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Efficacy of Virtual Reality Exerciseson Sarcopenia in Patients with Liver Transplantation: A Review Article

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Abstract

Liver transplantation (LT) is a life-saving procedure for patients with end-stage liver disease and acute liver failure. However, post-transplant recovery is often complicated by muscle weakness, reduced functional capacity, and a decline in overall quality of life. Sarcopenia is considered a significant complication observed in patients undergoing liver transplantation either candidates or recipients. The primary modalities for treating sarcopenia are exercise and nutritional interventions. Physical therapy plays a crucial role in enhancing recovery by improving muscle strength, endurance, and overall physical function. Virtual reality (VR) exercise offers a promising approach to combat sarcopenia. By immersing users in interactive virtual environments, VR can enhance exercise adherence and motivation. This review aims to analyze the existing research on the effects of physical therapy following liver transplantation, focusing on its impact on functional outcomes, quality of life, and prevention of post-operative complications.

Key Words: *Sarcopenic – Liver transplantation and virtual reality.*

Introduction

LIVER transplantation (LT) is a life-saving procedure performed to replace a diseased or nonfunctional liver with a healthy liver from either a living or deceased donor. As, Liver transplantation has altered the natural history of end stage liver disease and is now considered the preferred therapy for a wide range of previously fatal chronic hepatic diseases. This procedure restores liver function and provides a significant survival benefit, with advancements in surgical techniques, organ preservation, and immunosuppressive therapies improving outcomes *[1]*. Sarcopenia, a progressive age-related loss of muscle mass and function, significantly impacts the quality of life and increases the risk of frailty, falls, and disability in older adults. This condition results from a complex interplay of factors including decreased protein synthesis, increased protein breakdown, and reduced physical activity. The underlying mechanisms involve age-related changes in hormones, neurotransmitters, and cellular signaling pathways, leading to impaired muscle fiber regeneration and reduced muscle strength. Sarcopenia is a major public health concern, and interventions aimed at preventing and managing this condition are crucial for promoting healthy aging and maintaining functional independence in older populations *[2]*.

The primary modalities for treating sarcopenia are exercise and nutritional interventions. Resistance exercise, specifically, has been demonstrated to effectively increase muscle mass and strength. This type of exercise stimulates muscle protein synthesis, leading to hypertrophy and improved functional capacity. Additionally, high-protein diets, rich in essential amino acids, are crucial for promoting muscle repair and growth. A well-balanced diet, combined with regular physical activity, can significantly mitigate the effects of sarcopenia and improve quality of life *[3]*. Virtual reality (VR) exercise offers a promising approach to combat sarcopenia. By immersing users in interactive virtual environments, VR can enhance exercise adherence and motivation. Techniques such as gamification, biofeedback, and avatar embodiment can be incorporated to make exercise more engaging and effective. VR-based resistance training can target specific muscle groups, while VR-based aerobic exercise can improve cardiovascular health. By providing a controlled and immersive environment, VR can help older adults maintain muscle mass and function, ultimately mitigating the effects of sarcopenia *[4]*.

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Anatomy and function of liver:

The liver is one of the largest and most vital organs in the human body, located in the upper right quadrant of the abdomen. It has a unique structure, consisting of two main lobes the right and left lobes divided by the falciform ligament. The liver is composed of specialized cells called hepatocytes, which make up approximately 80% of its mass and are responsible for many of its critical functions. Blood supply to the liver is dual; it receives oxygenated blood from the hepatic artery and nutrient-rich blood from the portal vein, which carries blood from the gastrointestinal tract *[5]*. The liver performs numerous essential functions, including the metabolism of nutrients, detoxification of harmful substances, and synthesis of proteins. It plays a crucial role in carbohydrate metabolism by converting excess glucose into glycogen for storage and releasing glucose into the bloodstream when needed. The liver is also involved in lipid metabolism, producing bile acids that aid in the digestion and absorption of fats. Additionally, it synthesizes vital proteins, including albumin, which maintains oncotic pressure in the blood, and clotting factors necessary for blood coagulation *[6]*.

