RESEARCH ARTICLE

HandTutor™ Enhanced Hand Rehabilitation after Stroke — A Pilot Study

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Abstract

Background and Purpose. This study assessed the potential therapeutic benefit of using HandTutor™ in combination with traditional rehabilitation in a post-stroke sub-acute population. The study compares an experimental group receiving traditional therapy combined with HandTutor™ treatment, against a control group receiving only traditional therapy. Method. An assessor-blinded, randomized controlled pilot trial, was conducted in the Reuth rehabilitation unit in Israel. Thirty-one stroke patients in the sub-acute phase, were randomly assigned to one of the two groups (experimental or control) in sets of three. The experimental group (n = 16) underwent a hand rehabilitation programme using the HandTutor™ combined with traditional therapy. The control group (n = 15) received only traditional therapy. The treatment schedules for both groups were of similar duration and frequency. Improvements were evaluated using three indicators: 1) The Brunnström-Fugl-Meyer (FM) test, 2) the Box and Blocks (B&B) test and 3) improvement parameters as determined by the HandTutor™ software. Results. Following 15 consecutive treatment sessions, a significant improvement was observed within the experimental group (95% confidence intervals) compared with the control group: B&B $p = 0.015$; FM $p = 0.041$, HandTutor™ performance accuracy on x axis and performance accuracy on y axis $p < 0.0003$. Conclusion. The results from this pilot study support further investigation of the use of the HandTutor™ in combination with traditional occupational therapy and physiotherapy during post stroke hand function rehabilitation. Copyright © 2010 John Wiley & Sons, Ltd.

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Keywords
augmented feedback; hand; rehabilitation; stroke

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Introduction

Stroke is the third leading cause of death in the world, and causes more serious long-term disabilities than any other disease. Nearly three quarters of all strokes occur in patients over the age of 65, and the risks more than double for each decade above the age of 55. In Israel, the incidence of stroke is approximately 14 500 new cases every year.

Treatment for stroke is generally divided into three stages: 1) prevention, 2) acute management (i.e. medications) and 3) rehabilitation and secondary prevention.
Several researchers have shown in both animals and human studies that important variables in re-learning motor skills, and in changing the underlying neural architecture are dependent on the quantity, duration and intensity of training sessions (Nudo et al., 1996). The largest changes in cortical maps are seen in the first few months following stroke, during which time the steepest recovery curves are also seen (Traversa et al., 1997).

Several studies have been conducted to examine the recovery of the hemiplegic arm in stroke patients. Up to 85% of patients show an initial deficit in arm function. These problems persist in 55% to 75% of patients three to six months post initial assessment (Bard and Hirschberg, 1965; Wade et al., 1983; Parker et al., 1986; Olsen, 1990).

Intensive rehabilitation is now being employed more commonly as delivery of post-stroke care improves, and a reduction in long-term disability has been noted following intensive rehabilitation (Indredavik et al., 1997; Stroke Unit Trialist Collaboration, 1997). Recent evidence has demonstrated that intensive massed and repeated practice may enhance recovery and improve functional ability (Wolf et al., 1989a; Taub et al., 1993).

There is growing evidence from human brain imaging studies that movement of an affected limb with partial recovery after stroke is associated with altered activity in motor cortical regions (Chollet et al., 1991; Weiller et al., 1992; Cao et al., 1994; Caramia et al., 1996; Cicinelli et al., 1997; Cramer et al., 1997; Honda et al., 1997; Netz et al., 1997; Traversa et al., 1997; Marshall et al., 2000; Pineiro et al., 2001). In addition, a correlation has been demonstrated between improved motor function and improved outcomes (Taub et al., 1993). Evidence for repetitive massed practice can also be seen by the increasing use of advanced technology rehabilitation tools such as robotics as an adjunct to traditional therapy.

The traditional service delivery model in hospital or rehabilitation centres cannot provide the quantity or intensity of practice needed to effect neural and functional changes.

