

**The Effectiveness of supplementing a standard Rehabilitation  
Program with Super-Imposed NeuroMuscular Electrical Stimulation  
following Anterior Cruciate Ligament Reconstruction.**

**A Prospective, Randomised, Single Blind Study.**

## **Abstract:**

**Background:** Rehabilitation following anterior cruciate ligament reconstruction is a key determinant affecting patient return to usual activity levels. Neuromuscular Electrical Stimulation (NMES) is a novel treatment that can counteract strength loss and serve as an adjunct to conventional therapy.

**Study Design:** A Prospective, Randomised, Single Blinded Study

**Purpose:** The purpose of this study was to compare the effect of adding traditional NMES (Polystim) or a novel garment integrated NMES (KneeHab), to a standard postoperative rehabilitation program (Control).

**Methods:** Ninety-six patients who were each randomly assigned to 1 of 3 intervention groups, completed a standard rehabilitation program of voluntary exercises. Additionally, the two NMES groups underwent 20-minute sessions of NMES, 3 times a day, 5 days a week for 12 weeks, where stimulation was superimposed on isometric voluntary contractions. Outcome measures that included isokinetic strength of the knee extensors of the injured and uninjured leg at 90°/sec and 180°/sec, along with functional tests of proprioception were assessed at baseline and at 6 weeks, 12 weeks and 6 months post operatively.

**Results** Overall, the KneeHab group achieved significantly better results at each time point compared to the PolyStim and Control groups ( $p < 0.001$ ). Extensor strength of the KneeHab group at speeds of 90°/sec and 180°/sec increased by 30.2% and 27.8% respectively between pre-operative and 6 months follow up points in the injured leg. The corresponding changes for PolyStim were 5.1% and 5% while for the Control group they were 6.6% and 6.7% respectively. The mean single leg hop score of the KneeHab group improved by 50% between the 6 week and 6 month follow up while the corresponding changes for the PolyStim and Control groups were 26.3% and 26.2% respectively.

**Conclusion:** This study found that intensive garment integrated stimulation superimposed on voluntary contractions combined with standard rehabilitation is effective at accelerating recovery following knee surgery.

**Keywords:** Knee pathology, Novel treatment, Strength gains, Functional recovery, Accelerated recovery.

## 1. INTRODUCTION:

Neuromuscular electrical stimulation (NMES) can be a beneficial supplement to traditional forms of therapy in the post-operative period. Previously, it has been reported following knee joint replacement that highly intensive activation of the quadriceps muscle using electrical stimulation produced better results for strength and muscle activation compared with a control group<sup>1</sup>. Indeed, comparable studies following anterior cruciate ligament (ACL) reconstruction produced similar results where improved strength of the quadriceps muscle and better knee function were some of the aspects reported<sup>2-4</sup>. In contrast there are also studies that found no or only a slight difference between electrical stimulation and volitional strength training of the muscles affected<sup>5-7</sup>. The intensity of NMES induced muscle activation and extent of training are decisive factors in treatment outcomes and consequently patient compliance at high levels of stimulation is required.<sup>8-10</sup>

The primary objectives of rehabilitation following ACL reconstruction are to reduce inflammation, regain neuromuscular strength and functional performance, recover normal range of movement and reintegrate the patient to everyday activities. Studies have shown that the activation pattern of the quadriceps and hamstring muscles as well as restoration of proprioception play an important role in rehabilitation following ACL surgery.<sup>11-13</sup> A recent review concluded that rehabilitation training with NMES superimposed upon voluntary contraction (VC) was better than either NMES or VC practised separately<sup>14</sup>. In a further review of NMES combined with, but not directly superimposed on VC, results showed that the combination therapy (CT) induced greater muscle adaptation than VC alone.<sup>15</sup>

Conventional lead-wired NMES devices can be effective however patient compliance may be reduced by discomfort and inconvenience. The garment-integrated NMES device used in this

study is claimed to produce high levels of muscle activation with improved comfort in an easy-to-use thigh wrap. The purpose of the present, prospective, randomised, controlled study was to assess the effectiveness of combining each of two forms of NMES therapy superimposed on voluntary contractions, with a standard post-operative rehabilitation program of voluntary exercises. In this way the study sought to bring together a number of elements which the literature has indicated are important in optimising rehabilitation outcomes, namely, high intensity NMES superimposed on voluntary contractions, improved compliance with NMES, and combination with a standard voluntary exercise program. The primary outcome measures of effectiveness were knee extensor strength and performance of a single-leg-hop and shuttle-run tests.

