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IMPACT OF CONSTRAINT-INDUCED MOVEMENT THERAPY (CIMT) VS. ELECTROMYOGRAPHIC (EMG) BIOFEEDBACK ON UPPER LIMB MOTOR RELEARNING IN CEREBRAL PALSY

Original Research

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ABSTRACT

Background: Upper limb motor impairments in children with cerebral palsy (CP), particularly hemiplegic types, limit functional independence and reduce quality of life. Constraint-Induced Movement Therapy (CIMT) and Electromyographic (EMG) Biofeedback are two evidence-based rehabilitative approaches that aim to improve motor outcomes. CIMT facilitates cortical reorganization through intensive, task-specific training of the affected limb, while EMG Biofeedback supports motor learning via real-time visual or auditory feedback on muscle activation. Comparative evidence regarding their effectiveness in pediatric CP remains sparse.

Objective: To compare the effects of CIMT and EMG Biofeedback on upper limb motor function, spasticity, and functional hand use in children with spastic hemiplegic CP.

Methods: A randomized controlled trial was conducted at a tertiary pediatric rehabilitation center involving 60 children aged 6–12 years with spastic hemiplegic CP (GMFCS Levels I–III). Participants were randomized into two groups: CIMT ($n = 30$) and EMG Biofeedback ($n = 30$). Both groups received 2-hour sessions, 5 days a week for 4 weeks. The CIMT protocol included mitt restraint and task-specific training, while the EMG group received guided selective muscle activation training using surface electrodes. Primary outcomes were the Melbourne Assessment of Unilateral Upper Limb Function (MA2), Modified Ashworth Scale (MAS), and Assisting Hand Assessment (AHA). Evaluations were conducted at baseline and after 4 weeks.

Results: At baseline, no significant differences were observed between groups ($p > 0.05$). Post-intervention, the CIMT group demonstrated greater improvements in MA2 scores (52.3 ± 6.8 to 71.2 ± 7.4) compared to EMG Biofeedback (51.9 ± 7.2 to 61.8 ± 8.1; $p < 0.001$). Spasticity reduced more in CIMT (MAS mean change: -1.5 ± 0.6) than EMG (-0.8 ± 0.5; $p < 0.001$). AHA scores improved significantly in the CIMT group (45.6 ± 5.5 to 62.3 ± 6.1) versus the EMG group (45.2 ± 5.9 to 54.8 ± 6.7; $p < 0.001$).

Conclusion: CIMT resulted in significantly greater improvements in upper limb function, spasticity reduction, and hand use than EMG Biofeedback. These findings support prioritizing CIMT as a primary rehabilitation strategy in children with hemiplegic CP, with EMG Biofeedback as a supplementary option when CIMT is not feasible.

Keywords: Cerebral Palsy, Child, Constraint-Induced Movement Therapy, Electromyography, Hemiplegia, Motor Skills, Rehabilitation

INTRODUCTION

Cerebral palsy (CP) is a non-progressive neurological condition resulting from early injury to the developing brain, often during the prenatal, perinatal, or early postnatal period. It leads to lifelong impairments in motor function, posture, and movement (1). Among its various subtypes, hemiplegic CP is characterized by unilateral motor impairment, which frequently manifests as reduced upper limb control, spasticity, and impaired fine motor skills (2,3). These limitations significantly affect a child's ability to perform daily activities independently, making rehabilitation a critical component of long-term care and functional improvement (4). One of the most recognized interventions for upper limb rehabilitation in children with hemiplegic CP is Constraint-Induced Movement Therapy (CIMT). Designed to address the phenomenon of "learned non-use," CIMT involves restraining the less-affected limb while encouraging repeated, intensive use of the affected limb through task-specific activities (5,6). This approach has demonstrated neuroplastic benefits in adult populations post-stroke, contributing to cortical reorganization and functional recovery through forced use paradigms (7,8). In pediatric populations, modified versions of CIMT, tailored to be more engaging and developmentally appropriate, have shown encouraging outcomes in motor function and participation in daily activities (9,10).

