖尿病和高血压。它加速了生长诱导的大鼠骨骼肌氧化能力的增加，并抑制了与年龄相关的小鼠骨骼肌氧化能力的下降。暴露于轻度高压氧可抑制帕金森病小鼠黑质多巴胺能神经元的减少。这篇综述描述了暴露于轻度高压氧对某些代谢疾病的有益影响及其观点。

# Keywords Dissolved oxygen · Mild hyperbaric oxygen · Oxidative metabolism

# 溶解氧·轻度高压氧·氧化代谢

Oxygen is essential for energy production in most cells and is carried by red blood cells that flow in blood vessels. The oxygen bound to hemoglobin in red blood cells is referred to as the ‘oxygen bound to hemoglobin.’ The oxygen dissolved in blood plasma is referred to as the ‘dissolved oxygen.’ Although the quantity of dissolved oxygen is less than that of oxygen bound to hemoglobin, it can flow to peripheral cells, especially those in the brain, heart, and eyes, even if capillaries are very narrow, since it is dissolved directly in blood plasma (Fig. 1a).

氧气是大多数细胞产生能量所必需的，由血管中流动的红细胞携带。红细胞中与血红蛋白结合的氧气被称为“与血红蛋白结合的氧气”溶解在血浆中的氧气被称为“溶解氧”尽管溶解氧的数量少于与血红蛋白结合的氧气的数量，但它可以流向外周细胞，特别是大脑，心脏和眼睛中的细胞，即使毛细血管非常狭窄，因为它直接溶解在血浆中（图1a）

Enhanced atmospheric pressure and/or increased oxygen concentration can increase the oxygen content, especially the dissolved oxygen content in blood plasma [1, 2] (Fig. 1b). Exposure to mild hyperbaric oxygen at 1266–1317 hPa with 35–40% oxygen inhibited metabolic syndrome [3] and lifestyle-related diseases, including type 2 diabetes [4] and hypertension [5], in experimental animals since it improved oxidative metabolism, which was lower than that in controls [6].

增强的大气压和/或增加的氧气浓度可以增加氧气含量，特别是血浆中的溶解氧含量[1,2]（图1b）。暴露于1266-1317hPa的轻度高压氧和35-40%的氧气可抑制实验动物的代谢综合征（3）和生活方式相关疾病，包括2型糖尿病（4）和高血压（5），因为它改善了氧化代谢，低于对照组（6）

However, side effects associated with enhanced atmospheric pressure and/or increased oxygen concentration, including barotrauma and excessive production of reactive oxygen species in tissues and organs, are thought to occur. Hyperbaric oxygen therapy at 2026–3039 hPa with 100% oxygen for medical treatment is associated with the risk of inducing myopia and cataracts [7–9]. A previous study [7] reported that exposure to hyperbaric oxygen at 2534 hPa with 100% oxygen for 2–2.5 h, twice a week, up to 100 sessions, induces cataracts in guinea pigs. Similarly, myopia and cataracts developed in human lenses after exposure to prolonged hyperbaric conditions of 2026–2534 hPa with 100% oxygen for 90 min, once a day, from 150 to 850 sessions [8]; however, it was rarely seen to occur after only 48 sessions of hyperbaric oxygen conditions at 2534 hPa for 90 min [9]. Hyperbaric oxygen therapy increases the number of invasive inflammatory cells in mice [10] and causes excessive production of reactive oxygen species in rats [11, 12], rabbits [13], and humans [14]. Excessive production of reactive oxygen species plays a key role in the pathogenesis of many diseases and their complications; generation of free radicals and increased levels of oxidative stress are associ-­­­­ ted with atherosclerosis, cataracts, retinopathy, myocardial