## **2. Materials and Methods**

### **2.1 Subjects and Randomisation:**

One hundred and thirty-one patients, from a single clinical rehabilitation site, who were candidates for minimally invasive, endoscopically assisted reconstruction of the cruciate ligament and who met the study inclusion/exclusion criteria, were enrolled into the study. Patients were randomly assigned by drawing lots to one of three treatment groups. A different member of the study staff was responsible for measurement and assessment of subjects. Thirty-one (26.7%) patients were later excluded from study participation for reasons that included: deviation from the course of rehabilitation or additional extensive surgical treatment of meniscal tear or cartilage defect carried out on the involved knee. Of the remaining ninety-six patients available for analysis: twenty-two were female and seventy-four were male, ranging in age from eighteen to fifty-four. The three Groups were as follows: the KH group (n=33) trained with Kneehab®, (Biomedical Research, Ltd., neurotech®, Galway, Ireland) and the PS group (n=29) trained with Poly-Stim™, (Biomedical Research, Ltd., neurotech®, Galway, Ireland). Patients receiving either form of NMES treatment were instructed to isometrically contract the quadriceps muscle voluntarily with each electrical muscle stimulation. The Control CO group (n=34), which did not use muscle stimulation, performed voluntary isometric quadriceps muscle contractions. All group carried out these interventions as a supplement to a standard rehabilitation protocol.

### **2.2 Electrical Stimulation Protocols**

Kneehab is a garment-integrated NMES device that wraps around the thigh and locates four large electrodes over the quadriceps muscle. It is thought to improve muscle activation compared to traditional NMES devices because it can create current pathways between any



Electrode dimensions as outlined in Fig 1 was (1a) PS set-up using 4 x 70mm round electrodes. (1b) and (1c) KH set-up using multiple current pathways between 4 electrodes, A=10x20cm, B= 3x18cm , C=10x7.5cm, D=7x14cm

### **2.3 Rehabilitation protocol**

In the first and second day following surgery, all patients began physiotherapy. Active and passive movements of the injured leg in the pain-free range until a range of movement of 0 - 90° was achieved was incorporated as was a program of static muscle strengthening exercises with the injured and uninjured leg. In the first three weeks patients used walking aids, with partial weight bearing of 15 kg. When patients achieved normal, non-limping gait, the walking aid was discarded. Patients in the PS and KH groups trained with their respective NMES devices, for three, twenty-minute sessions per day, five days per week. The CO group performed voluntary isometric quadriceps muscle training for the same time schedule as the PS and KS groups, but without stimulation. The stimulation and voluntary muscle contractions continued during the entire twelve-week study period. Patients conducted training sessions at home.

All subjects followed the same physiotherapy program, with the exception of the group-specific electrotherapy intervention. During the sixth to the tenth day following surgery, physiotherapy exercises were increased and training therapy commenced with the addition of practice on the bicycle ergometer, rowing machine, knee bends and active flexion and extension exercises on a sling table. Strengthening exercises for the whole thigh musculature, in particular the Vastus Medialis, including adductors and hip flexors and extensors were performed with rubber bands (Thera-Band). Wearing waterproof, protective dressings,

patients performed aqua-jogging by walking slowly backwards and forwards against the water resistance in hip-high water.

The objectives by the tenth day following surgery were full, active extension, active flexion at a limit of 90° and a decrease in swelling. Ten to twelve days following surgery, sutures were removed at the study clinic. Swimming, using the crawl and backstroke only, was recommended. During the third to sixth week following surgery, patients performed progressively increasing exercises of strength, flexion and proprioception. Additionally, from the fourth week onwards, simultaneous, conscious tensing of the flexors and extensors was combined with stair climbing and leg presses, including ¼ to ½ knee-bends. When needed, patients trained to achieve normal gait pattern. Twelve weeks following surgery, sport or activity specific training, including jogging, commenced.

## **2.4 Testing Procedure**

The primary outcome measures of this study were the strength of the knee extensors, the ability to jump on one leg (single leg jump) and the time to complete the shuttle run. Secondary measures included objective assessment on the international knee documentation committee (IKDC) evaluation form. In addition, however not included in this report, were further measurements of the individual patient knee situation as assessed by the strength of the knee flexors and five other functional tests of coordination and proprioception. The three patient groups KH, PS and CO were examined and interviewed preoperatively, 1-2 days before the operation and at 6 weeks ( $\pm 3.1$  days); 12 weeks ( $\pm 4.3$  days) and 6 months ( $\pm 14.7$  days) postoperatively.