Pathophysiology of Liver:

The liver maintains homeostasis by controlling the metabolism of glucose, lipids, and amino acids. It is also crucial for metabolism, detoxification, and protein synthesis. Viral infections, alcohol use, metabolic diseases, and toxins are some of the things that might interfere with liver function and cause diseases like cirrhosis, hepatocellular carcinoma, and hepatitis *[7]*. An imbalance between the generation of reactive oxygen species (ROS) and antioxidant defenses leads to oxidative stress, which is a major factor in liver disorders. The liver is particularly susceptible to oxidative damage because of its function in xenobiotic metabolism, which can result in DNA damage, protein alteration, and lipid peroxidation. This mechanism speeds up the progression of diseases like alcoholic liver disease and non-alcoholic fatty liver disease (NAFLD) *[8]*. Liver damage is further exacerbated by chronic inflammation, with the NLRP3 inflammasome being a key player in immune activation. Pro-inflammatory cytokines are released as a result, worsening fibrosis and hepatocyte damage. Simple steatosis can progress to cirrhosis, steatohepatitis, and liver cancer over time due to ongoing inflammation *[9]*. Furthermore, excessive extracellular matrix deposition by activated stellate cells causes hepatic fibrosis, which gradually deteriorates liver function and raises the risk of hepatocellular cancer *[10]*.

Impact of Liver on Muscle Strength:

The liver's function significantly influences muscle strength and overall physical health. One of the critical ways the liver affects muscle function is through its role in protein metabolism. The liver is responsible for synthesizing amino acids and proteins, which are essential for muscle repair and growth. When the liver is compromised, as seen in liver diseases such as cirrhosis or fatty liver disease, its ability to produce these proteins is impaired, leading to muscle wasting and weakness. This condition, known as sarcopenia, is particularly prevalent in individuals with chronic liver disease and can significantly impact their quality of life *[11]*.

Moreover, the liver helps regulate metabolic processes that influence energy production. It converts carbohydrates and fats into energy, which is vital for muscle function during physical activity. When liver function is compromised, energy metabolism may be disrupted, leading to reduced energy availability for muscle contractions. This can manifest as fatigue and decreased exercise capacity, further exacerbating muscle weakness *[12]*. Additionally, the liver plays a crucial role in the clearance of toxins and metabolic byproducts from the bloodstream. Elevated levels of these substances due to liver dysfunction can lead to increased inflammation and oxidative stress, which can damage muscle cells and impair their function. Chronic inflammation has been linked to muscle wasting, highlighting the liver's indirect role in maintaining muscle health *[13]*.

Complications of Liver Disease:

Portal hypertension is one of the serious side effects of liver disease that can cause hemorrhage by increasing the portal vein's resistance. Endoscopic variceal ligation and medication to reduce portal pressure are part of the management *[14]*. Toxin buildup from liver malfunction causes hepatic encephalopathy, which impairs cognition from confusion to coma. Lactulose serves as the primary therapy ingredient to reduce ammonia levels *[15]*. Portal hypertension and hypoalbuminemia cause ascites, a fluid accumulation in the peritoneal cavity that raises the risk of spontaneous bacterial peritonitis (SBP) and necessitates therapeutic paracentesis *[16]*. Hepatocellular carcinoma (HCC) is also more likely to occur in patients with chronic liver disease, especially those with cirrhosis and hepatitis. Alpha-fetoprotein (AFP) monitoring and imaging surveillance are crucial for early detection and management *[17]*.

