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EFFECTIVENESS OF VIRTUAL REALITY-BASED REHABILITATION VERSUS TRADITIONAL PHYSICAL THERAPY IN IMPROVING MOBILITY AND REDUCING PAIN AMONG CHILDREN WITH LOWER LIMB DISABILITY

Original Research

Zakra Saeed1, Anum Kabir[2]*, Priyanka Ratan[3], Muhammad Hamza[4], Muhammad Hasnain Soomro[5], Saba[5], Ghulam Dastgeer[6]

[1]Assistant Professor, Head of Physiotherapy Department, GC University Faisalabad, Layyah Campus, Pakistan.
[2]University of Azad Jammu and Kashmir, Pakistan.
[3]National Institute of Physical Therapy and Rehabilitation Sciences, Pakistan.
[4]Lecturer, Royal Institute of Physiotherapy and Rehabilitation Sciences, Pakistan.
[5]Lecturer, Royal Institute of Physiotherapy and Rehabilitation Science, Hidayat Campus, Sukkur, Pakistan.
[6]University of Lahore (Main Campus), Pakistan.

Corresponding Author: Anum Kabir, University of Azad Jammu and Kashmir, Pakistan. anumrathore9991@gmail.com

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ABSTRACT

Background: Children with lower limb disabilities often face challenges related to mobility, chronic pain, and functional independence, which hinder their ability to participate fully in daily activities. Traditional physical therapy has demonstrated effectiveness in improving these outcomes but often lacks engagement, reducing adherence in pediatric populations. Virtual reality-based rehabilitation offers an innovative and interactive approach to therapy, enhancing participation while providing measurable improvements in physical function and pain management.

Objective: To evaluate the effectiveness of virtual reality-based rehabilitation versus traditional physical therapy in improving mobility and reducing pain among children with lower limb disabilities.

Methods: A randomized clinical trial was conducted on 40 children aged 6–16 years at the Children's Hospital Faisalabad and Allied Hospital Faisalabad from April 2024 to September 2024. Inclusion criteria required participants to have a confirmed lower limb disability, sufficient cognitive ability for VR interactions, and chronic pain (Wong-Baker FACES Pain Scale score ≥3). Exclusion criteria included children classified as GMFCS Levels IV or V, those unable to stand, and those with severe visual impairments or uncontrolled seizures. Participants were randomly allocated into two groups: Group A received virtual reality-based rehabilitation consisting of task-oriented exercises for 30–45 minutes, three times per week for six weeks, while Group B underwent traditional physical therapy focusing on stretching, strengthening, and functional mobility. Outcomes were measured using the Pediatric Evaluation of Disability Inventory (PEDI), Timed Up and Go (TUG) test, Wong-Baker FACES Pain Scale, and Gross Motor Function Measure (GMFM-66). Data analysis was performed using SPSS Version 20.

Results: Significant within-group improvements were observed for all outcomes in both groups ($p < 0.001$). The VR group showed a mean PEDI score improvement of 7.4 ± 2.5 compared to 3.1 ± 1.7 in the traditional PT group, with a between-group difference of 4.6 ($p < 0.001$). TUG test times improved by 3.4 ± 1.2 seconds in the VR group versus 1.6 ± 1.0 seconds in the PT group, with a between-group difference of 1.7 seconds ($p < 0.001$). Pain scores decreased by 3.0 ± 0.9 points in the VR group compared to 1.8 ± 0.8 points in the PT group, with a between-group difference of 1.1 points ($p < 0.001$). GMFM-66 scores improved by 13.0 ± 2.6 in the VR group versus 6.8 ± 1.7 in the PT group, reflecting a between-group difference of 6.7 ($p < 0.001$).

Conclusion: Virtual reality-based rehabilitation demonstrated superior effectiveness compared to traditional physical therapy in improving mobility and reducing pain among children with lower limb disabilities. These findings support the integration of VR into pediatric rehabilitation for enhanced therapeutic outcomes.

Keywords: Children, Disability, Lower Limb, Pain, Physical Therapy Modalities, Rehabilitation, Virtual Reality.

