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HEALTH AND REHABILITATION

# EFFECTS OF ROBOTIC HAND TRAINING ON UPPER LIMB MOTOR FUNCTION, HAND DEXTERITY AND GRIP STRENGTH IN POST STROKE PATIENTS

*Original Research*

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**Acknowledgement:** The authors sincerely thank the staff and patients of DHQ Hospital Sheikhupura for their cooperation in this study.

Conflict of Interest: None Grant Support & Financial Support: None

## ABSTRACT

**Background:** Stroke, or cerebrovascular accident (CVA), is a leading cause of long-term disability worldwide and occurs due to reduced cerebral blood flow leading to neurological impairment. Approximately 85% of stroke survivors experience upper limb dysfunction, and nearly 50–80% fail to regain full recovery within 3–6 months, even with conventional rehabilitation. Impairments in motor control, grip strength, and dexterity limit independence in activities of daily living, creating a need for innovative, intensive, and task-specific rehabilitation strategies.

**Objective:** This study aimed to evaluate the effects of a robotic hand training device on upper limb motor function, dexterity, and grip strength in chronic stroke patients.

**Methods:** A randomized controlled trial was conducted at the Physiotherapy Department of DHQ Hospital Sheikhupura on 38 chronic stroke patients aged 40–70 years. Participants were recruited using non-probability convenience sampling and randomly allocated into two groups. Group A (n=19) received robotic hand therapy for 30–45 minutes, five days per week, over eight weeks. Group B (n=19) underwent conventional physiotherapy including 20 minutes of exercise and 10–15 minutes of electrotherapy with the same frequency and duration. Outcomes were assessed at baseline and after eight weeks using the Fugl-Meyer Assessment (FMA), Modified Ashworth Scale (MAS), Nine-Hole Peg Test (9HPT), and SF-36 Quality of Life Scale. Statistical analysis was performed with SPSS version 25 using the Wilcoxon Signed Rank test for within-group and the Mann–Whitney U test for between-group comparisons, with significance set at $p<0.05$.

**Results:** Significant improvements were observed in both groups; however, Group A demonstrated superior outcomes. MAS scores improved by –2.74 in Group A versus –0.68 in Group B (p=0.00). FMA scores increased by +30.00 in Group A compared with +12.07 in Group B (p=0.00). Quality of life improved by +31.21 in Group A and +8.05 in Group B (p=0.00). Dexterity measured by 9HPT showed a reduction in completion time of –10.53 seconds in Group A compared with –2.37 seconds in Group B (p=0.00).

**Conclusion:** Both rehabilitation strategies improved upper limb outcomes in chronic stroke patients; however, robotic hand training produced significantly greater gains in motor function, dexterity, grip strength, and quality of life compared with conventional therapy. These findings support the integration of robotic devices as an effective adjunct to standard rehabilitation in stroke care.

**Keywords:** Activities of Daily Living, Dexterity, Grip Strength, Motor Function, Rehabilitation, Robotic Hand Training, Stroke.

