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EFFECTS OF OPEN KINETIC CHAIN KNEE EXTENSION EXERCISES WITH NEUROMUSCULAR ELECTRICAL STIMULATION IN PATIENTS WITH POST-ACL RECONSTRUCTION SURGERY

Original Research

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ABSTRACT

Background: Anterior cruciate ligament (ACL) reconstruction is a common orthopedic procedure aimed at restoring knee stability following ligament rupture. Despite surgical success, persistent quadriceps weakness, limited range of motion, and delayed functional recovery remain key rehabilitation challenges. Open kinetic chain (OKC) exercises are frequently used to restore muscle strength post-ACL reconstruction; however, the addition of neuromuscular electrical stimulation (NMES) may further enhance outcomes by targeting muscle activation and reducing inhibition.

Objective: To determine the effectiveness of combining NMES with OKC knee extension exercises in improving functional performance, range of motion, and patient-reported outcomes following ACL reconstruction.

Methods: A randomized clinical trial was conducted with 58 participants, four weeks post-ACL reconstruction, allocated into two groups: Group A (OKC + NMES, n=29) and Group B (OKC only, n=29). Interventions were delivered thrice weekly over eight weeks. Functional performance was assessed using the Single-Leg Hop Test (SLHT), patient-reported outcomes were evaluated via the Lysholm Knee Scoring Scale (LKSS), and range of motion (ROM) was measured using a universal goniometer. Data were analyzed using non-parametric tests, with significance set at $p < 0.05$.

Results: At 8 weeks, Group A showed significantly greater improvements than Group B. SLHT scores increased from 2.48 ± 1.96 cm to 48.66 ± 6.64 cm in Group A, versus 2.03 ± 2.08 cm to 36.97 ± 2.67 cm in Group B ($p < 0.001$). LKSS scores improved from 52.93 ± 6.34 to 91.55 ± 4.19 in Group A, and from 50.34 ± 7.78 to 81.06 ± 2.87 in Group B ($p < 0.001$). Flexion increased to $109.48° \pm 10.80$ in Group A vs. $90.48° \pm 3.90$ in Group B ($p < 0.001$). Full extension (0°) was restored only in Group A ($p < 0.001$).

Conclusion: Combining NMES with OKC exercises significantly enhances post-operative recovery in ACL-reconstructed patients by improving quadriceps function, knee mobility, and subjective outcomes.

Keywords: Anterior Cruciate Ligament Reconstruction, Goniometric Measurements, Lysholm Knee Scale, Neuromuscular Electrical Stimulation, Open Kinetic Chain Exercises, Postoperative Rehabilitation, Single-Leg Hop Test.

INTRODUCTION

Anterior cruciate ligament (ACL) injuries are among the most frequently encountered musculoskeletal traumas, particularly in athletic populations, and often necessitate surgical intervention followed by a structured rehabilitation program (1,2). ACL reconstruction (ACLr) has become the standard approach to restoring knee stability and function; however, one of the most persistent challenges postoperatively is the restoration of quadriceps strength (2). Deficits in quadriceps function can impair knee joint mechanics, contribute to altered gait patterns, and significantly increase the risk of reinjury, hindering the long-term recovery process (3). Following an ACL rupture, the resultant pain, edema, and neuromuscular inhibition can lead to a rapid decline in both hamstring and quadriceps muscle strength (4). In some cases, this weakness, particularly in the knee extensors, has been reported to persist for up to seven years following surgery (5). Even after successful surgical repair, long-term follow-up studies report extensor strength deficits ranging between 6% and 18% up to six years post-reconstruction (6). These prolonged deficits underline the need for effective rehabilitation strategies that go beyond traditional strength training. Anatomically, the ACL connects the anteromedial intercondylar eminence of the tibia to the medial wall of the lateral femoral condyle and plays a critical role in maintaining anterior-posterior and rotational stability of the knee joint (7). The injury mechanism is often non-contact in nature, typically occurring during rapid deceleration, twisting, or shearing movements, with patients frequently describing an audible “pop” at the time of injury (8). Various surgical techniques are available for ACL reconstruction, including allografting, bone–patellar tendon–bone (BPTB) transfer, and the use of autografts from the semitendinosus or gracilis muscles (9). Although these surgical methods are effective in restoring mechanical stability, the rehabilitation that follows is crucial for achieving functional outcomes. Recovery timelines typically range from five to nine months, depending on the intensity and progression of the rehabilitation protocol (10). Postoperative challenges such as limited range of motion—particularly terminal extension—along with persistent pain, joint stiffness, and muscle atrophy, continue to hinder optimal recovery (11).

