

Observed Carpal Tunnel Syndrome among Male Volleyball Players Following Four Different Training Approaches: A Comparative Prospective Study

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Abstract: Volleyball requires repetitive use of the hand and wrist. The increasing use of artificial intelligence (AI) in sports training has created new approaches to exercise prescription and training monitoring, but the occurrence of upper-limb symptoms across different training approaches has received limited attention. To compare the observed occurrence of carpal tunnel syndrome (CTS) among male volleyball players participating in conventional exercise training, sport-specific exercise training, AI-based training, and AI-based training with physiotherapist involvement. A comparative prospective study was conducted among 60 male volleyball players aged 17–26 years in Kadapa district, Andhra Pradesh, India, over 40 days. Participants were divided into four groups of 15 each. Group 1 underwent conventional exercise training, Group 2 sport-specific exercises, Group 3 AI-based training, and Group 4 AI-based training with physiotherapist involvement. Participants with a previous history of relevant wrist, hand, upper-limb, or neurological problems were excluded. Participants were monitored for hand pain, numbness, and tingling sensations. Symptomatic participants underwent CT-based assessment according to the study protocol. Frequencies and percentages were calculated, and the association between training group and CTS occurrence was assessed using Pearson's chi-square test and an exact 4×2 contingency-table analysis. Seven of 60 participants (11.7%) were identified with CTS. Group 3 had the highest observed occurrence, with 5/15 participants (33.3%), followed by Group 1 with 2/15 (13.3%). No cases were observed in Group 2 or Group 4. Pearson's chi-square test yielded $\chi^2(3) = 10.84$, $p = 0.0126$. Because expected cell frequencies were small, the exact two-sided p -value was approximately 0.0122. The observed occurrence of CTS differed significantly across the four training groups. The highest frequency occurred in the AI-based training group, whereas no cases were observed in the sport-specific or physiotherapist-supervised AI groups. These findings indicate an association rather than proof of causation. Larger controlled studies using standardized diagnostic criteria and objective assessment methods are warranted.

Keywords: Carpal tunnel syndrome; volleyball; artificial intelligence; AI-based training; sport-specific exercise; physiotherapy; sports injury; overuse injury.

1. INTRODUCTION

Volleyball is a high-intensity sport requiring repeated movements of the upper and lower extremities. Serving, setting, spiking, blocking, and defensive actions require repeated use of the wrist, hand, and forearm. In addition to acute injuries, repetitive loading may contribute to upper-limb overuse symptoms and disorders.

Carpal tunnel syndrome (CTS) is a compressive neuropathy of the median nerve at the wrist. Typical symptoms include pain, numbness, and tingling, while severe cases may include sensory loss, weakness, or thenar muscle atrophy. CTS is primarily diagnosed from the clinical history and physical examination; objective testing such as electrodiagnostic studies may be useful in selected or atypical cases [1–3].

Repetitive or forceful wrist and hand activity is recognized among factors associated with CTS, making symptom surveillance relevant in athletic populations [2,3]. Early recognition of pain, numbness, and paresthesia may allow timely assessment and modification of training exposure.

Artificial intelligence (AI) is increasingly being applied in sport for performance analysis, athlete monitoring, training-load management, and health-related decision support. Recent

reviews describe growing applications of AI in sports performance and healthcare, while also emphasizing the importance of data quality, validation, context, and practitioner expertise [4,5]. Physiotherapist involvement may provide an additional clinical layer during technology-assisted training by allowing direct observation, exercise modification, symptom monitoring, and individualized progression. Despite growing interest in AI-assisted training, limited evidence is available regarding the occurrence of CTS among volleyball players exposed to different training approaches.

The present study therefore compared the observed occurrence of CTS among male volleyball players participating in four training approaches: conventional exercise training, sport-specific exercise training, AI-based training, and AI-based training with physiotherapist involvement.

The primary aim of this study is to evaluate and compare the incidence of carpal tunnel syndrome (CTS) among male volleyball players subjected to four distinct training regimens. To achieve this, the study's specific objectives are to calculate the overall frequency and percentage of CTS occurrences within each intervention cohort—namely conventional exercise, sport-specific training, AI-based training, and physiotherapist-supervised AI training. Furthermore, it aims to conduct a comparative analysis across these four modalities to determine whether the distribution of observed CTS cases demonstrates a statistically significant difference between the groups.