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## INTRODUCTION

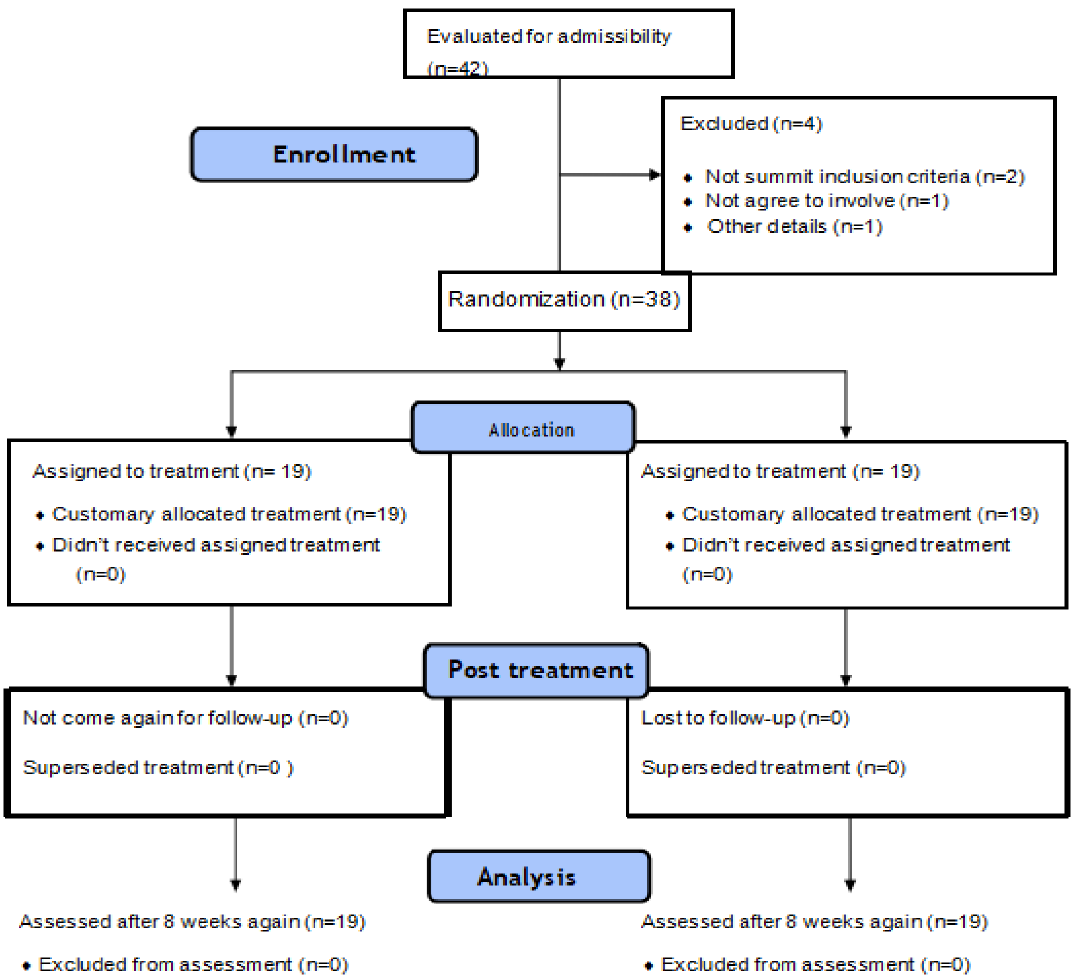
Stroke, or cerebrovascular accident (CVA), is a sudden neurological disorder caused by impaired blood supply to the brain, and it remains one of the leading causes of mortality and long-term disability worldwide (1). Global estimates suggest that stroke incidence continues to rise, particularly in low- and middle-income countries such as Pakistan, where the annual incidence is reported to be approximately 250 per 100,000 people (2). Despite advances in acute stroke care, a significant proportion of survivors are left with chronic impairments, most notably upper limb hemiparesis, spasticity, and reduced dexterity, which restrict independence in activities of daily living (ADLs) (3). Recovery of hand and wrist function is particularly challenging, as around 80% of stroke survivors experience upper extremity paralysis, leading to difficulties in performing essential tasks such as feeding, grooming, or grasping objects (4,5). Conventional rehabilitation strategies, including physiotherapy and task-oriented exercises, while beneficial, often demand prolonged therapist involvement, are time-consuming, and demonstrate limited effectiveness in regaining function of distal joints such as the wrist and fingers (6,7). In recent years, technological innovations have increasingly been explored to address these limitations. Robotic-assisted rehabilitation has gained considerable attention for its ability to provide repetitive, intensive, and task-specific training in a standardized manner (8,9). Soft robotic gloves and exoskeletons have been widely tested across Europe, North America, and East Asia, demonstrating improvements in Fugl-Meyer scores, hand dexterity, and grip strength among stroke survivors (10,11). Nonetheless, the generalizability of these findings is constrained by methodological heterogeneity, small sample sizes, short intervention periods, and limited inclusion of diverse populations.

Moreover, research from South Asia remains scarce, and the feasibility of integrating robotic devices into resource-constrained healthcare systems has not been adequately investigated (12). Emerging robotic hand devices, including soft exoskeletons and pneumatic gloves, offer promising avenues for improving functional outcomes by providing quantifiable therapy and interactive feedback that may enhance patient engagement (13,14). These devices are especially relevant for regions like Pakistan, where access to prolonged, therapist-led rehabilitation is restricted, and cost-effective, portable, and patient-friendly solutions are urgently needed. However, existing studies have largely been conducted outside of this context, with few addressing pneumatic robotic technologies specifically or assessing their suitability for local healthcare settings. Against this backdrop, the present study was designed to evaluate the therapeutic impact of a pneumatic robotic hand training device on upper extremity function in post-stroke patients in Pakistan. The study aimed to determine whether such an intervention could improve motor recovery, dexterity, and grip strength, thereby offering a feasible adjunct to conventional rehabilitation strategies in a low-resource environment.

