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Proprioceptive neuromuscular facilitation and virtual reality for improving hand functions post reconstructive surgeries

Zakaria M. Emam Mowafy[1], Ahmed G. El Sharkawy [2]and Bassem M. Fouda[3]

[1]Faculty of Physical Therapy1, Cairo University. **Egypt**
[2]Faculty of Medicine, Cairo University. Assistant Lecturer of Physical therapy, **Egypt**
[3]Department of Physical Therapy for surgery, Faculty of Physical Therapy, MTI University. **Egypt**.

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***Correspondence:** **bassemfouda_pt@hotmail.com** **Accepted: 08**Mar. 2019 **Published online:** 15Apr 2019

Tendon transfers are reconstructive techniques that restore motion or balance to the hand that has impaired or absent function of the extrinsic or intrinsic muscle-tendon units of the forearm and hand. The purpose of this study was to evaluate the efficacy of using PNF and VR for improving hand functions post reconstructive surgeries. Sixty patients from both genders aged 20 to 40 years who had post reconstructive surgeries for flexor tendons of the hand. They were selected from the plastic surgeries department of El Kaser El Aini Hospital Subjects were randomly assigned in three equal groups each one has 20 patients; Group A (Study group) had received PNF facilitative techniques in addition to their physical therapy program and medical treatment. Group B (Study group) had received VR-based exercise in addition to their physical therapy program and medical treatment. Group C (controlled group) had received only their physical therapy program (splinting, stretching ex., strengthening ex. and ROM ex.)and medical treatment. Results showed a statistically significant differences between the three groups, where the significant increasing of hand-held dynamometer assessment scores for the power of hand flexors (per kilogram) was shown in G1 and G2 compared to G3 (P<.0.000 and P<.0.007) respectively. the PNF group A showed the highest mean. These results suggested that PNF and VR-based exercise are effective in improvement of the power of hand flexors.

Keywords: Virtual reality, Hand reconstructive surgeries, Proprioceptive neuromuscular facilitation, Hand function, Dynamometer.

INTRODUCTION

Tendon transfers are reconstructive techniques that restore motion or balance to the hand that has impaired or absent function of the extrinsic or intrinsic muscle-tendon units of the forearm and hand. In a typical tendon transfer, the tendon of insertion of an expendable functioning muscle is detached, mobilized, and then reattached to another tendon or bone to substitute for the action of a nonfunctioning muscle-tendon unit (Jones et al., 2011).

There are 3 general indications for tendon transfers in the upper extremity:

To restore function to a muscle paralyzed by injuries of the peripheral nerves, the brachial plexus, or the spinal cord

To restore function following closed tendon ruptures or open injuries to the tendons or muscles

To restore balance to a hand deformed by various neurologic diseases.

Tendon transfers are best conceptualized as a means to restore a lost function rather than a means of substituting for a specific muscle (i.e., restoring strong pinch as opposed to restoring function of the flexor pollicis longus [FPL]). Tendon transfers are performed predominantly following peripheral nerve injuries and, therefore, the current techniques for reconstruction of radial, median, and ulnar nerve palsies are used. However, these same techniques can be used for post-traumatic reconstruction of the hand that is affected by injuries to the muscles and tendons of the fore- arm or hand (Jones et al., 2011).

Neural stimulation and motor reeducation seems to be essential to a successful rehabilitation program after muscle transfer, the role of therapists is to reeducate and facilitate each patient to acquire control of the new function of the transferred tendon or muscle. Sherrington defined the concepts of neuromuscular facilitation and inhibition in 1900s. Kabat developed the clinical proprioceptive neuromuscular facilitation (PNF) techniques in the 1940s. Knott and Voss further developed the PNF treatment approach to stimulate various neurological pathways. This technique places specific demands on the patient's neuromusculoskeletal system to facilitate natural functional movements (Chao et al., 2016).

PNF propose to reach the highest functional level through facilitation, inhibition, reinforcement and relaxation of muscle groups, increasing ability to move with coordination and synchronism. For such, procedures of the PNF as resistance, irradiation, reinforcement, a specific manual contact, verbal command, synchronization and facilitation patterns are used during specific techniques (Luciane et al., 2014).