To enhance rehabilitation outcomes, exercise-based strategies such as open kinetic chain (OKC) and closed kinetic chain (CKC) exercises have gained popularity in recent years (12). OKC exercises are particularly valuable in the early stages of rehabilitation because they facilitate isolated quadriceps activation in non-weightbearing positions, making them ideal for targeting muscle weakness without placing undue stress on healing tissues (13). When applied judiciously, these exercises have been shown to improve both strength and range of motion while promoting more efficient neuromuscular coordination (14). In addition to traditional exercise regimens, neuromuscular electrical stimulation (NMES) has emerged as a promising adjunct therapy in ACL rehabilitation (15). NMES uses controlled electrical impulses to elicit muscle contractions, bypassing voluntary activation pathways that may be compromised postoperatively (16). This approach has shown considerable potential in restoring quadriceps strength and mitigating muscle atrophy, especially in cases where voluntary contraction is limited by pain or disuse (17). The efficacy of NMES in enhancing muscle recovery and function has been demonstrated across various studies, though differences in stimulation parameters have created inconsistencies in reported outcomes (18). Integrating NMES with OKC exercises may offer a synergistic benefit, providing a more comprehensive approach to neuromuscular retraining during the critical early stages of rehabilitation (19,20). Given the high prevalence of quadriceps weakness following ACL reconstruction and the limitations of conventional rehabilitation techniques alone, this study aims to evaluate the combined effect of open kinetic chain exercises and neuromuscular electrical stimulation on quadriceps strength and functional recovery. Subjects in the immediate postoperative phase of ACL reconstruction will be randomized into two groups: one receiving OKC exercises alone and the other receiving OKC exercises supplemented with NMES. The study will assess range of motion, functional performance, and patient-reported outcomes including pain, function, and quality of life. The objective is to determine whether the integration of NMES into early rehabilitation protocols offers superior improvements in muscle strength and knee function compared to exercise alone, potentially refining best practices for postoperative care.

METHODS

The present study was designed as a randomized clinical trial (RCT) conducted over a period of four months at the Move Better physiotherapy clinic in Faisalabad, Pakistan. Ethical approval was obtained from the institutional review board, and all participants provided written informed consent prior to enrollment. The sample size was calculated using OpenEpi version 3, yielding a total of 58 participants who had undergone unilateral primary ACL reconstruction (ACLr). These individuals were randomly allocated into two equal groups: Group A (intervention group) and Group B (control group), with 29 participants in each arm. Randomization was achieved using computer-generated random numbers, ensuring allocation concealment to minimize selection bias. Eligible participants included males and females between 18 and 45 years of age who were exactly four weeks post-ACLr at the time of study initiation. Only those who had received either a hamstring tendon autograft or patellar tendon graft and were cleared by a physician to begin open kinetic chain (OKC) exercises were considered. Exclusion criteria included prior ACL reconstruction on the same knee, associated ligamentous injuries (e.g., meniscus, MCL, PCL), significant comorbidities such as rheumatoid arthritis or uncontrolled diabetes, recent surgery or trauma to the contralateral limb, and any neuromuscular conditions that could compromise voluntary muscle control. Additionally, individuals with poor compliance potential or those deemed unfit to follow the study protocol were excluded.

