

# Supine Positioning for Graft Attachment After Descemet Membrane Endothelial Keratoplasty: A Randomized Controlled Trial



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- **PURPOSE:** The Supine Positioning for Descemet Membrane Endothelial Keratoplasty Attachment (SUPER-DMEK) trial assessed the efficacy of prolonged supine head positioning on graft attachment.
- **DESIGN:** Randomized controlled trial.
- **METHODS:** Participants with Fuchs' dystrophy were randomized to 5 days of supine head positioning (intervention) or to 1 day (control). Participants, surgeons, and investigators were masked until the day after surgery. Adherence to the allocated intervention was monitored using a head sensor. Main outcome measures were area and volume of graft detachment (coprimary end points) 2 weeks after surgery quantified using a validated neural network for image segmentation on anterior segment optical coherence tomography images, and repeat air injection (re-bubbling), subjective visual function, and adverse events (secondary end points).
- **RESULTS:** A total of 86 participants received the allocated intervention (35 eyes intervention and 51 eyes control). In the intention-to-treat analysis, the mean area of graft detachment was 28.6% in the intervention arm and 27.5% in the control arm (adjusted between-arm difference, 1.3; 95% CI, -8.7 to 11.4;  $P = .80$ ). Results for volume of detachment and as-treated analyses based on head position sensor data indicated no potentially clinically relevant effect of prolonged supine positioning on graft attachment. Results were not compatible with a relevant treatment effect on rebubbling or subjective visual function. Adverse events, most commonly back pain, were more common and more severe with the intervention.

- **CONCLUSIONS:** In this randomized controlled trial, graft attachment was not improved with prolonged supine head positioning. Prolonged supine positioning frequently caused back pain. Prolonged supine positioning after Descemet membrane endothelial keratoplasty for Fuchs' dystrophy may not be needed in routine practice. (*Am J Ophthalmol* 2024;263: 117–125. © 2023 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>))

INCOMPLETE GRAFT ATTACHMENT IS THE MOST COMMON cause for delayed visual recovery and indication for secondary surgery after Descemet membrane endothelial keratoplasty (DMEK).<sup>1</sup> Intraoperatively, the unfolded graft is attached and pressed against the host's cornea using an air or gas bubble. How long this air or gas bubble needs to be directly underneath the graft to promote attachment is unclear. This question is important for clinical practice because supine positioning of the eye, and thus the patient, must be maintained for the air or gas bubble to be directly underneath the graft.

Protocols for postoperative supine positioning vary greatly from minutes<sup>2,3</sup> over hours<sup>4</sup> up to one<sup>5,6</sup> or more days.<sup>1,7-9</sup> This variation in clinical practice reflects the insufficient evidence base for a benefit of supine positioning<sup>3,4,10,11</sup> in light of weak, nonrandomized study designs, limited standardization of compared interventions, insensitive outcome assessments for graft detachment, and limited data on the safety of prolonged immobilization in this patient population.

To determine the efficacy and safety of prolonged supine positioning after DMEK for Fuchs' dystrophy, we conducted a randomized controlled trial comparing supine head positioning for 5 days vs 1 day postoperatively. The coprimary end points, area and volume of graft attachment at the 2-week postoperative visit, were assessed using anterior segment optical coherence tomography (AS-OCT) scans quantified with a previously validated convolutional neural network for image segmentation.<sup>12,13</sup> Secondary end points were rebubbling, visual function, and adverse events (AEs).

 Supplemental Material available at [AJO.com](http://AJO.com).

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## METHODS

• **STUDY DESIGN:** The Supine Positioning for Graft Attachment After Descemet Membrane Endothelial Keratoplasty (SUPER-DMEK) trial was a single-center, investigator-initiated, randomized controlled trial to assess the efficacy and safety of postoperative supine head positioning after DMEK in patients with Fuchs' dystrophy (ClinicalTrials.gov, NCT05399095). The study was approved by the ethics committee of Freiburg University Hospital and adhered to the tenets of the Declaration of

Helsinki. Informed written consent was obtained from all participants.

• **PARTICIPANTS:** After screening medical records of patients scheduled for DMEK ( $\pm$ cataract surgery), participants were recruited on admission to the eye center 1 day before surgery. Inclusion criteria were clinically advanced Fuchs' dystrophy with indication for DMEK. Participants with other corneal diseases, regular use of drugs potentially affecting the cornea, previous corneal surgery, diabetes mellitus with end organ complications, or participants who were bedridden, unable to lie flat, or unable to fixate during corneal imaging were not included.