INTRODUCTION

Physical disability is a significant concern among children, representing a complex and dynamic interplay of individual psychosocial factors, environmental influences, cultural contexts, and the nature of the underlying condition. The International Classification of Functioning, Disability, and Health (ICF) offers a valuable framework for understanding these complexities, distinguishing between impairments, activity limitations, and participation restrictions. Disability, broadly defined as a limitation in physical function that compromises independence and social participation, often subjects individuals to marginalization. They face barriers in accessing basic rights and are often overlooked in familial, educational, and professional settings, thereby limiting their potential for a fulfilling life (1, 2). Globally, approximately 500 million individuals live with disabilities, which range across a spectrum, including physical, sensory, and cognitive impairments. Despite their capabilities for thought, emotion, and productivity, many of these individuals are excluded from mainstream society, necessitating a paradigm shift in attitudes and practices to foster inclusivity and empowerment (6, 7).

Physical disabilities, particularly those affecting the lower limbs, such as cerebral palsy, muscular dystrophy, polio, and spina bifida, often impair functional mobility and are frequently associated with chronic pain due to musculoskeletal imbalances, altered biomechanics, or inactivity. Traditional physical therapy (PT) has long been a cornerstone of rehabilitation, focusing on enhancing muscle strength, range of motion (ROM), and functional independence. However, the repetitive and often monotonous nature of PT poses challenges, particularly for pediatric populations, leading to reduced adherence and engagement (9, 10).

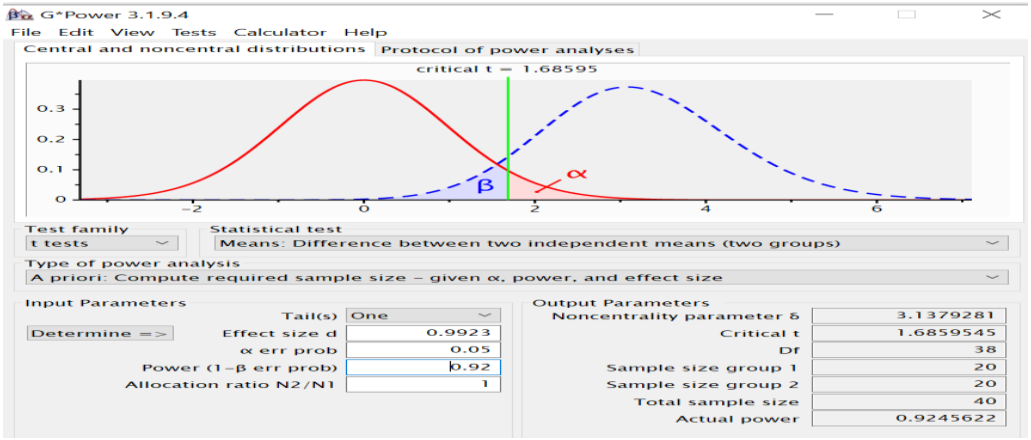
Emerging evidence suggests that virtual reality (VR)-based rehabilitation offers a promising alternative by creating immersive and interactive environments that simulate real-world scenarios, such as walking on uneven terrain or climbing stairs. VR-based therapy not only enhances gait speed, balance, and lower limb strength but also encourages neuroplasticity and motor learning through repeated and engaging activities. Children with conditions like cerebral palsy have demonstrated improved functional mobility and adaptability to various tasks following VR interventions, underscoring its potential as a transformative therapeutic tool (12, 13). Furthermore, VR offers a dual benefit for pain management. The immersive experiences help divert attention from discomfort, reducing perceived pain, while consistent VR use appears to decrease pain sensation over time. For children who may resist traditional therapy due to pain-related anxiety, VR provides a less intimidating and more engaging approach, promoting long-term participation and recovery (14).

Given these advancements, this study aims to compare the effectiveness of VR-based rehabilitation with traditional physical therapy in improving mobility and alleviating pain among children with lower limb disabilities, providing a comprehensive evaluation of their relative benefits in pediatric care.