At baseline, demographic and clinical data including age, gender, body mass index (BMI), time since injury, and type of graft were recorded. Participants in Group A received a combination of OKC knee extension exercises and neuromuscular electrical stimulation (NMES), whereas Group B performed OKC exercises only. OKC exercises included Seated Knee Extensions with resistance bands or weights (1–5 kg) performed at 30%–50% of 1-repetition maximum (1-RM), Straight Leg Raises with or without light ankle weights (0.5–2 kg), and Quadriceps Isometric Holds held for 5–20 seconds. All exercises were completed three times weekly for 8 weeks, with each session lasting approximately 20 minutes. In the intervention group, NMES was applied to the quadriceps muscle belly at a frequency of 35–50 Hz with a pulse duration of 200 microseconds. Electrodes were placed over motor points to elicit visible and strong but tolerable contractions. Each NMES session lasted 15 minutes and was synchronized with exercise sessions. Both groups received supervision from licensed physiotherapists to ensure correct form, progression, and safety throughout the intervention. Functional outcomes were evaluated using the Single-Leg Hop Test (SLHT), which has demonstrated high intra-rater reliability (ICC = 0.85) and test-retest reliability (ICC = 0.92–0.97), with a sensitivity and specificity of approximately 71% at an 88% limb symmetry index (LSI) cutoff. A limb-to-limb difference of less than 10% was considered a marker of good recovery. Patient-reported knee function was assessed using the Lysholm Knee Scoring Scale (LKSS), which is well-validated (ICC = 0.90) and demonstrates strong correlation with other outcome measures such as the International Knee Documentation Committee (IKDC) and SF-12 scores. LKSS scores were interpreted as follows: 95–100 = excellent, 84–94 = good, 65–83 = fair, and <65 = poor.

Knee range of motion (ROM) was measured using a universal goniometer, which has been shown to possess excellent validity (r = 0.97–0.98; ICC = 0.98–0.99) and inter-rater reliability (r = 0.98; ICC = 0.99). For knee extension measurements, the goniometer's axis was aligned with the lateral epicondyle of the femur, with the stationary arm pointing toward the greater trochanter and the movable arm aligned with the lateral malleolus. For flexion, standard anatomical landmarks were used, and participants were asked to perform the full range of motion while the examiner recorded the angle achieved. Data were analyzed using IBM SPSS version 22. Normality of the data was checked using the Shapiro-Wilk test. Independent t-tests or Mann-Whitney U tests were used for between-group comparisons depending on data distribution. Within-group changes across time points (baseline, 4 weeks, and 8 weeks) were evaluated using repeated measures ANOVA for parametric data or the Friedman test for non-parametric data. A p-value of <0.05 was considered statistically significant. Results were illustrated using appropriate tables and graphical representations to enhance interpretability.

RESULTS

The study enrolled 58 participants who were randomized into two equal groups of 29 each: Group A (OKC + NMES) and Group B (OKC only). The Kolmogorov-Smirnov test indicated that the data were not normally distributed, warranting the use of non-parametric statistical tests. Descriptive statistics confirmed proper randomization and demographic balance across both groups, with a slight male predominance in each. Mean age values and gender ratios were consistent, ensuring methodological comparability. In the Single-Leg Hop Test (SLHT), Group A showed marked improvements over time, with mean scores progressing from 2.48 ± 1.96 at baseline to 27.41 ± 2.71 at 4 weeks and 48.66 ± 6.64 at 8 weeks. The Friedman test revealed a statistically significant improvement (p = 0.000). Group B also improved from 2.03 ± 2.08 at baseline to 17.72 ± 1.73 at 4 weeks and 36.97 ± 2.67 at 8 weeks (p = 0.000). Between-group comparison using the Mann-Whitney U test showed no significant difference at baseline (p = 0.482), but Group A had significantly superior performance at both 4 weeks (p = 0.000) and 8 weeks (p = 0.000) Regarding patient-reported outcomes measured by the Lysholm Knee Scoring Scale (LKSS), Group A demonstrated a consistent increase from 52.93 ± 6.34 at baseline to 78.10 ± 5.10 at 4 weeks and 91.55 ± 4.19 at 8 weeks (p = 0.000). Group B followed a similar upward trajectory with scores improving from 50.34 ± 7.78 at baseline to 64.79 ± 2.80 at 4 weeks and 81.06 ± 2.87 at 8 weeks (p = 0.000). Baseline differences between groups were non-significant (p = 0.157), but Group A demonstrated significantly higher LKSS scores at 4 weeks (p = 0.000) and 8 weeks (p = 0.000).