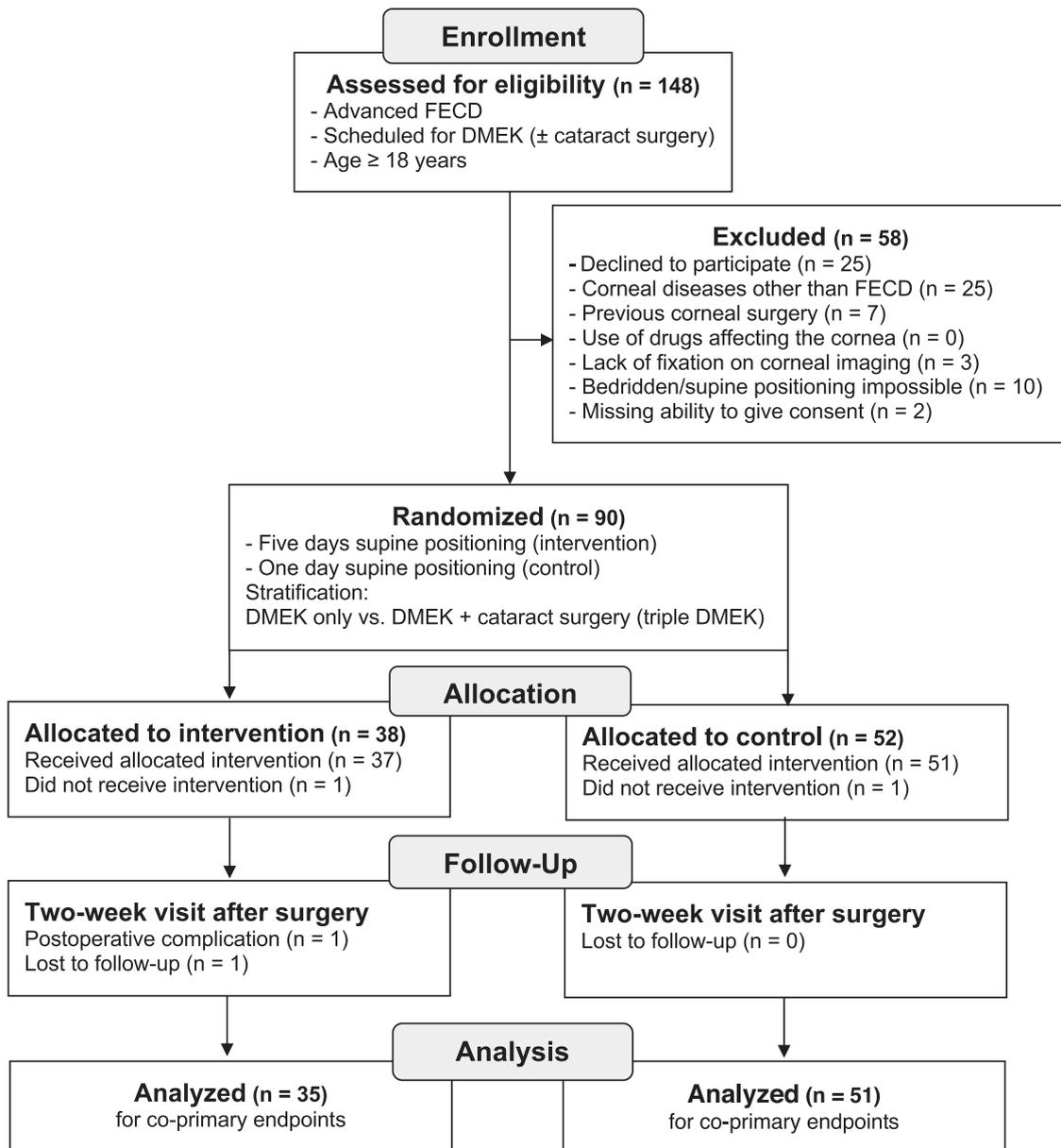


FIGURE 1. Consolidated Standards of Reporting Trials (CONSORT) flowchart. DMEK = Descemet membrane endothelial keratoplasty, FECD = Fuchs' endothelial corneal dystrophy, n = number of eyes.