Treatment Modalities of Liver Diseases:

The underlying cause, severity, and consequences of liver illnesses determine how they should be managed. Antiviral treatments are crucial for hepatitis B and C. Direct-acting antivirals have revolutionized the treatment of hepatitis C, with cure rates exceeding 90%, and nucleoside/nucleotide analogs such as entecavir and tenofovir have been shown to effectively suppress hepatitis B *[18]*. Liver histology in non-alcoholic fatty liver disease (NAFLD) can be improved by lifestyle changes, including losing weight, however in more severe cases, medication choices such pioglitazone and vitamin E may be prescribed; New treatments that focus on hepatic fat metabolism emphasize the necessity of individualized care [19]. Abstinence is essential for alcoholic liver disease, and in more severe cases, corticosteroids are employed. Recovery from the disease depends heavily on counseling, support groups, and nutritional assistance [20]. When liver disease progresses to end-stage liver failure or cirrhosis, liver transplantation becomes the definitive treatment option. Liver transplantation is indicated for patients with decompensated liver disease, acute liver failure, or certain malignancies. The success of liver transplantation hinges on careful patient selection, appropriate donor matching, and effective post-transplant care to prevent rejection and manage complications. Overall, transplantation offers a chance for a complete cure and significantly improves the quality of life for patients with advanced liver disease [21].

Liver Transplantation:

Liver transplantation is a critical surgical procedure that involves replacing a diseased or failing liver with a healthy liver from a donor. This procedure is primarily indicated for patients suffering from end-stage liver disease (ESLD), acute liver failure, or certain liver cancers that cannot be treated effectively through other means [22]. The most common causes leading to the need for liver transplantation include chronic hepatitis C, alcoholic liver disease, non-alcoholic fatty liver disease (NAFLD), and autoimmune liver diseases such as primary biliary cholangitis [23]. Despite the life-saving potential of liver transplantation, the procedure is not without complications. Post-operative challenges may include infections, bleeding, and complications related to immunosuppressive therapy required to prevent organ rejection. Furthermore, patients often experience complications such as biliary leaks or strictures, and there is a risk of developing new liver diseases in the transplanted organ [24]. These complications can significantly impact a patient's recovery and overall health status, making ongoing monitoring and management essential.

Complications of Liver Transplantation:

A liver transplant is a complicated operation that frequently necessitates further treatments due to the possibility of early problems such infections, bleeding, and bile leakage. The surgical nature of the treatment and the patient's pre-existing diseases are the causes of these problems, which makes careful observation crucial for improved post-transplant results [25]. Organ rejection is a serious long-term issue that calls for immunosuppressive treatment in order to avoid graft failure. To balance rejection prevention and reduce side effects, these drugs must be carefully managed because they can result in infections, renal failure, and metabolic abnormalities [26]. Furthermore, hepatocellular carcinoma (HCC) and recurrent liver disease are still hazards, especially for patients who have previously had viral hepatitis, underscoring the necessity of routine monitoring with imaging and serum markers [27]. Another serious post-transplant consequence is sarcopenia, which is characterized by weakness and muscle loss. While hospitalization, inactivity, and immunosuppressive therapy increase post-transplant muscle degradation, pre-existing sarcopenia can prolong recovery. Programs for rehabilitation and nutritional support are crucial for enhancing liver transplant recipients' quality of life and speed of recovery [23].

Role of Physical Therapy in Post-Transplant Recovery:

1- Early Mobilization and Functional Independence: Early mobilization after LT is associated with reduced hospital length of stay and decreased risk of complications such as deep vein thrombosis and pulmonary infections [28]. Studies have shown that structured mobilization protocols initiated within the first week post-transplant significantly improve muscle strength and overall mobility [29].

2- Aerobic and Resistance Training: Cardiorespiratory fitness is often impaired in liver transplant recipients, necessitating aerobic training to improve endurance and cardiovascular function [30]. Resistance training has also been demonstrated to counteract muscle wasting and enhance functional capacity [30,31].

3- Balance and Neuromuscular Rehabilitation: Neuromuscular impairments, including proprioceptive deficits and gait disturbances, are common post-transplant. Balance training and proprioceptive exercises help in fall prevention and functional independence [32].

4- Psychosocial and Quality of Life Improvements: Physical therapy not only improves physical function but also contributes to mental well-being. Several studies have reported significant improvements in depression, anxiety, and overall quality of life in liver transplant recipients who undergo structured rehabilitation [33].

