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Research Progress on Gait and Balance Function in Patients after Total Hip Arthroplasty

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Abstract: Total hip arthroplasty is regarded as the ultimate intervention for end-stage hip diseases, and its main role is to relieve pain and rebuild hip function. However, abnormal gait and balance disorders are still common in patients after surgery, and even leave dysfunction for a long time, which seriously affects the physiological function and social and psychological health of patients. In recent years, with the development of precision medicine and rehabilitation medicine, the research on gait and balance function of patients after total hip arthroplasty has attracted more and more attention, and the relevant research is becoming more refined and individualized. This article reviews the research progress of gait and balance function in patients after hip replacement by exploring the mechanism, influencing factors, adverse effects, evaluation methods and intervention strategies of gait and balance abnormalities in patients after hip replacement.

Keywords: Total Hip Arthroplasty; Gait; Balance; Rehabilitation.

1. Introduction

Total hip arthroplasty is regarded as the ultimate intervention for end-stage hip diseases. Its main role is to relieve pain and rebuild hip function. In recent years, with the aging population and the rise of obesity rate, the number of total hip arthroplasty has been increasing year by year. The surgery can effectively relieve pain and improve joint function, but patients still generally have gait abnormalities and balance disorders after surgery. For this, most patients can recover to the level of healthy individuals within 6 months after surgery, but there are still a small number of patients with symptoms may last for more than 6 months, or even exist for a long time[1]. Studies have shown that 5 years after total hip arthroplasty, about 9% of patients still have claudication, abnormal balance, and dissatisfaction with functional recovery[2, 3].

Patients with abnormal gait and balance function after total hip arthroplasty will not only increase the risk of falls, but also lead to the decline of motor ability, lumbar compensatory injury, prosthesis wear and social function limitation. However, the current treatment focuses on improving joint pain and range of motion, and the systematic understanding of postoperative gait and balance dysfunction is still insufficient, which is difficult to meet the increasing needs of patients for postoperative quality of life. This article aims to explore the research progress of gait and balance dysfunction in patients after total hip arthroplasty, and to provide new ideas for optimizing and personalized rehabilitation.

2. Mechanisms of Gait and Balance Dysfunction

2.1. Decreased Muscle Strength

Decreased muscle strength is a central factor in gait and balance abnormalities.Pre-existing hip and periarticular lesions before total hip arthroplasty may be accompanied by decreased muscle mass and function. On this basis, advanced age, surgical trauma and inflammation, preoperative and postoperative low nutritional status can interfere with the synthesis and release of growth hormone, insulin-like growth factor and other growth and metabolism-related hormones[4]. In addition, it can lead to microcirculation disturbance and accumulation of a large number of inflammatory factors in the affected muscle, which increase the decomposition rate of muscle protein and slow down the synthesis rate, resulting in the decline of muscle quality and function[5]. postoperative activity limitation leads to disuse atrophy of muscle, which further hinders muscle strength recovery and may even lead to long-term muscle strength defects[6]. Finally, it leads to secondary sarcopenia after surgery, which affects the gait stability and balance function of patients. Sekita et al. reported that about 21% of hip muscle strength decreases not only on the surgical side, but also on the non-surgical side[7], and such muscle strength decreases may persist for a long time, even 4 to 5 years after surgery [8]. It can be concluded that decreased muscle strength and asymmetric muscle strength in both lower limbs can have a significant impact on gait and balance function of patients.

2.2. Proprioception and Peripheral Nerves Were Impaired

Arthropathy and total hip replacement surgery damage some joint structures and surrounding elements, among which mechanoreceptors in the joint are the most affected elements by surgery[9], and mechanoreceptor damage can damage proprioception[10]. The decrease of proprioceptive signals, coupled with the degeneration of the neuromuscular junction, the coordination disorder of the two, the disorder of muscle activation and the prolongation of time lead to the decrease of neuromuscular coordination, which affects the gait and balance function of the patient, especially in the elderly[11-13]. Alshehri et al. also found a significant correlation between kinesiophobia and reduced proprioception more than 6 months after total hip arthroplasty, suggesting that impaired proprioceptive function may persist for a long time after total hip arthroplasty[14]. In addition, diseases such as hip joint disease or diabetes mellitus may lead to peripheral nerve

degeneration, and intraoperative excessive traction or compression may also cause peripheral nerve injury. Peripheral nerve injury will not only interfere with the efferent proprioception signal, but also weaken the motor regulation function of the nerve to the muscle, especially when the superior gluteus nerve innervating the gluteus medius muscle is injured. It can significantly affect the gait and balance function of patients after total hip replacement [15].

