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Effect of Nonelastic Compression With an Adjustable Wrap After Total Knee Arthroplasty

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Swelling is a common phenomenon after total knee arthroplasty, with potential for negative impact on the rehabilitation process and final outcome. The aim of this study was to investigate the effectiveness of a new compression protocol with a self-adjustable, nonelastic compression wrap for the knee region. This study was conducted as a prospective comparative study. Total leg volume and the circumference of the knee at three levels were compared between groups. The results of our study suggest that the application of the new compression protocol has no effect on swelling in the acute postoperative phase (0–2 days) but reduces swelling at Day 14 within the subacute phase. The observed positive effect of the compression protocol could be of clinical importance in the subacute phase as well as for a subgroup of patients suffering from aberrant quadriceps weakness concomitant with knee swelling.

Introduction

Swelling is a common phenomenon after total knee arthroplasty (TKA), with potential for negative impact on the rehabilitation process and the final outcome (Brock et al., 2015, 2017). The swelling is mainly caused by intra-articular bleeding and inflammation of periarticular tissues (Brock et al., 2015). In the early postoperative phase, swelling and pain can lead to problems with the activation of the quadriceps because of the arthrogenic reflex inhibition of the muscle (Holm et al., 2010; Mizner et al., 2005; Stevens et al., 2003). Combined with the loss of range of motion, this may contribute to a decline in functional performance in the short term, which can delay rehabilitation and increase the length of hospitalization (Mizner et al., 2005). Furthermore, excessive swelling is associated with increased rates of wound dehiscence and infection in surgical wounds (Yu et al., 2002). In the long term, up to 1 year postsurgery, gait speed limitations may exist with a negative impact on daily functioning and patient-reported outcomes (Mizner & Snyder-Mackler, 2005; Schache et al., 2013). Although the exact mechanisms are not fully understood, studies have shown associations between knee swelling, quadriceps strength, and gait speed (Loyd et al., 2019; Pua et al., 2016). A study by Pua (2015) demonstrated that 90 days post-TKA, around 11% of the patients had knee swelling levels that exceeded 20% of the median preoperative level.

Compression therapy is well accepted and proven effective in reducing swelling in patients with deep venous thrombosis, venous ulcers, and lymphedema (Partsch, 2012). Although compression therapy is a frequently used treatment modality after total knee replacement, the overall evidence about the clinical outcomes remains inconsistent. This inconsistency is probably due to the limited number of studies with small sample sizes and heterogeneity in methodology, types of materials, and time frames of application (Brock et al., 2015). In some compression therapy studies, no positive outcomes were found with regard to

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swelling, knee range of motion, pain, blood loss, length of stay, patient-reported knee function, nor on the three-level version of the EuroQol Five Dimensions Health Questionnaire (EQ-5D-3L index score) (Brock et al., 2017; Chen et al.,2018; Kayamori et al., 2016; Munk et al., 2013; Pinsornsak & Chumchuen, 2013). In contrast, two other studies showed positive effects. The first, a nonrandomized study, found that patients who received compression therapy had improved range of motion and decreased length of stay (Charalambides et al., 2005). The second study with positive outcomes showed that patients with a compression bandage had improved range of motion and ability to undertake the straight leg raise maneuver and were significantly more likely to be discharged with a walking stick and less likely to be discharged with a rollator (Cheung et al., 2014).

Compression therapy after TKA may limit and reduce swelling by several mechanisms. In the immediate postoperative phase, firm bandaging of the knee may prevent or limit bleeding by a tamponade effect (Charalambides et al., 2005). During ambulation, the application of external compression may lead to a decrease in hydrostatic pressure by supporting venous return by moving blood from the superficial to the deep venous system and by improving the efficacy of the calf muscle pump. This allows movement of fluid away from the interstitial space. In addition, compression aids the lymphatic drainage and a resultant hyperemic response improves arterial blood flow (Brock et al., 2015). The use of inelastic bandages is preferred in arthroplasty as they have a low, tolerable resting pressure but a higher labor pressure, creating a more effective activation of the deep venous system and calf muscle pump with ambulation compared with elastic materials (Spence & Cahall, 1996).