Because the HandTutor™ (Meditouch Ltd, Rotem Industrial Park, MP Arava, Israel) allows for intensive and challenging impairment-oriented training with augmented feedback, it was decided to explore the effectiveness of the HandTutor™ as an innovative rehabilitation system for hand rehabilitation. We postulate that the use of the HandTutor™ unit, in conjunction with traditional rehabilitation methods, will improve the motor recovery, function and outcomes of a post-stroke sub-acute population more effectively than those receiving traditional rehabilitation alone. In addition, we were encouraged to initiate a pilot-controlled randomized assessor blind trial, as no previous studies using the HandTutor™ have been documented.

HandTutor™ system

HandTutor™ is an impairment-oriented training system whose exercises are based on repetitive and intensive active flexion and extension movements of the finger/s and the wrist. The patient wears an ergonomic glove whose sensors allow the patient’s finger/s and wrist movements to be monitored on a computer screen, and various measurements can be recorded (Figure 1). The HandTutor™ system provides the exercise task that encourages the patient to flex and extend their finger/s and/or wrist. The specialist rehabilitation software provides the patient with impairment-oriented, augmented feedback (Figure 2).

Methods

Participants

The participants were recruited from clients recently admitted to the inpatient rehabilitation department, at Reuth Medical Center, Tel Aviv, Israel.

Inclusion criteria for the study were as follows: selected patients were aged between 18 and 80 years, from 10 days to 10 weeks after stroke onset, with a minimum score of 24 points on Mini Mental Test (Folstein et al., 1975), a minimum 10° extension...
and/or flexion of the wrist or fingers, an ability to flex and to extend the wrist joint five times continuously without losing active range of motion. The patients had the cognitive, behavioural and communicative abilities to warrant participation in the study. Patients were recruited over a period of six months.

Exclusion criteria included those patients with apraxia or hemianopsia, and other medical conditions that may interfere with the ability of the patient to perform the required task (late stage Parkinson Disease, Multiple Sclerosis, complete or severe partial spinal cord injury, rheumatoid arthritis etc).

This study was approved by the Ethical Review Board of the Reuth Medical Center, Tel Aviv, Israel, and all participating patients signed an informed consent form.

**Study design and procedures**

All participants (experimental and control groups) were evaluated at four stages during the study: initially (beginning of study) T1, midway (after 10 days) T2, end of study period (after 21 days and 15 consecutive treatment sessions) T3 and 10 days post-study treatment T4. The participants were randomly assigned to one of the two groups (experimental or control) in sets of three.

All patients were evaluated by Box and Block (B&B) dexterity test and the Fugl-Meyer (FM) impairment test. In addition, data sets on the HandTutor™ ball speed and track width in the HandTutor TM exercise task performed by the experimental group were also recorded. Clinical evaluations were performed by an independent assessor who was blinded to group assignment and not involved in the routine treatment of the patients. Demographic data and the clinical manifestation of the stroke were recorded by the physiotherapist research assistant.

Both experimental and control subjects continued to receive their usual rehabilitation treatment programme including occupational therapy (OT) and physiotherapy (PT) on the affected hand. Traditional hand therapy included passive and active therapeutic exercises focusing on range of motion, plus strength and endurance training of the wrist and fingers. In addition, the patients were trained to screw, twist, pull and stick certain objects using a ‘functional board’. The experimental group received a supplementary 20–30-minute hand rehabilitation programme using the HandTutor™ given by a physiotherapist research assistant.

To avoid possible bias associated with the experimental group receiving an additional treatment session, subjects in the control group were given an additional traditional hand therapy session lasting 20–30 minutes. The traditional treatment included functional activities and exercises that facilitate arm movements and enhance strength. These exercises included active, assisted and passive arm movements.