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Knee flexion angles in Group A increased significantly from 50.68° ± 5.49 at baseline to 79.72° ± 10.50 at 4 weeks and 109.48° ± 10.80 at 8 weeks (p = 0.000). In Group B, flexion improved from 49.62° ± 5.27 to 66.68° ± 3.63 at 4 weeks and 90.48° ± 3.90 at 8 weeks (p = 0.000). Between-group comparisons showed no significant baseline difference (p = 0.454), but significant improvement in Group A was evident at both 4 weeks (p = 0.000) and 8 weeks (p = 0.000). Knee extension recovery also differed significantly between groups. In Group A, mean extension deficit reduced from 7.55° ± 1.40 to 3.17° ± 0.93 at 4 weeks, reaching complete extension (0.00° ± 0.00) by 8 weeks (p = 0.000). Group B improved from 7.79° ± 1.52 to 5.52° ± 1.02 at 4 weeks and 1.24° ± 0.99 at 8 weeks (p = 0.000). No significant difference was observed at baseline (p = 0.605); however, Group A achieved significantly greater extension recovery at 4 weeks (p = 0.000) and 8 weeks (p = 0.000).

Table 1: Descriptive Statistics of Participant Groups by Gender and Group Assignment

Variable	**Group A (OKC + NMES)**			**Group B (OKC only)**		
	N	Min	Max	N	Min	Max
Groups of Participants	29	1	1	29	2	2
Mean	1.00			2.00		
Std. Error	0.000			0.000		
Standard Deviation	0.000			0.000		
Gender	29	1	2	29	1	2
Mean	1.28			1.34		
Std. Error	0.084			0.090		
Standard Deviation	0.455			0.484		

Table 2: Normality Assessment of Pre-Intervention Outcome Measures Using Kolmogorov-Smirnov and Shapiro-Wilk Tests

	Kolmogorov Smirnov			Shapiro Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pre-Intervention of Single Leg Hop Test	.283	58	.000	.791	58	.000
Pre-Intervention of Lysholm Knee Scoring Scale	.237	58	.000	.838	58	.000
Pre-Intervention of Knee Flexion	.140	58	.007	.948	58	.014
Pre-Intervention of Knee Extension	.178	58	.000	.899	58	.000

Table 3: Within-Group Analysis of Single-Leg Hop Test Scores in OKC + NMES and OKC Only Groups Over 8 Weeks (Friedman Test)

Time Point	**Group**	**N**	**Mean**	**S.D**	**Min**	**Max**	**Mean Rank**	**P-value**
Pre-intervention	OKC + NMES	29	2.48	1.957	0	5	1.00	.000
4 weeks post-intervention	OKC + NMES	29	27.41	2.706	20	33	2.00	
8 weeks post-intervention	OKC + NMES	29	48.66	6.635	31	59	3.00	
Pre-intervention	OKC only	29	2.03	2.079	0	5	1.00	.000
4 weeks post-intervention	OKC only	29	17.72	1.730	14	21	2.00	
8 weeks post-intervention	OKC only	29	36.97	2.666	31	42	3.00	

Table 4: Within-Group Analysis of Knee Extension in OKC + NMES and OKC Only Groups Over 8 Weeks (Friedman Test)

Time Point	**Group**	**N**	**Mean**	**S.D**	**Min**	**Max**	**Mean Rank**	**P-value**
Pre-intervention	OKC + NMES	29	7.55	1.403	5.0	10.0	3.00	.000
4 weeks post-intervention	OKC + NMES	29	3.17	0.928	2.0	5.0	2.00	
8 weeks post-intervention	OKC + NMES	29	0.00	0.000	0.0	0.0	1.00	
Pre-intervention	OKC only	29	7.79	1.520	6.0	10.0	3.00	.000
4 weeks post-intervention	OKC only	29	5.517	1.021	4.0	7.0	2.00	
8 weeks post-intervention	OKC only	29	1.24	0.987	0.0	2.0	1.00	

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Table 5: Between-Group Comparison of Functional, Patient-Reported, and Range of Motion Outcomes Using Mann-Whitney U Test (OKC + NMES vs. OKC Only)