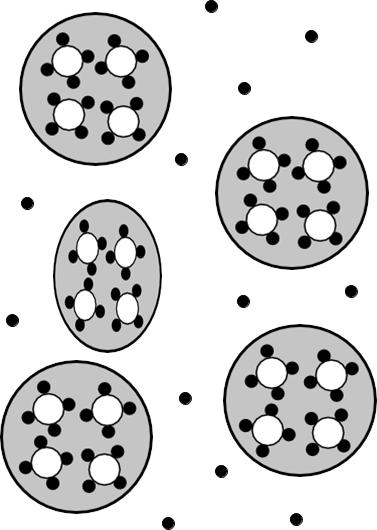
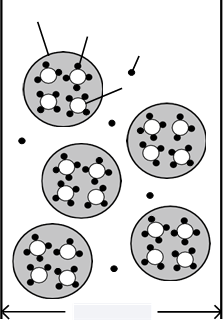
然而，人们认为会发生与大气压力升高和/或氧气浓度升高相关的副作用，包括气压伤和组织和器官中活性氧的过量产生。2026–3039 hPa的高压氧治疗，100%氧气用于治疗，与诱发近视和白内障的风险有关[7-9]。先前的一项研究（7）报道，在2534 hPa的高压氧和100%氧气下暴露2-2.5小时，每周两次，最多100次，会诱发豚鼠白内障。同样，人类晶状体在暴露于2026-2534hPa的长期高压条件下，每天一次，100%氧气90分钟，每天一次，从150到850次，出现近视和白内障[8]；然而，在2534 hPa的高压氧条件下仅进行48次90分钟后，很少发生这种情况。高压氧治疗增加了小鼠侵袭性炎症细胞的数量，并导致大鼠（11，12），兔子（13）和人类（14）过量产生活性氧。活性氧的过量产生在许多疾病及其并发症的发病机理中起着关键作用；自由基的产生和氧化应激水平的增加是相关的-­­­­

Fig. 1 Schematic diagram depicting the distribution of oxygen bound to hemoglobin and dissolved oxygen in blood vessels under normobaric (a) and mild hyperbaric oxygen (b) conditions. Abundant hemoglobin is distributed in red blood cells, and up to four oxygen molecules can bind to one hemoglobin (oxygen bound to hemoglobin). The other kind of oxygen is dissolved in blood plasma (dissolved oxygen). The quantity of dissolved oxygen is less than that of oxygen bound to hemoglobin. Enhanced atmospheric pressure and/or oxygen concentration can increase oxygen in the body, especially dissolved oxygen in blood plasma. In addition, dissolved oxygen is able to flow to the peripheral cells, especially those in the brain, heart, and eyes, even if capillaries are very narrow, since it is dissolved directly in blood plasma­­ and reduced quantity of oxygen bound to hemoglobin in rats [18]

图1示意图描绘了在常压（a）和轻度高压氧（b）条件下与血红蛋白和溶解氧结合的氧气在血管中的分布。丰富的血红蛋白分布在红细胞中，多达四个氧分子可以与一个血红蛋白结合（氧与血红蛋白结合）。另一种氧溶解在血浆中（溶解氧）。溶解氧的量小于与血红蛋白结合的氧的量。大气压和/或氧气浓度的增加会增加体内的氧气，尤其是血浆中的溶解氧。此外，溶解氧能够流向外周细胞，特别是大脑、心脏和眼睛中的细胞，即使毛细血管非常狭窄，它也能直接溶解在血浆中­­­并减少大鼠血红蛋白结合的氧气量。

Exposure to mild hyperbaric oxygen at a low oxygen concentration (35–40% oxygen) does not result in enhanced levels of oxidative stress in rats [5, 19] and humans [20]. Based on previous findings from experimental animal and human clinical studies, the effects of exposure to mild hyperbaric oxygen at 1266–1317 hPa with 35–40% oxygen are summarized in Table 1. It is noteworthy that these findings were obtained in the first step of exposure to mild hyperbaric oxygen. Therefore, it is expected to define a suitable recommendation regarding a generally applicable protocol for exposure to mild hyperbaric oxygen in the subsequent step. This review describes the beneficial effects of exposure to mild hyperbaric oxygen on some metabolic diseases and related perspectives.­­

暴露于低氧浓度（35-40%氧气）的轻度高压氧不会导致大鼠（5，19）和人类（20）的氧化应激水平升高。根据实验动物和人类临床研究的先前发现，表1总结了在1266–1317 hPa和35–40%氧气下暴露于轻度高压氧的影响。值得注意的是，这些发现是在暴露于轻度高压氧的第一步中获得的。因此，预计将在随后的步骤中定义一个关于暴露于轻度高压氧的普遍适用方案的合适建议。这篇综述描述了暴露于轻度高压氧对某些代谢疾病的有益影响和相关观点。