The HandTutor™ software provides augmented finger/s and wrist motion feedback. The therapist can customize the task to allow the patient to perform active flexion and extension exercises on the wrist and/or finger/s. The exercises can be tailored to train all fingers or isolated finger movements. In this study, the task chosen was called ‘Track’. This task consisted of a ball that moves along a track that moves horizontally.
across the screen (Figure 3). The movement of the ball along the track is controlled by flexion and extension of the finger/s or wrist. The therapist sets up the task so that only the required finger/s or wrist is exercised. The HandTutor™ software also allows the therapist to set the patient’s available Range of Motion (ROM) that will be exercised during the task. The software is set so that the patient’s maximal ROM represents the full vertical displacement of the ball on the screen. The ROM measurement that the HandTutor™ uses is a linear measurement. This measurement treats the fingers as a multi-joint system and does not measure the angle of each individual joint.

Once the task is set up, the HandTutor™ translates flexion of the patient’s finger/s and/or wrist into a downward movement of the ball, and extension of the finger/s and/or wrist into an upward movement of the ball according to the patient’s ROM ability. Thus, when the patient flexes his/her fingers to make a fist, the ball in the screen moves down, and opening the fist moves the ball up. The patient’s task is to keep the ball within the track that follows upward and downward gradients as the image scrolls horizontally across the screen. As the ball moves along the track, the augmented feedback (which provides both visual and audible warnings if the ball moves out of the track boundaries) encourages and trains the patient during the exercise.

All parameters of the track can be customized to the patient’s ability and this includes the width of the track and the speed that the track travels across the screen. These parameters were recorded for statistical analysis.

Before the treatment is started, the patient is comfortably positioned in a sitting position in front of the computer screen. The arm is supported on a table with the shoulder at 30 degrees forward flexion and the elbow at 120 degrees. A pillow can be added to further support the forearm if required.

The HandTutor™ exercise treatment consisted of six consecutive one-minute periods alternating between rest (A) and track (B), creating a sequence of A1,B1,A2,B2,A3,B3. During the test, there was no auditory input from the investigator to the subject. To assist the subject in remembering when to rest versus when to track, the augmented feedback was used.

```plaintext
Performance accuracy on y axis
S=0;
for (int n = 0; n < N; n++)
{
    if (T(n) + W) < P(n) <= E(n) W = Width / 2 -> Max(n) = E(n) Min(n) = T(n) + W
    if F(n) <= P(n) < (T(n) - W) W = Width / 2 -> Max(n) = T(n) - W Min(n) = F(n)
    if (T(n) - W) <= P(n) <= (T(n) + W) W = Width / 2 -> N = N Continue
    if P(n) > E(n) -> N = N Continue
    if P(n) < F(n) -> N = N Continue

    S = S + 1 / N * sum from i=1 to N (P(n) - Min(n)) / (Max(n) - Min(n))
}
Score = 100(1 - S)
```

Figure 3 Pattern to target Euclidian distance relation.
to track, the screen displaying the target also showed a prompt of either ‘rest’ or ‘track’.

Each HandTutor™ training session lasted 20–30 minutes. The frequency of training was five sessions per week.

**Evaluation and measurement instruments**

The section of the Brunnström-Fugl-Meyer test (Fugl-Meyer, 1980) that assesses upper limb recovery was used to evaluate motor recovery, providing a measurement of the level of impairment. The scale has proven to be sensitive, reliable and valid (Fugl-Meyer et al., 1975; Sanford et al., 1993; De Weerdt and Harrison, 1985).

With regards to manual dexterity, the B&B test was used to quantify performance of finger grasp and release function (Mathiowetz et al., 1985; Desrosiers, 1994).

As an additional controlled indication to functional measurements, the HandTutor™ track scroll speed and track width were recorded and the data sets were analyzed in order to determine the improvement in patient exercise performance within the experimental group.

**Data processing**

Repeated measures of t-test were applied to record the differences in improvement between the two groups over time, since the rating scales were continuous and met the assumption of normal distribution.

