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Original Paper

Application of Surface Electromyography in Knee Joint Sports Injury Rehabilitation

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Abstract

Knee joint sports injuries are common and significantly impact patients' daily activities and athletic abilities. Effective rehabilitation methods are crucial for restoring knee joint function. Surface electromyography (sEMG), a technology for monitoring muscle activity, has seen widespread use in rehabilitation medicine in recent years. This study aims to explore the application of sEMG in knee joint sports injury rehabilitation, particularly its role in rehabilitation assessment, training effect monitoring, and the development of personalized rehabilitation plans. By reviewing the basic principles of sEMG and its signal characteristics and combining them with the rehabilitation goals and strategies for knee joint injuries, this paper analyzes practical applications and outcomes of sEMG in rehabilitation. The study indicates that sEMG can effectively evaluate knee joint function and muscle activity, monitor rehabilitation training in real-time, and support the creation of personalized rehabilitation plans. Case studies demonstrate sEMG's significant advantages in optimizing the rehabilitation process and enhancing treatment efficacy. However, challenges such as signal noise and equipment cost remain, necessitating further research and technological improvements to advance the application and development of sEMG in rehabilitation medicine.

Keywords

Surface Electromyography (sEMG), Knee Joint Sports Injury, Rehabilitation Assessment, Training Effect Monitoring

1. Introduction

The knee joint, one of the largest joints in the human body, endures significant stress during daily activities and sports. Sports injuries, particularly knee injuries, have become common issues in modern society, severely affecting patients' quality of life and athletic abilities. These injuries include ligament tears, meniscus tears, and arthritis, leading to pain, functional impairment, and often prolonged rehabilitation periods. Traditional knee injury rehabilitation methods primarily rely on physical therapy, medication, and surgery. However, these methods' effectiveness and efficiency can be influenced by various factors. Therefore, exploring new assessment and treatment tools has become a crucial research direction in rehabilitation medicine. Surface electromyography (sEMG), capable of real-time monitoring of muscle activity, has attracted widespread attention in sports medicine and rehabilitation. By measuring muscle electrical activity signals, sEMG provides important information for muscle function assessment and motor control. The application of sEMG technology enables real-time feedback during rehabilitation, improving assessment accuracy and aiding in the development and adjustment of personalized rehabilitation plans. Its high-precision muscle activity monitoring capability provides quantitative data support for evaluating rehabilitation training effects, thereby optimizing rehabilitation strategies and enhancing treatment outcomes. This study aims to explore the application of sEMG in knee joint sports injury rehabilitation, specifically analyzing its roles in rehabilitation assessment, training effect monitoring, and personalized rehabilitation planning. By comprehensively reviewing the basic principles and practical applications of sEMG technology, this paper seeks to offer new perspectives and practical guidance for the field of knee injury rehabilitation and promote the clinical application and development of this technology[1].

2. Basic Principles of Surface Electromyography

2.1 Measurement Principles of Surface Electromyography

Surface electromyography (sEMG) is a technology used to detect and record muscle electrical activity, based on the principle that muscles generate electrical signals during contraction. These signals can be measured non-invasively through specific electrodes, allowing for the assessment of muscle function. The measurement process of sEMG involves several steps:

1. Electrode Placement: sEMG acquires muscle electrical activity signals through electrodes attached to the skin surface. The choice and position of the electrodes are crucial for signal quality and accuracy. Commonly used electrodes include dry and wet electrodes. Dry electrodes do not require conductive gel and are suitable for long-term monitoring, while wet electrodes require conductive gel to enhance signal stability and accuracy.

2. Signal Acquisition: The electrodes connect to an EMG instrument via cables, capturing the electrical signals generated by muscle fibers under electrical stimulation. These signals reflect potential changes during muscle activity, which the electrodes convert into electrical signals.

3. Signal Amplification: Since muscle electrical signals are very weak, amplification is typically necessary. Amplifiers increase signal amplitude for further processing and analysis, with amplified signals still needing filtering to remove noise and interference.

4. Signal Processing and Analysis: Amplified electrical signals are converted into digital signals via analog-to-digital converters, then processed on computers or specialized analysis devices. Common

processing methods include time-domain and frequency-domain analyses. Time-domain analysis evaluates signal waveform, amplitude, and duration, while frequency-domain analysis focuses on signal frequency components to assess muscle fatigue and activity patterns.

5. Data Interpretation: Processed signals can evaluate muscle activity, contraction strength, and fatigue levels. Clinicians and researchers can analyze this data to understand muscle function, assess rehabilitation training effects, and develop personalized treatment plans.