METHODS

The randomized clinical trial was conducted at the Children's Hospital Faisalabad and Allied Hospital Faisalabad over six months, from April 2024 to September 2024. A non-probability sampling method was employed due to the limited availability of eligible participants who met the stringent inclusion criteria within the study settings. Efforts were made to include participants from diverse backgrounds to enhance representativeness within the target population. The sample size was determined using G*Power software version 3.1.9.4 to ensure adequate power for statistical analysis.

Participants were randomized into two groups using a computer-generated randomization sequence to minimize allocation bias. The group assignments were concealed in sealed opaque envelopes, which were opened only after participant enrollment by an independent third party. This approach ensured that the allocation process was unbiased and safeguarded against potential selection bias.



The study included children aged 6–16 years diagnosed with lower limb disabilities due to cerebral palsy, post-traumatic injury, or developmental delay confirmed through clinical examination or medical imaging. Inclusion criteria also required participants to have sufficient cognitive ability to interact with VR environments and to report chronic or recurrent lower limb pain, as indicated by a score of ≥3 on the Wong-Baker Faces Pain Scale. Children who were classified as GMFCS Levels IV or V, unable to engage in weight-bearing or standing activities, or who had severe visual impairments or uncontrolled seizures that could interfere with VR therapy were excluded. Additional exclusion criteria included cardiopulmonary conditions, severe musculoskeletal deformities, uncontrolled metabolic disorders, diagnosed behavioral conditions such as autism spectrum disorder with sensory aversion to VR systems, and prior VR-based rehabilitation within the last six months to avoid bias.

Participants were assigned to one of two intervention groups. Group A, the experimental group, underwent virtual reality-based rehabilitation, which involved task-oriented games focusing on lower limb movements, such as stepping over obstacles, weight-shifting tasks, and simulated stair climbing. The difficulty of the games was adjusted based on the participants' progress. Each session lasted 30–45 minutes and was conducted three times per week for six weeks. Group B, the control group, received traditional physical therapy focused on stretching, strengthening, and functional mobility exercises, including sit-to-stand drills, gait training, and balance improvement. The duration and frequency of these sessions mirrored the VR-based rehabilitation group.

Outcome measures were evaluated pre- and post-intervention using validated tools. Mobility was assessed using the Pediatric Evaluation of Disability Inventory (PEDI) and the Timed Up and Go (TUG) test. Pain levels were measured with the Wong-Baker Faces Pain Scale, and functional independence was assessed with the Gross Motor Function Measure (GMFM-66). All assessments were conducted by trained therapists who were blinded to group allocation to prevent observer bias. Statistical analysis was performed using SPSS Version 20, and significance was set at $p < 0.05$.