Sarcopenia:

Sarcopenia is defined as the age-related loss of skeletal muscle mass and strength, characterized by a progressive decline in muscle function, which significantly impacts mobility, physical performance, and overall health in older adults. It is recognized as a syndrome that not only affects physical capability but also increases the risk of falls, disability, and mortality [34,35].

Sarcopenia and Its Effect on Quality of Life:

The effects of sarcopenia extend beyond physical health; it significantly impacts the quality of life (QoL) for affected individuals. Patients with sarcopenia experience reduced physical performance, leading to limitations in daily activities and increased dependence on caregivers [35]. This decline in functional capacity can contribute to feelings of helplessness and depression, further diminishing QoL. In patients with liver diseases, managing sarcopenia is crucial, as it can adversely affect clinical outcomes, including survival rates and overall well-being [36]. Therefore, interventions aimed at improving muscle mass and strength, such as nutritional support and physical therapy, are essential components of holistic care for patients with liver disease and those undergoing transplantation.

Epidemiology of Sarcopenia:

Sarcopenia is increasingly recognized as a critical public health issue, particularly among older adults. The epidemiological aspects of sarcopenia can be summarized as follows:

- Prevalence: Sarcopenia is prevalent among older populations, with estimates suggesting that it affects approximately 10% to 30% of individuals aged 60 and older, increasing to about 50% in those aged 80 and above. The prevalence rates can vary significantly based on geographic location, sex, and diagnostic criteria used [37].
- Risk Factors: The risk of sarcopenia is increased by a number of factors, such as age-related physiological changes that dramatically increase muscle loss [38]. Another factor is gender: women age with a more noticeable loss of muscle strength than males, who typically have larger muscle mass [39]. Furthermore, long-term conditions like diabetes, heart disease, and chronic obstructive pulmonary disease (COPD) worsen muscle loss and raise the risk of developing sarcopenia [40].
- Impact of Lifestyle: While regular exercise, especially strength training, helps maintain muscular mass and function, sedentary behavior dramatically raises the likelihood of sarcopenia [37]. Furthermore, sarcopenia is exacerbated by low protein intake, which is prevalent in older persons and hinders muscle growth and repair [38].
- Geographic and Ethnic Variations: Epidemiological studies indicate variations in the prevalence of sarcopenia across different regions and ethnic groups. For instance, studies conducted in Asian populations have highlighted unique genetic and environmental factors influencing sarcopenia prevalence compared to Western populations [40].
- Consequences: The implications of sarcopenia extend beyond muscle loss. It is associated with increased morbidity, frailty, falls, and mortality. Individuals with sarcopenia face a higher risk of disability and a reduced quality of life [37].
- Screening and Diagnosis: Early identification of sarcopenia is vital for intervention. Various diagnostic criteria exist, including the European Working Group on Sarcopenia in Older People (EWGSOP) guidelines, which emphasize the assessment of muscle mass, strength, and physical performance [39].

The assessment of sarcopenia:

It is essential for identifying individuals at risk of adverse health outcomes. One of the most widely accepted methods for diagnosing sarcopenia involves measuring skeletal muscle mass, strength, and physical performance. Techniques such as dual-energy X-ray absorptiometry (DXA) and bioelectrical impedance analysis (BIA) are commonly used to evaluate muscle mass. These methods have been shown to provide reliable estimates of body composition, allowing clinicians to detect changes in muscle mass over time [41]. Muscle strength is another critical component of sarcopenia assessment, typically evaluated using handgrip strength tests. Handgrip dynamometry is a simple and effective measure that correlates well with overall muscle strength and functional capacity. Low handgrip strength has been associated with increased risks of falls, disability, and mortality, making it a valuable tool in the clinical setting. Additionally, performance-based assessments, such as the Timed Up and Go (TUG) test and the Short Physical Performance Battery (SPPB), provide insight into functional mobility and balance, further informing the diagnosis of sarcopenia [42].