An alternative yet less commonly studied approach is Electromyographic (EMG) Biofeedback, which offers real-time visual or auditory cues to individuals based on their muscle activity (11,12). This modality fosters improved awareness and control over muscle contractions, aiming to reduce maladaptive co-contraction patterns and promote selective motor recruitment. Particularly in children with CP, EMG Biofeedback may enhance voluntary motor control and assist in reducing spasticity when integrated into rehabilitative training (13,14). Despite its potential, EMG Biofeedback remains underexplored compared to CIMT, and the literature offers limited comparative evidence evaluating the effectiveness of these two modalities in pediatric CP (15). Given the clinical significance of optimizing upper limb function in children with hemiplegic CP and the need for evidence-based guidance in selecting rehabilitation strategies, this study aims to conduct a randomized controlled trial comparing Constraint-Induced Movement Therapy and EMG Biofeedback. The objective is to assess their relative effectiveness in promoting motor relearning, reducing spasticity, and enhancing functional hand use in this population.

METHODS

This study employed a prospective, randomized, single-blinded controlled trial design conducted at the pediatric rehabilitation unit of a tertiary care hospital in Lahore. Sixty children, aged between 6 and 12 years, diagnosed with spastic hemiplegic cerebral palsy (CP), were recruited based on defined eligibility criteria. Participants were classified under Gross Motor Function Classification System (GMFCS) Levels I to III. Children were included if they had unilateral upper limb involvement, mild to moderate spasticity (Modified Ashworth Scale score ≤ 3), sufficient cognitive ability to follow simple instructions (Mini-Mental State Examination score ≥ 24), and had not received botulinum toxin injections or undergone orthopedic surgery in the six months preceding the study. Exclusion criteria encompassed severe cognitive impairment, fixed joint deformities, and uncontrolled epilepsy, as these could interfere with participation or the accuracy of outcome measurements. Randomization was performed using computer-generated sequences in a 1:1 ratio, assigning participants to either the Constraint-Induced Movement Therapy (CIMT) group or the Electromyographic (EMG) Biofeedback group. Allocation concealment was maintained by a physiotherapist who was not involved in assessment or treatment delivery. Outcome assessors remained blinded to group allocation throughout the study to reduce bias.

In the CIMT group (n = 30), children wore a lightweight mitt on the less-affected hand for 10 hours per day, including 6 hours during structured therapy and 4 hours at home for supervised activity participation. Therapy sessions were conducted five days per week for four consecutive weeks. Each two-hour session included task-specific shaping activities (e.g., stacking blocks, pegboard tasks), repetitive practice (e.g., reach–grasp–release sequences), and functional bimanual tasks such as painting or cutting. Parents were instructed to engage children in an additional hour of play-based home exercises daily, focusing on affected limb use to reinforce therapeutic goals. The EMG Biofeedback group (n = 30) underwent similarly scheduled therapy sessions using surface EMG equipment. Electrodes were positioned over wrist extensors, wrist flexors, and finger flexors. Each session began with skin preparation, electrode placement, and calibration of auditory and visual feedback systems. Training focused on selective activation of target muscles, encouraging children to reach predefined activation thresholds displayed on a monitor. Functional tasks, such as reaching and object manipulation, were guided by real-time EMG feedback. Additionally, muscle relaxation training was included to target overactive muscles contributing to spasticity. A simplified tablet-based home program using portable EMG devices was provided, with children instructed to engage in 30-minute sessions daily.

Outcome measures were assessed at baseline and immediately post-intervention (week 4). Primary measures included the Melbourne Assessment of Unilateral Upper Limb Function (MA2), which scores movement quality across dexterity, accuracy, fluency, and range on a 0–100 scale, and the Modified Ashworth Scale (MAS) for spasticity of wrist and finger flexors. The Assisting Hand Assessment (AHA), a Rasch-scaled tool scoring spontaneous use of the affected hand during bimanual activities, was also included. Secondary measures encompassed the Pediatric Quality of Life Inventory (PedsQL) physical functioning subscale and caregiver strain measured using the Caregiver Strain Questionnaire. Sample size estimation was based on detecting a minimum 10-point difference in MA2 scores between groups, with $\alpha = 0.05$ and power set at 80%. A total of 26 participants per group was required; however, to accommodate potential attrition, 30 children were recruited into each arm. Statistical analyses were conducted using SPSS version 26. Descriptive statistics included means and standard deviations for continuous variables, and frequencies and percentages for categorical variables. Within-group differences (pre vs. post) were analyzed using paired t-tests, while between-group comparisons were performed using independent samples t-tests on post-intervention scores and mean change scores. Cohen's d was calculated to determine effect sizes. A p-value of less than 0.05 was considered statistically significant. All procedures were conducted following the Declaration of Helsinki. Ethical approval was obtained from the Institutional Review Board of the hospital. Informed consent was obtained from the caregivers of all participating children prior to study enrollment, with assent obtained from the children when appropriate.