One of the major goals of rehabilitation is to make quantitative and qualitative improvements in daily activities in order to improve the quality of independent living. Three determinants of motor recovery are early intervention, task-oriented training, and repetition intensity, while a major objective of rehabilitation is to identify the means to provide repeated opportunities for tasks that involve multimodal processes (different sensory modalities including vision, haptics, proprioception, audition) and that further enable increases in function (Sveistrup, 2004).

The successful integration of virtual reality into multiple aspects of medicine, psychology, and rehabilitation has demonstrated the potential for the technology to present opportunities to engage in challenging behaviors safely, ecologically valid environments while maintaining experimental control over stimulus delivery and measure, Moreover, in VR, the user (patient, therapist) interacts with a multidimensional, multisensory computer generated environment, a virtual environment, which can be explored in real time. Virtual reality also offers the capacity to individualize treatment needs while providing increased standardization of assessment and training protocols. In fact, preliminary evidence indicates that VR provides a unique medium where therapy can be provided within a functional, purposeful and motivating context and can be readily graded and documented (Sveistrup et al., 2004).

MATERIALS AND METHODS

Design:

A pre and post study design was used as randomized study with intra- rater reliability and inter-rater agreement.

Setting and timescales:

Study was conducted in Outpatient clinic of Faculty of Physical Therapy, Modern University for Technology and Information (MTI) University from period May 2017 to May 2018.

Participants:

Subjects eligible to participate in this study were sixty patients form both genders who had post reconstructive surgeries for flexor tendons of the hand. They were selected from the plastic surgeries department of El Kaser El Aini Teaching Hospital, Cairo university, the selected patients had completed intervention program and they were randomly assigned in three equal groups (control group n=20, and each group of two study groups n=20) indicated by power analysis to calculate sample size. All subjects read and signed a consent form before the beginning of the study. The study was approved by the Institutional Ethics Committee of the Faculty of Physical Therapy, Cairo University, Egypt (No: P.T. REC/012/001607). The anonymity and confidentiality were assured and all the procedures were performed in compliance with relevant laws and institutional guidelines.

All patients were randomly selected for each group by using closed envelope contains patient's names, they participated in the study directly after cast removal, mostly after three weeks postoperative, and all of them had adequate range of motion of the shoulder girdle, elbow and wrist joints to be able to participate in VR ga.The following exclusion criteria were established for this study: Patients suffered from Deafness or blindness, patients with exposed hand tendons or infected open sutures and medically unstable patients were excluded.

Instrumentations:

The patients underwent to pre-treatment and post-treatment baseline assessment, the Hand-held Dynamometer (figure 1) (Jamar Plus+ Digital Dynamometer. Inc. Sammons Preston, 1000 Remington Blvd., Ste 210 Bolingbrook, IL 60440 A Patterson Company 800-228-3693) was used for measuring a patient's hand strength, grip strength and pinch strength to initially evaluate a patient's hand function, and also to determine how a patient is responding to ongoing therapy.(Figure 1)

Figure 1 hand held dynamometer:

Intervention:

Evaluation protocol to measure hand-held dynamometer assessment scores for the power of hand flexors (per kilogram):

The patient were sitting, holding the dynamometer in the hand to be tested, with the arm at right angles and the elbow by the side of the body. The handle of the dynamometer was adjusted when required - the base was rested on first metacarpal (heel of palm), while the handle was rested on middle of four fingers. When was ready the patient squeezed the dynamometer with maximum isometric effort, which was maintained for about 5 seconds. No other body movement was allowed The patient was strongly encouraged to give a maximum effort. Three trials was made with a pause of about 10-20 seconds between each trial to avoid the effects of muscle fatigue (Helen et al.,2011).

Treatment protocol:

The sixty patients from both gender were randomly divided into three equal groups; Patients in Group 1 received PNF facilitative techniques, the facilitation phase will start at the 4th week after the tendon transfer followed by a strengthening phase (Chao et al., 2016), in addition to their physical therapy program (splinting, stretching ex., strengthening ex. and ROM ex.) and medical treatment.

While Patients in Group 2 received VR-based exercise using Xbox 360 training procedures as in bowling simulation game (Joon-Ho Shin, et al., 2016), in addition to their physical therapy program (splinting, stretching ex., strengthening ex. and ROM ex.) and medical treatment. And Patients in Group 3 only received physical therapy program(splinting, stretching ex., strengthening ex. and ROM ex.) and medical treatment.