Purpose

The aim of this study was to investigate the effectiveness of a compression protocol on the volume of the total leg and the knee region in the first 12 weeks postsurgery. We hypothesized that there will be positive effects of compression on swelling after knee arthroplasty using a self-adjustable, nonelastic compression wrap for the knee region in combination with a thigh high elastic stocking (23–32 mmHg), starting immediate postoperatively and worn 24 hours a day for 6 weeks. In a former study, feasibility for pain in rest and action was demonstrated. The visual analog scale (VAS) scores postsurgery showed no significant differences between the group applying the new compression protocol and the usual care group. This was considered positive because more pain could be expected by adding extra compression, especially in the first phases of recovery. The effects of the compression protocol on swelling have not been studied yet (Hendrickx et al., 2017). It is expected that the resting pressure of the nonelastic material will create a tamponade effect in the acute postoperative phase and will prevent an increase in swelling during the night and at rest in the first 6 weeks after surgery with 24-hour use. The higher labor pressure of the material is expected to lead to a faster reduction in the swelling during ambulation than with elastic materials. The compression wrap enables patients to adjust the compression dose themselves, which is expected to contribute to an effective dose and to enhance the tolerability of day-and-night use. As self-management strategies contribute positively to health outcomes, this device is preferable to other compression technologies that require the help of healthcare providers (Fibel, 2015; Stevens et al., 2004; Van der Sluis et al., 2015).

Method

Study Design and Population

This study was conducted as a prospective comparative study with convenience sampling and group allocation based on willingness to participate, availability of staff and materials, and the number of patients needed per group.

The study was performed at Nij Smellinghe Hospital, Drachten, the Netherlands. The local Medical Ethical Committee in Drachten approved the study (dated November 4, 2014, REF NH/PT/14-1546), and all patients signed an informed consent. The materials used in the treatment group were provided by medi BH Bayreuth.

Patient Recruitment

Patients were enrolled in the study from January 2015 until December 2015. When the indication and decision for a TKA were made at the outpatient Orthopaedic Department, patients were invited to participate and received oral and written information about the study. During their second visit to the clinic for their preoperative screening, patients signed their informed consent.

Inclusion criteria included the following:

- Patients 18 years or older;
- Patients undergoing a primary elective TKA; and
- Patients able to understand the study.

Exclusion criteria included the following:

- Allergy to one of the used materials;
- Severe systemic diseases causing peripheral edema;
- Acute superficial or deep vein thrombosis;
- Arterial occlusive disease (Stadium II, III, or IV) (ankle brachial pressure index< 0.8);
- Local infection in the therapy area;
- Autoimmune disorders or vasculitis;
- Use of systemic corticosteroids; and
- Inability to don, doff, and adjust the device.

Study Interventions

Table 1 summarizes treatment received by the two groups. The control group received compression therapy, according to the usual care protocol. This consisted of immediate postoperative compression with elastic bandages for the knee region, with Elastomull

Table 1. Compression and Exercise Protocols

Control Group	Treatment Group
• First 12-24 hours postoperative: compression with elastic bandages for the knee region with Elastomuhl Haft® (Jobst), applied from toes to midthigh • From 12 to 24 hours until 6 weeks postoperative: an antithrombosis stocking, Comprinet stocking® (BSN Medical) • Ambulation and exercise program according to the "fast track principles"	• Immediately postoperative until 6 weeks postoperative: 24 hours a day compression with the Struva 23®, a Class 2 thigh high antithrombosis stocking (Medi) in combination with the RK® (Medi) • Ambulation and exercise program according to the "fast track principles"