## **2.5 Test Measurements**

Objective measurements included isokinetic strength tests of the knee extensors and flexors

using the Isomed 2000 (D&R Ferstl GmbH®), as well as functional hopping and walk tests to measure coordination and proprioception. Measurement of the knee extensors was performed as in previous protocols in a seated position, in the open kinetic system with active extension and flexion (concentric muscle activity), at a limited range of movement of 90° flexion to 45° extension<sup>11, 16, 17</sup>. A set of ten repetitions each was measured on the injured and uninjured side. The patient had the opportunity to get used to the load, being allowed to perform up to five submaximal practice movements. Strength was measured isokinetically at two speeds; 180°/sec and 90°/sec, on both the injured and uninjured legs similar to previous studies.<sup>2, 18</sup>

The relative maximum strength of the extensors was calculated in relation to body weight and the strength ratio of the injured leg to the uninjured leg. The relative value is stated in Nm/kg body weight and the strength ratios in %. In comparison to isokinetic strength measurements, functional jump and walk tests bear relation to everyday movements. Jumping from the one-leg stance is generally used as a clinical test of knee function in patients with a missing anterior cruciate ligament or in the case of anterior cruciate ligament reconstruction<sup>19-21</sup>. Hopping tests are regarded as a valid instrument for recording knee joint function, including neuromuscular function<sup>18</sup> and the strength of the extensor mechanism<sup>22, 23</sup>. Some studies on the comparability of various function tests show that there is a positive correlation between muscle strength and the hopping test<sup>19, 24</sup>.

The single or one-leg hop test is a one-legged jump, in which the landing is on the same leg as that from which the jump was made. In a standardized form the one-legged jump is done with the arms are crossed behind the back. The result is a distance of jump achieved, averaged over three attempts. Three sets were performed on each leg, with the uninjured leg being tested first. The injured/uninjured quotient of the averages was calculated. The shuttle run is a walk/sprint test, where patients have to cover a fixed distance (6.3 m) four times with changes of direction. The measurement reading is the time required to cover this distance. The final result was the average value from three attempts. In addition to the main outcome measures

additional functional and proprioceptive data was collected; the triple jump, side step test, carioca test, timed hop and the cross-over hop.

All functional tests were performed by the patients during each of the test sessions in such a way that they were not exposed to any additional risk to the injured or operated structures. For reasons of safety and weight-bearing capacity, the triple hop, the cross-over hop and the timed hop were not performed in the first follow-up examination at 6 weeks postoperatively.

### **2.5.1 Questionnaire data**

The IKDC Knee Examination Form was used to standardize comparative assessment of the treatment methods as reported by the patient and investigator. This form is the standard form for treatment of knee ligament injuries. It is a concise one-page document that includes a documentation section, a qualification section and an evaluation section. For evaluation there are four problem areas (subjective assessment, symptoms, range of motion and ligament examination). The form can be used pre- and post-operatively and at follow-up. The largest part of the sheet is the qualification section. Each parameter is qualified as "normal", "nearly normal", "abnormal" or "severely abnormal".

Additionally, patients also kept a diary to document training at home, (number of physiotherapy treatment units, pain, intake of analgesics, function and satisfaction, date of full weight-bearing capability and return to the daily work activities. Although not reported here a VAS score was used to determine pain as were questionnaires to determine activity levels and satisfaction with the knee joint .The Tegner Activity Score and Lysholm Score were additional subjective measures taken.

### **Statistical Techniques**

Statistical analysis was blinded to the meaning of the different treatment codes. Given the Within-Subjects design employed, the response variables were calculated as the change from

baseline measurements in order to account for baseline variability between subjects. Linear Mixed Modelling techniques were used which included a random effect associated with the intercept for each subject, a Between Subject Factor Treatment (with levels CO, KH, PS; subject nested within Treatment) and Within Subject Factor Time Post Baseline (with levels 6, 12 and 24 weeks), and Age as a covariate. The significance of the Between and Within Subject factors on the response variables was determined at the  $\alpha=0.05$  significance level. Follow up Tukey multiple comparisons were used to identify which levels of the Between Subject Factor Treatment had significantly different mean responses - as and when appropriate. The final model for each response was justified based on suitable model diagnostics i.e. examination of relevant residual plots, tests for homogeneity of variance and compound symmetry. The IKDC categorisation was available for each individual at Baseline, and 6, 12 and 24 weeks post baseline. In order to compare the Treatments, Ordinal Logistic Regression was used to model the probability of being in a particular IKDC categorisation (or one of less severity) while adjusting for Time. The study was powered to detect a difference of 10% in the primary response variables. Minitab 14 and *R* were used for all statistical analyses.