RESULTS

A total of 82 children were screened for eligibility, out of which 60 met the inclusion criteria and were randomized equally into two groups. One participant in the Constraint-Induced Movement Therapy (CIMT) group withdrew due to skin irritation caused by the mitt, resulting in 59 children completing the intervention. Baseline characteristics including age, gender distribution, Gross Motor Function Classification System (GMFCS) level, and outcome scores were comparable between groups with no significant differences ($p > 0.05$ for all). Both groups demonstrated statistically significant improvements in the Melbourne Assessment of Unilateral Upper Limb Function (MA2) scores from baseline to post-intervention. In the CIMT group, the MA2 score increased from 52.3 ± 6.8 to 71.2 ± 7.4, showing a mean improvement of 18.9 ± 6.2 points ($p < 0.001$). The EMG Biofeedback group improved from 51.9 ± 7.2 to 61.8 ± 8.1, with a mean gain of 9.9 ± 5.4 points ($p < 0.001$). Between-group comparison revealed a significant difference in favor of CIMT, with a mean difference of 9.4 points (95% CI: 5.4–13.4, $p < 0.001$), and a large effect size (Cohen's d = 1.26).

Regarding spasticity reduction measured by the Modified Ashworth Scale (MAS), both groups experienced significant decreases. The CIMT group showed a reduction in median MAS score from 2 [1–2] to 1 [0–1] ($p < 0.001$), while the EMG Biofeedback group decreased from 2 [1–2] to 1 [1–2] with a mean change of –0.8 ± 0.5 ($p = 0.002$). The between-group analysis indicated a significantly greater reduction in the CIMT group (mean change: –1.5 ± 0.6 vs. –0.8 ± 0.5, $p < 0.001$; Cohen's d = 1.21). The Assisting Hand Assessment (AHA) scores also improved significantly in both groups. CIMT participants improved from 45.6 ± 5.5 to 62.3 ± 6.1, with a mean gain of 16.7 ± 4.8 ($p < 0.001$), whereas EMG Biofeedback participants improved from 45.2 ± 5.9 to 54.8 ± 6.7, showing a mean increase of 9.6 ± 4.5 ($p < 0.001$). The between-group difference was significant (mean difference: 7.5 points, 95% CI: 4.1–10.9, $p < 0.001$; Cohen's d = 1.14), highlighting a greater functional improvement with CIMT.

In terms of quality of life, both groups demonstrated notable increases in the Pediatric Quality of Life Inventory (PedsQL) physical functioning scores. The CIMT group improved from 63.4 ± 8.1 to 75.2 ± 7.9 (mean change: +11.8 ± 5.6, $p < 0.001$), while the EMG Biofeedback group increased from 62.9 ± 7.8 to 70.1 ± 8.3 (mean change: +7.2 ± 4.9, $p < 0.001$). Between-group comparison favored CIMT ($p = 0.002$), with a 4.6-point greater mean improvement. Caregiver strain, assessed through the Caregiver Strain Questionnaire, increased significantly in the CIMT group from 15.2 ± 4.5 to 17.8 ± 5.1 ($p = 0.03$), suggesting a modest added burden. The EMG Biofeedback group showed no significant change (14.8 ± 4.7 to 15.1 ± 5.0, $p = 0.68$), indicating greater caregiver tolerability. Descriptive comparisons also revealed superior outcomes for CIMT across all primary measures. The group demonstrated more marked improvements in MA2 and AHA scores, and a greater reduction in MAS spasticity ratings. Collectively, these findings underscore the superior efficacy of CIMT in enhancing upper limb function and reducing muscle tone in children with spastic hemiplegic CP.