Outcome Measure	Time Point	Group	N	Mean Rank	Sum of Ranks	Z Score	Asymp. Sig. (2-tailed)
Single-Leg Hop Test	Pre-intervention	OKC + NMES	29	30.98	898.50	-0.703	.482
		OKC only	29	28.02	812.50		
	4 weeks post-intervention	OKC + NMES	29	43.90	1273.00	-6.515	.000
		OKC only	29	15.10	438.00		
	8 weeks post-intervention	OKC + NMES	29	41.97	1217.00	-5.633	.000
		OKC only	29	17.03	494.00		
Lysholm Knee Scoring Scale	Pre-intervention	OKC + NMES	29	32.51	943.00	-1.414	.157
		OKC only	29	26.48	768.00		
	4 weeks post-intervention	OKC + NMES	29	43.96	1275.00	-6.534	.000
		OKC only	29	15.03	436.00		
	8 weeks post-intervention	OKC + NMES	29	43.67	1266.50	-6.403	.000
		OKC only	29	15.32	444.50		
Knee Flexion	Pre-intervention	OKC + NMES	29	31.15	903.50	-0.748	.454
		OKC only	29	27.84	807.50		
	4 weeks post-intervention	OKC + NMES	29	39.48	1145.00	-4.513	.000
		OKC only	29	19.51	566.00		
	8 weeks post-intervention	OKC + NMES	29	41.93	1216.00	-5.682	.000
		OKC only	29	17.06	495.00		
Knee Extension	Pre-intervention	OKC + NMES	29	28.38	823.00	-0.516	.605
		OKC only	29	30.62	888.00		
	4 weeks post-intervention	OKC + NMES	29	16.62	482.00	-5.927	.000
		OKC only	29	42.37	1229.00		
	8 weeks post-intervention	OKC + NMES	29	20.50	594.50	-5.064	.000
		OKC only	29	38.50	1116.50		

Figure 2 Knee Extension Mean Scores Over Time

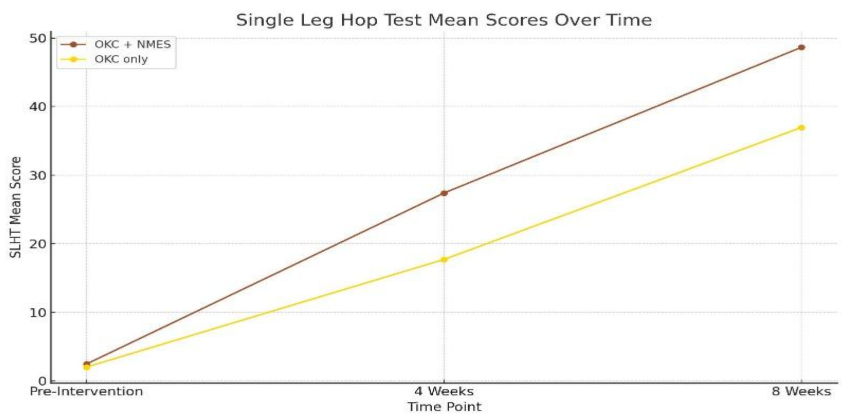

Figure 2 Single Leg Hop Test Mean Scores Over Time

DISCUSSION

The findings of this study demonstrated that both groups experienced statistically significant improvements across all measured outcomes over the 8-week intervention period. However, the group that received open kinetic chain (OKC) exercises combined with neuromuscular electrical stimulation (NMES) exhibited superior gains in functional performance, patient-reported knee function, and range of motion compared to the OKC-only group. These results reinforce the clinical value of incorporating NMES into rehabilitation protocols following anterior cruciate ligament reconstruction (ACLR), particularly in addressing quadriceps weakness and accelerating functional recovery. Functional performance, assessed using the Single-Leg Hop Test (SLHT), improved significantly in both groups, yet the NMES group displayed greater enhancement at both the 4- and 8-week time points. This is consistent with previous findings that highlight NMES as a potent adjunct for promoting neuromuscular control and activating the quadriceps more effectively, which is critical for generating the dynamic strength and stability required during unilateral functional tasks (17,18). In this trial, the OKC + NMES group increased their hop distance from 2.5 m to 4.87 m, while the OKC-only group improved from 2.03 m to 3.70 m, with the between-group differences being statistically significant ($p < 0.005$). These improvements are in line with prior evidence showing enhanced hop distances in NMES-treated patients postoperatively (19,20). The observed magnitude of improvement in the NMES group suggests a clinically relevant enhancement in lower limb power and stability, which may positively influence return-to-activity timelines.