2.3. Central Motor Program Remodeling

Due to the long-term pain before surgery, some patients will form a "protective gait" by reducing the load and activity of the affected hip joint. Although the pain is relieved after surgery, the movement pattern will still retain the habit, which may be related to the remodeling of the central motor program, and the habit may still be manifested 1 year after surgery[16].

3. Influencing Factors of Abnormal Gait and Balance Function

3.1. Individual Factors

Age is an important factor affecting the recovery of gait and balance function after total hip arthroplasty. With the increase of age, muscle strength shows a significant downward trend [17], which may directly delay the rehabilitation process of gait and balance function after total hip arthroplasty. In terms of gender differences, gait and balance function of male patients after total hip arthroplasty are better than those of female patients[8, 18]. This may be due to weaker lower limb muscle strength and age-related hormonal changes in female patients. In addition, abnormal body mass index is also closely related to the risk of postoperative complications. The incidence of postoperative persistent pain in patients with low body mass index is 9% higher than that in patients with normal body mass index[19], which affects their functional exercise compliance. Obesity can also significantly hinder patients' return to sports after surgery[20], and inhibit the recovery of gait and balance function after surgery. It is worth noting that patients with a variety of comorbidities such as diabetes before surgery may have hyperalgesia and reduced analgesic sensitivity due to peripheral nerve function damage[21]. Such patients are prone to problems such as poor pain control and prolonged pain duration after surgery, which further affect the rehabilitation of their gait and balance function.

3.2. Surgical Related Factors

The direct anterior approach can better preserve the abductor function due to its characteristics of access through the anterior muscle space, while the posterolateral approach needs to peeling off the gluteus maximus and external rotator muscle group, which causes more soft tissue damage during operation, resulting in increased release of inflammatory factors and obvious pain in the early postoperative period. Cankaya et al. demonstrated that patients with a direct anterior approach showed better abductor strength, pain control, and balance in the early postoperative period[22]. In addition, Ulivi et al. also found through comparative analysis that the direct anterior approach had more advantages in intraoperative blood loss than the posterolateral approach and was more conducive to the recovery of muscle strength[23], which may be related to its minimally invasive characteristics of reducing muscle damage and promoting the early recovery of gait and balance function. However, it is worth noting that the functional recovery results of the two surgical approaches tend to be similar at more than 6 months after surgery[22], suggesting that the differences in the effects of different approaches on long-term postoperative gait and balance dysfunction may be limited. Leg length discrepancy after total hip arthroplasty is an important factor affecting postoperative function. The study by Bianco et al. confirmed that unequal length of the lower limbs can lead to compensatory pelvic tilt, which in turn can trigger gait abnormalities[24]. Mao-Yong Li et al. found a positive correlation between the degree of leg length discrepancy and femoral offset[25]. At the same time, the femoral offset is positively correlated with the muscle strength of hip abductors, which may be related to the significant changes in the muscle moment arm around the hip after surgery, leading to joint instability[26]. The recovery or moderate increase of femoral offset (2-3 mm) can provide better mechanical advantages for hip abductors and external rotators. Thereby enhancing joint stability and functional performance[27]. This finding suggests that accurate reconstruction of femoral offset during total hip arthroplasty not only helps to improve muscle strength but may also indirectly reduce gait compensation problems caused by leg length discrepancy.

3.3. Rehabilitation Related Factors

The start time of rehabilitation training after total hip arthroplasty has a significant impact on functional recovery. Patients who start rehabilitation training within 24 hours after operation have earlier hip function recovery, while delayed rehabilitation training may lead to delayed rehabilitation process[28]. It should be noted that postoperative pain can lead to a low willingness of patients to self-exercise, which may become an obstacle to early rehabilitation and then affect the postoperative recovery effect. At the same time, the inhibition of muscle contraction caused by pain and braking after total hip arthroplasty may further cause muscle weakness of the affected limb[29], leading to pelvic retropulsion and decreased gait stability[30]. In addition, the compliance of rehabilitation training after discharge is easily interfered by many factors, and some patients are difficult to achieve the expected rehabilitation goal due to lack of training willingness or objective conditions. Adebero et al. found that only 43.7% of patients after total hip replacement remembered that they had been taught to prevent falls during the rehabilitation period after total hip replacement[31], which may reflect the lack of clinical education, as well as the common problems of memory loss and compliance in the elderly population. As a result, their ability to understand and implement rehabilitation programs is reduced. However, rehabilitation after total hip arthroplasty is a long-term and continuous process, and even some rehabilitation tasks are difficult for elderly patients to complete independently without the assistance of their children or other family members. Therefore, the lack of family support will further affect the gait, balance function and overall rehabilitation effect of patients. The psychological state of patients after total hip replacement can also directly affect the rehabilitation effect. Some studies have found that some patients will actively reduce their activities after surgery due to fear-avoidance, especially the fear of falling, which will accelerate muscle atrophy and reduce their balance function[32]. In addition, anxiety, depression and other negative emotions not only increase the risk of social alienation, but also reduce the