Haft® applied from the toes to midthigh. The knee was bandaged in the extended position. After 12–24 hours, this bandage was replaced by an antithrombosis stocking, Comprinet® (16–22 mmHg), that was worn for 6 weeks during daytime. The treatment group received compression therapy with a Struva 23® (23–32 mmHg) thigh high antithrombosis stocking in combination with the Reduction Kit® (RK®) (see Supplemental Digital Content, available at: http://links.lww.com/ONJ/A15), a self-adjustable, nonelastic compression wrap for the knee region; both the Struva stocking and RK® were worn 24 hours a day for 6 weeks. Immediately after the operation, the Struva stocking and the wrap were applied by the staff of the operating room. Following initial application, the stocking and the wrap were changed daily by the patient. Patient education on the use of the RK® started preoperatively at the outpatient Orthopaedic Department and was reinforced during their stay in the hospital. Patients were observed applying a firm but tolerable amount of compression and adjusting the pressure level up and down using the Velcro ties (see Figure 1). Patients were instructed to watch for any complications associated with the tightness of the bandaging and for circulation and sensation in the toes or other discomfort associated with the compression therapy. In addition, patients received written information on the procedure and a contact number in case they had any questions after discharge. Pain management, ambulation, and exercise regimens were equal in both groups. To minimize postoperative immobilization, the "fast track" rehabilitation principles have been implemented in our hospital. These principles include optimal pain control by a multimodal pain management strategy in combination with preemptive analgesia, the use of a Continuous Passive Motion device for 4 hours immediate postoperatively (2 hours of immobilization in a position of 90° flexion, followed by 2 hours of passive motion in a range of 60°–90° flexion), early ambulation starting 4 hours postsurgery, and intensive physical therapy starting on the day of surgery. The physical therapy consisted of (1) exercises to improve the range of motion of the knee joint; (2) muscle exercises to regain muscle control; (3) exercising the functional milestones (supine to sit, sit to supine, sit to stand, walking, and stair climbing) to retrieve functional independence. The functional milestones were assessed daily with the Modified Iowa Level of Assistance Scale (MILAS), and patients were discharged when they were able to perform them safely and independently.

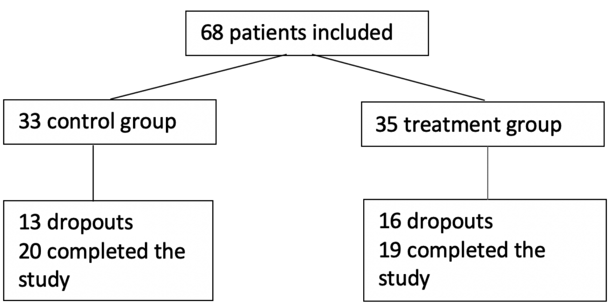

Figure 1. Flow diagram of patients included in the study.

Study Outcomes

Baseline characteristics were recorded prior to the operation concerning gender, age, body mass index (BMI), American Society of Anesthesiologists (ASA) classification, pain in rest and action, and whether or not patients used compression therapy prior to the operation. Outcome measures included the total leg volume (TLV) and the circumference of the knee at three levels: infra-, mid-, and suprapatellar (CIP, CMP, and CSP). The TLV was calculated by an indirect method by tape measurements (Kuhnke, 1976; Sukul et al., 1993; Tan et al., 2013). According to this method, the leg was divided into discs of 4 cm height, starting at the distal point of the medial malleolus and working up to the groin. By taking circumference measurements at all these levels, the volume of each disc was calculated by the following formula: Volume = Circumference^2/π. The results of all individual discs were counted up to calculate the TLV. For the knee region, the circumference measurements were also taken by tape measurement. The measurements were performed by four experienced therapists preoperatively, at Day 1 and Day 2 during the hospital stay, and during regular follow-ups at the outpatient Orthopaedic Department at Day 14, Day 42, and Day 84. No intra- or interrater reliability testing was performed, as circumference measurements have shown to be sufficient in studies in the field of lymphedema and orthopaedic surgery (Soderberg et al., 1996; Tidhar et al., 2015).

Statistical Analyses

All data were analyzed with the programming language R Version 3.3.0 for statistical computing (R Core Team, 2017). A p value of .05 or less was considered statistically significant.