Similarly, patient-reported outcomes, evaluated using the Lysholm Knee Scoring Scale (LKSS), revealed significant improvements in both groups; however, the NMES group achieved notably higher scores. From a baseline of 53, this group reached a mean score of 92 at 8 weeks, compared to an increase from 50 to 81 in the control group. These gains exceeded the minimal detectable change threshold (8–9 points), indicating meaningful clinical improvement. The significant differences between groups at 4 and 8 weeks ($p < 0.005$) suggest that NMES may contribute not only to improved objective recovery but also to enhanced subjective perceptions of knee function, possibly attributed to better pain modulation, muscle engagement, and psychological reassurance. Such findings are supported by earlier clinical trials that demonstrated the positive influence of NMES on patient-reported recovery trajectories when integrated into conventional rehabilitation protocols (21,22). Restoration of knee range of motion (ROM), particularly in terms of flexion and extension, also showed greater improvement in the NMES group. The addition of NMES facilitated more complete recovery, with active flexion reaching 109° and extension deficits fully resolved by the end of 8 weeks. In contrast, the control group achieved only 90° of flexion and retained a residual extension deficit of 1.2°. These differences were statistically significant ($p < 0.005$) and reflect the capacity of NMES to counteract arthrogenic muscle inhibition, a common barrier to early motion recovery post-ACLR (23,24). Early regaining of full ROM, particularly terminal extension, is strongly associated with reduced long-term functional impairments and is therefore a key milestone in ACL rehabilitation. The study protocol, which initiated OKC exercises within a controlled range by four weeks post-op, aligns with established guidelines and did not compromise joint motion (25).

This study adds to the growing body of literature supporting the synergistic effects of combining NMES with active rehabilitation. It also provides novel insights into the early-stage benefits of NMES within an 8-week timeframe—an area where limited high-quality data currently exist. The structured and consistent use of NMES, standardized across all participants in the intervention group, enabled meaningful comparison and reinforces the reproducibility of the intervention. However, several limitations should be acknowledged. The duration of the study was restricted to 8 weeks, preventing the evaluation of longer-term outcomes such as return-to-sport readiness or reinjury incidence. The sample size, while statistically adequate, remained relatively small and was predominantly composed of male participants, which may limit generalizability to the broader ACLR population. Furthermore, NMES parameters were uniformly applied and may not reflect optimal individualized stimulation settings that could enhance outcomes further. The absence of direct isokinetic strength measurements also restricts interpretation of muscular strength gains, despite the observed functional and ROM improvements. Despite these limitations, the strengths of the study include a robust randomized design, clear outcome measures, reliable statistical analysis, and high protocol adherence. These elements contribute to the credibility of the findings and offer clinically relevant guidance. Future research should aim to investigate the long-term impact of NMES on reinjury rates, return-to-play criteria, and muscular endurance. Additionally, expanding the sample to include diverse demographics and incorporating strength and proprioceptive assessments would enrich understanding of NMES's full rehabilitative potential.

CONCLUSION

This study concluded that incorporating neuromuscular electrical stimulation (NMES) into open kinetic chain (OKC) knee extension exercises significantly enhances early rehabilitation outcomes following anterior cruciate ligament reconstruction. The addition of NMES led to greater improvements in functional performance, subjective knee function, and range of motion recovery compared to exercise alone. These results highlight the clinical value of NMES in accelerating quadriceps activation and neuromuscular recovery, ultimately supporting earlier joint mobility, enhanced stability, and a more efficient rehabilitation process. Integrating NMES into standard ACL rehabilitation protocols may offer a practical and effective strategy to optimize recovery and reduce the risk of long-term deficits.

AUTHOR CONTRIBUTION

Author	Contribution
Muhammad Asad Ali*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Arif Ali Rana	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
Muhammad Hasaan Umar Butt	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Kiran Samdani	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Mubashir Hakeem	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published

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