Table 1: Baseline Characteristics of Participants in CIMT and EMG Biofeedback Groups

Characteristic	CIMT (n=30)	EMG Biofeedback (n=30)	p-value
Age, years (mean ± SD)	8.7 ± 1.9	8.5 ± 2.1	0.72
Gender (M/F)	18/12	17/13	0.79
GMFCS Level I/II/III	10/12/8	11/11/8	0.95
MA2 (mean ± SD)	52.3 ± 6.8	51.9 ± 7.2	0.81
MAS (median [IQR])	2 [1–2]	2 [1–2]	0.87
AHA (mean ± SD)	45.6 ± 5.5	45.2 ± 5.9	0.84
PedsQL Physical (mean ± SD)	63.4 ± 8.1	62.9 ± 7.8	0.77

Table 2: Comparison of Upper Limb Motor Function (MA2 Scores) Before and After Intervention in CIMT and EMG Biofeedback Groups

Group/Comparison	Pre-intervention MA2 (mean ± SD)	Post-intervention MA2 (mean ± SD)	Mean Change (mean ± SD)	p-value	Mean Difference (95% CI)	Cohen's d
CIMT Group	52.3 ± 6.8	71.2 ± 7.4	+18.9 ± 6.2	< 0.001	–	–
EMG Biofeedback	51.9 ± 7.2	61.8 ± 8.1	+9.9 ± 5.4	< 0.001	–	–
Between-group	–	71.2 ± 7.4 vs 61.8 ± 8.1	–	< 0.001	9.4 points (95% CI 5.4 – 13.4)	1.26

Table 3: Comparison of Spasticity Reduction (MAS Scores) Following CIMT and EMG Biofeedback Interventions

Group/Comparison	Pre-intervention MAS (median [IQR])	Post-intervention MAS (median [IQR])	Change	p-value	Cohen's d
CIMT Group	2 [1–2]	1 [0–1]	–	< 0.001	–
EMG Biofeedback	2 [1–2]	1 [1–2]	−0.8 ± 0.5	0.002	–
Between-group	–	–	−1.5 ± 0.6 (vs −0.8 ± 0.5)	< 0.001	1.21

Table 4: Comparison of Assisting Hand Assessment (AHA) Scores Pre- and Post-Intervention in CIMT and EMG Biofeedback Groups

Group/Comparison	Pre-intervention AHA (mean ± SD)	Post-intervention AHA (mean ± SD)	Mean Change (mean ± SD)	p-value	Mean Difference (95% CI)	Cohen's d
CIMT Group	45.6 ± 5.5	62.3 ± 6.1	+16.7 ± 4.8	< 0.001	–	–
EMG Biofeedback	45.2 ± 5.9	54.8 ± 6.7	+9.6 ± 4.5	< 0.001	–	–
Between-group	–	62.3 ± 6.1 vs 54.8 ± 6.7	–	< 0.001	7.5 points (95% CI 4.1–10.9)	1.14

Table 5: Comparison of Pediatric Quality of Life (PedsQL) Scores Pre- and Post-Intervention Between CIMT and EMG Biofeedback Groups

Group/Comparison	Pre-intervention PedsQL (mean ± SD)	Post-intervention PedsQL (mean ± SD)	Mean Change (mean ± SD)	p-value
CIMT Group	63.4 ± 8.1	75.2 ± 7.9	+11.8 ± 5.6	< 0.001
EMG Biofeedback	62.9 ± 7.8	70.1 ± 8.3	+7.2 ± 4.9	< 0.001
Between-group	–	–	+11.8 ± 5.6 vs. +7.2 ± 4.9	0.002

Table 6: Comparison of Caregiver Strain Before and After Intervention in CIMT and EMG Biofeedback Groups

Group	Pre-intervention Strain (mean ± SD)	Post-intervention Strain (mean ± SD)	Mean Change	p-value
CIMT Group	15.2 ± 4.5	17.8 ± 5.1	+2.6	0.03
EMG Biofeedback	14.8 ± 4.7	15.1 ± 5.0	+0.3	0.68

Table 7: Pre- and Post-Intervention Comparison of Motor Function, Hand Use, and Spasticity in CIMT and EMG Biofeedback Groups

Group	Measure	Pre-Mean	Pre SD	Post Mean	Post SD
CIMT	MA2	52.3	6.8	71.2	7.4
CIMT	AHA	45.6	5.5	62.3	6.1
CIMT	MAS	2.0	0.5	1.0	0.6
EMG	MA2	51.9	7.2	61.8	8.1
EMG	AHA	45.2	5.9	54.8	6.7
EMG	MAS	2.0	0.5	1.2	0.6