**TABLE 1.** Baseline Characteristics of Eyes Included in the Supine Positioning for Descemet Membrane Endothelial Keratoplasty Attachment (SUPER-DMEK) Trial

	Intervention (5 Days Supine Positioning)	Control (1 Day Supine Positioning)
Eyes, n	35	51
Fellow eye included, n	4	2
Participants, n	33	50
Age (y)	69 (62, 76)	70 (63, 76)
Women	20 (63)	30 (59)
Characteristics before surgery		
Best-corrected visual acuity, ETDRS letters <sup>a</sup>	75 (70, 80)	72 (64, 78)
Straylight, logS <sup>b</sup>	1.4 (1.2, 1.6)	1.5 (1.3, 1.6)
Visible corneal edema	12 (34)	29 (57)
Characteristics of surgery		
DMEK + cataract surgery (triple DMEK)	29 (83)	38 (75)
DMEK	6 (17)	13 (25)
Preoperative back pain (within 4 wk) <sup>c</sup>	19 (54)	23 (45)

ETDRS = Early Treatment Diabetic Retinopathy Study.  
 Data are presented as median (interquartile range) or n (%) unless otherwise specified.  
<sup>a</sup>Best-corrected visual acuity was assessed in 85 eyes.  
<sup>b</sup>High-quality data on disability straylight were available in 47 eyes.  
<sup>c</sup>Reported using patient questionnaire at enrollment for 78 eyes.

• **RANDOMIZATION AND INTERVENTION ALLOCATION:**

Participants were randomized to either 5 days (intervention) or 1 day (24 hours; control) of supine positioning postoperatively after DMEK. Randomization with an intended ratio of 1:1 was based on a computer-generated list of random codes<sup>14</sup> according to the guidelines of the Consolidated Standards of Reporting Trials 2010 (CONSORT)<sup>15</sup> and was stratified by type of planned surgery (DMEK with cataract surgery vs DMEK alone), a potential risk factor for graft detachment.<sup>13</sup> Randomization was done on study inclusion before surgery.

• **MASKING:** Investigators, participants, corneal surgeons, and other personnel remained masked until the first postoperative day after DMEK, that is, after 24 hours of supine positioning in all patients. Investigators then opened the sealed and opaque envelope with the study assignment together with the participant and informed the surgeon and clinical staff of the assignment in order to administer the assigned intervention.

• **BASELINE EXAMINATIONS AND SURGERY:** Baseline examinations, performed on the preoperative day, included best-corrected visual acuity, disability glare using a straylight meter (C Quant; Oculus), and slitlamp biomicroscopy for clinical grading on Krachmer scales.<sup>16</sup>

DMEK and, as indicated, cataract surgery were performed in all participants according to local clinical standards, including surgical peripheral iridectomy before stripping and near-complete filling of the anterior chamber with air.<sup>13,17,18</sup> Postoperative anti-inflammatory treatment,

measures to decrease intraocular pressure, and repeat air injection (re-bubbling) were at the discretion of the treating surgeon.

• **INTERVENTION AND ASSESSMENT OF ADHERENCE TO THE ALLOCATED INTERVENTION:** During the first 24 hours after surgery, all participants were instructed to take a supine (head) position, reducing time spent upright to only 10 minutes per hour. In the intervention arm, participants were instructed to maintain this regimen for 5 days after surgery. In the control arm, participants were instructed to resume regular activity starting 24 hours after surgery, that is, when informed of allocation. To incentivize regular activity during hospitalization, participants in the control arm received a daily voucher for the local bakery, located 600 m (approximately 1000 ft) away. Participants in the intervention arm received the vouchers when returning for the 2-week visit.

To monitor head positioning, participants in both trial arms wore a 3-dimensional motion sensor (Pendant G data logger; HOB0) with an elastic headband for 5 days after surgery (Supplemental Figure 1).<sup>10,19</sup> Participants received a diary to document times when the sensor was not worn. The data were analyzed and depicted graphically using a custom-written program that classified head positioning as supine, as supine with pillow (30°-55° elevation), as supine with face rotated to the left or right side, or as upright. The supine position was defined as a head elevation less than 30° above the horizontal plane.

• **OUTCOMES:** Coprimary outcomes were area (range, 0%-100% of graft surface; continuous) and volume (in μL)

of graft detachment at the 2-week follow-up visit after surgery. Trained study personal performed AS-OCT imaging (Casia-1; Tomey) on the first postoperative day and at the 2-week postoperative visit. In individual cases, medical reasons or public holidays postponed scheduled assessments by an order of days. All 256 cross-sectional images of an AS-OCT scan were used to quantify graft detachment by segmenting the posterior cornea surface and the graft.<sup>12</sup>

Secondary outcomes included the use of secondary air injection (rebubbling), subjective visual function assessed on a numeric analog scale from 1 (worst) to 10 (best) at the 2-week visit, and AEs.