# Metabolic syndrome

# 代谢综合征

Metabolic syndrome, linked to chronic physical inactivity and consumption of a high-fat and high-cal-orie diet, is characterized by obesity, high blood pressure, and increased blood glucose, low density lipoprotein-cholesterol, and triglyceride levels [, ]. Experimental animals with metabolic syndrome have a nonsense mutation in the leptin receptor [, ]. Rats with metabolic syndrome have a low oxidative capacity in the skeletal muscle compared to normal rats [, ]. Reduced oxidative capacity in the skeletal muscle is suggested to impair glucose metabolism and increase the risk of development of metabolic syndrome [, , , ]. Rats with metabolic syndrome exposed to mild hyperbaric oxygen had lower blood pressure, blood glucose, total cholesterol, triglyceride, and insulin levels, but higher adi-ponectin levels than those not exposed to mild hyperbaric oxygen []. In addition, rats with metabolic syndrome exposed to mild hyperbaric oxygen had high oxidative capacity and increased levels of peroxisome proliferator-activated receptor γ coactivator-1α (Pgc-1α) mRNA, which plays an important role in oxidative metabolism by regulating mitochondrial biogenesis in the skeletal muscle [, ].­­­

代谢综合征与慢性缺乏运动和高脂高钙饮食有关，其特征是肥胖，高血压，血糖，低密度脂蛋白胆固醇和甘油三酯水平升高[，]。患有代谢综合征的实验动物在瘦素受体中具有无意义的突变[，]。与正常大鼠相比，代谢综合征大鼠骨骼肌的氧化能力较低[，]。建议骨骼肌氧化能力降低会损害葡萄糖代谢并增加代谢综合征发生的风险[，]。暴露于轻度高压氧的代谢综合征大鼠的血压，血糖，总胆固醇，甘油三酯和胰岛素水平较低，但adi-ponectin水平高于未暴露于轻度高压氧的大鼠[]。此外，暴露于轻度高压氧的代谢综合征大鼠具有高氧化能力，过氧化物酶体增殖物激活受体γ共激活因子-1α（Pgc-1α）mRNA水平升高，其通过调节线粒体生物发生在氧化代谢中起重要作用。骨骼肌[，]。­­­

Exposure to mild hyperbaric oxygen is thus considered to inhibit the growth-related increase in blood glucose levels and decrease the muscle oxidative capacity of rats with metabolic syndrome owing to the improved oxidative metabolism [].

因此，由于氧化代谢的改善，暴露于轻度高压氧被认为可以抑制与生长相关的血糖水平升高，并降低代谢综合征大鼠的肌肉氧化能力[]。

# Type 2 diabetes

# 2型糖尿病

In general, blood glucose, hemoglobin A1c (HbA1c), and triglyceride levels are higher in patients with diabetes than in healthy lean people. Hyperglycemia worsens vascular disorders including a stroke, myocardial infarction, retinopathy, nephropathy, and peripheral neuropathy. Patients with type 2 diabetes have decreased oxidative capacity in the skeletal muscle, similar to those with metabolic syndrome [28]. Decreased oxidative capacity in the skeletal muscle of patients with diabetes is suggested to be related to insulin resistance and impaired glucose metabolism. Both non-obese and obese rats with diabetes, which were developed as Goto-Kakizaki [29, 30] and Otsuka Long-Evans Tokushima Fatty [31] models, respectively, have lower oxidative capacity in the skeletal muscle than that of normal rats [32–34]. Zucker diabetic fatty rats show similar muscle properties as obese rats with diabetes [35]. Blood glucose, HbA1c, and triglyceride levels were higher in non-obese and obese rats with diabetes than in normal rats [33, 34], and those levels improved by exposure to mild hyperbaric oxygen [4, 36]. In the skeletal muscle, Pgc-1α, myogenin, and myogenic factor 5 mRNA levels and oxidative capacity were higher in rats with diabetes exposed to mild hyperbaric oxygen than in those not exposed to mild hyperbaric oxygen [37, 38].­­­