An intent-to-treat analysis was carried out in which all data of enrolled subjects was analysed. Missing data was dealt with by multiple imputation. A logistic regression model was used to estimate the probability of being missing as a function of age and the baseline values for each of the primary response variables of interest. No bias was detected.

### **3. Results**

Summary statistics and plots of the mean Baseline Adjusted Responses by Treatment and Time are presented for each variable (Table 2, and Fig 2). In each plot the longitudinal benefit of KH is evident as the sample mean improvement from baseline is larger than the mean for the other treatments. The mean improvement appears additive as the difference between the groups is comparable at each level of Time. Note that for some responses, for example the shuttle run, improvement is represented by a negative trend.

On the basis of the models fitted, there was convincing evidence ( $p < 0.001$  in all cases) of a significant Treatment and Time effect, with no Treatment by Time interaction, for all responses. Interval estimates of the difference in the mean baseline adjusted response are given for all pairwise comparisons of factors identified as significant (Table 3). Where the confidence interval for the difference does not include zero it follows that the difference is significant at the  $p < 0.05$  level. The results of the multiple comparisons are reflective of an improvement in the KH group for all (baseline adjusted) responses, as nearly all comparisons involving this Treatment group with the other two were significant.). Expressed in terms of percentage change compared to pre-operative values, the extensor strength gain of the KH group at speeds of  $90^\circ/\text{sec}$  and  $180^\circ/\text{sec}$  increased by 30.2% and 27.8% respectively. The corresponding changes for PS were 5.1% and 5% while for the CO they were 6.6% and 6.7% respectively. The mean single leg hop score of the KH group improved by 50% between the 6-week and 6 month follow up visits, while the corresponding changes for the PS and CO groups were 26.3% and 26.2% respectively.

An intention to treat analysis was performed to compare the estimated treatment effect (pairwise comparison between KH and Control group only) when imputing values for all missing data to the results obtained when analysing the data while removing subjects with missing data.

Multiple imputation was performed using a Predictive Model Based Method where each missing value was replaced by 5 imputed values. Continuous and ordinal responses were

imputed using Ordinal Least Squares regression. The multiple imputations were generated using a regression model of the imputation variable using the complete baseline variables and age as covariates.

An estimate of the difference in the mean response, for each of the primary and secondary response variables, when comparing those on the KH intervention to the Controls, was carried out by pooling the results of each 'complete' model (i.e. with imputed values) using the Barnard-Rubin adjustment method<sup>25</sup>. The estimated coefficients (mean differences), standard errors and p-values for the KH to Control comparison from the original and complete analyses were compared for each of the primary and secondary responses. In each and every case the treatment effect was unchanged between the actual and imputation model.