In recent years, advancements in imaging technologies have enhanced the assessment of sarcopenia. Computed tomography (CT) and magnetic resonance imaging (MRI) allow for precise quantification of muscle area and density, offering more detailed insights into muscle quality. These imaging modalities can help differentiate between sarcopenia and other conditions, such as obesity sarcopenia, where fat infiltration into muscle can complicate the assessment. Moreover, the integration of artificial intelligence (AI) in analyzing imaging data is emerging as a promising approach to standardize and streamline sarcopenia evaluation [43].

New techniques, such as ultrasound, are being investigated for the assessment of sarcopenia since they provide a non-invasive, economical means of determining the thickness and quality of muscles. Research demonstrates its potential as a widely used diagnostic tool and demonstrates its efficacy in a variety of populations [44]. Accurate diagnosis and treatment of sarcopenia will depend on the integration of several assessment modalities as research progresses.

The management of sarcopenia:

A multimodal strategy is necessary to manage sarcopenia, combining pharmaceutical, medical, and physical therapy approaches to maximize muscular health. In addition to routine screening for early detection, medical management emphasizes on treating underlying problems such as diabetes, heart disease, and renal failure. Strength and muscular mass can be increased by controlling metabolic diseases, keeping an eye on diet, and taking into account hormonal treatments like testosterone supplements for men [45]. In order to effectively manage sarcopenia, particularly in patients who have underlying medical disorders, pharmaceutical therapies are crucial. Supplements containing protein and necessary amino acids aid in the synthesis of muscle protein, while anabolic substances such as myostatin inhibitors and SARMs have the potential to encourage muscle growth. Furthermore, especially in older persons, vitamin D and omega-3 fatty acids may help reduce the onset of sarcopenia [46]. Physical interventions are critical in the management of sarcopenia, with resistance training being the cornerstone of rehabilitation strategies. Resistance exercises have been shown to improve muscle strength, mass, and overall physical function. Tailored exercise programs should be designed based on individual capabilities, with a focus on progressive overload to stimulate muscle adaptation. In addition to resistance training, incorporating aerobic exercises can enhance cardiovascular health and overall physical endurance. Recent research highlights the importance of structured exercise regimens in long-term care settings, emphasizing that regular physical activity can significantly reduce the incidence and severity of sarcopenia among older adults [47].

Role of Physical Therapy in Treatment of Sarcopenia:

Physical therapy is a critical component in the management of sarcopenia, particularly among older adults. It focuses on enhancing muscle strength, improving functional performance, and reducing the risk of falls. Evidence suggests that structured physical therapy programs can significantly increase muscle mass and strength in sarcopenic individuals. For example, a study demonstrated that preoperative physical therapy in patients with sarcopenia undergoing spinal surgery resulted in improved postoperative mobility and shorter hospital stays. The findings highlight the importance of preemptive physical interventions in mitigating the adverse effects of sarcopenia on recovery and functional independence (48).Further supporting the efficacy of physical therapy, a network meta-analysis revealed significant improvements in sarcopenia indices among patients who engaged in physical therapy compared to those receiving other treatments for knee osteoarthritis, a condition commonly associated with sarcopenia. This study emphasizes the role of physical therapy not only in addressing pain and functional limitations but also in targeting the underlying muscle degeneration associated with sarcopenia. By incorporating resistance training and tailored exercise regimens, physical therapy can effectively promote muscle hypertrophy and enhance overall physical function in affected individuals [49]. Moreover, physical therapy has been shown to improve balance and reduce fall risk in elderly patients with sarcopenia. Rakaieva and Aravitska [50] investigated the effects of a specialized physical therapy program on balance indicators in older adults with sarcopenia, finding significant improvements that contributed to a decreased risk of falls. Given that falls are a major concern for the elderly, effective physical therapy interventions can play a vital role in enhancing safety and quality of life for those suffering from sarcopenia.

Virtual Reality (VR) exercise:

Virtual Reality (VR) exercise refers to an interactive, computer-generated environment that immerses users in a simulated physical space, allowing them to engage in various physical activities while receiving real-time feedback. This technology employs VR headsets, motion sensors, and haptic devices to create an engaging and motivating exercise experience. It enables users to perform exercises in a virtual setting that may resemble real-world environments or entirely fantastical landscapes, thus enhancing user engagement and adherence to exercise regimens [51].