一般来说，糖尿病患者的血糖，血红蛋白A1c（HbA1c）和甘油三酯水平高于健康瘦人。高血糖会加重血管疾病，包括中风，心肌梗塞，视网膜病变，肾病和周围神经病变。2型糖尿病患者骨骼肌氧化能力下降，与代谢综合征患者相似（28）。糖尿病患者骨骼肌氧化能力降低与胰岛素抵抗和糖代谢受损有关。分别开发为Goto-Kakizaki[29，30]和Otsuka Long-Evans-Tokushima Fatty[31]模型的非肥胖和肥胖糖尿病大鼠的骨骼肌氧化能力均低于正常大鼠[32-34]。Zucker糖尿病脂肪大鼠表现出与肥胖糖尿病大鼠相似的肌肉特性（35）。非肥胖和肥胖糖尿病大鼠的血糖，HbA1c和甘油三酯水平高于正常大鼠[33，34]，并且这些水平通过暴露于轻度高压氧而得到改善[4，36]。在骨骼肌中，暴露于轻度高压氧的糖尿病大鼠的Pgc-1α，肌生成素和肌源性因子5 mRNA水平和氧化能力高于未暴露于轻度高压氧的大鼠[37，38]。

The growth-related increase in blood glucose levels in rats with type 2 diabetes was inhibited by exposure to mild hyperbaric oxygen [, –]. The decreased blood glucose levels induced by exposure to mild hyperbaric oxygen in rats with type 2 diabetes were maintained even after these rats were subsequently returned to breeding under normobaric conditions []. The increased blood glucose levels of adult rats with type 2 diabetes not exposed to mild hyperbaric oxygen were lowered even if they were exposed to mild hyperbaric oxygen afterward []. These results indicate that low blood glucose levels in rats with type 2 diabetes can be maintained by exposure to mild hyperbaric oxygen compared to those not exposed to mild hyperbaric oxygen, both when blood glucose levels are increasing during growth [–] and after blood glucose levels are high in adulthood [].Exposure to mild hyperbaric oxygen, therefore, seems to prevent the decrease in oxidative capacity of the skeletal muscle of rats with type 2 diabetes, irrespective of their age [36–38]. In addition, exposure to mild hyperbaric oxygen is effective for the inhibition [4, 36–38] as well as improvement [39] of hyperglycemia in rats with type 2 diabetes.­

暴露于轻度高压氧可抑制2型糖尿病大鼠血糖水平的生长相关增加[，–]。即使这些大鼠随后在常压条件下恢复繁殖，2型糖尿病大鼠暴露于轻度高压氧引起的血糖水平降低也得以维持[]。即使在之后暴露于轻度高压氧，未暴露于轻度高压氧的成年2型糖尿病大鼠的血糖水平升高也会降低[]。这些结果表明，与未暴露于轻度高压氧的大鼠相比，暴露于轻度高压氧可以维持2型糖尿病大鼠的低血糖水平，无论是在生长过程中血糖水平升高[–]还是在成年后血糖水平高。因此，无论年龄大小，暴露于轻度高压氧似乎都可以防止2型糖尿病大鼠骨骼肌氧化能力的下降[36-38]。此外，暴露于轻度高压氧可有效抑制2型糖尿病大鼠的高血糖[4，36-38]并改善[39]。­

The morphological and histochemical properties of fibers in the skeletal muscle correspond well with those of spinal motoneurons that innervate muscle fibers [40–43]. A previous study [44] had shown decreased oxidative capacity of spinal motoneurons in rats with type 2 diabetes. In addition, this study [44] had examined the effects of exposure to mild hyperbaric oxygen on oxidative capacit

骨骼肌纤维的形态和组织化学特性与支配肌纤维的脊髓运动神经元的形态和组织化学特性非常吻合[40-43]。先前的一项研究（44）显示，2型糖尿病大鼠脊髓运动神经元的氧化能力降低。此外，这项研究还研究了暴露于轻度高压氧对氧化能力的影响­­。

of spinal motoneurons. The inhibition of growth-related decrease in oxidative capacity of spinal motoneurons by exposure to mild hyperbaric oxygen corresponds well with that observed in muscle fibers innervated by spinal motoneurons, thereby implying that the properties and responses of spinal motoneurons and their innervating muscle fibers are closely related under diabetic, as well as normal conditions [44].