- **SAFETY:** AEs were actively recorded by investigators via patient assessments on the day of surgery, the first postoperative day, at discharge from the hospital, and at the first follow-up visit approximately 2 weeks after surgery. AEs of special interest included back pain, headache, local eye pain, and deep vein thrombosis/venous thromboembolism. In addition, clinical staff were instructed to report potential AEs to investigators at any other time. Participants also received a diary to grade back pain on a 0 to 10 numeric analog scale.

Severity of AEs was graded according to the Common Terminology Criteria of Adverse Events as moderate (grade 2) if participants reported a significant level of AEs and as severe (grade 3) if intervention was needed but the AE did not threaten vision or life. AEs were documented electronically and reported to head of the safety board (D.B.) or its members (S.H.-M., T.L., P.C.M.) within 24 hours.

- **SAMPLE SIZE AND STATISTICAL ANALYSIS:** The sample size was determined for the first coprimary end point, area of graft detachment, based on our previous study, which showed a 20% mean area of graft detachment at the 2-week visit after uncomplicated DMEK for Fuchs' dystrophy with prolonged supine positioning.<sup>12,13</sup> The minimal clinically relevant difference in the area of graft detachment is unknown and often assumed to be as large as 33%;<sup>20,21</sup> our study was planned to conservatively be able to detect a difference between intervention and control of as low as 8 percentage points. To detect this difference with 80% power at an alpha of 0.05, 43 eyes per arm were planned, corresponding to total contributing outcome data from 86 participants to be enrolled.

All participants who had an AS-OCT scan at the 2-week follow-up visit were included in the prespecified modified intention-to-treat analysis. Area of graft detachment, defined as a proportion of the trephine area used (diameter range, 7-8 mm), was compared between arms using linear mixed-effects models according to the study protocol, with patient-level random effects. The relative risk for a graft detachment area >33% at the 2-week follow-up visit and for any rebubbling was estimated using a Poisson model with robust variance, and subjective visual function at the 2-

week follow-up visit was compared using a linear mixed model. As prespecified, these models were adjusted for participant age, the extent of detachment on the first postoperative day before the start of the intervention (linear terms), the stratification factor type of surgery (DMEK with cataract surgery vs DMEK alone, binary), and the precise day of the 2-week outcome visit (continuous). In addition, visible edema at enrollment (binary) was adjusted for despite no notable change in estimates. Back pain intensity was analyzed using a linear mixed effects model with robust variance, with eye-level random effects, and adjusted for preoperative back pain (binary), back pain intensity on the day of surgery (before intervention/control allocation), and postoperative day.

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## RESULTS

- **BASELINE CHARACTERISTICS, INTERVENTIONS, AND PROTOCOL ADHERENCE:** In total, 148 patients scheduled for DMEK were assessed for eligibility from May 23, 2022, to April 27, 2023. The CONSORT flowchart lists reasons for noninclusion (Figure 1). One participant withdrew from the study before opening the sealed allocation envelope. One participant was assigned to a positioning regimen by the treating surgeon. This left a total of 88 participants who received the allocated intervention: 37 eyes in the intervention arm and 51 eyes in the control arm (Figure 1). All but 3 participants contributed 1 eye only. The greater number of participants assigned to the control arm was the play of chance with simple randomized assignment ( $P = .14$  on a binomial test for deviation from the expected 1:1 ratio between arms among the randomized). No severe intraoperative complications such as intraoperative bleeding occurred. One participant experienced severe complications with graft expulsion through the wound after having intensively manipulated their own eye, and 1 participant was lost to follow-up after discharge from the hospital, leaving 86 eyes from 83 patients for analysis.

Baseline characteristics were well balanced between intervention arm and control arm, except for more participants in the control group with visible corneal edema (Table 1), which further analyses adjusted for.

The head sensor to measure adherence to the allocated intervention was worn by 68 participants. In the intervention arm, a supine head position was maintained on average 13.4 hours per day until the fifth postoperative day, compared with 7.8 hours in the control arm (mean difference in supine position, 5.6 hours per day; 95% CI, 4.1-7.2) (Figure 2).