compliance of treatment[33, 34], thus interfering with the rehabilitation process of gait and balance function and affecting the prognosis.

4. Adverse Effects of Abnormal Gait and Balance Function

4.1. Long-Term Postoperative Functional Deficits and the Risk of Secondary Injury Increase

Although patients have achieved significant functional improvement after total hip arthroplasty, many studies have shown that many patients still have abnormal gait and balance dysfunction for several years after surgery[1, 2, 16, 18]. This results in decreased walking efficiency, increased energy expenditure, and significantly increased risk of falls. Adebero et al. found that the incidence of falls in patients within 1 year after total hip arthroplasty can reach 23%[31], which is easy to cause serious complications such as periprosthetic fracture and dislocation, and even require secondary surgery. From the biomechanical point of view, the weakening of hip abductor and extensor muscle strength after total hip arthroplasty will cause abnormal compensatory gait such as Trendelenburg gait, which will not only affect the walking function, but also lead to a series of overuse and secondary injuries such as the lumbar spine and the healthy hip[35-37]. At the same time, it can also cause non-physiological load of hip prosthesis, worsen the mechanical environment of hip prosthesis, reduce the stability of hip prosthesis, and accelerate the wear of hip prosthesis[38].

4.2. Reduced Quality of Life and Increased Medical Burden

Persistent motor function limitation can reduce the range of daily activities, reduce social participation, increase the risk of anxiety and depression, and lead to a decline in the overall quality of life[17, 39]. At the same time, delayed functional recovery will prolong the rehabilitation period and increase the risk of prosthesis dislocation, fragility fracture, deep vein thrombosis and other complications. It not only affects the prognosis, but also significantly increases the medical burden due to the need for more medical intervention and complex care[40].

5. Methods of Assessment

5.1. Advantages And Limitations of Traditional Assessment Methods

At present, the common assessment methods for gait and balance dysfunction after total hip arthroplasty are Berg balance scale, timed up and go test, single leg standing test, joint position sense, etc. However, gait not only includes the kinematic parameters such as step length, step width, stride, pace, acceleration and symmetry, but also includes the dynamic parameters such as impact load, active moment and ground reaction force of the lower limbs. The Timed up and Go test was used to assess gait and dynamic balance, joint position sense was used to test proprioception, Berg balance scale was used to test fall risk, and one-leg standing test was used to test balance. These methods can provide a good overall assessment of the highly changed gait and balance function after surgery, but their sensitivity is low, and they largely rely on the subjective test and evaluation of the patient and the doctor.

5.2. Development and Application of Modified Clinical Assessment Tools

In recent years, many more accurate and personalized assessment methods have emerged in the evaluation of gait and balance function after total hip arthroplasty, which can better evaluate the postoperative gait and balance function of patients, and help to guide the intervention treatment of patients with different functional disorders after surgery. Compared with Berg balance scale, Tinetti scale can analyze gait and balance problems separately for targeted training. In this regard, the study of Kloos et al. also indicated that the Tinetti scale may be an effective tool for the assessment of gait and balance function in the future with high reliability[41]. Dynamic YBT-LQ test also has high reliability for dynamic balance function test, especially for patients who can stand on one foot and have good balance function. Dynamic YBT-LQ test can more finely evaluate the dynamic balance function of patients[18]. However, for methods tested manually, the sensitivity is low.