2. MATERIALS AND METHODS

This comparative prospective study was conducted over a 40-day observation period among male volleyball players in the Kadapa district of Andhra Pradesh, India. The study cohort comprised 60 male athletes aged 17 to 26 years, who were evenly distributed into four experimental groups of 15 participants each. To qualify for inclusion, participants had to meet the specified age criteria, commit to their assigned exercise regimen, and maintain complete availability for clinical monitoring throughout the entire 40-day duration. In contrast, individuals with a prior medical history of upper-limb, hand, or wrist disorders, or relevant neurological conditions, were excluded from the study protocol.

The four cohorts were structured to evaluate different training methodologies. Group 1 underwent conventional exercise training, while Group 2 participated in a sport-specific training program designed around the physical and functional demands of volleyball. Group 3 was assigned to an AI-based training program, and Group 4 followed an identical AI-based protocol with additional oversight and active involvement from a physiotherapist. Throughout the 40-day study, all athletes underwent continuous clinical monitoring for symptoms indicative of carpal tunnel syndrome (CTS), with systematic observation of hand and wrist pain, numbness, paresthesia, or other abnormal sensations. Any participant presenting with these symptoms received a CT-based diagnostic evaluation in accordance with the study protocol. The primary outcome measure evaluated across all four training cohorts was the incidence of CTS during the investigation period.

Statistical Analysis

Categorical data were summarized using frequencies and percentages. A 4×2 contingency table was constructed with training group as the exposure variable and CTS occurrence (yes/no) as the outcome. Pearson's chi-square test was performed. Because several expected frequencies were below 5, an exact two-sided contingency-table analysis was additionally performed. The Pearson chi-square statistic was $\chi^2(3) = 10.84$, $p = 0.0126$, and the exact two-sided p-value was approximately 0.0122. Cramér's V was 0.425, indicating a moderate-to-large association. Statistical significance was set at $p < 0.05$. No multivariable analysis was performed because individual-level data on potential confounders were not available.

3. RESULTS

The study cohort comprised 60 male volleyball players aged 17 to 26 years, with 15 participants distributed equally into each of the four intervention groups. Over the course of the 40-day observation period, 7 of the 60 participants (11.7%) were identified with carpal tunnel syndrome (CTS). The distribution of these CTS cases varied markedly across the different training approaches. The highest proportion of affected athletes occurred in Group 3 (AI-based training), where 5 out of 15 participants (33.3%) developed the condition. Group 1 (conventional training) recorded 2 CTS cases out of 15 athletes (13.3%). In contrast, neither Group 2 (sport-specific training) nor Group 4 (physiotherapist-supervised AI training) registered any cases of CTS during the study period.

Table 1: Distribution of observed CTS cases among the four training groups.

Training group	n	CTS cases	No CTS	CTS (%)	95% CI for CTS %
Group 1 – Conventional exercises	15	2	13	13.3	1.6–40.5
Group 2 – Sport-specific exercises	15	0	15	0.0	0.0–21.8
Group 3 – AI-based training	15	5	10	33.3	11.8–61.6
Group 4 – AI + physiotherapist	15	0	15	0.0	0.0–21.8
Total	60	7	53	11.7	4.8–22.3

Inferential Analysis

Pearson's chi-square test demonstrated a statistically significant association between training group and observed CTS occurrence, $\chi^2(3) = 10.84$, $p = 0.0126$. Because several expected cell frequencies were below 5, the exact two-sided analysis was prioritized, yielding $p \approx 0.0122$. Cramér's $V = 0.425$, indicating a moderate-to-large association between training group and CTS occurrence. These results indicate a difference in distribution across groups but do not establish a causal effect of any training approach.