The categorical variables in the control and experimental groups were compared through the use of chi-squared test and Fisher’s exact test.

All statistical procedures were performed with the SAS System by Medistat Ltd, 2006, Israel.

**Results**

Thirty-four eligible subjects were selected from a total pool of 134 patients or medical records. The ineligible subjects included: Stroke onset > 10 weeks (n = 1), Hemianopsia (n = 12), Neglect (n = 10), Orthopaedic problem (n = 2), Absence of finger movement (n = 48), Apraxia (n = 11), Neurological diseases (n = 1) and Aphasia (n = 15). The 34 eligible subjects chosen were randomly assigned to the experimental (n = 18) and control (n = 16) groups. Two of the 18 participants in the experimental group dropped out during the experimental period as one patient died and another did not want to continue treatment. One patient also dropped out in the control group as he did not want to continue the treatment. This left 16 subjects in the experimental group and 15 subjects in the control group.

As shown in Table 1, the subjects in both groups were equivalent in terms of socio-demographic and clinical variables indicating that the stratified randomization was effective. No relationship between the stroke side and the patient’s dominant hand was found. It was also noted that at the T1 measurement both groups were statistically equivalent in the dependent variables (Table 2).

**Table 1.** Comparison of experimental and control group on the sociodemographic and clinical variables at pretest (T1)

<table>
<thead>
<tr>
<th>Sociodemographic and clinical variables</th>
<th>Experimental group (n = 16)</th>
<th>Control group (n = 15)</th>
<th>p-valuea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous variablesc</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>57.8</td>
<td>8.9</td>
<td>62.5</td>
</tr>
<tr>
<td>Time between stroke and admission to rehabilitation (days)</td>
<td>8.41</td>
<td>7.54</td>
<td>11.25</td>
</tr>
<tr>
<td>Categorical variablesb</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td>5</td>
<td>31.25</td>
<td>4</td>
</tr>
<tr>
<td>Men</td>
<td>11</td>
<td>68.75</td>
<td>11</td>
</tr>
<tr>
<td>Stroke type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ischemic</td>
<td>14</td>
<td>87.5</td>
<td>13</td>
</tr>
<tr>
<td>Hemorrhagic</td>
<td>2</td>
<td>12.5</td>
<td>2</td>
</tr>
<tr>
<td>Stroke side</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>10</td>
<td>62.5</td>
<td>5</td>
</tr>
<tr>
<td>Left</td>
<td>6</td>
<td>37.5</td>
<td>10</td>
</tr>
</tbody>
</table>

aMean (standard deviation).
bFrequency.
cp-Value associated with Mann–Whitney test for the continues variable and chi-squared test or Fisher exact test for the categorical variables.
### Table 2. Comparison of experimental and control groups on the dependent variable