- **EFFICACY OF SUPINE POSITIONING ON GRAFT ATTACHMENT:** In the AS-OCT at the 2-week follow-up visit, on median 15 days after DMEK (interquartile range: 14-19),

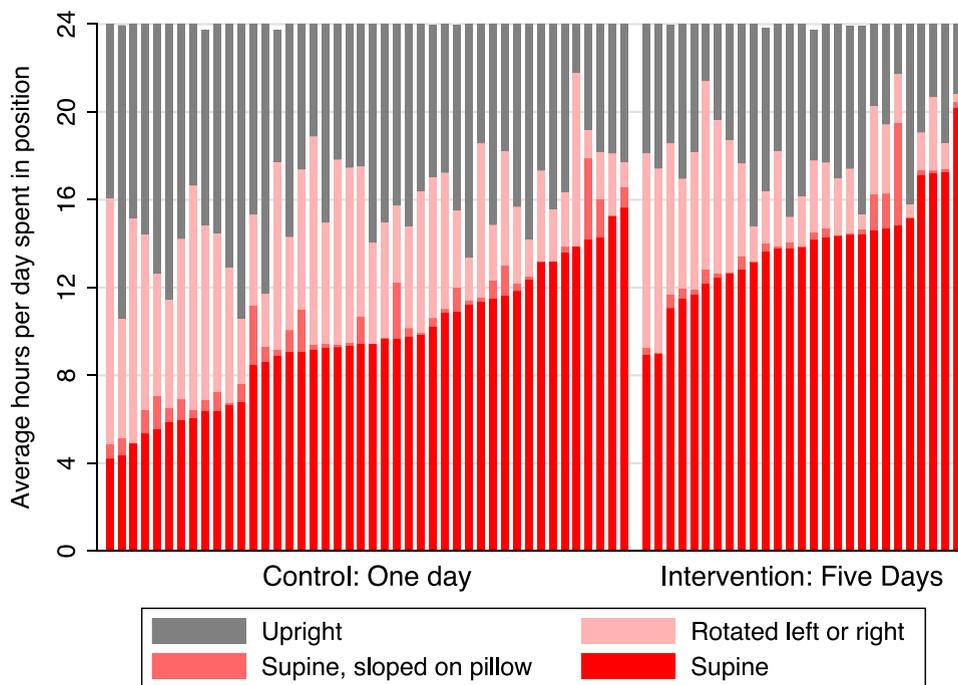


FIGURE 2. Intervention adherence. Average hours per day spent in different positions, according to movement sensor data, by the trial arm (n = 68).

the mean area of graft detachment was 28.6% in the intervention arm and 27.5% in the control arm, with an adjusted mean between-arm difference in area of graft detachment of 1.3 percentage points (95% CI, -8.7 to 11.4 percentage points;  $P = .80$ ), indicating no statistically significant or clinically relevant effect of postoperative supine head positioning after DMEK (Table 2; Figure 3). The mean volume of graft detachment in the intervention arm was 0.8  $\mu\text{L}$ , compared with 0.7  $\mu\text{L}$  in the control arm (adjusted mean difference, 0.0  $\mu\text{L}$ ; 95% CI, -0.3 to 0.4  $\mu\text{L}$ ;  $P = .85$ ). The risk of having more than one-third of graft detachment 2 weeks after surgery was not noticeably different in the intervention arm (11 eyes, 31%) compared with the control arm (19 eyes, 37%; adjusted relative risk, 0.98; 95% CI, 0.54-1.77).

In as-treated analyses among the 68 patients with head position sensor data, there was no association between the duration of supine positioning and the area of detachment (adjusted mean difference, 0.8 percentage points per increment of 12 hours supine positioning per day; 95% CI, -12.2 to 13.8 percentage points) and the volume of detachment (adjusted mean difference 0.2  $\mu\text{L}$  per 12 hours supine positioning per day; 95% CI, -0.3 to 0.7  $\mu\text{L}$ ).

Detachment on the first postoperative day, before intervention, was a predictor of detachment at the 2-week visit, with an adjusted mean difference of 0.44 percentage points higher detachment at the 2-week visit for every 1 percentage point on the first preoperative day (95% CI, 0.18-0.70).

• **EFFICACY OF SUPINE POSITIONING ON REBUBBLING AND SUBJECTIVE VISUAL FUNCTION:** A secondary injection of air in the first 2 weeks after DMEK was performed in 10 eyes (29%) in the intervention arm and 14 eyes (27%) in the control arm (adjusted risk ratio, 1.07; 95% CI, 0.52-2.17).