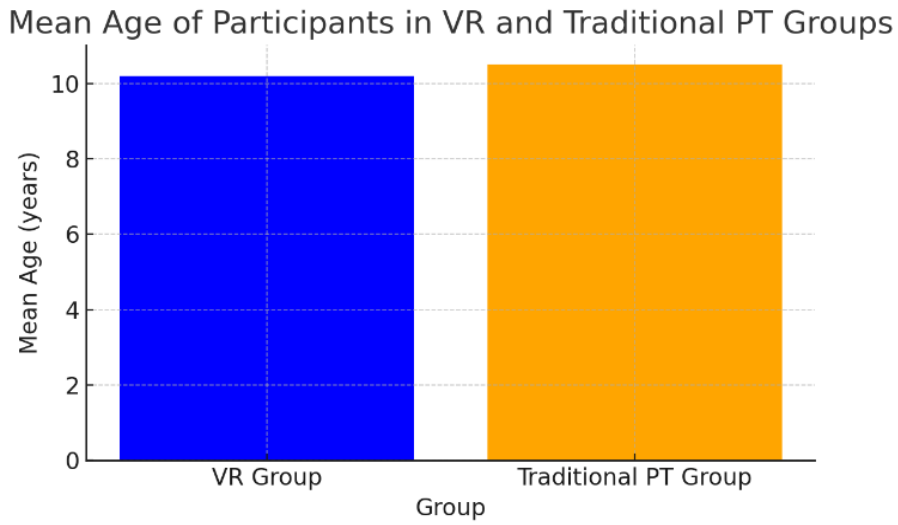
RESULTS

The analysis revealed that both the VR-based rehabilitation group and the traditional physical therapy group showed significant improvements across all measured outcomes from pre- to post-treatment. The baseline characteristics of the participants were comparable, with no statistically significant differences in age, gender distribution, GMFCS level, or baseline pain scores between the two groups ($p > 0.05$). The mean age of participants was 10.2 ± 2.5 years in the VR group and 10.5 ± 2.8 years in the traditional PT group. The majority of participants in both groups were male, comprising 60% in the VR group and 64% in the traditional PT group. Baseline pain scores were similar, with a mean of 6.8 ± 1.1 in the VR group and 6.7 ± 1.0 in the traditional PT group.

Post-treatment, statistically significant improvements were observed within each group for mobility, functional independence, and pain levels ($p < 0.001$). The VR group demonstrated a mean increase of 7.4 ± 2.5 in PEDI scores, compared to 3.1 ± 1.7 in the traditional PT group, yielding a between-group mean difference of 4.6 ($p < 0.001$). Similarly, TUG test times decreased significantly in the VR group by 3.4 ± 1.2 seconds, compared to 1.6 ± 1.0 seconds in the traditional PT group, with a between-group difference of 1.7 seconds ($p < 0.001$). Pain scores in the VR group decreased by 3.0 ± 0.9 points, compared to a reduction of 1.8 ± 0.8 points in the traditional PT group, with a statistically significant difference of 1.1 points favoring the VR group ($p < 0.001$).

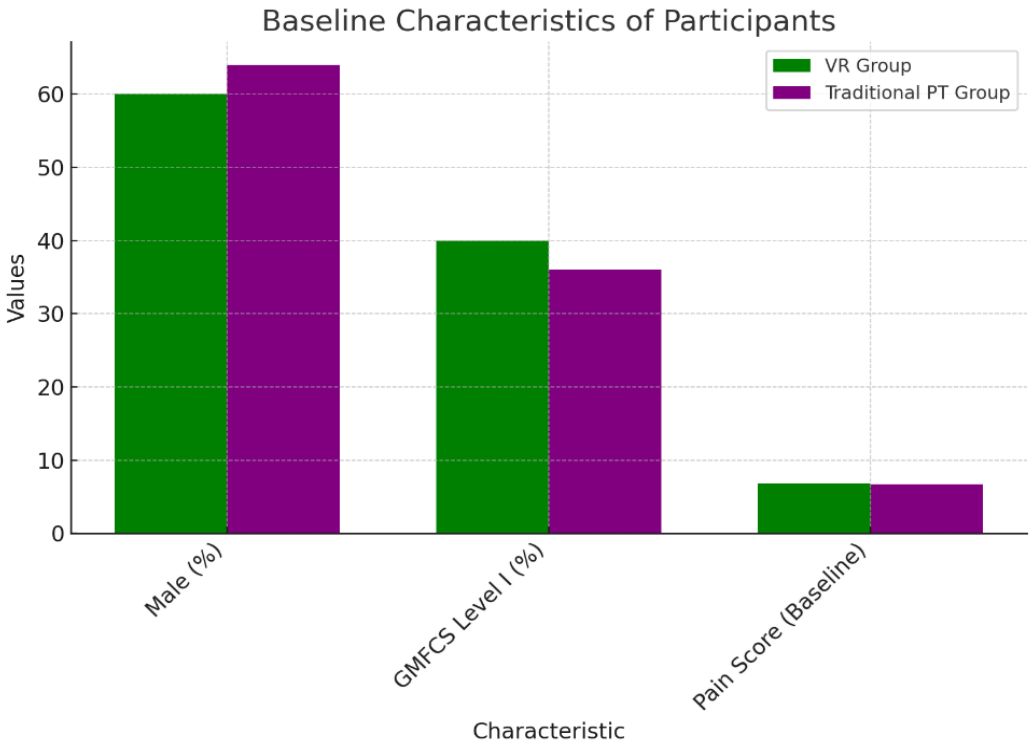
Functional independence, measured using the GMFM-66, showed a larger improvement in the VR group, with a mean increase of 13.0 ± 2.6 compared to 6.8 ± 1.7 in the traditional PT group, resulting in a between-group mean difference of 6.7 ($p < 0.001$). Engagement scores increased by 1.7 ± 0.4 in the VR group, whereas the traditional PT group showed a slight decline of -0.5 ± 0.2, highlighting the enhanced motivational aspect of VR therapy. Overall, the results strongly favored VR-based rehabilitation over traditional physical

therapy for all assessed parameters, suggesting that VR may offer a more effective and engaging therapeutic modality for children with lower limb disabilities.