## METHODS

The study was designed as a randomized controlled trial (RCT) to evaluate the effectiveness of a pneumatic robotic hand training device in post-stroke rehabilitation. It was carried out in the Physiotherapy Outpatient Department of District Headquarters (DHQ) Hospital, Sheikhupura, over a period of six months, following formal approval of the research synopsis by the institutional review board. Ethical approval was obtained from the concerned committee, and the trial was conducted in accordance with the principles of the Declaration of Helsinki. Informed consent was obtained from all participants prior to enrollment, and the consent process was conducted in the participant's preferred language to ensure clarity and voluntariness. Participants were recruited using non-probability convenience sampling. The sample size was calculated with EPITOOL software based on parameters derived from a previous study (8), assuming mean values of 20.4 and 22.44, a variance of 5, a 95% confidence level, 80% power, and two-tailed testing. This calculation yielded a requirement of 38 participants (19 per group). After adjustment for a 10% attrition rate, the final target sample size was 42. Eligible participants were male and female chronic stroke patients aged 45 to 70 years, with a history of stroke between six and twenty-four months, medically stable conditions, and Mini-Mental State Examination (MMSE) scores ranging from 24 to 30 (8,9). Patients with severe apraxia, recurrent or acute stroke, systemic disease, severe comorbidities, cardiac pacemakers, or Modified Ashworth Scale (MAS) scores above 3 were excluded to minimize confounding factors and maintain internal validity (10,11).

Randomization was performed using a computer-generated random sequence to ensure equal allocation into the experimental (robotic therapy) or control (conventional therapy) groups. A single-blind approach was adopted, with outcome assessors blinded to the treatment allocation. The experimental group underwent robotic hand therapy using a pneumatically controlled device capable of delivering passive, active-assisted, and active-resistive movements. The device also provided automated assistance for incomplete voluntary movements. Each session lasted 30–45 minutes, five days per week, for a total of eight weeks. The control group received conventional physiotherapy, which included range of motion exercises, stretching, strengthening routines, and electrotherapy modalities such as transcutaneous electrical nerve stimulation (TENS) or electrical muscle stimulation (EMS). These sessions involved 20 minutes of therapeutic exercise followed by 15–20 minutes of electrotherapy, delivered at the same frequency and duration as the experimental group (12). The study protocol was developed and reported in line with CONSORT guidelines to ensure methodological rigor and transparency. Outcome measures were collected at baseline and after eight weeks of intervention. Spasticity was assessed using the Modified Ashworth Scale, which has moderate-to-good interrater reliability (ICC 0.61–0.87) (9). Motor recovery was evaluated with the Fugl-Meyer Assessment, a performance-based stroke-specific tool with excellent reliability (ICC = 0.96). Manual dexterity was examined through the Nine-Hole Peg Test, which demonstrates strong test-retest reliability (r = 0.86–0.98). Quality of life was measured with the Stroke-Specific Quality of Life Scale (SS-QOL), which has been validated in stroke populations (11). Data were analyzed using SPSS version 25. Descriptive statistics were reported for demographic and baseline characteristics. Within-group changes were assessed with the Wilcoxon signed-rank test, while between-group comparisons were analyzed using the Mann-Whitney U test. Statistical significance was set at $p < 0.05$, and all analyses were two-tailed.