Subjective visual function, on an analog scale from 1 (worst vision) to 10 (best vision) at the 2-week follow-up visit, was on average similar between arms (intervention 6.0, control 5.9) for an adjusted between-arm difference of -0.1 (95% CI, -1.2 to 1.0).

• **ADVERSE EVENTS:** An AE was recorded for 17 eyes randomized to the intervention arm (49%) and 21 eyes randomized to the control arm (41%). All AEs but one (in the intervention arm) were of mild or moderate severity (Table 3).

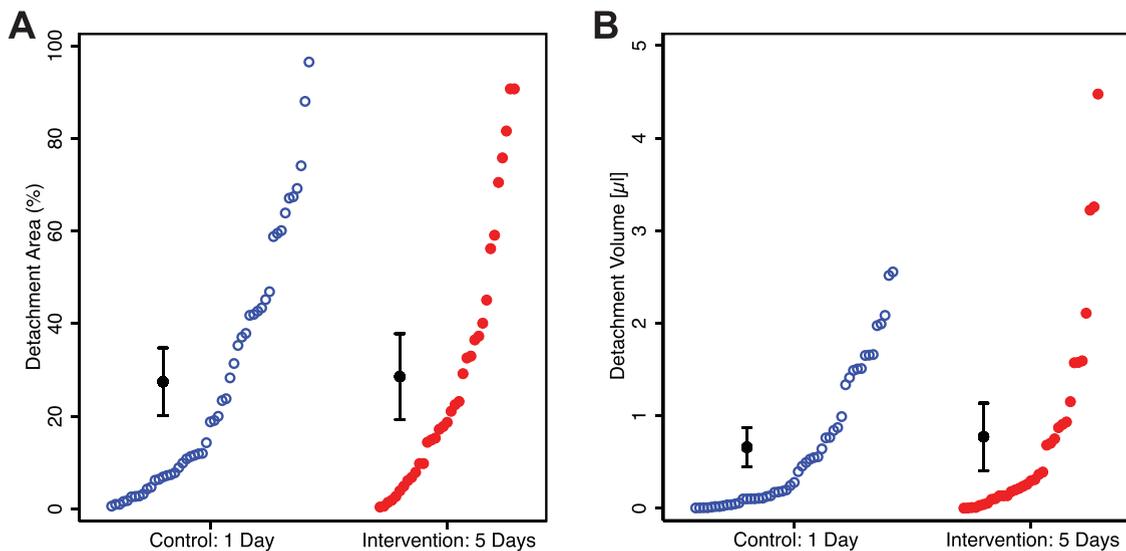
Back pain was the most frequently reported AE at 43% in the intervention arm and 27% in the control arm. Accounting for the high burden of pre-existing back pain (Table 1) and back pain intensity on the operative day, the intensity of back pain (n = 71) was 2.2 points higher (worse, on a scale from 0 to 10) in the intervention arm than in the control arm (95% CI for the adjusted mean difference, 1.3-3.1; Figure 4). No other AEs of special interest were recorded in either arm, including no deep vein thrombosis/venous thromboembolism.

**TABLE 2.** Efficacy of Supine Head Positioning After Descemet Membrane Endothelial Keratoplasty 2 Weeks After Surgery

	Intervention	Control	Intervention Effect <sup>a</sup> (95% CI)	P Value
Coprimary outcomes, mean				
Graft detachment: area (%)	28.6	27.5	1.3 (−8.7 to 11.4)	<i>P</i> = .80
Graft detachment: volume (μL)	0.8	0.7	0.0 (−0.3 to 0.4)	<i>P</i> = .85
Secondary outcomes				
Rebubbling, n (%)	10 (29)	14 (27)	1.07 (0.52 to 2.17)	—
Subjective visual function, <sup>b</sup> mean	6.0	5.9	−0.1 (−1.2 to 1.0)	—

<sup>a</sup>For primary outcomes and subjective visual function, mean differences are reported (0 indicates no effect); for rebubbling, a risk ratio is reported (1 indicates no effect). All models were adjusted for age, extent of detachment on the first postoperative day before start of the intervention, type of surgery, day of the 2-week outcome visit, and visible edema at enrollment, and models account for clustering of eyes within participants.

<sup>b</sup>Rating of visual function on the 1 to 10 numeric analog scale by the study participant. Higher values are better (*n* = 79).