Tests for confounding variables at baseline were performed with the Welch two-sample t test for age, BMI, pain at rest and pain with activity, TLV, and knee circumference. For the ASA classification and gender variables, a "Pearson's Chi-squared test" was used to determine difference and for the variable, use of preoperative compression, a "Pearson's Chi-squared test with Yates continuity correction" was used.

Mixed-model analysis was used to test differences in postoperative swelling of the total leg and knee region between groups (Pinheiro & Bates, 2000). Main as well as group-by-time interaction effects for the response variable were taken as fixed, whereas for the patients, a random effect was taken into account. Group-by-time interaction effects were studied by interaction plots.

Results

Of 204 patients undergoing total knee replacement during this time frame, 68 patients consented to participate in the study. Thirty-three patients were assigned to the control group and 35 to the treatment group. Of these 68 patients, 39 completed the study: 20 patients in the control group (13 dropouts) and 19 patients in the treatment group (16 dropouts). The high number of dropouts (39% in the control group and 46% in the treatment group) was influenced by both personal and organizational factors. Examples of personal factors were the time and effort needed to participate, problems with putting on and taking off the Struva stocking, and simply forgetting the appointment. Organizational factors were related to the availability of the materials at the time of surgery and failure to notify the researchers of changes to follow-up visits. Forgetting appointments and changes in follow-up dates resulted in a lack of data and influenced patients' decision to drop out from the study. No complications (e.g., deep venous thrombosis and postoperative wound infections) occurred.

Baseline Demographics

Table 2 presents the baseline demographics by group. The groups were similar at baseline except for the BMI variable, with the control group having a significantly higher BMI than the treatment group.

Table 2. Baseline Demographics

	Control Group (n = 20), Mean (SD)	Treatment Group (n = 19), Mean (SD)	*p*
Gender			.83[a]
Female	12	13	
Male	8	6	
Age, years	66 (9)	66 (10)	.91[b]
BMI, kg/m^2	31.6 (4.0)	28.7 (3.9)	**.03**[b,c]
ASA classification			.15[a]
Class I	1	4	
Class II	11	15	
Class III	0	0	
Use of compression presurgery			.76[d]
No compression	16	16	
Knee high compression	4	2	
Thigh high compression	0	0	
Pain in rest (VAS 0–10)	3 (3)	4 (3)	.25[b]
Pain in action (VAS 0–10)	6 (3)	6 (2)	.86[b]
Total leg volume, L	9.1 (1.7)	8.4 (1.9)	.26[b]
Knee circumference infrapatellar, cm	40.9 (3.5)	39.4 (3.2)	.18[b]
Knee circumference midpatellar, cm	43.5 (3.7)	41.4 (3.5)	.08[b]
Knee circumference suprapatellar, cm	45.0 (4.7)	43.0 (3.9)	.15[b]

Note. ASA = American Society of Anesthesiologists; BMI = body mass index; VAS = visual analog scale.
[a]Pearson's Chi-squared test.
[b]Welch two-sample *t* test.
[c]Significant at $p < .05$.
[d]Pearson's Chi-squared test with Yates continuity correction.

Volume Measurements

Table 3 shows the results of the mixed-model analysis related to the TLV in liters and the knee CIP, CMP, and CSP in centimeters over time. As can be seen, in both groups, knee circumference and total leg swelling were present the day after surgery, increased through Day 2, and decreased by Day 14. Comparing the two groups over the total time period, the group effect of the intervention was absent with the exception of Day 14, where the decrease of the swelling was significant in favor of the intervention group for both TLV and CIP. Both CMP and CSP showed the same trend; however, the size of these effects was not significant.

Discussion

The results of our study suggest that after knee arthroplasty, the use of an adjustable, nonelastic wrap for the knee region in combination with a thigh high elastic stocking (23–32 mmHg) has no effect on swelling in the acute postoperative phase (0–2 days). However, we demonstrated a significant decrease in swelling at Day 14 within the subacute phase in favor of the intervention group for both TLV and CIP.