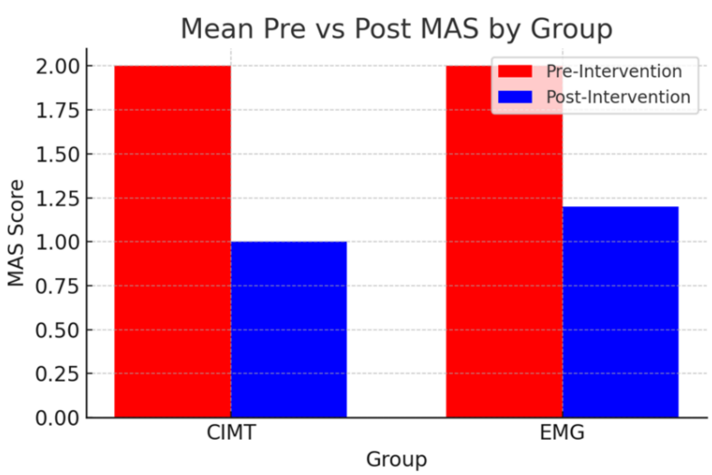

Figure 1 Mean Pre vs Post MAS by Group

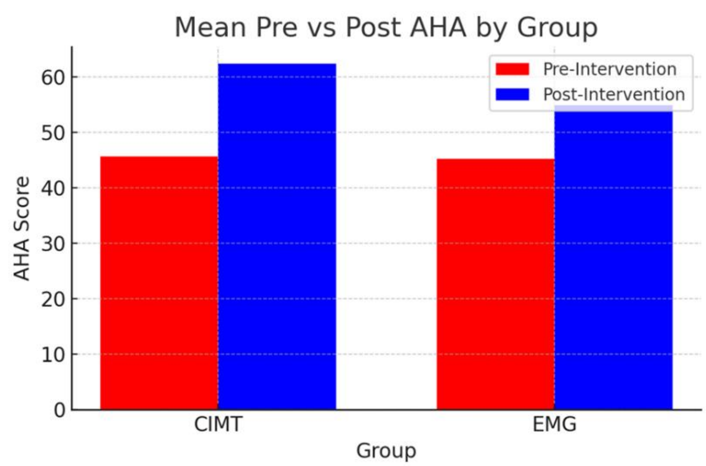

Figure 2 Mean Pre vs Post AHA by Group

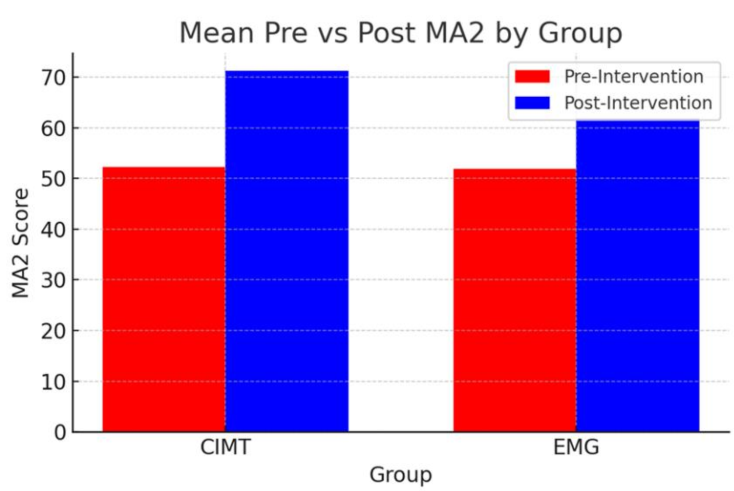

Figure 3 Mean Pre vs Post MA2 by Group

DISCUSSION

This randomized controlled trial provided comparative evidence on the efficacy of Constraint-Induced Movement Therapy (CIMT) versus Electromyographic (EMG) Biofeedback in children with hemiplegic cerebral palsy (CP), specifically targeting upper limb motor relearning, spasticity reduction, and functional hand use. The findings supported the superiority of CIMT in producing clinically meaningful improvements across all primary outcome domains, reinforcing its neurorehabilitative potential in pediatric populations. CIMT produced significantly greater improvements in motor function, as indicated by a mean gain of 18.9 points in the Melbourne Assessment of Unilateral Upper Limb Function (MA2) compared to 9.9 points in the EMG Biofeedback group. These results aligned with previous evidence suggesting that intensive, task-specific training paired with forced use mechanisms can facilitate cortical reorganization and promote motor recovery in unilateral motor impairments (16). The restraining of the unaffected limb likely mitigated compensatory behaviors, thus amplifying use-dependent plasticity of the affected hemisphere and encouraging more functional motor patterns. In terms of spasticity management, both interventions yielded statistically significant reductions, though the CIMT group experienced a greater decline in Modified Ashworth Scale (MAS) scores. While both groups started with comparable spasticity levels, the greater magnitude of change in the CIMT group reflected its ability to normalize tone through repetitive, active engagement of the paretic limb and suppression of maladaptive synergies. The therapeutic mechanism may be attributed to rebalancing agonist-antagonist muscle activation and improving central motor control (17,18).

Functional hand use, measured by the Assisting Hand Assessment (AHA), also favored CIMT with a mean increase of 16.7 points, compared to 9.6 points in the EMG Biofeedback group. Although EMG Biofeedback enhanced voluntary muscle activation, it appeared less effective in facilitating real-world bimanual coordination and integration of the affected limb into daily tasks. The structured, goal-oriented activities embedded in CIMT were more effective in driving practical skill acquisition and transfer to everyday contexts (19). Quality of life outcomes further supported the use of CIMT, with higher gains in the Pediatric Quality of Life Inventory (PedsQL) physical functioning subscale. These improvements likely reflected broader functional gains that extended beyond isolated motor skills to daily participation. However, a modest increase in caregiver strain associated with CIMT, attributed to mitt adherence and supervision demands, highlighted an important practical consideration. While EMG Biofeedback imposed a lower caregiver burden, its comparatively lesser gains in motor function and