5.3. Advantages and Application Prospects of Machine-Assisted Assessment Technology

Machine-assisted assessments such as 3D gait analysis, motion analysis systems with wearable inertial sensors, and oscillatory platforms are effective methods for identifying subtle functional limitations with high sensitivity. Some studies have shown that gait parameters such as joint Angle, intra-articular torque and joint power can be calculated by three-dimensional gait analysis, which can guide the recovery of knee extensor muscle strength, hip flexor concentric contraction force and eccentric contraction force, and promote the recovery of gait function after surgery[42]. The wearable inertial sensor motion analysis system can be used to obtain the kinematic parameters of the joint at different angles such as flexion and extension, abduction and adduction, and internal-external rotation under different motion states such as squat, walking, and stair climbing[43]. For the assessment of balance function, it is necessary to consider the risk of falls and other factors in the early postoperative period, and it is often difficult to conduct a single leg standing test. The static balance function of patients can be assessed early by the plantar pressure plate balance test system[44]. Pohl et al. also showed that in the early postoperative period, the dynamic balance ability of patients in different directions such as mediolateral and anteroposterior can be tested by using an oscillating platform in the standing state[45]. At the same time, Alshehri et al. showed that the balance ability of patients in different directions was different after surgery through the test of the computer dynamic posturography system, which could be used to evaluate the multi-direction balance function of patients in the medium and long term after surgery[14]. In general, these robot-assisted assessment tests are more sensitive than traditional assessment tests, and can be more targeted to guide the gait and balance rehabilitation treatment in the whole process after total hip arthroplasty. However, these evaluation methods are mostly used in clinical trials, and have not been widely used in clinical work. With the improvement of people's requirements for quality of life, these detailed assessment methods may be needed to guide the formulation of personalized postoperative rehabilitation programs in the future, but more high-quality studies are still needed to prove their clinical applicability.

6. Intervention Strategies

6.1. Strength Training

The conventional rehabilitation methods mainly include ankle pump exercise, isometric contraction of lower limb muscles, squatting against the wall, translation and abduction of the affected limb on the bed, straight leg raising and side raising. However, in recent years, more targeted and more effective new strength training methods are gradually applied to clinical practice. Through directional muscle group guidance training, progressive guidance training can be carried out for different muscle groups of the lower limbs, which is more effective in restoring the strength and coordination of the muscles around the hip joint than conventional training[46, 47]. At the same time, the maintenance of gait and balance function not only depends on the hip muscle group, but also closely related to the whole motion chain of lumbar pelvis femur. The core muscle group of thoracolumbar back is also the basis for maintaining the balance of the trunk and limbs, so the postoperative strengthening of the bridge exercise and other core muscle group training also has a significant role in promoting the recovery of gait and balance function[48, 49]. In addition, the enhancement of upper limb muscle strength cannot be ignored, which can provide necessary support and assistance for daily activities and rehabilitation process. The recovery of muscle strength depends not only on the targeted strengthening of specific muscle groups, but also on the overall and systematic whole-body collaborative training. Through the mutual coordination and promotion of multiple muscle groups, the functional recovery can be promoted. Training with the help of professional equipment is also an indispensable supplementary way in the process of rehabilitation. Some studies have pointed out that isokinetic exercise of the lower limbs with the help of isokinetic muscle strength trainers to perform concentric contraction training of quadriceps femoris and other muscles at different angular velocities can significantly promote muscle strength recovery[50]. Neuromuscular electrical stimulation (NES), which simulates nerve impulses by an external current and induces muscle contraction in a passive manner, can effectively enhance neural responses and improve muscle cell metabolism. The study by Klika et al. also showed that the use of this technique to strengthen the quadriceps femoris after hip arthroplasty significantly reduced muscle atrophy and improved muscle strength recovery[51]. Strength training is the most important part of gait and balance rehabilitation after hip replacement. It is necessary to integrate multiple training methods to accelerate rehabilitation in the precious rehabilitation window.

6.2. Gait Training

At present, conventional training methods such as walking assisted by walking AIDS, figure-shaped gait and stride gait are mainly used.In recent years, 3D gait analysis systems have been applied in clinical practice. The system can monitor the gait data and hip muscle function of patients after hip replacement, which is helpful to develop more targeted muscle strength and gait training plans, so as to correct abnormal gait more effectively[42]. At the same time, robot-assisted gait training is also an important training method. Lower limb rehabilitation robots combined with conventional rehabilitation training can effectively improve the gait and balance function of patients[52], which may be especially suitable for patients with severe dysfunction, poor conventional training effect or high fall risk.