脊髓运动神经元。通过暴露于轻度高压氧抑制脊髓运动神经元氧化能力的生长相关降低与在脊髓运动神经元支配的肌纤维中观察到的一致，从而暗示脊髓运动神经元及其支配肌纤维的性质和反应在糖尿病以及正常情况下密切相关。

# Diabetes‑induced catarac

# 糖尿病引起的白内障

Cataracts are characterized by an accumulation of sorbitol, mediated by aldose reductase activity. The polyol pathway is the major contributor to diabetes-induced cataracts, i.e., the denaturation of lens protein, since an increased flux of glucose via this pathway leads to diabetic lesions in the lens, and large quantities of glucose are reduced to sorbitol, which is not metabolized any further [45]. The increased availability of oxygen by exposure to mild hyperbaric oxygen inhibited the growth-related increase in blood glucose levels in rats with type 2 diabetes, thereby delaying cataract formation induced by the accumulation of sorbitol in the lens [46].­

白内障的特征是由醛糖还原酶活性介导的山梨醇积累。多元醇途径是糖尿病引起的白内障的主要原因，即晶状体蛋白的变性，因为通过该途径增加的葡萄糖通量导致晶状体中的糖尿病病变，并且大量葡萄糖被还原为山梨醇，山梨醇不再被代谢。通过暴露于轻度高压氧增加氧气的可用性抑制了2型糖尿病大鼠血糖水平的生长相关增加，从而延缓了山梨醇在晶状体中积累引起的白内障形成。

# Hypertension

# 高血压

Spontaneously hypertensive rats (SHRs) were developed by repeated inbreeding of normal Wistar–Kyoto rats, which exhibited high blood pressure levels [47]. SHRs exposed to mild hyperbaric oxygen showed lower systolic and diastolic blood pressure levels than those of age-matched SHRs not exposed to mild hyperbaric oxygen [5]. Furthermore, SHRs exposed to mild hyperbaric oxygen had lower oxidative stress and higher antioxidant levels than age-matched SHRs not exposed to mild hyperbaric oxygen [5]. Abnormalities of central neural mechanisms regulating the peripheral sympathetic outflow, i.e., an enhanced sympathetic activation and catecholamine metabolism following neurotransmitter release from nerve endings, have been associated with hypertension [48, 49]. An enhanced sympathetic activation in rats with hypertension is mediated by the overproduction of highly reactive oxygen species, which induces sympatho-excitation and thus hypertension [50, 51], whereas exposure to mild hyperbaric oxygen has been suggested to eliminate reactive oxygen species and maintain normal blood pressure levels [5]. An enhancement of oxidative metabolism in cells and tissues increases the carbon dioxide concentration in the surrounding region, which in turn, facilitates blood flow in blood vessels [52, 53].­­

自发性高血压大鼠（SHR）是通过正常Wistar-Kyoto大鼠的反复近交而产生的，表现出高血压水平（47）。暴露于轻度高压氧的SHR的收缩压和舒张压水平低于未暴露于轻度高压氧的年龄匹配的SHR（5）。此外，与未暴露于轻度高压氧的年龄匹配的SHR相比，暴露于轻度高压氧的SHR具有较低的氧化应激和较高的抗氧化水平。调节外周交感神经流出的中枢神经机制异常，即神经递质从神经末梢释放后交感神经激活和儿茶酚胺代谢增强，与高血压有关[48，49]。高血压大鼠交感神经激活增强是由高活性氧的过量产生介导的，高活性氧可诱导交感神经兴奋，从而引起高血压[50，51]，而轻度高压氧暴露可消除活性氧并维持正常血压水平（5）。细胞和组织中氧化代谢的增强会增加周围区域的二氧化碳浓度，进而促进血管中的血流[52，53]。­­

# Arthritis

# 关节炎

Exposure to mild hyperbaric oxygen is effective in decreasing levels of reactive oxygen species overproduced in arthritis [19]. Oxidative stress and C-reactive protein levels are high in rats with arthritis [54], whereas the levels shifted to those in normal rats by exposure to mild hyperbaric oxygen [19]. Arthritic joints are characterized by hypoxia caused by an increased oxygen demand and decreased blood flow triggered by the increased intraarticular pressure [55–57]. Therefore, exposure to mild hyperbaric oxygen is effective in reducing reactive oxygen species levels overproduced during arthritis [19].­­­

