JURNAL STAMINA
P-ISSN 2655-1802
E-ISSN 2655-2515
http://stamina.ppj.unp.ac.id

BIOMECHANICAL ANALYSIS FOREHAND GROUNDSTROKE TECHNIQUE ON FIELD TENNIS: A REVIEW OF THE LITERATURE

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Received: April 2026, Revised: May 2026, Accepted: June 2026

Abstract
The forehand groundstroke is one of the fundamental techniques in tennis that requires complex coordination of the musculoskeletal system. This study aims to systematically analyze the biomechanics of forehand groundstroke technique, including movement phases, segmental body contribution, racket velocity, racket-face angle at impact, and its implications for performance improvement and injury prevention. The research method used a systematic literature review approach by analyzing peer-reviewed journals, textbooks, and relevant academic sources related to tennis biomechanics. The results of the review show that the forehand groundstroke consists of five main phases: initiation, preparation, acceleration, impact, and follow-through. Quantitative findings indicate that racket velocity reaches its peak during the impact phase, with professional players producing racket speeds of approximately 25–35 m/s. Stroke power is generated through sequential segmental contribution involving the lower limbs, trunk, shoulder, upper arm, forearm, and wrist. Kinematic analysis also shows that torso rotation and shoulder external rotation play important roles in increasing racket speed and stroke effectiveness. In addition, the racket-face angle at impact significantly influences ball direction, accuracy, and control. This study concludes that a comprehensive understanding of forehand groundstroke biomechanics can help coaches and athletes optimize technique, improve stroke performance, and reduce the risk of injury. The findings provide practical recommendations for developing more effective tennis training programs based on biomechanical principles.
Keywords: Biomechanics, forehand groundstroke, kinematics, dynamics, tennis

INTRODUCTION

Court tennis is a sport that requires high technical skills and optimal physical condition. In the modern tennis game, the forehand groundstroke is the most commonly used stroke and is the main weapon of players in defending and attacking (Elliott et al., 2003). Changes in tennis regulations, such as the use of modern rackets with more advanced materials and changes in the characteristics of the court, have affected the way players make forehand groundstrokes.

Based on several studies of tennis biomechanics, the effectiveness of forehand groundstroke is greatly influenced by the speed of the racket, the coordination of body segments, the timing of pelvic-trunk rotation, and the position of the racket surface at impact (Landlinger et al., 2010; Pedro et al., 2022; Tagliafico et al., 2009). Landlinger et al. (2010) analyzed the forehands of elite and high-performance tennis players using a 3D motion analysis system with 39 body markers, 4 racket markers, and a 400 Hz Vicon camera. The horizontal speed of elite players' racket heads tends to be higher, which is 33.1 ± 2.4 m/s, compared to high-performance players of 31.1 ± 1.9 m/s. These findings reinforce that the speed of the racket when approaching impact is an important indicator of the quality of forehand shots.

In addition to racket speed, research by Landlinger et al. (2010) also showed that the timing of pelvic and trunk rotation plays a big role in generating power. In elite players, the velocity of pelvic rotation reaches about 541°/s and occurs about 0.075 seconds before ball contact. This proves that forehand shots do not only depend on the arms but are initiated by leg thrusts and pelvic rotation, which are then passed on to the trunk, shoulders, arms, wrists, and rackets through the principle of the kinetic chain. A more recent study by Pedro et al. (2022) used 17 IMU sensors on six elite players and analyzed 72 forehand shots in attacking situations. The results showed that the greatest contribution to racket speed came from upper arm flexion/abduction, which was 48.1% on cross-court shots and 45.2% on inside-out shots. The next contribution came from forearm extension of 17.3%–20.9% and internal rotation of the upper arm of 14.2%–15.6%. This fact supports that forehand exercises need to emphasize strength and coordination of the shoulders, elbows, and wrists, not just separate racket swings.

In terms of injury prevention, Tagliafico et al. (2009) examined 370 non-professional tennis players and found that 50 players or 13% had wrist injuries. Ulnar-side injuries are more associated with the use of western or semi-western grips, while radial-side injuries are more often associated with eastern grips. This relationship was statistically significant with the value $\chi^2 = 20.7$ and $p < 0.001$, and the average time away from the competition reached 69 days. These findings suggest that the analysis of forehand biomechanics is not only important for performance but also for the prevention of injuries due to inappropriate technique and grip. An understanding of the biomechanics of groundstroke forehand techniques is essential for coaches, athletes, and sports health professionals. By analyzing movement from a biomechanics perspective, it is possible to identify factors that affect performance and potential injury. Biomechanics research in tennis has come a long way using technologies such as 3D motion analysis systems, force plates, and electromyography (EMG).