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Stage</th>
<th>Mean</th>
<th>SD</th>
<th>( p )-value ( ^{\text{a}} )</th>
<th>( p )-value ( ^{\text{a}} ) on diff. (T1–T3) vs. (T3–T4)</th>
<th>Control group ( n = 15 )</th>
<th>( p )-value ( ^{\text{a}} ) on differences between the group</th>
<th>( p )-value ( ^{\text{a}} ) between groups by pretest measurement</th>
<th>( p )-value ( ^{\text{a}} ) on differences between the group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor function (Fugl-Meyer/66)</td>
<td>T1</td>
<td>46.8</td>
<td>13.1</td>
<td>0.0152</td>
<td>0.0056</td>
<td>49.3</td>
<td>9.4</td>
<td>0.539</td>
<td>0.075</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>53.1</td>
<td>9.3</td>
<td></td>
<td></td>
<td>53.7</td>
<td>8.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>56.6</td>
<td>6.6</td>
<td></td>
<td></td>
<td>52.4</td>
<td>8.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>56.9</td>
<td>7</td>
<td></td>
<td></td>
<td>51.9</td>
<td>6.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manual dexterity (Box and block test no. of blocks)</td>
<td>T1</td>
<td>18.1</td>
<td>10.9</td>
<td>0.0045</td>
<td>0.0025</td>
<td>25.5</td>
<td>14.3</td>
<td>0.217</td>
<td>0.102</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>25.5</td>
<td>10.6</td>
<td></td>
<td></td>
<td>27.4</td>
<td>15.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>32</td>
<td>11.6</td>
<td></td>
<td></td>
<td>31.4</td>
<td>16.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>35</td>
<td>8.8</td>
<td></td>
<td></td>
<td>33.2</td>
<td>17.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performance accuracy on x axis (Track speed)</td>
<td>T1</td>
<td>1.3</td>
<td>0.29</td>
<td>0.0003</td>
<td>0.00026</td>
<td>1.32</td>
<td>0.27</td>
<td>0.587</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>2.05</td>
<td>0.88</td>
<td></td>
<td></td>
<td>1.39</td>
<td>0.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>2.77</td>
<td>1.25</td>
<td></td>
<td></td>
<td>1.39</td>
<td>0.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>2.89</td>
<td>1.35</td>
<td></td>
<td></td>
<td>1.32</td>
<td>0.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performance accuracy on y axis (Track width)</td>
<td>T1</td>
<td>6.34</td>
<td>1.77</td>
<td>0.00005</td>
<td>0.000023</td>
<td>6.63</td>
<td>1.61</td>
<td>0.942</td>
<td>0.1584</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>4.12</td>
<td>1.39</td>
<td></td>
<td></td>
<td>6.75</td>
<td>1.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>3.51</td>
<td>1.31</td>
<td></td>
<td></td>
<td>6.67</td>
<td>1.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>3.51</td>
<td>1.2</td>
<td></td>
<td></td>
<td>7.18</td>
<td>0.73</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( ^{\text{a}} \) \( p \)-value associated with \( t \)-test.
Statistical analysis indicated a significant improvement of the experimental group over the control group, between T1 and T3 in the different dependent variables evaluated: 1) B&B manual dexterity test: $p = 0.015$ and 2) FM upper extremity sensory motor impairment test: $p = 0.041$. In addition, there was a significant improvement within the experimental group between T1 and T3 following analysis of the HandTutor™ software track scroll speed (performance accuracy on x axis $p < 0.001$) and track width (performance accuracy on y axis $p < 0.001$).

There was no significant change in patient performance between T3 and T4 in both the experimental and control groups.

**Discussion**

On average, when compared with the control group, the experimental group managed to transport and release an additional eight blocks in the allotted time at T3. Moreover, results from the FM tests of upper extremity sensory motor impairment showed a statistically significant improvement in the experimental group compared with the control group.

The fact that there was no significant change in patient performance between T3 and T4 in both the experimental and control groups indicates that patient functional performance attained during the pilot study was maintained for at least 10 days following the final treatment session.

Intensive massed and repetitive practice has been demonstrated as being necessary to promote brain reorganization (Jenkins and Merzenich, 1987; Nudo et al., 1996). Studies have also reported that intensive massed and repeated practice is effective in the recovery of functional ability and motor skills, and also that improvement of motor skills and functional ability enables the patient to better perform active daily living (ADL) activities (Wolf et al., 1989; Taub et al., 1993).

Other studies reported significant improvement in activities of daily living as a result of higher intensity of treatment (Langhorne et al., 1996).

In order to achieve optimal functional recovery, it is not sufficient to perform repetitive functional tasks alone. Instead the patient is required to challenge their motor, sensory and cognitive impairments by combining repetitive functional tasks with repetitive and controlled impairment oriented training.

The HandTutor™ concept works on repetitive finger/s and wrist movements with kinematics augmented feedback. To emphasize this point, the HandTutor™ can work on isolated finger/wrist movements by targeting the kinematics impairments of ROM, speed, accuracy, and homogeneity of finger/s and wrist movement.