**FIGURE 3.** Area and volume of graft detachment in participants randomized to 5 days (intervention) or 1 day (control) supine positioning. (A) Area and (B) volume of graft detachment were quantified at the postoperative 2-week visit after Descemet membrane endothelial keratoplasty (*n* = 86). The dots with whiskers indicate mean and 95% confidence interval for the mean. Other dots are individual data points.

## DISCUSSION

This investigator-initiated, randomized controlled trial in patients undergoing DMEK compared the effect of prolonged supine positioning for 5 days with supine positioning for 1 day on graft attachment. Two weeks after surgery, endothelial grafts were clinically attached in approximately 3 quarters of patients, requiring no secondary intervention. Supine positioning for 5 days did not reduce the area or volume of graft detachment, the coprimary end points of this trial quantified from AS-OCT scans. Likewise, the need for secondary interventions with rebubbling was not reduced by prolonged supine positioning. The precise estimates from this trial are incompatible with clinically relevant effect sizes for these outcomes and for subjective visual function.

The most frequent AE caused by supine positioning was back pain.

Lack of efficacy of prolonged supine positioning should be viewed in light of the natural history of graft attachment. Attachment regardless of positioning has been suggested by previous observational studies, including a retrospective comparison of eyes undergoing DMEK for Fuchs' dystrophy and bullous keratopathy by an experienced surgeon.<sup>9</sup> Some surgeons are even apprehensive of potential damage to the endothelial cells by the bubble and suggest supine positioning with alternating left and right rotation of the head.<sup>22</sup> Upright positioning may also prevent intraocular pressure decompensation directly after surgery.<sup>23</sup>

In contrast to previous studies, the current trial allowed for precise longitudinal comparisons of attachment using a sensitive, validated neural network analyzing AS-OCT

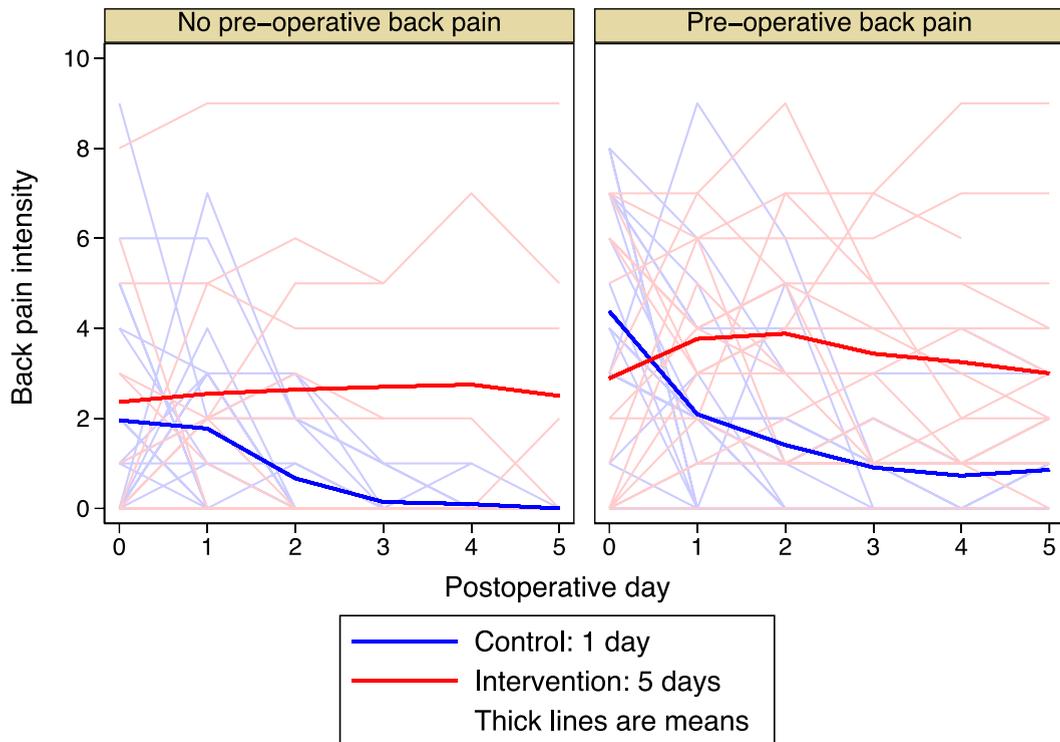
**TABLE 3.** Adverse Events After the Intervention Period Started.