The lack of results of the compression in the acute phase is in line with other studies and could indicate that the compression did not control the intra-articular bleeding of the knee effectively. An intra-articular pressure of 50–60 mmHg is needed to achieve a tamponade effect, according to the study by Charalambides et al. (2005). The pressure on the skin under a compression bandage should be between 28 and 32 mmHg to reach this dose. Their study suggests that in addition to the pressure supplied by the bandage, the tissue elasticity around the knee contributes to the development of an intra-articular pressure that may achieve a tamponade effect with only a small volume of blood within the joint. We instructed our patients to apply a firm but tolerable compression dose and to adjust it when the

TABLE 3. RESULTS RELATED TO VOLUME AND CIRCUMFERENCE

	T_0	T_1	T_2	T_{14}	T_{42}	T_{84}	T_0–T_{84}
Total leg volume: Control group, Mean (*SD*), L	9.1 (1.7)	9.6 (1.7)	10.1 (1.9)	9.6 (1.8)	9.5 (1.9)	9.5 (1.7)	
Total leg volume: Treatment group, mean (*SD*), L	8.4 (1.9)	8.9 (2.0)	9.2 (2.2)	8.4 (1.9)	8.6 (2.2)	8.9 (2.1)	
Time effects,[a] ml/*p* value		468/.008	1,080/<.001	526/.003	433/.013	376/.031	
Group-by-time interaction effects, ml/*p* value		−25/.918	−344/.186	−**545/.031**[b]	−242/.330	87/0.726	
Group effects, ml/*p* value							−676/.276
Circumference infrapatellar: Control group, mean (*SD*), cm	40.9 (3.5)	43.3 (4.1)	43.8 (3.4)	43.4 (4.5)	41.8 (3.8)	41.6 (3.2)	
Circumference infrapatellar: Treatment group, mean (*SD*), cm	39.4 (3.2)	41.4 (3.9)	42.1 (4.1)	39.6 (5.3)	39.9 (3.5)	40.3 (3.7)	
Time effects,[a] cm/*p* value		2.4/<.001	2.8/<.001	2.5/<.001	0.9/.109	0.8/.180	
Group-by-time interaction effects, cm/*p* value		−0.4/.656	−0.1/.877	−**2.3/.005**[b]	−0.4/.586	0.02/.981	
Group effects, cm/*p* value							−1.5/.234
Circumference midpatellar: Control group, mean (*SD*), cm	43.5 (3.7)	46.3 (4.0)	47.3 (3.2)	45.9 (3.6)	45.8 (3.6)	43.6 (3.9)	
Circumference midpatellar: Control group, mean (*SD*), cm	41.4 (3.5)	43.7 (4.5)	44.6 (4.3)	43.0 (4.2)	42.1 (3.9)	42.6 (4.3)	
Time effects,[a] cm/*p* value		2.8/<.001	3.5/<.001	2.3/<.001	2.3/<.001	0.1/.866	
Group-by-time interaction effects, cm/*p* value		−0.5/.571	−0.5/.559	−0.8/.363	−1.6/.057	1.0/.239	
Group effects, cm/*p* value							−2.1/.101
Circumference suprapatellar: Control group, mean (*SD*), cm	45.0 (4.7)	48.4 (4.8)	49.8 (4.9)	47.8 (4.6)	47.2 (4.3)	46.3 (3.7)	
Circumference suprapatellar: Control group, mean (*SD*), cm	43.0 (3.9)	45.6 (4.6)	46.4 (4.7)	44.7 (4.7)	44.1 (4.3)	44.0 (4.4)	
Time effects,[a] cm/*p* value		3.4/<.001	4.5/<.001	2.7/<.001	2.2/<.001	1.2/.006	
Group-by-time interaction effects, cm/*p* value		−0.8/.206	−1.2/.074	−1.1/.096	−1.1/.085	−0.3/.643	
Group effects, cm/*p* value							−2.0/.160

[a]Time effects: contrasts with respect to T_1 mean as reference value.
[b]Significant at $p < .05$.

pressure dropped. As we did not measure the compression dose, we cannot state whether or not the lack of results was due to an ineffective dose. Developments in the field of real-time dose measuring could be of great value for future studies.