The patients attended the rehabilitation center for one on one therapy for 30 minutes 3 times per week. These techniques were practiced Up to 8 weeks after reconstructive surgery.

Statistical Analysis

The statistical methods for collection presentation and analysis of the results were used according to the following:

1- Power analysis revealed that sample size was 20 subjects for each group.

2.Test of normality (Shapiro-Wilk W Test) was used before apply statistical analysis, and it show that data was not normally distributed so we used non-parametric test.

3-Comparison of numerical variables between the study groups was done using Kruskal Wallis ANOVA test with post-hoc multiple 2-group comparisons.

4-Within group comparison between pre- and post-values was done using Wilcoxon signed rank test for paired (matched) samples.

5-P-values less than 0.05 were considered statistically significant and less than 0.01 was considered highly significant.

6-All statistical calculations were done using computer program IBM SPSS (Statistical Package for the Social Science; IBM corp., USA) release 22 for Microsoft Windows (Maronna et al., 2006).

RESULTS

The general demographic data:

The age and BMI in the three groups had no significant difference with p value (P=0.837and

P=0.202) respectively. (figure.2, 3and Table.1)

2) The effect of the different training approaches within each group and between the three groups on hand-held dynamometer assessment scores for the power of hand flexors (per kilogram):

A significant difference of hand-held dynamometer assessment scores for the power of hand flexors (per kilogram) between the three groups were detected for post test (P<.0.001) but not pre test (P<.0.981). The significant increasing of the power scores of hand was shown in G1 and G2 compared to G3 (P<.0.000 and P<.0.007) respectively It could be concluded that the significant increasing of scores for the power of hand flexors (per kilogram) was in G1 and G2; the PNF group 1 showed the highest mean. (figure.4 and Table.2).

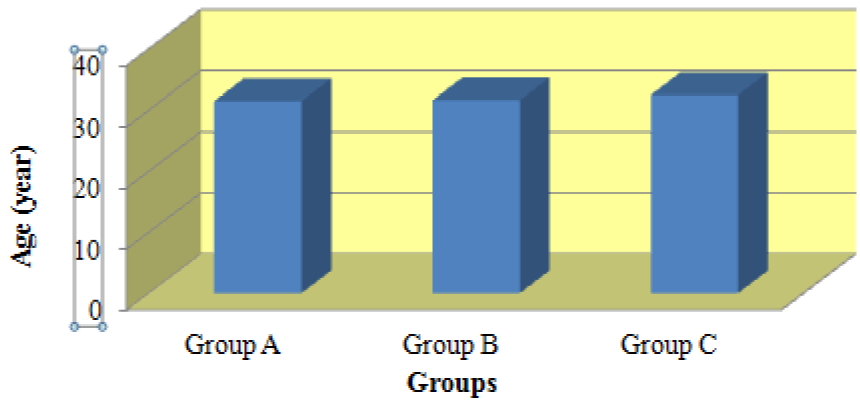

Figure 2: mean values of age in groups (a,b and C)

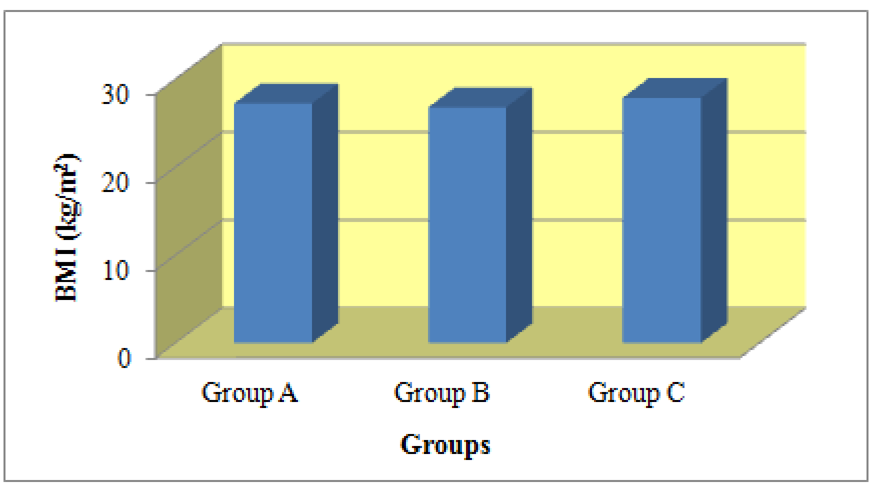

Figure 3: mean values of BMI in groups (a,b and c)