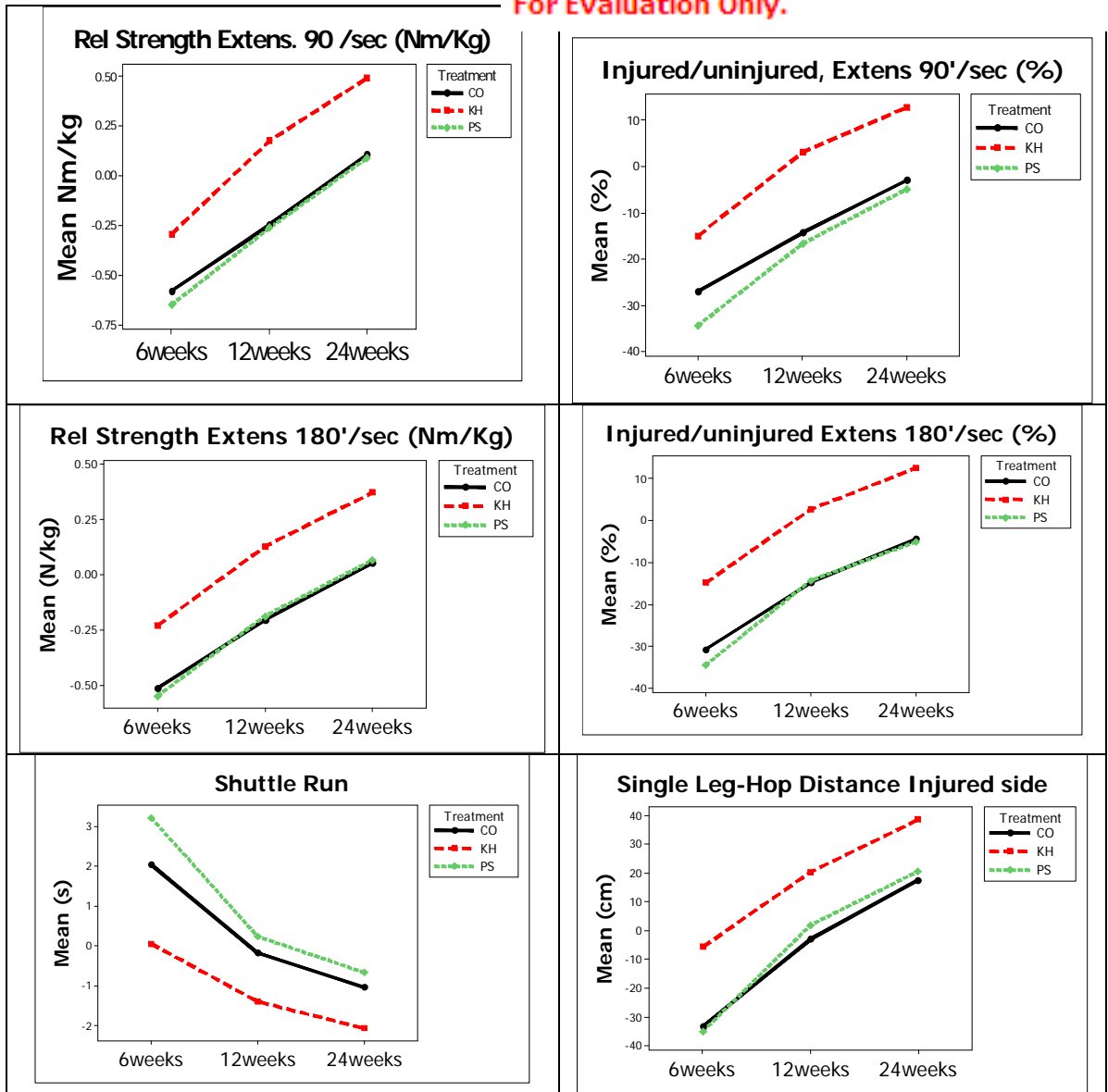


Figure 2: Plots of mean baseline corrected responses, by treatment group, by time.

Table 2. Baseline Adjusted Response Variable at 6, 12 and 24 weeks post Baseline by Treatment

<b>CO Group (Controls)</b>	<b>6 Weeks</b>		<b>12 Weeks</b>		<b>24 Weeks</b>	
<b>Response Variable</b>	<b>mean</b>	<b>sd</b>	<b>mean</b>	<b>sd</b>	<b>mean</b>	<b>sd</b>
Relative Strength Extens. 90°/sec (Nm/Kg)	<b>-0.58</b>	0.35	<b>-0.25</b>	0.42	<b>0.11</b>	0.35
Injured/uninjured, Extens 90°/sec (%)	<b>-26.94</b>	17.12	<b>-14.26</b>	19.83	<b>-2.85</b>	15.86
Rel. Strength Extens. 180°/sec (Nm/Kg)	<b>-0.51</b>	0.36	<b>-0.20</b>	0.38	<b>0.05</b>	0.31
Injured/uninjured, Extens 180°/sec (%)	<b>-30.65</b>	18.10	<b>-14.67</b>	18.28	<b>-4.31</b>	14.45
Shuttle Run (s)	<b>2.04</b>	1.92	<b>-0.17</b>	1.35	<b>-1.03</b>	1.49
Single Hop (cm)	<b>-33.25</b>	27.87	<b>-2.91</b>	29.08	<b>17.59</b>	29.51

<b>PS Group (Polystim)</b>	<b>6 Weeks</b>		<b>12 Weeks</b>		<b>24 Weeks</b>	
<b>Response Variable</b>	<b>mean</b>	<b>sd</b>	<b>mean</b>	<b>sd</b>	<b>mean</b>	<b>sd</b>
Relative Strength Extens. 90°/sec (Nm/Kg)	<b>-0.65</b>	0.38	<b>-0.26</b>	0.38	<b>0.09</b>	0.40
Injured/uninjured, Extens 90°/sec (%)	<b>-34.32</b>	17.93	<b>-16.67</b>	19.30	<b>-4.83</b>	16.45
Rel. Strength Extens. 180°/sec (Nm/Kg)	<b>-0.55</b>	0.31	<b>-0.19</b>	0.31	<b>0.07</b>	0.27
Injured/uninjured, Extens 180°/sec (%)	<b>-34.41</b>	20.47	<b>-14.21</b>	19.27	<b>-5.03</b>	16.01
Shuttle Run (s)	<b>3.21</b>	2.60	<b>0.24</b>	1.76	<b>-0.66</b>	1.27
Single Hop (cm)	<b>-34.99</b>	27.19	<b>1.93</b>	26.72	<b>20.63</b>	26.17