Three other studies had follow-up measurements of swelling, enabling comparison with the results of our study. The study by Munk et al. (2013) did not show any clinical effect on swelling after using a medical elastic compression stocking for 4 weeks as compared with no stocking. Both groups received a two-layer compression bandage with high stiffness for the first 24 hours. The second study by Brock et al. (2017) randomized 50 consecutive patients selected for primary TKA to receive a short-stretch, inelastic compression bandage or a standard wool and crepe bandage for the first 24 hours postoperatively. After 24 hours, no further compression therapy was applied. Knee swelling was measured preoperatively, daily during hospital stay, and at 6 weeks. No statistically significant differences with regard to swelling were seen between the groups. A recent study by Chen et al. (2018), comparing the use of an elastic compression bandage for 4 weeks with no bandage, did not show any clinical improvement of the measured outcomes, including swelling. They concluded that applying compression bandages is not necessary for routine primary TKA. In contrast to these results, we did observe a significant difference with the control group at Day 14 for TLV and CIP. These observations are new and may be explained by the use of the nonelastic compression material, which supplies a higher labor pressure during ambulation, creating a faster reduction in the swelling than with the elastic materials as used in the studies by Munk et al. (2013) and Chen et al. (2018). In the study by Brock et al. (2017), the period of compression was just 24 hours, probably too short to realize results on swelling later in time. Studies focusing on the decrease of quadriceps strength postsurgery demonstrate associations between knee swelling, quadriceps strength, and gait speed. The greater the postoperative swelling, the greater the decrease in knee extension strength and the greater the negative impact on gait speed (Holm et al., 2010; Mizner et al., 2005; Pua, 2015). Gait speed, in turn, is very important for daily functioning and limitations may still persist 1 year postsurgery (Meier et al., 2008; Pua et al., 2016). A recent study demonstrated that peak swelling, representing the maximum value in the involved limb, is significantly correlated with quadriceps strength at 2 and 6 weeks postsurgery. This peak swelling would typically occur between 6 and 10 days postsurgery (Loyd et al., 2019). Another study demonstrated that 90 days post-TKA, around 11% of the patients had knee swelling exceeding 20% of the median preoperative level (Pua, 2015). These findings highlight the potential relevance of the recognition of patients with quadriceps weakness concomitant with persistent knee swelling as a subgroup and raise the question whether interventions to improve knee swelling are indicated and effective to preserve and improve quadriceps function. We wonder whether our findings could be of clinical importance in this perspective. Based on our current observations, the prescription of 14 days of compression therapy combining the nonelastic compression wrap with the antithrombosis stocking could well be the optimum to target the peak swelling. If patients suffer from aberrant quadriceps weakness in combination with swelling, prolonged use of the compression can be considered as well as application in later phases of the rehabilitation process. More research is needed to look into these options and has to include functional outcome measurements, especially quadriceps strength, and gait speed. A longer follow-up period, until 1 year postsurgery, is preferable to answer questions about the interactions between swelling, quadriceps strength, and gait speed in the long term.

Limitations of our study concern the lack of randomization and the small sample size. Both could have biased the results of the study. Despite these limitations, we consider our results to be important. First, they have possible clinical relevance because of the observed reduction in swelling at Day 14, which could moderate the peak swelling and because they could offer treatment options for the subgroup of patients with aberrant quadriceps strength concomitant with knee swelling. Second, our results open opportunities for the application of new compression technologies in the field of orthopaedic surgery.

Conclusions and Recommendations

The observed positive effect of our compression protocol on swelling of the TLV and CIP at Day 14 could be of clinical importance. A subgroup of patients, suffering from aberrant quadriceps weakness concomitant with knee swelling, could benefit from prolonged compression with our protocol. Both interventions need more research, including pressure and functional measurements, with a follow-up of 1 year.

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