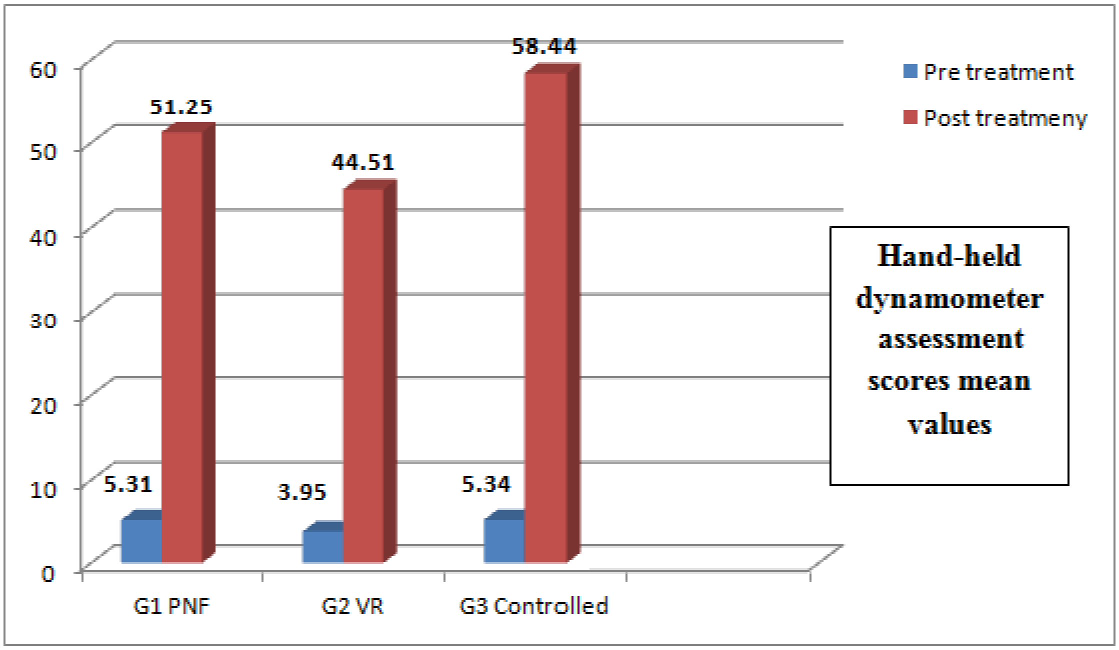

Figure 4: mean values for hand held dynamometer assessment scores for groups (a,b and C):

Table (1): Comparison mean values of demographic data among groups A, B and C:

Items	Age (Year)	Weight (kg)	Height (cm)	BMI (kg/m^2)
	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD
Group A (Conventional)	31.47 ±4.53	82.20 ±6.23	173.73 ±5.07	27.23 ±1.64
Group B (Manipulation)	31.60 ±4.92	79.23 ±6.27	170.67 ±5.77	26.80 ±1.84
Group C (Mulligan)	32.47 ±5.41	78.80 ±5.30	171.47 ±6.09	27.87 ±1.32
F-value	0.179	1.444	1.183	1.663
P-value	0.837	0.247	0.316	0.202
P<0.05	NS	NS	NS	NS

Table (2): Comparison of hand-held dynamometer assessment scores for the power of hand flexors (per kilogram) among the groups (G1, G2, and G3):

hand-held dynamometer assessment scores mean values	Group	Groups	Mean Difference	p value
	1	2	6.745	*0.003
		3	12.813	*0.000
	2	1	6.745	*0.003
		3	6.06	*0.007
	3	1	12.813	*0.000
		2	6.06	*0.007

DISCUSSION

This study demonstrated a significant improvement in scores for the power of hand flexors which markedly related to hand function in G1, G2 and G3; all patients received the commonly used physical therapy intervention program but it was obvious that applying PNF facilitative techniques and VR- based exercise shown higher significant difference in results and improvement of Power, ROM and function of hand.