<b>KH group (Kneehab)</b>	<b>6 Weeks</b>		<b>12 Weeks</b>		<b>24 Weeks</b>	
<b>Response Variable</b>	<b>mean</b>	<b>sd</b>	<b>mean</b>	<b>sd</b>	<b>mean</b>	<b>sd</b>
Relative Strength Extens. 90°/sec (Nm/Kg)	<b>-0.29</b>	0.57	<b>0.17</b>	0.62	<b>0.49</b>	0.68
Injured/uninjured, Extens 90°/sec (%)	<b>-14.98</b>	26.11	<b>3.07</b>	27.75	<b>12.82</b>	28.04
Rel. Strength Extens. 180°/sec (Nm/Kg)	<b>-0.23</b>	0.43	<b>0.13</b>	0.46	<b>0.37</b>	0.53
Injured/uninjured, Extens 180°/sec (%)	<b>-14.81</b>	24.19	<b>2.70</b>	25.10	<b>12.60</b>	25.21
Shuttle Run (s)	<b>0.06</b>	3.11	<b>-1.39</b>	3.02	<b>-2.06</b>	3.06
Single Hop (cm)	<b>-5.68</b>	41.21	<b>20.32</b>	38.52	<b>38.57</b>	40.67

Table 3. Sample Mean Difference, 95% CI and p-value for each Baseline Adjusted Response Variable Treatment Level Comparison

Relative Strength Extens 90°/sec (Nm/Kg)	Mean Difference	Lower	Upper	p-value
PS-CO	<b>-0.03</b>	<b>-0.20</b>	<b>0.13</b>	<b>0.87</b>
KH-CO	<b>0.36</b>	<b>0.21</b>	<b>0.52</b>	<b>&lt;0.001</b>
KH-PS	<b>0.40</b>	<b>0.23</b>	<b>0.57</b>	<b>&lt;0.001</b>
Inj/Uninj Extensor 90°/sec (%)				
PS-CO	<b>-3.94</b>	<b>-11.36</b>	<b>3.47</b>	<b>0.42</b>
KH-CO	<b>14.97</b>	<b>7.80</b>	<b>22.14</b>	<b>&lt;0.001</b>
KH-PS	<b>18.91</b>	<b>11.48</b>	<b>26.35</b>	<b>&lt;0.001</b>
Rel Strength Extens. 180°/sec (Nm/Kg)				
PS-CO	<b>0.00</b>	<b>-0.13</b>	<b>0.13</b>	<b>1.00</b>
KH-CO	<b>0.31</b>	<b>0.18</b>	<b>0.44</b>	<b>&lt;0.001</b>

<b>KH-PS</b>				
<b>Inj/Uninj Extens 180°/sec (%)</b>				
<b>PS-CO</b>	<b>-1.34</b>	<b>-8.39</b>	<b>5.70</b>	<b>0.89</b>
<b>KH-CO</b>	<b>16.70</b>	<b>9.88</b>	<b>23.52</b>	<b>&lt;0.001</b>
<b>KH-PS</b>	<b>18.05</b>	<b>10.98</b>	<b>25.11</b>	<b>&lt;0.001</b>
<b>Shuttle Run (s)</b>				
<b>PS-CO</b>	<b>0.65</b>	<b>-0.15</b>	<b>1.45</b>	<b>0.14</b>
<b>KH-CO</b>	<b>-1.41</b>	<b>-2.18</b>	<b>-0.64</b>	<b>&lt;0.001</b>
<b>KH-PS</b>	<b>-2.06</b>	<b>-2.86</b>	<b>-1.26</b>	<b>&lt;0.001</b>
<b>Single Hop (cm)</b>				
<b>PS-CO</b>	<b>2.06</b>	<b>-9.16</b>	<b>13.28</b>	<b>0.90</b>
<b>KH-CO</b>	<b>23.94</b>	<b>13.09</b>	<b>34.79</b>	<b>&lt;0.001</b>
<b>KH-PS</b>	<b>21.88</b>	<b>10.63</b>	<b>33.13</b>	<b>&lt;0.001</b>