Importance of Virtual Reality Exercise:

The rising prevalence of sarcopenia, characterized by the age-related loss of muscle mass and strength, necessitates effective intervention strategies. The importance of VR exercise in this context lies in its potential to address several barriers to traditional exercise, such as a lack of motivation, fear of injury, and limited access to fitness facilities. VR exercise can facilitate safe and enjoyable environments for physical activity, encouraging older adults to engage in regular exercise routines [52]. Furthermore, the interactive nature of VR encourages social interaction and cognitive engagement, which are vital for mental health and overall well-being in older adults, thus providing a holistic approach to managing sarcopenia [53]. Virtual reality (VR) exercise has emerged as an innovative approach to enhance muscle strengthening, particularly in populations at risk of physical decline, such as individuals recovering from transplantation surgeries. The action of VR exercise involves the integration of immersive technology that engages users in a simulated environment, allowing them to perform physical activities while receiving real-time feedback. This interactive experience can significantly enhance motivation, adherence, and overall enjoyment of exercise, which are critical factors in muscle rehabilitation [51]. By providing a safe and engaging environment, VR exercise encourages users to participate in strength training exercises that target specific muscle groups, thereby promoting muscle hypertrophy and functional improvements [52].

The mechanism through which VR exercise facilitates muscle strengthening includes the stimulation of neuromuscular pathways and the enhancement of motor learning. When users engage in VR activities, their bodies respond to the visual and auditory cues presented in the virtual environment, which can lead to improved coordination, balance, and strength [53]. This is particularly beneficial for patients recovering from transplantation, as they often experience muscle weakness and reduced physical function due to prolonged periods of inactivity or the effects of medications. Regular engagement in VR exercise can counteract these effects by promoting muscle activation and endurance, thus facilitating a gradual return to pre-transplant physical capabilities [54]. This is particularly important as respiratory function can be compromised due to surgical interventions, and effective rehabilitation strategies are essential for optimizing recovery outcomes.This multidimensional approach to rehabilitation not only addresses muscle strength but also supports the respiratory system, making VR exercise a valuable tool in post-transplant care.

Mechanism of Action:

The mechanism of action of VR exercise involves the integration of physical movement with cognitive and sensory stimulation. When users engage in VR exercise, the brain processes the simulated environment, which can enhance motor learning and coordination. This immersive experience encourages participants to perform exercises that mimic real-life movements, thereby facilitating neuromuscular adaptations critical for muscle growth and strength [51]. Additionally, the feedback provided through VR systems helps users monitor their performance, adjust their movements, and maintain optimal exercise intensity, which is crucial for effective muscle training. The combination of physical activity, cognitive engagement, and real-time feedback forms a comprehensive approach that enhances the efficacy of rehabilitation programs for sarcopenia.

Advantages of Virtual Reality Exercise:

The advantages of VR exercise extend beyond traditional physical therapy modalities. One of the primary benefits is its ability to enhance motivation and enjoyment through gamified elements, making exercise more appealing to older adults who may feel intimidated by conventional workout routines. VR exercise can significantly increase adherence to exercise programs, as users are more likely to participate in activities that are enjoyable and engaging [52]. Furthermore, VR exercise can be tailored to individual needs, allowing for customized regimens that address specific deficits in strength, balance, and coordination. This personalization is crucial for older adults with sarcopenia, as it enables therapists to focus on the unique challenges faced by each individual, thereby optimizing treatment outcomes [54].

Assessment of Strength, Function, and Quality of life in Sarcopenia:

Hand Grip Strength. One important measure of muscle strength and functional ability that is frequently used to forecast health consequences is hand grip strength. Exercises in virtual reality (VR) improve grip strength by offering dynamic, captivating activities that promote regular practice. By simulating real-world situations, virtual reality settings encourage muscle activation and neuroplasticity. To test improvements objectively, grip strength is usually measured using a dynamometer both before and after VR sessions [55]. A dynamometer is used to test hand grip strength. Participants sit with their arm at a 90-degree angle and their wrist in a neutral posture, doing three maximal grip trials per hand [56]. To measure muscle strength, identify imbalances, and monitor the effectiveness of rehabilitation, the highest reading is noted and compared to normative data based on age and gender [57,58].