	Intervention	Control
Eyes any AE, n (%)	17 (49)	21 (41)
Type of AE (multiple possible), n (%)		
Eye		
Sensation of burning/tearing/local pain	2 (6)	2 (4)
Corneal erosion	3 (9)	1 (2)
Transplant not attached centrally/floating in anterior chamber	0 (0)	0 (0)
Repeat DMEK	0 (0)	2 (4)
Symptomatic eye pressure 30-50 mm Hg	0 (0)	0 (0)
Symptomatic eye pressure >50 mm Hg	1 (3)	0 (0)
Headache	0 (0)	7 (14)
Nausea	1 (3)	1 (2)
Neck or chest pain or pressure <sup>a</sup>	2 (6)	1 (2)
Back pain	15 (43)	14 (27)
Leg pain <sup>b</sup>	0 (0)	1 (2)
Maximum intensity (CTCAE), n (%)		
Grade 1, mild	7 (20)	15 (29)
Grade 2, moderate	9 (26)	6 (12)
Grade 3, severe/intervention <sup>a</sup>	1 (3)	0 (0)
Grade 4, sight-threatening	0 (0)	0 (0)

AE = adverse event, CTCAE = Common Terminology Criteria of Adverse Events, DMEK = Descemet membrane endothelial keratoplasty. Recording of AEs was based on a checklist on postoperative visits and on spontaneous reports by participants during the first 2 weeks after surgery.

<sup>a</sup>Includes 1 serious adverse event of angina pectoris in the intervention arm.

<sup>b</sup>Deep venous thrombosis ruled out by Doppler ultrasound.



**FIGURE 4.** Intensity of back pain. Participants reported back pain in the past 24 hours on a numeric scale from 0 (none) to 10 (worst). The graph is split into participants without and with preoperative back pain in the 4 weeks before admission. The thick lines indicate mean values per trial arm and day (n = 71).

images that synthesizes hundreds of segmental scans and therefore can detect and quantify detachments that would be missed by clinicians on slitlamp examinations only.<sup>12,13</sup> With this objective diagnostic tool, this trial showed that prolonged supine positioning had no effect on attachment. The precise estimates from these data are incompatible with larger, potentially clinically relevant differences in detachment area and volume. In contrast, early graft attachment predicted remaining graft detachment at the 2-week visit, as suggested previously.<sup>13</sup> Although treating surgeons were necessarily aware of the assigned trial arm after the intervention period started, they were blinded to the primary end point measures; nevertheless, rebubbings were no more or less common in the intervention arm.

Under the tightly controlled circumstances in our trial, which may not always be achievable in routine practice, assignment to the intervention arm prolonged supine positioning, on average, by close to an additional 6 hours per day. Neither trial arm assignment, as tested in the intention-treat analysis, nor actual time spent in each position, which was recorded continuously by position monitors worn by trial participants and which was tested in the as-treated analysis, was suggestive of the efficacy of prolonged supine positioning.

AEs of prolonged supine positioning are important to consider in light of the comorbidity burden of patients undergoing DMEK. About half of participants reported back pain in the 4 weeks before surgery, and both among participants with such pre-existing back pain and those without,

prolonged supine positioning caused, on average, a 2-point increase in back pain intensity on a scale from 0 to 10. The trial was not designed to conclusively quantify risks of potentially serious AEs of prolonged supine positioning, such as deep venous thrombosis and venous thromboembolism. Moreover, this trial was also not designed to assess whether hospitalization is necessary for DMEK; this question must take other factors than supine positioning into consideration, such as a sudden onset of monocular vision in often advanced-age patients who have postoperative corneal edema and an air or gas bubble in the optical axis of the operated eye.

Collectively, the empirical data from this randomized controlled trial are not compatible with a clinically meaningful beneficial effect of prolonged supine positioning on graft attachment after DMEK for Fuchs' dystrophy without other ocular comorbidities even in a tightly controlled clinical research setting. One of our trial participants, a physicist, offered a simple mechanistic explanation: the eye ball is a closed system, and thus instilling an air or gas bubble increases pressure regardless of where this bubble happens to be located in the anterior chamber. In a similar vein, even in a supine position, there may be a fluid layer between the bubble and the endothelium when imaging the anterior segment in a supine position using an OCT (Mark Terry, personal communication, EK breakfast meeting, San Francisco, October 2019). Thus, prolonged supine positioning after DMEK may not be needed in routine practice.

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