**CONSORT Diagram**

## RESULTS

The study included 26 post-stroke patients who fulfilled the eligibility criteria and were randomized equally into the experimental group, which received robotic hand training, and the control group, which underwent conventional physiotherapy. The mean age of participants was comparable between groups, recorded as 55.68 ± 8.18 years in the experimental group and 55.78 ± 8.33 years in the control group. Gender distribution revealed a predominance of male participants, with males representing 52.6% in the experimental group and 63.2% in the control group, while females accounted for 47.4% and 36.8%, respectively. Normality testing using the Shapiro–Wilk test confirmed that the data were not normally distributed ($p < 0.05$). Accordingly, non-parametric statistical analyses were performed. Within-group comparisons demonstrated significant improvements across all measured outcomes following the eight-week intervention. In the experimental group, spasticity measured by the Modified Ashworth Scale (MAS) decreased from 4.68 ± 0.58 at baseline to 1.94 ± 0.70 post-intervention, reflecting a mean reduction of –2.74 (p = 0.00). The control group also showed a reduction, though smaller in magnitude, from 5.10 ± 0.93 to 4.42 ± 0.69, with a mean difference of –0.68 (p = 0.00). Motor recovery assessed by the Fugl-Meyer Assessment (FMA) improved significantly in both groups, with the experimental group increasing from 26.26 ± 5.84 to 56.26 ± 4.84, a gain of +30.00 (p = 0.00), whereas the control group improved from 27.47 ± 4.58 to 39.54 ± 3.87, yielding a smaller increase of +12.07 (p = 0.00). Quality of life, as measured by the SF-36, also demonstrated greater enhancement in the experimental group, with scores rising from 35.68 ± 3.24 to 66.89 ± 4.84, a difference of +31.21 (p = 0.00), compared with an increase from 36.05 ± 3.06 to 44.10 ± 4.75, a difference of +8.05 (p = 0.00), in the control group.

Dexterity, evaluated using the Nine-Hole Peg Test (9HPT), showed marked improvements among participants receiving robotic training, with mean times reducing from 31.21 ± 3.62 seconds at baseline to 20.68 ± 1.88 seconds post-intervention, reflecting a mean decrease of –10.53 seconds (p = 0.00). In contrast, the control group improved more modestly, with mean times reducing from 27.94 ± 3.82 seconds to 25.57 ± 4.52 seconds, a mean difference of –2.37 seconds (p = 0.00). Between-group analysis revealed no statistically significant differences at baseline across all variables. However, post-intervention comparisons highlighted significant differences favoring the experimental group in all outcomes. Spasticity scores were lower in the robotic therapy group (1.94 ± 0.70) compared to the control group (4.42 ± 0.69, p = 0.00). Similarly, FMA scores were higher in the experimental group (56.26 ± 4.84) compared to the control group (39.54 ± 3.87, p = 0.00). Quality of life scores were significantly greater in the experimental group (66.89 ± 4.84) than in the control group (44.10 ± 4.75, p = 0.00). Dexterity improvements also favored robotic therapy, with lower 9HPT completion times observed in the experimental group (20.68 ± 1.88 seconds) compared to the control group (25.57 ± 4.52 seconds, p = 0.00).

**Table 1: Demographic Characteristics of Participants**

| Variable | Experimental (Robotic Hand) | Control (Conventional PT) |
|---|---|---|
| Age (years, mean ± SD) | 55.68 ± 8.18 | 55.78 ± 8.33 |
| Gender | | |
| Male | 10 (52.6%) | 12 (63.2%) |
| Female | 9 (47.4%) | 7 (36.8%) |

**Table 2: Within-Group Analysis (Pre Vs. Post Intervention)**

| Outcome Measure | Group | Pre (Mean ± SD) | Post (Mean ± SD) | Mean Difference | p-value |
|---|---|---|---|---|---|
| MAS | Exp | 4.68 ± 0.58 | 1.94 ± 0.70 | –2.74 | 0.00 |
| | Ctrl | 5.10 ± 0.93 | 4.42 ± 0.69 | –0.68 | 0.00 |
| FMA | Exp | 26.26 ± 5.84 | 56.26 ± 4.84 | +30.00 | 0.00 |
| | Ctrl | 27.47 ± 4.58 | 39.54 ± 3.87 | +12.07 | 0.00 |

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| Outcome Measure | Group | Pre (Mean ± SD) | Post (Mean ± SD) | Mean Difference | p-value |
|---|---|---|---|---|---|
| SF-36 QOL | Exp | 35.68 ± 3.24 | 66.89 ± 4.84 | +31.21 | 0.00 |
| | Ctrl | 36.05 ± 3.06 | 44.10 ± 4.75 | +8.05 | 0.00 |
| 9HPT (sec) | Exp | 31.21 ± 3.62 | 20.68 ± 1.88 | –10.53 | 0.00 |
| | Ctrl | 27.94 ± 3.82 | 25.57 ± 4.52 | –2.37 | 0.00 |