Pinch Grip Strength. Strengthening your pinch grasp is essential for daily tasks and hand function. Through interesting challenges that encourage repetitive practice a crucial component of muscle strengthening VR exercise programs can improve pinch strength. Before and after VR training, the dynamometer is used to measure the three-point, two-point, and lateral pinch kinds. To monitor improvement depending on age, gender, and other variables, the highest reading from several trials is noted and contrasted with normative data [58].

Quadriceps Muscle Strength: For mobility and freedom, quadriceps strength is crucial, particularly for post-operative patients and older persons. Strength training is improved by VR exercise because it uses gamified environments that promote participation and muscle activation. Virtual challenges enhance quadriceps function and endurance by simulating real-life motions. Objective measures are obtained both before and after VR training using strength evaluation techniques including manual muscle testing and isokinetic dynamometry. A dependable method of monitoring development and assessing the efficacy of interventions is to use dynamometers, which measure the maximum isometric force during knee extension. Because of their simplicity of use, they can be used for both clinical and extensive evaluations [59].

Quality of Life: Quality of life in patients who have undergone liver transplantation is a crucial aspect of their recovery, as it encompasses physical, emotional, and social well-being. VR exercise programs can significantly impact quality of life by promoting physical activity in a supportive and immersive environment. Such programs often include tailored exercises that improve physical fitness, reduce anxiety, and foster social interaction through shared VR experiences. Assessment of quality of life can be conducted using validated questionnaires such as the WHOQOL-BREF before and after VR interventions, highlighting changes in various health domains [60]. The WHOQOL-BREF is a 26-item questionnaire used to evaluate quality of life in connection to social interactions, environment, psychological health, and physical health. From "very poor" to "very good," the responses reveal information on general life satisfaction. Researchers and medical professionals utilize it extensively to assess and enhance well-being [61].

Respiratory Function: While incentive spirometry is primarily used as a therapeutic tool to improve lung function, particularly after surgery or in patients with respiratory conditions, it can also provide indirect insights into respiratory function. By measuring the volume of air inhaled and the patient's ability to sustain a deep breath, incentive spirometry can help assess lung capacity and identify potential limitations in inspiratory effort [62].

Fatigue and Exercise Capacity: Fatigue and exercise capacity are critical factors in determining the overall health and functional ability of individuals, particularly in chronic disease populations. VR exercise can effectively address these issues by creating immersive environments that motivate users to engage in physical activity despite feelings of fatigue. By incorporating enjoyable and interactive elements, VR encourages longer and more frequent exercise sessions, which can enhance stamina and reduce fatigue over time. Assessment of exercise capacity can be performed through graded exercise testing or questionnaires that evaluate perceived exertion and fatigue levels before and after VR interventions [54].

According to Girard et al. [63] and Zhang et al. [36], the fatigue Index Scale (FIS) measures the percentage decrease in power output from peak to lowest levels after prolonged activity, such as treadmill or cycling tests, in order to quantify weariness. Greater weariness and decreased exercise tolerance are indicated by a higher FIS score, which aids in identifying physiological constraints. This instrument is useful for monitoring how well interventions improve exercise performance and tiredness in both clinical and research contexts.