暴露于轻度高压氧可有效降低关节炎中过量产生的活性氧水平（19）。关节炎大鼠的氧化应激和C反应蛋白水平较高（54），而暴露于轻度高压氧（19）后，其水平转移至正常大鼠。关节炎关节的特征是由需氧量增加引起的缺氧和由关节内压力增加引起的血流量减少[55-57]。因此，暴露于轻度高压氧可有效降低关节炎期间过量产生的活性氧水平。

# Pigmentation and proliferation

# 色素沉着和增殖

The skin undergoes age-related degenerative changes, including tissue dehydration and transepidermal water loss [58]. Proliferation of epidermal basal cells decreases with age [59]. Exposure to mild hyperbaric oxygen has been reported to accelerate the proliferative activity of epidermal basal cells in aged mouse skin [60]. An adequate oxygen supply from exposure to mild hyperbaric oxygen may accelerate the turnover rate of aged skin by enhancing the proliferative activity of epidermal basal cells. Therefore, the dissolved oxygen, which is increased by exposure to mild hyperbaric oxygen, is considered to diffuse from the dermis to the epidermis through blood microcirculation, thus accelerating proliferation of epidermal basal cells and inhibiting epidermal aging [60].­­­皮肤经历与年龄相关的退行性变化，包括组织脱水和经表皮水分流失（58）。表皮基底细胞的增殖随着年龄的增长而减少（59）。据报道，暴露于轻度高压氧可加速老年小鼠皮肤表皮基底细胞的增殖活性。暴露于轻度高压氧的充足氧气供应可以通过增强表皮基底细胞的增殖活性来加速衰老皮肤的周转率。因此，通过暴露于轻度高压氧而增加的溶解氧被认为通过血液微循环从真皮扩散到表皮，从而加速表皮基底细胞的增殖并抑制表皮衰老。­­­

Suppression of ultraviolet B irradiation-induced pigmentation is due, at least in part, to the reduction in prostaglandin synthesis via the inhibition of cyclooxygenase by indomethacin, and to the induction of annexin or lipoco-rtin by corticosteroids [61]. Exposure to mild hyperbaric oxygen was found to accelerate the fading of ultraviolet B irradiation-induced melanin pigmentation of the skin [62]. Furthermore, senile spot sizes on faces became smaller after exposure to mild hyperbaric oxygen [62]. Keratinocyte proliferation and epidermal cell regeneration are considered to be activated by enhanced oxidative metabolism induced by exposure to mild hyperbaric oxygen, which may be effective for damage repair in the epidermis.­­

抑制紫外线B照射诱导的色素沉着至少部分是由于吲哚美辛通过抑制环氧合酶来减少前列腺素合成，以及皮质类固醇诱导膜联蛋白或脂质体。发现暴露于轻度高压氧可加速紫外线B照射引起的皮肤黑色素沉着的消退。此外，暴露于轻度高压氧后，面部老年斑变小。角质形成细胞增殖和表皮细胞再生被认为是通过暴露于轻度高压氧诱导的氧化代谢增强而激活的，这可能对表皮损伤修复有效。­­

# Adaptation of the neuromuscular system

# 神经肌肉系统的适应

Exposure to mild hyperbaric oxygen facilitates oxidative metabolism, particularly in pathways such as the mitochondrial tricarboxylic acid cycle, thus enhancing the oxidative capacity of skeletal muscle fibers and the spinal motoneurons innervating them [63, 64]. Growing rats exposed to mild hyperbaric oxygen exhibited greater voluntary running activities compared to those maintained under normobaric conditions (without exposure to mild hyperbaric oxygen); the oxidative capacity of muscle fibers and the innervating spinal motoneurons in rats increased after exposure to mild hyperbaric oxygen [64].­

暴露于轻度高压氧有助于氧化代谢，特别是在线粒体三羧酸循环等途径中，从而增强氧化骨骼肌纤维和支配它们的脊髓运动神经元的能力[63，64]。与常压条件下（不暴露于轻度高压氧）相比，暴露于轻度高压氧的生长大鼠表现出更大的自愿跑步活动；暴露于轻度高压氧后，大鼠肌纤维和神经支配脊髓运动神经元的氧化能力增加。­