PNF techniques have been recommended for facilitation of neuromuscular control, stability, strength improvement, endurance, coordination, motor control, flexibility (ROM) enhancement, relaxation, and pain release. Application of this technique in a study conducted by Chen YH, et.al (2016) of a patient with a an avulsion brachial plexus injury demonstrated the effectiveness of PNF following a pedicled latissimus dorsi (LD) musculocutaneous flap transfer for elbow and fingers extension concluded that PNF may be an effective and specific component of rehabilitation in the recovery of function in the early phase post injury, Irlenbusch et al., (2008), Studied EMG activation after LD transfer and could not detect any finding after 6 weeks. The activation took place 6 months postoperatively and reached higher activity after 12 months, while in the study of Chen YH, et.al (2016), the patient and the therapist were aware of LD muscle contractions through PNF interventions 6 weeks postoperatively, with evidence of muscle control documented 8 weeks post muscle transfer.

Adler et al., (2008) suggested that PNF initiates and provokes learning of a new motion, as “rhythmic initiation” and “repeated stretch from the beginning of range” are suggested to achieve the goal of initiate motion. “Rhythmic initiation”, “combination of isotonics”, “repeated stretch from the beginning of range”, “repeated stretch through range” and “replication” are the suggested approaching techniques to learn new motions. (Gontijo et al., 2012) reported movement pattern of lower limbs could be triggered by irradiation resulting from PNF motions of trunk flexion or extension, the concept of irradiation (also known as overflow) promotes transferred muscle strength and motor function.

Although PNF is a widely used technique in clinical practice, its neurophysiological mechanisms are still unknown. (Hindle et al., 2012) tried to investigate the possible theoretical mechanisms and concluded that autogenic inhibition, reciprocal inhibition, stress relaxation, and the gate control theory could explain the increase in range of motion, as well as in strength and athletic performance under consistent PNF protocol.

According to Shimura K. and Kasai T. (2002) research, PNF position improves movement efficiency of the joint by changing the muscle discharge order. These researchers mentioned that peripheral organs such as muscle spindles stimulated by the change of muscle length, and limb position may influence the initiation of voluntary movement. So, the stretch reflex of PNF technique was integrated to change elbow or finger muscle length to facilitate motion initiation as the patient perceived transferred muscle contraction and tried to control it. Under this mechanism, it was easy to initiate the motion with the newly transplanted muscle. Once the transferred muscle could be stretched, and the patient intended to contract the transfer, the D1 extension pattern was used to facilitate the muscle contractions needed to extend the elbow and fingers. The D1 extension pattern is a full upper extremity extension patterns with abduction, medial rotation along with elbow extension and wrist extension that happens to resemble the combinational role of its former and new function of the transferred muscle.

Another study conducted by Henseler et al. (2014) applied EMG for LD muscle activation 1 year after transfer for rotator cuff tears. Their study showed transferred LD predominately active in new functional movement as a synergy, but still active in its original antagonistic function with lesser extension. a PNF technique with a partial pattern or full D1 extension pattern to facilitate the new function of the transferred LD through its original function, and successfully developed muscle control 6 weeks postoperatively.

On the other hand a study conducted by (Bradley et al., 2007; Mikolajec et al., 2012) suggested that PNF application prior to exercise has been found to decrease performance when maximal muscle effort is required such as during sprinting, plyometrics, cutting, weight-lifting and other high intensity exercises. Also, a study conducted by (Marek et al., 2005) showed a decrease in strength, power output and muscle activation following PNF technique prior to high intensity exercise as jumping.

Although PNF may decrease performance in high intensity exercises, it has been found to improve performance in submaximal exercises such as jogging. (Caplan et al., 2009) showed a significant increase in both stride rate and stride length after a five week PNF protocol in 18 professional rugby players. Nelson et al., 2005) showed PNF protocol to be similar in effectiveness to weight training in enhancing muscular strength; however, a significant increase in performance in untrained females was determined as well. Vertical jump and throwing distance increased more than double in those in the PNF group than those in the weight training group.

(Dallas et al., 2014) conducted a study in the sport of gymnastics on a sample of 18 athletes to compare static and PNF stretching method using vibration platform to determine if mobility of the lower limbs and the force by jumping from semi seat and swing improved. The results showed significant process using PNF, the improvement was almost 6,8 % and PNF was the best stretching method.