If the patient to be treated has an impairment in proprioception, then in the initial stages of HandTutor™ treatment, the track width is set to a wide track and track scroll speed is set to a low setting. The software encourages the patients to move their fingers or wrist in order to stay within the track and patients are provided with feedback on their ability to perform the task. The HandTutor™ software therefore provides kinematics augmented feedback in the form of Knowledge of Results (KR) and Knowledge of Performance (KP). KR refers to the outcome and KP gives the patient an instruction on what to do to achieve an improved outcome. To further emphasize these factors, the fact that the ball stays or does not stay within the track, and the trajectory of the ball within the track provides KR, whereas the shape of the track provides KP. As the patient’s proprioception improves, the accuracy of their finger/s and wrist movement will also improve. This allows the therapist to increase the speed of the track scroll, and decrease the track width.

The augmented feedback provided to the patient and the therapist through the HandTutor™ software is quantitative and objective and consists of concurrent and/or terminal quantitative kinematics feedback, for example, speed of finger movement. The feedback is simple and easily understood by both the therapist and the patient.

There is increasing evidence emphasizing the strong relationship between the challenge of training and the patient’s motivation to continue with the rehabilitation programme. Many studies have indicated the essential influence of the challenge in rehabilitation treatment outcomes (Ghez et al., 1995; Noreau et al., 2004). The HandTutor™ programme provides challenging tasks that motivated the experimental group to continue with the practice and meet the goal of performing intensive massed and repetitive practice.

Despite the importance of intensive massed and repeated practice, there are financial limitations to the amount of PT/OT in-patient and out-patient treatment sessions that can be administered. For example, the time from hospital admission to discharge from out patient rehabilitation centres in Israel is usually around 42 days (Rijken and Dekker, 1998). The use of the
HandTutor™ allows for additional motivating intensive and massed repetitive practice that can be made available to both in-patient, out-patient and home care patients.

Repetitive functional tasks alone without the appropriate feedback may lead to the patient learning a compensatory pattern of movement. A compensatory pattern of movement may be learnt as the only measured outcome is the achievement of the function. A combination of HandTutor™ exercises with repetitive functional tasks encourages the learning of movements with minimum compensatory components.

**Study limitations**

Study limitations included small subject numbers, relatively short follow-up periods and minimal outcome measures. In addition, patients in the traditional therapy group were treated by only two therapists working at the same institute. Traditional therapy treatments vary from clinic to clinic. The results are therefore hard to monitor and to follow for specific changes or improvements.

**Conclusion**

The limited results suggest that the HandTutor™ may improve the function of grasping when combined with traditional hand exercises in a sub-acute post-stroke population. The results also suggest that HandTutor™ training should be further investigated as an adjunct to functional training in patients with hand motor dysfunction who are in the sub acute stage following stroke.

In order to support our hypothesis that the functional improvement measured in this study carries over to additional everyday objects and tasks, follow-up studies should incorporate additional reach, grasp, grip and release ADL tests. In addition, larger subject numbers and an extended follow-up period should be considered. Further studies are also needed to assess the efficacy of HandTutor™ treatment in the chronic phase of stroke hand rehabilitation.

In this pilot study, we recorded the HandTutor™ software variables of track scroll speed and track width. Keeping the ball on the track during increased track scroll speed is an indication of an improvement in finger and or wrist movement velocity. Further studies are needed to determine whether there is a relationship between increasing the velocity of finger movement and a facilitation in movement or wrist/finger(s) ROM.

Additional studies investigating the efficacy of HandTutor™ treatment on patients with neurological indications such as spinal cord injuries, head injuries and MS in addition to orthopaedic injuries and surgery are also needed.

Finally studies investigating the open question of whether co-coordinated training using a HandTutor™ task on both hands is more effective than treating the impaired hand alone can be considered.

**Acknowledgement**

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**REFERENCES**