### 3.1 IKDC Knee Examination Score

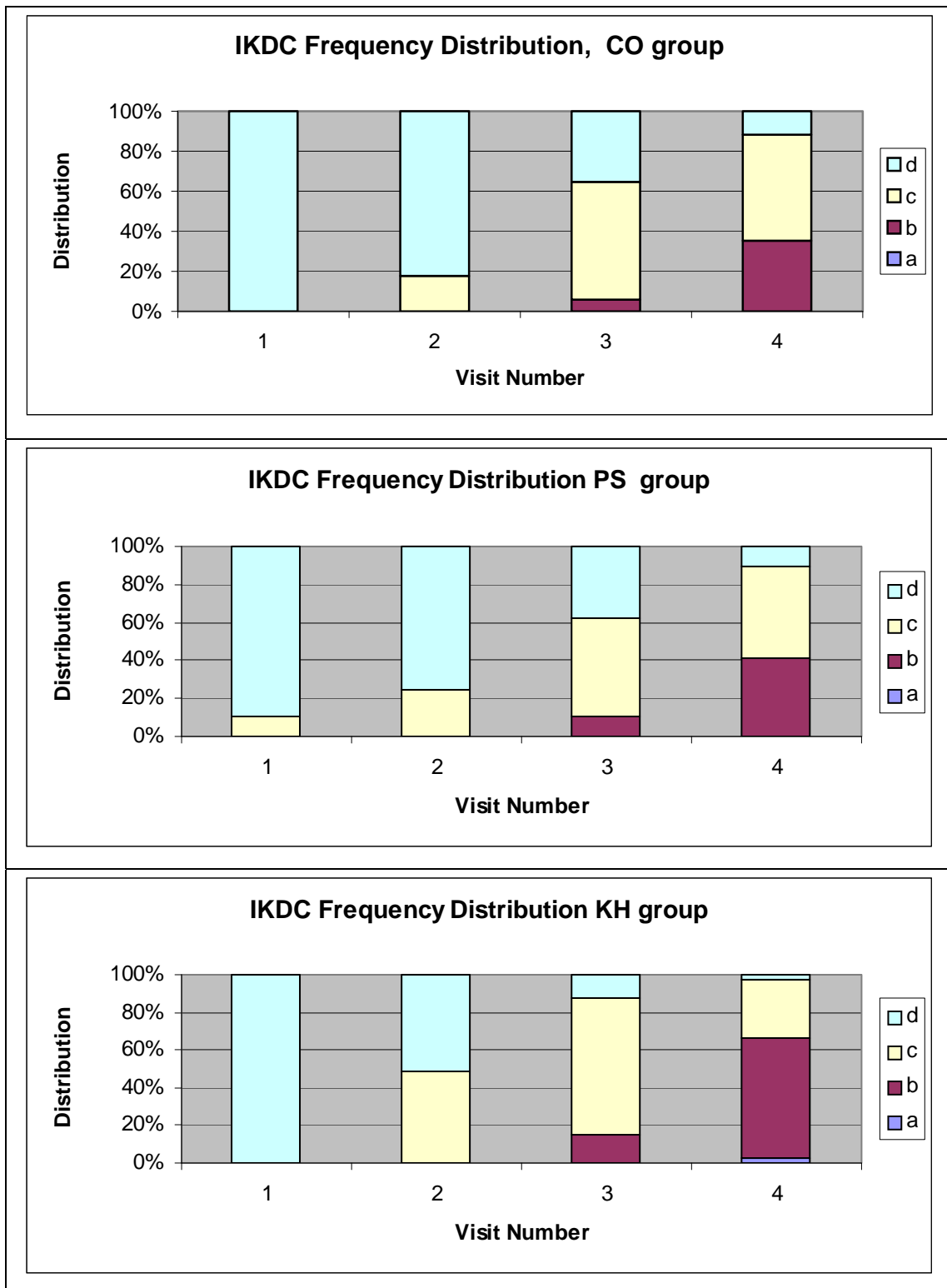


Figure 4. Distribution of IKDC grades by group, over time. Visit 1 is the pre-operative visit. a=normal, b=nearly normal, b=abnormal, d=severely abnormal

Fig 4 shows the progression of the frequency of examination rating during the course of the study. There was evidence of a change in IKDC categorisation across Time ( $p < 0.001$ ) and between Treatments ( $p < 0.001$ ). There was no evidence of a significant Time Treatment interaction. There was evidence of a significantly higher probability of improvement (i.e. an improving IKDC classification across Time) for the KH group compared to the Controls ( $p < 0.001$ ) with an estimated Odds Ratio of 3.53 (95% CI [1.98, 6.30]) and compared to the PS group ( $p = 0.002$ ) with an estimated Odds Ratio of 2.50 (95% CI [1.39, 4.48]). There was no evidence of a significant difference in classification probability across time when comparing the Controls to the PS group ( $p = 0.254$ ).