6.3. Balance Training

At present, the training methods such as bipedal standing, unstable plane standing, single leg standing with eyes closed, left and right center of gravity transfer, and weight bearing of the affected limb are widely used. In recent years, with the continuous progress of rehabilitation technology, a variety of new balance training methods have been gradually applied to clinical practice and have shown good results. Some studies have shown that plantar vibration stimulation can enhance somatosensory input to plantar skin mechanoreceptors and reshape neuromuscular control, thus playing an important role in improving balance function[53]. This kind of plantar stimulation method is not only limited to vibration stimulation, but also effective for textured insoles and ground stimulation methods. Task-oriented training focuses on improving individual mobility and motor skills by guiding patients to complete functional motor tasks. Studies have shown that such task-oriented training also has a significant effect on the recovery of gait and balance function after surgery[54]. This training method, which combines training tasks with activities in life and work, can effectively improve the enthusiasm of rehabilitation of patients and improve the rehabilitation effect. Progressive balance training can accelerate the recovery of balance ability in the early postoperative period[55]. At the same time, a number of studies have pointed out that the balance training methods represented by professional equipment and visual feedback technology have become popular in recent years, which can effectively improve the function and balance coordination of the hip joint after surgery through the center of gravity transfer and stability control exercises[3, 56].

6.4. Proprioceptive Training

Proprioceptive training is often overlooked in the training after hip replacement, but it is also one of the important culprits of postoperative gait and balance abnormalities. At present, it mainly includes tactile and vibration stimulation training, joint position reproduction training, eye closing movement control training and balance training. The proprioceptive neuromuscular facilitation technique promotes neuromuscular reflexes through specific proprioceptive motor stimuli such as traction and resistance, enhances position sense, motion sense and joint perception input, improves proprioceptive function, and promotes the recovery of gait function. The technology is mainly used in motor dysfunction training of brain diseases, but in recent years, some studies have confirmed its role in hip replacement, which has significantly improved the gait and balance function of patients after surgery[57].

6.5. Progressive Training

Progressive training is a highly concerned therapy for rehabilitation after hip replacement. Functional recovery after total hip arthroplasty is progressive in stages. In the early postoperative period, swelling reduction and muscle strength training are the main measures. In the middle rehabilitation stage, gait function training was strengthened on the basis of muscle training. In the rehabilitation intensive stage, after completing the basis of independent walking, balance training is carried out and high-intensity activities are gradually resumed[3, 58, 59]. This progressive rehabilitation treatment plan is more conducive to the recovery of gait and balance

function after surgery. A number of studies have also pointed out that progressive training according to functional recovery cycle after surgery can significantly shorten the recovery time of gait and balance function of patients, and the effect is better[47, 55].

6.6. Preoperative Pre-Rehabilitation and Diversified Traditional Therapies

With the deepening of the concept of enhanced recovery after surgery, pre-rehabilitation has become an important development trend in the field of early rehabilitation. Through a series of pre-rehabilitation measures such as comprehensive exercise, nutritional support and psychological intervention before operation, it can effectively improve the quality of life of patients after operation, enhance the tolerance of surgery and improve the success rate of surgery. In this regard, studies have shown that preoperative intensive training through muscle and joint range of motion training before hip arthroplasty can significantly improve the balance ability and hip function of patients in the early postoperative period[60]. Preoperative prehabilitation is one of the key links in the recovery of gait and balance function after surgery, which still needs to be explored and studied. At the same time, physiotherapist, Tai chi, Baduanjin and other traditional comprehensive training methods also have positive significance in improving postoperative gait and balance function. For patients with appropriate interests and conditions, incorporating these into the rehabilitation program is also an effective personalized rehabilitation program.

7. Conclusion

The mechanism of gait abnormalities and balance disorders in patients after total hip arthroplasty involves the interaction of multiple factors, which can lead to an increased risk of postoperative falls and physiological function damage. Among them, the individual factors such as age, gender, body mass index, postoperative pain degree and comorbidities, as well as the psychological state, compliance and family support during the rehabilitation process were the main factors affecting postoperative functional recovery. The choice of surgical approach, the accuracy of femoral offset reconstruction, and the start time of rehabilitation training are important regulatory variables affecting postoperative functional recovery, which jointly affect the rehabilitation outcome. Based on this, the risk stratification and management of patients were carried out. For high-risk groups, in addition to prospective intervention and guidance, long-term follow-up should be strengthened. Through standardized and differentiated functional tests, targeted training such as muscle strength, gait and balance training should be guided to improve the rehabilitation effect. In the future, more individualized intervention strategies need to be further explored.

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