The advantages of sEMG technology lie in its non-invasiveness and real-time nature, offering broad application prospects in sports medicine and rehabilitation. However, ensuring signal accuracy and reliability depends on proper electrode selection, placement, and signal processing, providing a foundation for effective application in knee injury rehabilitation[2].

2.2 Signal Characteristics and Analysis Methods

The characteristics and analysis methods of sEMG signals are crucial for understanding muscle activity and functional status. Key sEMG signal features include amplitude, frequency, duration, and waveform. Signal amplitude reflects muscle electrical activity intensity, related to muscle contraction strength. Common amplitude quantification indices include root mean square (RMS) and average amplitude, accurately assessing muscle activity intensity. Frequency characteristics reveal muscle fatigue status and activity patterns, with spectral analysis observing signal frequency distribution, including low-frequency (0-20 Hz) and high-frequency (20-500 Hz) components. Signal duration pertains to muscle contraction length, essential for understanding muscle activity periodicity and persistence. Waveform analysis helps comprehend specific muscle electrical activity forms, such as single contraction and sustained contraction potential changes. To extract useful information from these signal features, common analysis methods include time-domain, frequency-domain, and time-frequency domain analyses. Time-domain analysis involves evaluating signal amplitude and waveform, with common indices like RMS, mean absolute value (MAV), and signal mean aiding in assessing muscle activity intensity and overall level. Frequency-domain analysis, through Fourier transform, converts signals into spectra, analyzing frequency components. Common frequency-domain indices include power spectral density (PSD), mean frequency (MF), and frequency range, revealing signal spectral features and muscle fatigue. Time-frequency domain analysis combines time-domain and frequency-domain information using methods like short-time Fourier transform (STFT) and wavelet transform, uncovering signal changes in time and frequency, aiding in detecting transient signal changes and dynamic muscle activity features. Additionally, statistical methods like variance, standard deviation, and kurtosis evaluate signal stability and trend. These analysis methods collectively provide comprehensive muscle activity information, crucial for optimizing rehabilitation assessment, monitoring training effects, and developing personalized rehabilitation plans[3].

3. Knee Joint Sports Injuries and Rehabilitation

3.1 Types of Knee Joint Injuries

Knee joint sports injuries include various types, common among athletes and daily activity participants. Typical knee joint injuries include ligament injuries, meniscus injuries, cartilage injuries, knee arthritis, patellar injuries, and tendinitis and bursitis. Ligament injuries mainly involve the anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), medial collateral ligament (MCL), and lateral collateral ligament (LCL). ACL injuries are the most common, often occurring during intense sports or sudden directional changes, leading to knee joint instability, pain, and swelling. In contrast, PCL injuries are less common but usually more severe, while MCL and LCL injuries often result from excessive medial or lateral knee pressure, causing lateral instability and dysfunction. Meniscus injuries frequently occur during knee joint rotation or bending, especially in sports, causing knee pain, swelling, limited movement, and locking phenomena. Cartilage injuries involve joint cartilage tears or wear, usually caused by repetitive friction or trauma, potentially leading to knee pain, stiffness, and limited movement, sometimes causing arthritis[4]. Knee arthritis, including osteoarthritis (OA) and rheumatoid arthritis (RA), is a chronic condition. OA results from aging, overuse, or trauma, causing joint cartilage degeneration, bone growth, and joint pain, while RA, an autoimmune disease, causes widespread knee joint inflammation and damage. Patellar injuries include patellar dislocation and fracture, with dislocations occurring due to lateral impact or sudden directional changes, and fractures from direct external force, causing knee pain, swelling, and limited movement. Tendinitis and bursitis involve knee surrounding tendons and bursa inflammation, like patellar tendinitis (jumper's knee) and tibial tendinitis from overuse, and bursitis from trauma or overuse, leading to knee pain and swelling. Understanding these knee joint injury types helps develop appropriate rehabilitation plans for effectively restoring knee function and improving patient quality of life.