**Table 3: Between-Group Analysis (Post-Intervention)**

| Outcome Measure | Experimental (Mean ± SD) | Control (Mean ± SD) | p-value |
|---|---|---|---|
| MAS | 1.94 ± 0.70 | 4.42 ± 0.69 | 0.00 |
| FMA | 56.26 ± 4.84 | 39.54 ± 3.87 | 0.00 |
| SF-36 QOL | 66.89 ± 4.84 | 44.10 ± 4.75 | 0.00 |
| 9HPT (sec) | 20.68 ± 1.88 | 25.57 ± 4.52 | 0.00 |

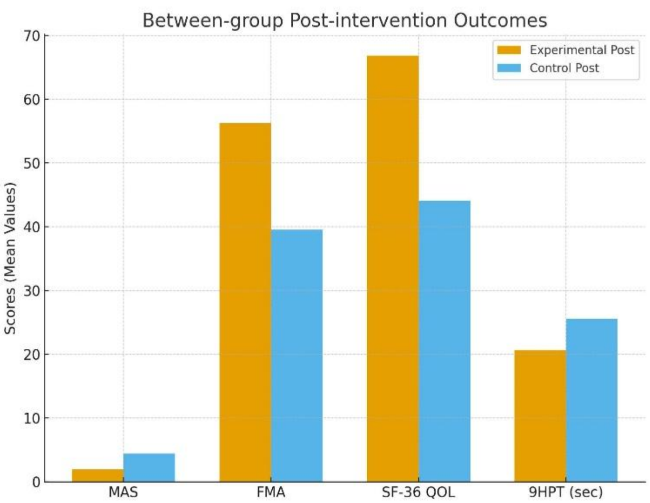


*Figure 2 Between-group Post-intervention Outcomes*

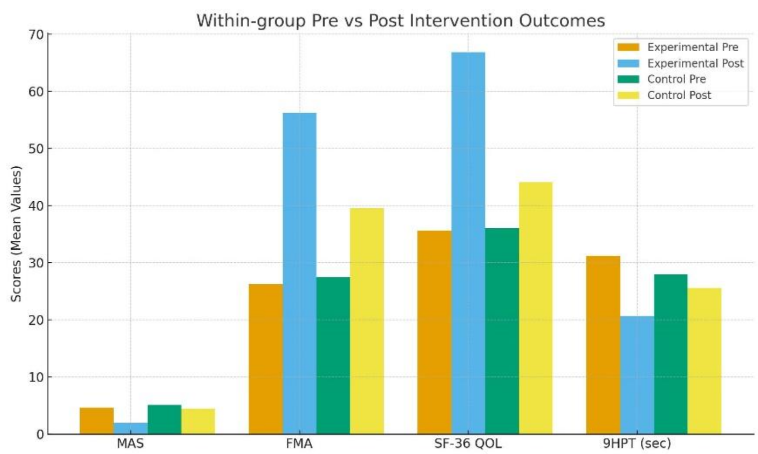


*Figure 2 Within-Group pre vs Post Intervention Outcomes*

## DISCUSSION

The present study demonstrated that robotic hand training resulted in significantly greater improvements in upper limb motor function, grip strength, and manual dexterity compared with conventional physiotherapy among post-stroke patients. These outcomes reinforce the growing body of evidence that robotic-assisted rehabilitation offers an effective means of enhancing functional recovery, particularly in chronic stroke survivors where conventional therapy often provides limited distal limb improvements. The superiority of robotic therapy in reducing spasticity, improving motor recovery, and enhancing quality of life highlights the therapeutic potential of such devices when rehabilitation requires intensive and repetitive practice. Findings from this study align with several previously reported trials and systematic reviews that have shown robotic-assisted rehabilitation to be effective in improving upper extremity outcomes, particularly when training sessions are intensive and structured. Reports from randomized controlled trials have consistently observed that robotic interventions enhance functional independence more effectively than routine physiotherapy, particularly in patients beyond the subacute stage of recovery. The present findings extend this evidence base by confirming comparable benefits in a South Asian population, where robotic rehabilitation has rarely been studied (14-16). Importantly, the inclusion of chronic stroke patients in this trial provides additional insights into populations that remain underrepresented in earlier research. The improvements in quality of life observed in the experimental group also resonate with earlier work demonstrating that robotic rehabilitation not only restores physical function but also positively influences psychosocial well-being (17,18). Gains in motor function and hand dexterity likely contributed to enhanced independence in daily activities, which in turn improved perceived quality of life. Furthermore, the use of a pneumatic robotic device provides novel evidence in this context, as most prior studies have primarily investigated soft robotic gloves or exoskeletons. The pneumatic device, with its capacity for adjustable stiffness and repetitive finger movements, may have contributed to the significant improvements in grip strength and dexterity noted in this trial (19,20).