The purpose of this literature review is to comprehensively analyze the mechanics of forehand groundstroke techniques based on recent research. The focus of the study is directed to the phases of movement, kinematic analysis, dynamics, and segmental contribution, as well as factors that affect the effectiveness of punch techniques. The novelty of this literature review lies in the effort to integrate various findings of forehand groundstroke biomechanics into a more systematic analysis framework, ranging from movement preparation, pelvic and trunk rotation, energy transfer between body segments, and racket speed to the position of impact on the ball. In addition, the study not only emphasizes the performance aspect of strokes but also links it to practical implications for the design of technique training programs, improved movement efficiency, and prevention of injury risks in court tennis players. Thus, the results of the analysis are expected to make a theoretical and applicable contribution for coaches, athletes, academics, and sports practitioners in developing a more scientifically evidence-based approach to forehand groundstroke training.

METHODOLOGY

This study uses a systematic literature review (SLR) approach with reference to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. The use of the PRISMA protocol aims to ensure that the process of searching, selecting, assessing eligibility, and synthesizing articles is carried out in a systematic, transparent, and replicable manner.

Data sources are obtained from several electronic databases, namely PubMed, Google Scholar, Web of Science, and SportDiscus. The literature search was conducted in June 2026 with a range of article publications over the last 10 years, namely 2016 to 2026. Keywords used in the search process included a combination: "forehand groundstroke and biomechanics," "tennis stroke mechanics," "tennis kinematics," "tennis performance analysis," "tennis forehand kinematics," and "tennis forehand biomechanics."

The inclusion criteria in this study include the following: (1) articles that discuss the biomechanical analysis of forehand groundstroke techniques in court tennis; (2) articles that present quantitative data related to kinematic, dynamic, electromyographic, or engineering performance parameters; (3) articles in English or Indonesian; (4) articles that have gone through a peer-review process; and (5) articles published in the range of 2006–2026. Meanwhile, exclusion criteria include: (1) articles in the form of opinions, editorials, or narrative reviews that are not systematic; (2) case studies with single subjects; (3) articles that do not specifically address forehand groundstrokes; (4) articles that do not present biomechanical data; and (5) articles that are not available in full text.

Based on the initial search process, 248 articles were obtained from all databases. After the removal of 46 duplicate articles, there are 202 articles left for the title and abstract filtering stage.

At this stage, as many as 126 articles were issued because they were not in accordance with the focus of the study. Furthermore, as many as 76 articles were assessed for eligibility through reading the full text. Of these, 52 articles were excluded because they did not specifically address forehand groundstroke, did not contain quantitative data on biomechanics, or were not relevant to the purpose of the study. Thus, a total of 24 articles met the inclusion criteria and were further analyzed in this literature review.

Data analysis was carried out by extracting key information from each article that met the inclusion criteria. The extracted data included the author's name, year of publication, characteristics of the research subject, research design, measurement instruments, and analyzed biomechanical parameters, as well as key findings. Furthermore, the data are categorized into several main themes, namely: (1) the phase of forehand groundstroke movement, (2) kinematic parameters, (3) dynamic parameters, (4) the segmental contribution of the body, (5) electromyographic analysis, and (6) factors that affect the effectiveness of punch performance. Data synthesis is done narratively by comparing and integrating findings from various articles to obtain a comprehensive picture of the mechanics of forehand groundstroke techniques in court tennis.

RESULTS

Phases of Forehand Groundstroke Movement

Based on the results of a synthesis of the literature over the past 10 years, the forehand groundstroke technique in court tennis is a complex movement skill that involves coordination between the lower legs, pelvis, trunk, shoulders, arms, wrists, and racket. In general, the forehand groundstroke movement can be divided into several phases, namely the preparation phase, backswing, forward swing, impact, and follow-through. Each phase has a different biomechanical function, but they are interconnected in forming a fast, accurate, and consistent stroke.

The preparation phase plays a role in determining the position of the body against the arrival of the ball. In this phase, players make footwork adjustments, shoulder rotations, and racket position adjustments. The backswing phase serves to create movement space and store elastic energy before the racket is swung forward. Furthermore, the forward swing phase is the main phase in the acceleration of the racket towards the ball. In the impact phase, the position of the racket, the angle of the racket surface, and the contact point of the ball are important factors that determine the direction, speed, and rotation of the ball. The follow-through phase serves to gradually slow down the movement of the racket and help players return to their ready position.