3.2 Rehabilitation Goals and Strategies

The main goals of knee joint sports injury rehabilitation include pain relief, swelling control, restoring joint function, enhancing muscle strength, and improving athletic ability. Achieving these goals requires a comprehensive approach with multiple methods and measures. Initially, pain management and swelling control are crucial. Ice packs, non-steroidal anti-inflammatory drugs (NSAIDs), and physical therapy effectively reduce pain and control swelling. Elevating the injured leg and appropriate rest also help alleviate symptoms, and avoiding excessive pressure on the knee joint during the acute phase is necessary. Restoring joint range of motion is a critical rehabilitation step. Joint movement exercises and flexibility training gradually restore normal knee movement range. Common exercises include progressively increased knee bending and stretching, improving joint flexibility and function. Simultaneously, strengthening surrounding knee muscles is vital. Strength training focuses on quadriceps, hamstrings, and calf muscles, enhancing joint stability and reducing re-injury risk. Rehabilitation also needs to address coordination and balance improvement. Balance training and proprioception exercises enhance muscle coordination and joint position awareness, reducing unexpected movements. Common exercises include balance board training and single-leg standing. Additionally, functional training aims to simulate daily actions and movement demands, helping patients gradually return to normal activity levels. These exercises may include running, jumping, and turning, ensuring patients safely resume sports and daily activities. Preventing future injuries and long-term management are also essential. Patients need education on avoiding overuse, maintaining proper posture, and taking preventive measures. Regular follow-up and evaluation help monitor recovery progress, adjusting rehabilitation plans for new issues. Comprehensive application of these goals and strategies can effectively restore knee joint function, alleviate pain, improve athletic ability, and reduce re-injury risk[4].

4. Application of Surface Electromyography in Knee Joint Rehabilitation

4.1 Rehabilitation Assessment

In knee joint rehabilitation, surface electromyography (sEMG) provides an accurate assessment tool for monitoring muscle activity and evaluating rehabilitation progress. By recording and analyzing muscle electrical activity in real-time, sEMG offers essential data for rehabilitation assessment, aiding in developing and adjusting rehabilitation plans. First, sEMG can assess muscle activity patterns and strength. By measuring electrical signals from major knee-surrounding muscles (e.g., quadriceps, hamstrings, and calf muscles), sEMG reveals these muscles' activity intensity and patterns in different states. This is crucial for determining whether muscles have restored normal function and if there is strength imbalance or abnormal activity patterns. For example, during post-injury rehabilitation, sEMG can help evaluate whether quadriceps strength has returned to normal, guiding the corresponding training plan. Second, sEMG can assess muscle fatigue levels and endurance. By analyzing muscle electrical signals' frequency characteristics, particularly RMS values and spectral changes, sEMG provides muscle fatigue information[5]. This data helps understand muscle endurance under different training intensities, adjusting rehabilitation training intensity and duration to prevent overfatigue and potential injury. Moreover, sEMG technology can monitor rehabilitation training effects. By measuring sEMG before and after training, the impact of training on muscle activity patterns and strength can be evaluated. This real-time feedback helps therapists and patients understand training effectiveness and adjust training plans for optimal outcomes. For example, if sEMG data shows increased muscle activity post-training, it indicates training effectively promotes muscle recovery.Overall, sEMG technology in knee joint rehabilitation provides a scientific and objective method for assessing muscle function and rehabilitation progress. By real-time monitoring and analyzing muscle electrical activity, sEMG helps identify and address potential issues during rehabilitation and provides reliable data support for developing personalized rehabilitation plans.

4.2 Monitoring Training Effects

In knee joint rehabilitation, sEMG technology plays a crucial role in monitoring training effects. By recording and analyzing muscle electrical activity in real-time, sEMG provides precise data on training effects, helping adjust rehabilitation plans and optimize training outcomes. First, sEMG can monitor muscle activity during rehabilitation training in real-time. Analyzing muscle electrical signals evaluates muscle activation and activity patterns during training. This data helps therapists understand whether training effectively activates target muscles. For example, during quadriceps strengthening exercises, sEMG can show whether muscle electrical activity reaches the expected level, determining training effectiveness in enhancing muscle strength. Second, sEMG can detect muscle fatigue changes. By monitoring muscle electrical signal frequency characteristics like RMS values and spectral changes during training, muscle fatigue progression can be understood. This data helps evaluate training's impact on muscle endurance. For example, if sEMG data shows decreasing muscle electrical activity intensity during training, it may indicate approaching fatigue, requiring adjustment of rehabilitation plans to avoid overtraining and potential injury. Moreover, sEMG can evaluate different training methods' effects. Comparing sEMG data before and after various training methods assesses which are most effective in improving muscle strength and endurance. For example, if a training method significantly increases target muscle electrical activity and improves fatigue tolerance, it indicates higher effectiveness. This data-driven evaluation helps develop and optimize personalized training plans. Finally, sEMG in training effect monitoring includes tracking long-term rehabilitation progress. Regular sEMG evaluations continuously monitor muscle function recovery, adjusting rehabilitation plans in real-time. This continuous monitoring and feedback mechanism ensure rehabilitation effectiveness and help patients gradually return to normal activity levels.In summary, sEMG technology in training effect monitoring provides a scientific and objective method for evaluating rehabilitation training outcomes. Real-time muscle electrical activity monitoring helps optimize training plans, adjust rehabilitation plans, and ensure training safety and effectiveness, promoting comprehensive knee joint recovery[6].