图片包含 游戏机, 照片, 体育, 房间

描述已自动生成Reduction in skeletal muscle mass is one of the most striking features of the aging process [65]. Atrophy and reduced oxidative capacity of the skeletal muscle have been observed with age [66, 67]. Muscle atrophy in aged rats is associated with reduced activity levels of certain enzymes involved in oxidative metabolism [68]. An age-related decrease in oxidative capacity of the skeletal muscle in mice was reported to be reversed by exposure to mild hyperbaric oxygen [69] as much as by exercise in aged rats [70]. Exposure to mild hyperbaric oxygen has an advantage over exercise since it can increase the dissolved oxygen content owing to the enhanced atmospheric pressure and/ or increased oxygen concentration, which does not occur in exercise. Therefore, it is concluded that exposure to mild hyperbaric oxygen reduces the age-related decrease in oxidative capacity of the skeletal muscle due to the improvement in oxidative metabolism [69].­­骨骼肌质量的减少是衰老过程中最显着的特征之一。随着年龄的增长，骨骼肌萎缩和氧化能力降低[66，67]。老年大鼠的肌肉萎缩与某些参与氧化代谢的酶的活性水平降低有关（68）。据报道，通过暴露于轻度高压氧（69）和老年大鼠（70）的运动，可以逆转小鼠骨骼肌氧化能力的年龄相关下降。暴露于轻度高压氧比运动具有优势，因为它可以增加溶解氧含量，因为大气压力增加和/或氧气浓度增加，这在运动中不会发生。因此，可以得出结论，由于氧化代谢的改善，暴露于轻度高压氧可降低骨骼肌氧化能力的年龄相关性降低（69）

Chronic inactivity, as in hind limb unloading and microgravity exposure, induces atrophy and degenerative changes in the skeletal muscle and its fibers [71–75], as well as in spinal motoneurons that innervate the muscle fibers [76–82]. Muscle atrophy and decreased oxidative capacity were shown to be unaffected by either pre- or post-conditioning with exposure to mild hyperbaric oxygen [83]. In contrast, the degenerative changes were almost restored to normal levels after reloading, when pre- and post-conditionings with exposure to mild hyperbaric oxygen were combined [83]. Only a combination of pre- and post-conditionings is considered to activate the signaling cascades required for the recovery from atrophy and decreased oxidative capacity of the skeletal muscle.­

慢性不活动，如后肢卸载和微重力暴露，会引起骨骼肌及其纤维的萎缩和退行性变化[71-75]，以及支配肌纤维的脊髓运动神经元[76-82]。肌肉萎缩和氧化能力下降被证明不受暴露于轻度高压氧的预处理或后处理的影响（83）。相反，当暴露于轻度高压氧的前后条件结合时，重新加载后退行性变化几乎恢复到正常水平（83）。只有预处理和后处理的组合被认为可以激活从萎缩中恢复所需的信号级联反应，并降低骨骼肌的氧化能力。

# Parkinson’s disease

# 帕金森氏病

Parkinson’s disease is a progressive neurodegenerative disorder in the elderly that is characterized by typical motor symptoms such as resting tremors, rigidity, bradykinesia, and gait disturbances [84]. Parkinson’s disease results from the progressive decrease in dopaminergic neurons in the substantia nigra [85]. Exposure to mild hyperbaric oxygen was shown to inhibit the decrease in dopaminergic neurons in the substantia nigra of a neurotoxic experimental animal with Parkinson’s disease [86]. The number of times the feet of the mouse slid off the stick in a balance beam test was fewer in mice with Parkinson’s disease exposed to mild hyperbaric oxygen than in those not exposed to mild hyperbaric oxygen []. PGC-1α, a transcriptional co-activator, may be one of the factors that contribute to the improvement in oxidative metabolism of dopaminergic neurons in Parkinson’s disease [], since oxidative metabolism, mitochondrial biogenesis, oxidative stress, and gene expression are regulated by PGC-1α [, ].­­­ It is concluded that exposure to mild hyperbaric oxygen activates oxidative metabolism in the dopaminergic neurons in the substantia nigra and inhibits the reduction in dopaminergic neurons, thereby resulting in the inhibition of Parkinson’s disease [86].­