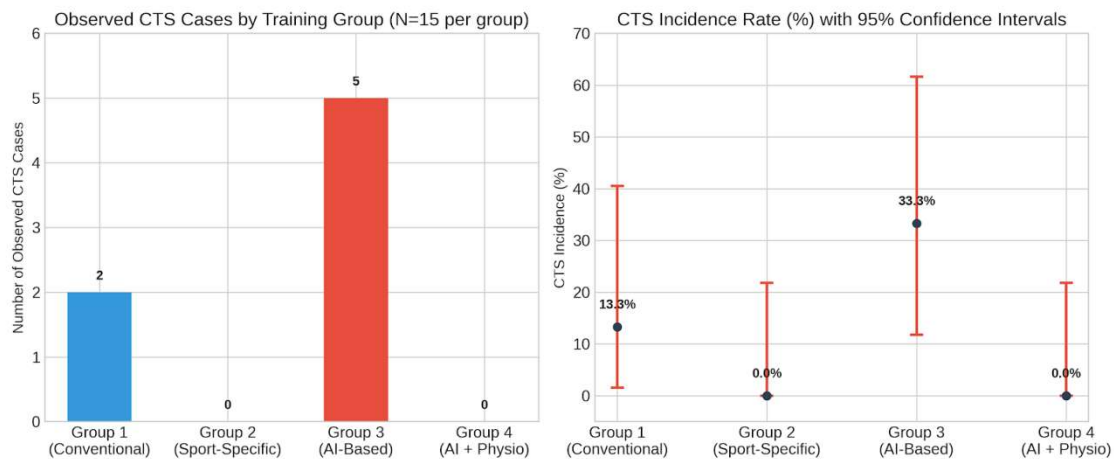


Figure 1. Observed number of CTS cases in each training group.

4. DISCUSSION

The present study found that 7 of 60 male volleyball players (11.7%) were identified with CTS during the 40-day observation period. The greatest observed frequency occurred in the AI-based training group, where 5 of 15 participants (33.3%) were affected. Two cases occurred in the conventional exercise group, while no cases were observed in the sport-specific exercise group or the AI-based physiotherapist-supervised group.

The overall association between training group and CTS occurrence was statistically significant. The finding is noteworthy because the observed pattern was not evenly distributed across the four groups. However, statistical association does not establish causation, particularly in a small observational study without detailed individual-level exposure and confounder data.

CTS is a median-nerve entrapment neuropathy and is commonly recognized through a combination of symptoms and clinical findings. Current evidence emphasizes clinical evaluation and, when appropriate, objective testing such as electrodiagnostic studies [1–3]. In the present study, symptomatic participants underwent CT-based assessment according to the study protocol. The specific CT criteria used should be documented in the study records to support reproducibility.

The higher observed occurrence in the AI-based training group may reflect differences in exercise selection, repetition, progression, movement execution, or training exposure. However, these mechanisms were not measured in the present study. Recent sports literature indicates that AI applications can support training, performance monitoring, and healthcare decision-making, while their usefulness depends on context, data quality, validation, and practitioner expertise [4,5].

The absence of observed cases in the sport-specific exercise group is notable but should not be interpreted as proof of a protective effect. Similarly, the absence of cases in the physiotherapist-supervised AI group may support further research into the role of professional supervision in technology-assisted training, but the present design cannot demonstrate prevention.

The findings therefore provide preliminary evidence of an association between training approach and observed CTS occurrence. Future research should use larger samples and collect detailed information on training volume, session frequency, repetitions, wrist position, playing position, dominant hand, previous exposure, and objective diagnostic measures.

5. CLINICAL IMPLICATIONS

Athletes participating in repetitive or technology-assisted training should be monitored for persistent hand or wrist pain, numbness, and tingling. Early clinical assessment may permit appropriate modification of training exposure. The present findings also support further evaluation of physiotherapist involvement when AI-assisted training is used.

6. LIMITATIONS

Small sample size, with only 15 participants per group.

- Only group-level occurrence data were available; symptom severity, grip strength, functional measures, and nerve-conduction parameters were not recorded in the supplied dataset.
- Detailed training load, exercise frequency, repetition count, intensity, wrist position, playing position, and dominant hand were not available for adjustment.
- CT-based assessment was used for symptomatic participants, but the exact CT protocol and diagnostic criteria were not supplied in the study records.
- The method of allocation to the four groups was not specified as randomized; therefore, the study should not be described as a randomized controlled trial unless random allocation was actually performed.
- The 40-day observation period limits conclusions regarding longer-term development or persistence of CTS.
- Because participants aged 17 years were included, the final submission must accurately report the consent/assent process used for minors.

7. CONCLUSION

In this sample of male volleyball players, the observed occurrence of CTS differed significantly across four training approaches. The highest frequency occurred in the AI-based training group (33.3%), followed by the conventional exercise group (13.3%), while no cases were observed in the sport-specific or physiotherapist-supervised AI groups. These results demonstrate an association in the present sample and should not be interpreted as evidence that AI-based training causes CTS or that physiotherapist supervision prevents it. Larger, well-controlled studies using standardized diagnostic criteria and objective assessment are required.

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