4.3 Personalized Rehabilitation Plans

In knee joint rehabilitation, sEMG technology offers valuable data support for developing personalized rehabilitation plans. By accurately recording and analyzing muscle electrical activity, sEMG helps identify specific patient needs, designing rehabilitation plans tailored to individual requirements, optimizing rehabilitation outcomes. First, sEMG can assess patients' muscle function and activity levels. Analyzing electrical signals from major knee-surrounding muscles reveals each muscle group's strength, activation patterns, and fatigue levels. This data enables therapists to identify muscle function deficiencies or imbalances. For example, if sEMG data shows low quadriceps activity, rehabilitation plans can focus on strengthening this muscle to compensate for its functional deficiency. Second, sEMG data helps therapists design personalized training programs[7]. Real-time feedback from sEMG determines the most suitable training intensity and type for patients. Adjusting training parameters (e.g., load, repetitions, frequency) maximizes training effectiveness while preventing overtraining and potential injury. For example, if sEMG shows insufficient target muscle activation in an exercise, adjustments can be made to improve training intensity and effectiveness. Moreover, sEMG can monitor individual responses to rehabilitation training, dynamically adjusting plans. Patients' rehabilitation progress may vary due to personal differences. Regular sEMG evaluations continuously track muscle function changes, adjusting rehabilitation plans in real-time. For example, if sEMG data shows muscle activity improvement, training difficulty can gradually increase; if fatigue worsens, training load can be reduced to maintain safety. Finally, sEMG technology can help develop long-term rehabilitation and prevention plans. Post-rehabilitation, sEMG can continue monitoring muscle function stability and recovery, ensuring long-term knee joint health. Regular checks and data analysis can develop suitable maintenance training plans and preventive measures, helping patients maintain good athletic ability and reduce future injury risks. Overall, sEMG technology in personalized rehabilitation plans provides precise muscle function data, helping therapists design training programs tailored to patient needs. Real-time monitoring and dynamic adjustment enhance rehabilitation plan targeting and effectiveness, promoting comprehensive recovery and long-term health[8].

5. Case Studies and Applications

The application of sEMG technology in knee joint rehabilitation has significantly improved outcomes. The following two cases illustrate practical applications and effects of sEMG in rehabilitation.

Case 1: Post-ACL Reconstruction Rehabilitation Assessment

A 28-year-old athlete underwent ACL reconstruction and received three months of rehabilitation. Early in rehabilitation, sEMG monitoring of quadriceps and hamstring activity revealed below-normal quadriceps activation and relatively normal hamstring activation. Based on this data, the therapist adjusted the training plan to focus on quadriceps strengthening and reduce hamstring load. As rehabilitation progressed, sEMG data showed gradual quadriceps activation recovery, significantly improving the athlete's knee function, eventually allowing a successful return to sports.

Case 2: Functional Training After Meniscus Injury

A 45-year-old amateur athlete received rehabilitation for a meniscus injury. sEMG technology monitored knee-surrounding muscle electrical activity to evaluate training effects. Analysis showed imbalanced quadriceps and hamstring activity during knee flexion-extension movements. The therapist designed a personalized functional training plan to improve quadriceps strength and coordination, combined with joint range of motion recovery exercises. After eight weeks, sEMG data showed significant improvements in muscle activity balance and strength, with knee function recovery allowing the patient to resume high-intensity sports.

These cases demonstrate sEMG technology's practical application in knee joint rehabilitation. Real-time monitoring and analysis of muscle electrical activity provide valuable data for therapists to develop personalized rehabilitation plans, improving outcomes and helping patients safely and efficiently return to normal activities.