Nevertheless, there remains some variability in findings across the literature. While many studies report superiority of robotic therapy, some trials have indicated outcomes comparable to conventional physiotherapy. These discrepancies may reflect differences in patient characteristics, stroke chronicity, device type, and intensity of intervention. The present study applied an intensive, standardized protocol of 30–45 minutes per session, which may have amplified the benefits observed. This emphasizes that therapeutic dosage and device-specific characteristics play an important role in determining the magnitude of outcomes. The study has several notable strengths. It adopted a randomized controlled design, applied standardized and intensive interventions in both groups, and assessed multiple validated outcome measures including spasticity, motor recovery, dexterity, and quality of life (21). Both robotic and conventional therapies were matched for duration, allowing a fair comparison of therapeutic effectiveness. Additionally, the study adds evidence from Pakistan, addressing a gap in regional data on robotic rehabilitation. At the same time, limitations must be acknowledged. The sample size was relatively small, which may restrict statistical power and generalizability. Recruitment through convenience sampling could have introduced selection bias despite randomization. The absence of a follow-up period limited the ability to determine the long-term sustainability of observed improvements. Conducting the trial in a single center further narrows external validity, and the study did not test combined interventions, such as integrating robotic therapy with conventional physiotherapy, which might provide synergistic effects (22,23). Moreover, while improvements in grip strength were highlighted as part of the objectives, the analysis and presentation of this outcome could have been more clearly detailed.

Despite these limitations, the findings carry important implications for clinical practice. Robotic therapy should be considered as a promising adjunct or alternative to conventional rehabilitation, particularly in resource-constrained healthcare settings where prolonged therapist-led interventions are often impractical. The feasibility and effectiveness of robotic therapy observed in this trial suggest potential for its integration into structured hospital-based rehabilitation, with future adaptation for home-based use to extend therapeutic access. Future studies should prioritize larger multicenter randomized controlled trials to strengthen external validity. Long-term follow-up assessments are essential to establish whether functional gains are sustained. Furthermore, research should explore the comparative benefits of combining robotic devices with conventional therapy, as well as evaluating cost-effectiveness and acceptability in low-resource environments. Such work will help determine how best to incorporate robotic devices into existing rehabilitation frameworks while ensuring equitable patient access. In conclusion, this study provides strong evidence that robotic hand training, when delivered in an intensive and standardized protocol, can outperform conventional physiotherapy in improving motor recovery, dexterity, grip strength, and quality of life in post-stroke patients. These findings underscore the role of robotics as a practical tool to facilitate repetitive, high-intensity training, thereby addressing a key limitation of conventional rehabilitation approaches.

## CONCLUSION

The study concluded that robotic hand training offered superior benefits over conventional physiotherapy in enhancing upper limb motor function, hand dexterity, and grip strength among stroke survivors. While both interventions led to improvements, robotic rehabilitation consistently produced more meaningful gains, underscoring its potential as a practical and effective tool to support recovery. These findings highlight the importance of integrating innovative technologies into stroke care, particularly in contexts where intensive, repetitive, and structured therapy is required to maximize functional independence and quality of life.

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**AUTHOR CONTRIBUTION**

| Author | Contribution |
|---|---|
| Syeda Pakeeza Bukhari* | Substantial Contribution to study design, analysis, acquisition of Data<br>Manuscript Writing<br>Has given Final Approval of the version to be published |
| Shaheer Haider | Substantial Contribution to study design, acquisition and interpretation of Data<br>Critical Review and Manuscript Writing<br>Has given Final Approval of the version to be published |
| Muhammad Ibtesam | Substantial Contribution to acquisition and interpretation of Data<br>Has given Final Approval of the version to be published |
| Abdul Salam | Contributed to Data Collection and Analysis<br>Has given Final Approval of the version to be published |
| Hamaiyon Mujahid | Contributed to Data Collection and Analysis<br>Has given Final Approval of the version to be published |
| Ayesha Sadiqua | Substantial Contribution to study design and Data Analysis<br>Has given Final Approval of the version to be published |
| Tayyaba Khan | Contributed to study concept and Data collection<br>Has given Final Approval of the version to be published |
| Noorulain Malik | Writing - Review & Editing, Assistance with Data Curation |

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