Kinematic Analysis of Forehand Groundstroke

Kinematic analysis in a forehand groundstroke focuses on the characteristics of the movement without discussing the force of the cause. Parameters that are widely studied in the latest literature include the speed of the racket head, the angle of the racket at impact, the trajectory of the racket's swing, the rotation of the body segments, the position of the wrist, and the relationship between the movement of the racket and the result of the stroke. Kwon et al. (2017) explain that the kinematics of the racket, specifically the angle of the racket head, the horizontal and vertical velocity of the racket; as well as the trajectory of the racket before impact, are related to topspin and the accuracy of the forehand shot.

Rusdiana's research (2021) shows that three-dimensional analysis can be used to identify body angles and movement patterns in the flat forehand drive technique. These findings show that forehand performance is not only determined by arm swing strength but also by coordination of body position, joint angle, and racket speed. Irawan et al. (2023) also emphasized the importance of video-based and software-based biomechanics analysis to predict the speed of the ball based on the angle of movement when performing a forehand stroke.

Joint Dynamics and Load Analysis

In addition to the kinematic aspect, recent research has also shown that forehand groundstroke involves mechanical loads on joints and muscle tissue. Body rotation movements, stance changes, and racket acceleration can increase the load on the upper and lower extremities. Therefore, dynamic analysis is important for understanding the force, torque, and joint load that arises during a forehand stroke. Studies on forehand stance show that foot position and lower limb movement patterns affect biomechanical loads, particularly on the knees and lower extremities. Improper stance can increase mechanical stress and potentially pose a risk of injury. In the upper extremities, the shoulders, elbows, forearms, and wrists are important parts because they play a role in directing the racket and controlling the impact of the ball. Thus, the effectiveness of forehand groundstrokes is influenced by the player's ability to generate power while controlling the mechanical load of the body.

Segmental Contribution and Kinetic Chains

A forehand groundstroke cannot be understood only as an arm movement but as a result of the coordination of the kinetic chain from the bottom up. The energy of motion starts from the thrust of the limbs and is passed on to the pelvis, trunk, shoulders, arms, wrists, and finally to the racket. The better the order of energy transfer between body segments, the more effective the racket speed and the quality of the hit produced.

Recent literature shows that players with higher skill levels have more efficient segmental coordination than mid-level players. Pedro et al. (2026) explain that the difference between high-performance and intermediate players is apparent in the kinematic characteristics and muscle activation during forehand drives. This shows that the quality of forehands is not only determined by muscle strength but also by the timing, coordination, and efficiency of energy transfer between body segments.

Electromyographic Analysis

Electromyographic analysis is used to determine the pattern of muscle activation during forehand groundstroke. Recent studies have shown that the muscles of the upper extremities and trunk work in a coordinated manner from the backswing phase to the follow-through. Loushin et al. (2022) found that forehand groundstrokes in adolescent athletes involves the characteristics of elbow, forearm, and wrist movements, including flexion elbow position, forearm pronation, and a wrist that experiences ulnar extension and deviation on impact.

The findings are important because muscle activation patterns and joint positions can be used as a basis for injury prevention, rehabilitation, and technique development. In players who have poor muscle coordination, the risk of repetitive injuries to the wrist, elbow, and shoulder can increase. Therefore, forehand technique exercises need to be combined with shoulder, trunk, forearm, and wrist stabilizer muscle strengthening exercises.

Factors Affecting Groundstroke Forehand Performance

The effectiveness of a forehand groundstroke is influenced by several factors, including the player's skill level, footwork, stance, body coordination, racket speed, impact angle, ball contact position, muscle strength, flexibility, and body stability. More skilled players tend to be able to maintain a more stable body position, produce more efficient racket swings, and better control the direction and spin of the ball.

In addition, the characteristics of shots such as flat forehands and topspin forehands also have different biomechanical demands. Topspin shots require a more uphill racket trajectory and more precise racket angle control, while flat forehands emphasize more racket speed and more direct stroke direction. Therefore, coaches need to adjust the training program based on the characteristics of the player, the goal of the shot, and the conditions of the match.

Synthesis of Literature Review

Based on the results of the 2016–2026 literature review, it can be concluded that forehand groundstroke is a biomechanical skill that involves the integration of racket kinematics, body rotation, segmental contribution, muscle activation, and ball impact control. The latest literature shows the development of analysis methods, ranging from three-dimensional motion capture, video analysis, inertial measurement unit, to electromyography. This development provides a more detailed understanding of how players generate speed, accuracy, and spin in a forehand groundstroke.