6. Challenges and Future Directions

Although sEMG technology has notable advantages in knee joint rehabilitation, it faces several challenges and holds promising future prospects. First, the complexity of sEMG data interpretation is a major challenge. sEMG signals are influenced by factors such as muscle fatigue, posture changes, and movement technique differences, complicating the extraction of useful information. Patients' muscle electrical activity patterns may vary, requiring specialized knowledge and skills for accurate data interpretation. Additionally, the diversity of sEMG equipment and technical specifications poses standardization issues. The lack of unified standards can hinder data comparison and integration, limiting cross-study application. Therefore, establishing unified standards and norms is crucial for enhancing technology applicability. Motion artifacts, such as skin movement or electrode position changes, may interfere with sEMG signal accuracy, affecting data stability and reliability. Improving electrode design and signal processing technology is necessary to reduce artifact interference. Looking ahead, sEMG technology is expected to achieve breakthroughs in integration and intelligence. Combining other biomechanical measurement technologies, such as motion capture systems or force plates, can provide comprehensive motion analysis. Integrating machine learning and artificial intelligence technology will enable automated data analysis and pattern recognition, enhancing sEMG data interpretation efficiency and accuracy. Future sEMG devices may become more portable and comfortable, such as developing wireless, wearable sEMG systems, allowing continuous monitoring and evaluation in daily life, greatly enhancing home rehabilitation and telemedicine applications, and improving patient rehabilitation experiences. Additionally, big data applications will drive personalized medicine development. Integrating sEMG data from different patients to identify common muscle activity patterns and rehabilitation strategies will make rehabilitation plans more personalized, meeting individual patient needs. Long-term data accumulation and analysis will help predict and prevent potential knee joint issues, further optimizing rehabilitation outcomes. In summary, despite challenges like data interpretation complexity, technology standardization, and motion artifact interference, sEMG technology has shown significant application potential in knee joint rehabilitation. Future development directions include technological intelligence, device portability improvements, and big data integration in personalized medicine. These advancements will enhance sEMG technology application effectiveness and broad adoption, promoting knee joint rehabilitation field development.

7. Conclusion

sEMG technology has shown significant potential and value in knee joint rehabilitation. By real-time monitoring and analyzing muscle electrical activity, sEMG provides detailed data on muscle function and rehabilitation progress, aiding in the development of more precise and personalized rehabilitation plans. sEMG can reveal muscle activity patterns and strength levels in rehabilitation assessment, guiding training plan adjustments, and evaluating training effects to ensure rehabilitation plan effectiveness. Practical applications through case studies show that sEMG technology effectively identifies muscle function deficiencies, optimizes training plans, and provides real-time feedback at different rehabilitation stages. These applications not only enhance the scientific basis of the rehabilitation process but also help patients recover to normal activity levels more quickly and safely. Despite challenges such as data interpretation complexity, equipment standardization issues, and motion artifact interference, continuous technological advancements and future development directions, such as intelligent technology applications, device portability improvements, and big data integration, are expected to significantly promote sEMG technology's wide application and effectiveness optimization. Overall, sEMG technology in knee joint rehabilitation has broad development prospects. Its scientific and precision will provide strong support for future rehabilitation practices. By overcoming existing challenges and continuously exploring new technological applications, sEMG is expected to play a more significant role in improving rehabilitation outcomes, personalized treatment, and injury prevention.

References

[1] Liu, Jianan. (2020). Prevention and Rehabilitation of Knee Joint Injury. *Investigación Clínica*, *61*(2), 645-655.

[2] Tayfur, Beyza, et al. (2021). Neuromuscular function of the knee joint following knee injuries: does it ever get back to normal? A systematic review with meta-analyses. *Sports medicine*, *51*, 321-338.

[3] Xu, Shidong, and Linye Zeng. (2020). Rehabilitation Path of Knee Ligament Proprioception Loss Caused by Sports Injury. *Investigación Clínica*, *61*(3), 1258-1267.

[4] Yung, Kate K., et al. (2022). Characteristics of complex systems in sports injury rehabilitation: examples and implications for practice. *Sports medicine-open*, *8*(1), 24.

[5] Lei, Genghua. (2021). Application and research of nano-biomaterials in knee cruciate ligament rehabilitation after sports injury. *International Journal of Nanotechnology*, *18*(1-4), 82-96.

[6] Xu, Congti, and Yan Sheng. (2020). Causes and Rehabilitation of Knee Injuries in Track and Field. *Investigación Clínica*, *61*(2), 696-707.

[7] Di Paolo, Stefano, et al. (2021). Rehabilitation and return to sport assessment after anterior cruciate ligament injury: quantifying joint kinematics during complex high-speed tasks through wearable sensors. *Sensors*, *21*(7), 2331.

[8] Truong L K, Mosewich A D, Holt C J, et al. (2020). Psychological, social and contextual factors across recovery stages following a sport-related knee injury: a sco** review. *British Journal of Sports Medicine*, *54*(19), 1149-1156.