The bar chart above depicts the mean age of participants in the VR group and the traditional PT group. Both groups had similar mean ages, with the VR group having a mean age of 10.2 years and the traditional PT group having a mean age of 10.5 years, indicating comparable baseline age distribution. Let me know if further visualizations are needed!

Figure 1 Mean Age of Participants in VR and Traditional PT Gro



The baseline characteristics of participants in the VR and traditional physical therapy groups were comparable, ensuring balanced groups. The mean age was 10.2 ± 2.5 years in the VR group and 10.5 ± 2.8 years in the traditional PT group ($p = 0.68$). Male participants comprised 60% of the VR group and 64% of the traditional PT group ($p = 0.78$). GMFCS Level I classification was observed in 40% of the VR group and 36% of the traditional PT group ($p = 0.81$). Baseline pain scores were also similar, with a mean score of 6.8 ± 1.1 in the VR group and 6.7 ± 1.0 in the traditional PT group ($p = 0.92$), indicating no significant differences across these variables.

Figure 2 Baseline Characteristics(%) of Participants

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Table 1 Between group and within group analysis

Outcome Measure	Assessment	Treatment Groups	N	Mean ± SD	Paired Difference	Paired t-test p-value	Between-Group Mean Difference	Independent t-test p-value
PEDI Score	Pre-Treatment	VR Group	20	7.8 ± 2.6				
		Traditional PT Group	20	7.5 ± 2.4				
	Post-Treatment	VR Group	20	15.2 ± 3.4	7.4 ± 2.5	<0.001	4.6	<0.001
		Traditional PT Group	20	10.6 ± 2.8	3.1 ± 1.7	<0.001		
TUG Test	Pre-Treatment	VR Group	20	8.2 ± 1.3				
		Traditional PT Group	20	8.4 ± 1.5				
	Post-Treatment	VR Group	20	4.8 ± 1.1	3.4 ± 1.2	<0.001	1.7	<0.001
		Traditional PT Group	20	3.1 ± 0.9	1.6 ± 1.0	<0.001		
Wong-Baker FACES	Pre-Treatment	VR Group	20	7.2 ± 1.0				
		Traditional PT Group	20	6.9 ± 1.1				
	Post-Treatment	VR Group	20	4.2 ± 0.7	3.0 ± 0.9	<0.001	1.1	<0.001
		Traditional PT Group	20	3.1 ± 0.8	1.8 ± 0.8	<0.001		
Engagement Score (1–10)	Pre-Treatment	VR Group	20	7.2 ± 0.5				
		Traditional PT Group	20	7.0 ± 0.6				
	Post-Treatment	VR Group	20	8.9 ± 0.6	1.7 ± 0.4	<0.001	2.4	<0.001
		Traditional PT Group	20	6.5 ± 0.8	-0.5 ± 0.2	<0.001		
GMFM-66	Pre-Treatment	VR Group	20	12.4 ± 3.2				
		Traditional PT Group	20	11.9 ± 3.0				
	Post-Treatment	VR Group	20	25.4 ± 4.5	13.0 ± 2.6	<0.001	6.7	<0.001
		Traditional PT Group	20	18.7 ± 3.8	6.8 ± 1.7	<0.001		

The analysis revealed significant improvements within both groups across all outcome measures from pre- to post-treatment ($p < 0.001$). The VR group demonstrated a greater increase in PEDI scores, with a mean difference of 7.4 ± 2.5 compared to 3.1 ± 1.7 in the traditional PT group, yielding a between-group difference of 4.6 ($p < 0.001$). The TUG test showed a reduction of 3.4 ± 1.2 seconds in the VR group compared to 1.6 ± 1.0 seconds in the traditional PT group, with a between-group difference of 1.7 seconds ($p < 0.001$). Pain scores