On the other hand, in a research conducted by (Reis et al., 2013) with indoor soccer players the acute effects of PNF exercises compared to those of static stretching. The parameters that examined by electromyography was the volitional muscle contraction of the vastus lateralis and rectus femoris after isometric contraction of the dominant leg immediately after using the three protocols with PNF stretching, static stretching and no stretching. The results showed that short-term use of both exercises did not affect the parameters examined.

PNF maneuvers include functional movements and therefore the increase of strength in some muscles may be due to functionality gained from performing such maneuvers. The muscles showed increased strength in the case of these patients were probably the most recruited in functional activities. As (Youdas et al., 2012) suggested that the motor areas respond with adaptive plasticity and become mediators of the necessary adjustments for a more functional response, so the results showed an improvement of hand function after the rehabilitation program.

Recent studies show evidence of the potential of VR-based interventions to benefit patients with disordered movement due to neurological dysfunction. (Sveistrup H. 2004) suggested that the known neurophysiological and behavioral benefits of movement observation, imagery, repetitive massed practice and imitation therapies in facilitating voluntary production of movement can be easily incorporated into VR to optimize the training experience and allow the clinician to use sensory stimulation through VR as a tool to facilitate targeted brain networks, such as the motor areas, critical for neural and functional recovery.

A study conducted by (Holden ,et al., 2002) developed a VE training system based on the principle of learning by imitation. Prerecorded movements of a virtual 'teacher' are displayed as either movements of the limb's endpoint or as an entire arm. Patient movements are recorded using an electromagnetic tracking device for the arm and hand segment or a Cyber-Glove for hand kinematics. The "teacher" shows the patient the trajectory of the end-point (hand) path for the movement to be reproduced. Frequency of visual feedback, speed of motion, degree of movement synchronization and other aspects of the teacher-patient relationship can be modulated. Data from eight chronic post-stroke patients demonstrated variable improvements on clinical measures of upper extremity function including strength.

Another study conducted by (adamovich, et al., 2009) founded that the potential for functional recovery can be optimized by tapping into a number of neurophysiological processes that occur after a brain lesion, such as enhanced potential for neuroplastic changes early in the recovery phase and stimulation of sensorimotor areas that may otherwise undergo deterioration due to disuse. VR may be useful in a number of ways to deal with these processes and potentially trigger compensatory neuroplastic changes.

(Piron et al., 2001) used a virtual reality task to assess functional motor progress of a group of 20 post-stroke patients undergoing conventional rehabilitation. The patients were required to move an envelope instrumented with a magnetic receiver to a virtual mailbox slot. The participant was provided with a view of the trajectory of the corresponding virtual envelope as it moved. Patients improved on reach velocity and reach duration with the changes related to improvements on a clinical measure of upper extremity voluntary movement. The authors suggest that the reach trajectory characteristics also improved although limited data were presented.

(Shin et al., 2016) conducted a study noted a greater improvement in multiple outcomes of the distal upper extremity, including motor impairment (FM-total, FM-prox, and FM-dist scores), hand functions (JTT-total and JTT-gross scores), and HRQoL (composite SIS, overall SIS, SIS-social participation, and SIS-mobility scores) using VR-based rehabilitation on Patients with Stroke.
Finally (Somya Prasad et al., 2016) conducted a

study concluded that virtual reality Wii gaming system is feasible, promotes motor recovery after spinal injury, increases patient motivation and enriches the treatment.

CONCLUSION

PNF facilitative techniques and VR based exercise therapy are effective modalities in improving hand functions post reconstructive surgeries. And applying any of these modalities added evidence for improvement of hand function than performing traditional rehabilitation protocol alone.

This study was limited by decreased patient's ability to understand the PNF or VR commands during treatment session and the infrequent attendance of some patients.

- To study the combined effect of applying both PNF facilitative techniques and VR based exercise therapy on the same sample.
- To study the effect of applying both PNF facilitative techniques and VR based exercise therapy on other reconstructive surgeries.
-To study the effect of immersive and non immersive VR based exercise on hand function and the use of different assessment scales to evaluate patient’s pre and post treatment.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

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AUTHOR CONTRIBUTIONS

All authors contributed equally in all parts of this study.

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