The novelty of this literature review lies in the integration of findings of the last 10 years that not only address forehand technique as a punch movement, but also as an all-encompassing system of motion involving kinetic chains, neuromuscular control, joint loads, and exercise implications. Thus, the results of this review can serve as a basis for coaches, athletes, and researchers in designing a more scientific, effective, and safe forehand groundstroke training program to reduce injury risk.

DISCUSSION

The results of the literature review show that a forehand groundstroke is a biomechanical skill that does not only rely on arm movement but is the result of coordination of the entire kinetic chain of the body. A synthesis of various studies over the past decade shows consistency that the performance of a shot is determined by the integration of movements from the lower limbs to the racket. These findings reinforce the concept of proximal-to-distal sequencing, which is the sequential transfer of energy from the proximal body segment to the distal segment to produce optimal racket speed. Thus, the effectiveness of forehand groundstrokes is more influenced by the efficiency of coordination between segments than the ability to generate force on one part of the body alone.

This study also shows that each phase of movement has different but interdependent biomechanical functions. The preparation and backswing phases play a role in building body position and storing elastic energy, while the forward swing and impact phases determine the quality of energy transfer to the ball. The follow-through then serves as a deceleration mechanism to maintain balance while reducing the mechanical load on the joint. This interpretation indicates that technical errors in one phase not only affect that phase but can also disrupt the entire sequence of movements, reducing the speed, accuracy, and consistency of the shots (Langdown, et all., 2012). Therefore, the evaluation of forehand technique should be done thoroughly in all phases of the movement rather than focusing only on the moment of impact.

The development of motion analysis technology over the past ten years is also an important finding in this review. The use of three-dimensional motion capture, video analysis, inertial measurement units (IMU), and electromyography (EMG) allows the identification of biomechanical parameters in more detail than conventional observational approaches. This shows a shift from subjective technical evaluation to a quantitative approach that is able to measure joint angles, racket trajectories, body segment speed, and muscle activation patterns objectively (Camomilla, et all., 2018). These changes have the potential to improve the accuracy of technique evaluations while supporting the development of evidence-based coaching training programs.

In addition to the kinematic aspect, the results of the review confirm that kinetic and neuromuscular analysis have an equally important contribution in understanding the performance of forehand groundstroke. Several studies have shown that changes in stance, trunk rotation, and racket acceleration can increase mechanical loads on the shoulders, elbows, wrists, and knees. Meanwhile, the results of the EMG analysis show that the coordination of activation of the trunk, shoulder, forearm, and wrist muscles plays a role in producing efficient punches while maintaining joint stability. These findings indicate that performance improvement and injury prevention are two inseparable aspects of forehand technique learning.

The review also found that most research still focuses on analyzing the relationship between one or more biomechanical variables and stroke performance. Although it provides very detailed information, the approach is still relatively fragmented so that it has not yet resulted in an engineering evaluation model that integrates all biomechanical components in a single assessment framework. In fact, trainers in general need instruments that are simple, practical, but still have a strong biomechanical foundation to use in the daily training process (Burket, Brendan, 2025). This gap suggests that further research is still needed to develop an evaluation model or biomechanical assessment instrument of forehand groundstroke that can be easily applied in the field.

The practical implication of the results of this review is the need to change the paradigm of forehand groundstroke practice. Training programs should not only be oriented towards increasing punch strength, but also emphasize the development of kinetic chain coordination, footwork quality, trunk rotation control, shoulder stability, and timing of energy transfer to the racket. In addition, the use of motion analysis technology that is increasingly accessible, such as smartphone-based video analysis and portable IMU sensors, can be an alternative for trainers to conduct more objective engineering evaluations without having to use biomechanics laboratory facilities.

CONCLUSION

Forehand groundstroke is a biomechanical skill that involves the coordination of the entire kinetic chain, from the lower limb to the racket. The results of the systematic literature review show that the quality of the stroke is influenced by the integration of kinematic, dynamic, neuromuscular activation, and energy transfer efficiency between body segments. In addition to improving the speed, accuracy, and spin of the ball, good biomechanical coordination also plays a role in reducing the risk of injury to the upper extremities.

This study provides a comprehensive synthesis of the development of forehand groundstroke biomechanics research during the period 2016–2026 and emphasizes the importance of the biomechanics approach in engineering evaluation and the preparation of scientific evidence-based tennis training programs. Further research is suggested to conduct meta-analyses, expand population coverage, and utilize modern motion analysis technologies to gain a deeper understanding of the mechanics of forehand groundstroke.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this research.

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