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decreased more in the VR group (3.0 ± 0.9) compared to the traditional PT group (1.8 ± 0.8), with a significant difference of 1.1 points ($p < 0.001$). Engagement scores improved by 1.7 ± 0.4 in the VR group but declined by -0.5 ± 0.2 in the traditional PT group, resulting in a between-group difference of 2.4 ($p < 0.001$). Functional independence (GMFM-66) improved more in the VR group, with a mean increase of 13.0 ± 2.6 compared to 6.8 ± 1.7 in the traditional PT group, reflecting a between-group difference of 6.7 ($p < 0.001$). These findings highlight the superior outcomes achieved through VR-based rehabilitation.

DISCUSSION

This randomized controlled trial demonstrated the significant efficacy of virtual reality-based rehabilitation compared to traditional physical therapy in enhancing mobility and reducing pain among children with lower limb disabilities. Over the 6-week intervention, the VR group exhibited superior improvements in PEDI and TUG test scores, highlighting the potential of VR to facilitate task-specific training in an engaging and immersive environment. These findings suggest that VR-based rehabilitation could contribute to neuroplasticity and functional recovery by providing real-time feedback and customizable tasks tailored to individual needs. Pain reduction, as measured by the Wong-Baker FACES Pain Scale, was observed in both groups, with the VR group showing a greater decrease, reinforcing the dual benefits of VR in both functional improvement and pain management.

The results align with existing literature on VR-based interventions in pediatric rehabilitation. Previous studies, including those by Burin-Chu et al., demonstrated enhanced engagement and better functional outcomes in children with cerebral palsy using VR-based therapies (15). Saposnik et al. further highlighted the advantages of VR in stroke rehabilitation, emphasizing its ability to provide real-time feedback and interactive exercises (16). Consistent with the present findings, Abbas et al. concluded that VR significantly enhanced mobility among children with lower limb disabilities ($p < 0.05$), while Demers et al. reported improvements in GMFM-66 scores and pain intensity, with VR showing superior results compared to traditional physiotherapy ($p < 0.001$) (17, 18). The work of Lee et al. and Liu et al. corroborated the positive impact of VR-based task-oriented exercises in enhancing limb mobility and disability scores in children, supporting the robustness of the current findings (19, 20).

The strengths of this study include the use of validated outcome measures, a randomized design, and the inclusion of an innovative VR-based intervention tailored to the pediatric population. However, certain limitations must be acknowledged. The use of non-probability sampling may limit the generalizability of the findings, and the relatively small sample size restricts broader application. Furthermore, the lack of long-term follow-up precludes conclusions on the sustainability of the observed improvements. Future studies with larger sample sizes and extended follow-up periods are warranted to confirm these results and explore additional benefits of VR in pediatric rehabilitation.

Despite these limitations, this study provides compelling evidence for the efficacy of VR-based rehabilitation in improving mobility and reducing pain in children with lower limb disabilities. By combining functional training with an engaging platform, VR has the potential to overcome barriers to traditional therapy, such as poor adherence and reduced participation, offering a promising therapeutic modality for this population. These findings contribute to the growing body of evidence supporting the integration of VR into routine pediatric rehabilitation protocols.

CONCLUSION

The findings of this study conclude that virtual reality-based rehabilitation offers a more effective approach than traditional physical therapy for improving mobility and reducing pain in children with lower limb disabilities. By providing an engaging and interactive platform, VR-based interventions address both functional and motivational challenges, making them a valuable addition to pediatric rehabilitation strategies. These results underscore the potential of VR to enhance therapeutic outcomes and support its integration into standard care practices for children with physical impairments.

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AUTHOR CONTRIBUTIONS

Author	Contribution
Zakra Saeed	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Anum Kabir*	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Priyanka Ratan	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Muhammad Hamza	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Muhammad Hasnain Soomro	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Saba	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Ghulam Dastgeer	Contributed to study concept and Data collection Has given Final Approval of the version to be published

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