hand use suggested it may be more suited for children unable to tolerate intensive regimens or as a complementary tool in multi-modal rehabilitation plans (20,21). The study demonstrated notable strengths, including a well-defined sample, rigorous randomization, blinding of assessors, and the use of validated outcome measures. Effect sizes were consistently large, underscoring the clinical relevance of the findings. Nonetheless, limitations must be acknowledged. The intervention period was relatively short, limited to four weeks, which may not capture the durability of motor gains or long-term functional integration. A lack of follow-up data restricts conclusions regarding retention or sustainability of outcomes. Furthermore, the modest sample size, although statistically powered, may reduce generalizability across broader clinical settings.

Additional limitations included potential variability in home-based adherence, particularly in the CIMT group, and the absence of stratified analysis based on age or severity of motor involvement, which could have revealed differential responses. Despite these constraints, the trial provided valuable direction for clinical decision-making, particularly in prioritizing CIMT for children with adequate cognitive and behavioral readiness. Future research should focus on longitudinal follow-up to assess retention at 6 to 12 months post-intervention. Exploration of hybrid protocols combining CIMT and EMG Biofeedback could offer synergistic benefits, particularly by enhancing voluntary motor control while maintaining functional intensity. Tailored dosing strategies based on developmental stage or baseline motor capacity may further optimize outcomes, particularly in younger children with limited attention spans or lower tolerance for intensive training. Additionally, caregiver support interventions should be integrated into CIMT protocols to minimize burden and promote sustained engagement.

CONCLUSION

This study concluded that Constraint-Induced Movement Therapy (CIMT) is more effective than Electromyographic (EMG) Biofeedback in improving upper limb motor function, reducing spasticity, and promoting functional hand use in children with hemiplegic cerebral palsy. While EMG Biofeedback supports selective muscle control, the structured intensity and forced-use approach of CIMT translate into more meaningful functional outcomes. These findings highlight the practical value of CIMT as a primary intervention in pediatric neurorehabilitation, with EMG Biofeedback serving as a valuable adjunct or alternative in cases where CIMT is not feasible.

AUTHOR CONTRIBUTION

Author	Contribution
Marish Memon*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Kaneez Fatima	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
Peraha Wagan	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Mahrukh	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Marina Khan Soomro	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Huma Memon	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published

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