Efficacy of VR in Treating Sarcopenia:

Growing evidence supports VR exercise as an effective intervention for sarcopenia, with meta-analyses showing improvements in muscle strength, balance, and physical function in older adults [51]. Vieira et al. [63] found that home-based VR exercise significantly enhanced strength and mobility compared to standard care, while Wang [53] highlighted its positive impact on mental health, reducing anxiety and depression. These findings emphasize VR exercise's potential to improve both physical and psychological well-being in individuals with sarcopenia. Liao et al. [49] divided 36 participants into three groups: Control, traditional exercise, and VR exercise in order to investigate the effect of VR on muscle strength in Parkinson's patients. According to their findings, VR training improved muscle strength more than traditional exercise, and the advantages lasted for up to a month. In a similar vein, Park and Yim [64] assessed a 3-D virtual reality kayak program for improving the cognitive abilities, muscular strength, and balance of seventy-two senior citizens who live in the community. According to their findings, this VR intervention shows promise in enhancing older persons' cognitive and physical abilities.

Htut et al. [65] investigated how 21 older people' physical and cognitive function was affected by VR-based exercise. According to their findings, participants favored VR-based exercise, which also produced quantifiable gains in cognitive and physical capacities. In a similar vein, Maynard et al. [66] investigated how VR-enhanced exercise training affected the quality of life and functionality of hemodialysis patients with sarcopenia. They came to the conclusion that functional ability and some characteristics of health-related quality of life were enhanced when virtual reality and physical training were combined.These results were corroborated by Kim et al. [67], who showed that VR-based interventions in physical therapy and rehabilitation markedly improved muscle strength and function, thereby confirming VR's promise as a promising therapeutic technique.

Chen et al. [4] evaluated 30 patients' hand grip strength and walking speed in order to investigate the effects of VR therapy on sarcopenic older individuals. After treatment, their results showed notable changes. In a similar vein, Sadeghi et al. [3] investigated how eight weeks of balancing, virtual reality, and combined training affected the strength, balance, and mobility of sixty-four older men. They found significant gains, especially in the areas of functional mobility and balance. These results were further supported by Corregidor et al. [68], who suggested that VR technology effectively improves older persons' functional mobility.Stavrou et al. [69] investigated the impact of VR exercise on respiratory and cognitive symptoms in long-post COVID-19 patients, concluding that VR is a safe and effective rehabilitation tool that enhances exercise performance. Similarly, Riaz et al. [70] examined Kinect-based VR training in patients with osteopenia, reporting improvements in physical performance and quality of life, highlighting VR's potential in musculoskeletal rehabilitation.

Challenges and Barriers to Rehabilitation:

Despite the proven benefits, several barriers hinder the implementation of physical therapy programs for liver transplant patients. These include lack of standardized rehabilitation protocols, limited access to specialized rehabilitation centers, and patient adherence issues [25]. Future research should focus on developing tailored rehabilitation strategies that address these barriers.

Conclusion:

Sarcopenia, characterized by the progressive loss of muscle mass and function, poses a significant risk for patients undergoing liver transplantation (LT). Physical therapy is a crucial component of post-liver transplant care, offering significant benefits in muscle strength, functional mobility, cardiovascular endurance, and quality of life. Understanding the efficacy of interventions such as virtual reality (VR) exercises could provide innovative solutions to mitigate the impacts of sarcopenia in this vulnerable population Future studies should aim at establishing standardized rehabilitation protocols to maximize patient benefits.

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تأثير الواقع الافتراضى على مرضى زراعة الكبد والذين يعانون من وهن العضلات

يشكل ضمور العضلات، الذى يتميز بالفقدان التدريجى لكتلة العضلات ووظيفتها، خطرًا كبيرًا على المرضى الذين يخضعون لعملية زرع الكبد (LT). يعد العلاج الطبيعى عنصرًا حاسمًا فى رعاية ما بعد زراعة الكبد، حيث يقدم فوائد كبيرة فى قوة العضلات، والتنقل الوظيفى، وتحمل القلب والأوعية الدموية، ونوعية الحياة. إن فهم فعالية التدخلات مثل تمارين الواقع الافتراضى (VR) يمكن أن يوفر حلولاً مبتكرة للتخفيف من آثار ضمور الأعضاء فى هذه الفئة الضعيفة من السكان. وينبغى أن تهدف الدراسات المستقبلية إلى إنشاء بروتوكولات إعادة تأهيل موحدة لتحقيق أقصى قدر من الفوائد للمرضى.