### **3.2 Patient diaries**

The frequency of training over the period of 12 weeks reveals differences in group compliance. The target was 20 minutes training three times daily, five times per week, which amounts to a total target training time of 60 hours over a period of 12 weeks. The actual compliance was as follows;

- Control group: 48 hours and 48 minutes
- Poly-Stim group: 39 hours and 18 minutes
- Kneehab group: 45 hours and 20 minutes

The compliance of the KH and PS groups could be verified by inspection of the stimulator data readout whereas the control group times could not be verified.

The period for which the patients had to use the walking aids was set at 3 weeks postoperatively. This period is standard in the rehabilitation programme used here and was not set in the light of the study design. There were also differences between the groups, although without achieving statistical significance:

- Control group: 3.21 weeks
- Poly-Stim group: 3.24 weeks
- Kneehab group: 2.83 weeks

The return to everyday working life showed a strong trend in favour of the Kneehab group:

- Control group: 3.67 weeks
- Poly-Stim group: 3.88 weeks
- Kneehab group: 2.7 weeks

#### 4. Discussion:

This study combined physiological tests of strength with tests more representative of functional ability in an attempt to better reflect the varied objectives of rehabilitation. In common with several others, this study combined NMES with a programme of voluntary exercises; however, it was unusual in that the NMES subjects activated their muscles voluntarily during each electrically induced contraction. A final point of difference in this study was the inclusion of a group (KH) who used a garment-integrated stimulation that incorporated a new form of electrode switching designed to improve levels of muscle activation.

Considering the strength and performance measures, there is a clear pattern as demonstrated in the plots of Figure 2. For all groups, there is apparently a loss of performance with respect to pre-surgical baseline at the 6-week follow-up point. Thereafter, there is a general recovery in performance that restores or exceeds the pre-surgical performance level. Within this general picture there are differences between the groups. The KH group demonstrates less of a deficit compared to the other groups at the 6-week point, and generally preserves, but does not increase, this advantage at the subsequent time points. Such a scenario would appear to bear out the conclusion of reviews that NMES in the early stages of rehabilitation helps to build capacity which is required in the later stages<sup>14, 15</sup>. It would appear from these graphs that the KH group consistently leads the other groups in reaching a given level of recovery performance, and that this arises because the deficit was less at the 6 week point.

Others have systematically reviewed the evidence for quadriceps strengthening using NMES in both healthy and impaired subjects<sup>26</sup>. For the latter group, comparing NMES with voluntary exercise, results show that only one study of three acceptable

studies showed clear results in favour

Notably, that study, also superimposed a voluntary co-contraction on the NMES exercise, possibly enhancing the training stimulus<sup>27</sup>. Although both NMES groups in this study used the superimposed voluntary contraction technique, the KH group performed consistently better than PS across most response variables. Both NMES strategies used similar treatment parameters as indicated in Table 1. The main distinctions between the systems were convenience of use of the KH device, which may account for the improved compliance, and an improved activation resulting from the multipath technique.

A recent review examining the evidence for the combined technique of adding NMES (not necessarily simultaneous) to a voluntary exercise programme in knee rehabilitation concluded that the combined therapy was better than voluntary exercise alone in reducing strength loss and atrophy, and moreover restored more functional abilities<sup>14</sup>. Here, the complementary role of NMES may be in the early phase of rehabilitation, where it produces a strength increase that is necessary to perform voluntary exercises in the later phases of rehabilitation.

The single leg hop test also shows a clear significant difference between the KH and CO and PS groups. The KH group achieved significantly better values than the CO group at all three follow-up examinations. A direct comparison with other studies is not possible as the majority of studies only considered the effects of electrical stimulation on the musculature and the strength of the thigh muscles. Others did however also study functional aspects of gait, coordination and walking speed and these studies also reported improvement in gait and knee function in a NMES intervention group.<sup>2, 46</sup>. The results of the IKDC score showed that patients in the KH group achieved better results faster than the CO and PS groups. Evaluation of patient diaries reveals that patients in the KH group dispensed with crutches three days

sooner (full weight bearing) and retur

CO groups. These findings illustrate not only the functional benefits of augmenting rehabilitation with NMES but also highlight the health economic implications.

## 5. Conclusion

In summary, the results of this study show that patients in the KH group achieved consistently better results for strength and functional performance measures at all time points in the rehabilitation period. Additionally, the KH patients achieved higher rates of compliance than conventional NMES, progressed faster and were able to return to their usual work activity 7 days sooner than both the CO and PS groups.

## 6. References:

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