帕金森病是一种老年人进行性神经退行性疾病，其特征是典型的运动症状，如静息性震颤、僵硬、运动迟缓和步态障碍。帕金森病是由黑质多巴胺能神经元逐渐减少引起的（85）。暴露于轻度高压氧可抑制帕金森病神经毒性实验动物黑质多巴胺能神经元的减少。在平衡木测试中，暴露于轻度高压氧的帕金森病小鼠的脚从棍子上滑落的次数少于未暴露于轻度高压氧的小鼠[]。PGC-1α是一种转录共激活因子，可能是改善帕金森病多巴胺能神经元氧化代谢的因素之一[]，因为氧化代谢，线粒体生物发生，氧化应激和基因表达受PGC-1α调控[，]。­­­

结论是，暴露于轻度高压氧可激活黑质多巴胺能神经元的氧化代谢，抑制多巴胺能神经元的减少，从而抑制帕金森病（86）。­

# Infertility

# 不孕症

Hyperbaric oxygen therapy, an established medical treatment usually conducted under conditions of 2026–3039 hPa with 100% oxygen, has been investigated for improving female [90–93] and male [94, 95] infertility. However, several side effects, including barotrauma and excessive production of reactive oxygen species, associated with hyperbaric oxygen therapy, have been reported [7–12, 14]. Low metabolism in the uterus and ovaries may be a factor responsible for infertility since the former reduces the ability of fertilized eggs to remain in the uterus. Exposure to mild hyperbaric oxygen has been suggested to enhance oxygen supply to cells and tissues, thus improving oxidative metabolism, without barotrauma and excessive production of reactive oxygen species. In a recent study [96], 37 women with intractable infertility, who had previously received over 5 embryo transfers with a low clinical pregnancy rate (4.9%) and without birth, were exposed to mild hyperbaric oxygen before receiving any further embryo transfer. As a result, 13 women achieved clinical pregnancy with a rate of 13.8%; 5 women gave birth after in vitro fertilization treatment. Two women achieved natural conception and gave birth. However, 1 woman had an extra-uterine pregnancy, and 5 women had miscarriages.­­­

高压氧治疗是一种既定的医学治疗方法，通常在2026-3039 hPa的条件下进行，氧气含量为100%，已被研究用于改善女性[90-93]和男性[94，95]不育。然而，已经报道了与高压氧治疗相关的几种副作用，包括气压伤和活性氧的过量产生[7-12，14]。子宫和卵巢的低代谢可能是导致不孕症的一个因素，因为前者降低了受精卵留在子宫中的能力。已经提出暴露于轻度高压氧可以增强细胞和组织的氧气供应，从而改善氧化代谢，而不会产生气压伤和活性氧的过量产生。在最近的一项研究（96）中，37名患有顽固性不孕症的女性，之前曾接受过5次以上的胚胎移植，临床妊娠率较低（4.9%），并且没有出生，在接受任何进一步的胚胎移植之前暴露于轻度高压氧。结果，13名女性达到了临床妊娠率，为13.8%；5名女性在体外受精治疗后分娩。两名妇女自然受孕并分娩。然而，1名女性有宫外孕，5名女性流产。­­­

# Perspectives on exposure to mild hyperbaric oxygen

# 轻度高压氧暴露的前景

Exposure to mild hyperbaric oxygen is effective for elderly people, those with physical disability, as well as injured athletes, since no special movement needs to be performed under mild hyperbaric oxygen conditions. In future, exposure to mild hyperbaric oxygen may be investigated for: (1) prevention and improvement of dementia, (2) improvement of functional imbalances of autonomic (sympathetic and parasympathetic) nerves, e.g., menopausal disorders and emotional instability, (3) maintenance and improvement of­ immunity, health, and physical fitness, and (4) early recovery from an injury. Further studies are required to solve these problems and define a useful protocol for exposure to mild hyperbaric oxygen.­

暴露于轻度高压氧对老年人，身体残疾者以及受伤的运动员是有效的，因为在轻度高压氧条件下不需要进行特殊运动。将来，可能会研究暴露于轻度高压氧的原因：（1）预防和改善痴呆；（2）改善自主神经（交感神经和副交感神经）的功能失衡，例如更年期障碍和情绪不稳定；（3）维持和改善­免疫力，健康和身体健康，以及（4）受伤后的早期康复。需要进一步的研究来解决这些问题，并确定暴露于轻度高压氧的有用方案。­