Short-term and long-term outcomes of minimally invasive and open transforaminal lumbar interbody fusions: is there a difference?

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Object. Previous studies comparing minimally invasive transforaminal lumbar interbody fusion (MITLIF) with open TLIF have demonstrated that MITLIF reduces blood loss and decreases postoperative pain while preserving fusion rates and reducing complications. In this study, the authors wanted to compare outcomes of MITLIF with those of open TLIF to determine whether MITLIF also improves postoperative functional mobility and decreases the usage of pain medication.

Methods. In total, 75 consecutive patients who underwent either single-level open TLIF or MITLIF at the University of California, San Francisco, between 2006 and 2011 were included, and patients were followed up for an average of 5.05 years. Fifty patients underwent MITLIF and 25 underwent open TLIF. Primary outcomes included administration of morphine-equivalent narcotics and functional status on postoperative Day 1. Secondary outcomes included operative characteristics, complications, long-term fusion rates, and visual analog scale (VAS) scores.

Results. No statistically significant differences in age, sex, body mass index (BMI), level of disease, or surgical indication were detected between the open TLIF and MITLIF groups. Similarly, preoperative medication usage did not significantly differ between these groups. Intraoperatively, compared with TLIF, MITLIF resulted in decreased lengths of operation, lower blood loss, and fewer complications ($p < 0.05$). Total administration of morphine-equivalent pain medication in the hospital also tended to be lower in the MITLIF than in the TLIF group. Functional assessment by physical therapy on postoperative Day 1 demonstrated higher function in the MITLIF patients for transfer-related tasks, ambulatory ability, and distance walked than in the TLIF patients ($p < 0.05$). This translated to shorter inpatient hospitalizations (6.05 vs 4.8 days for open TLIF vs MITLIF patients, respectively, $p = 0.006$) and an average cost reduction of \$3885 per MITLIF patient. Long-term fusion rates were 92% in the MITLIF group and 100% in the open TLIF group ($p = 0.09$). Preoperative VAS pain scores were 7.1 for the MITLIF patients and 7.6 for the TLIF patients ($p = 0.26$). At the last follow-up, the reported VAS pain score was 2.9 in the MITLIF patients and 3.5 in the open TLIF patients, but this difference was not statistically significant ($p = 0.25$). There was also no statistically significant difference in the degree change in this score ($p = 0.44$).

Conclusions. The MITLIF approach achieves improved functional mobility, decreases the usage of postoperative pain medication, and significantly reduces cost compared with open TLIF while preserving long-term fusion rates. To the authors' knowledge, this is the first study comparing the postoperative usage of pain medication between treatments in the postoperative period before discharge.

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KEY WORDS • MITLIF • minimally invasive • spinal disorders •
transforaminal lumbar interbody fusion

OPEN TLIF remains a mainstay surgical treatment for degenerative lumbar disc disease. The development of MITLIF procedures represents the logical evolution of this proven surgical technique. Recent reports comparing MITLIF with open TLIF have shown that these 2 approaches result in similar long-term fusion rates, long-term quality-adjusted life years gained,

and health care costs.^{1,3,11,13,24} Short-term metrics, however, including length of hospitalization, blood loss, return to work, and short-term quality-adjusted life years, all indicate significant benefits of the MITLIF approach, suggesting the primary advantages of the MITLIF technique may be observable in the early postoperative period.^{1,12,13,19}

To better assess additional short-term factors that may underlie the benefits of the MITLIF technique, we chose to evaluate postoperative physical function on Day 1 along with the amount of pain medication used by inpatients. Both measures have been understudied in the literature to date, but likely represent important factors

Abbreviations used in this paper: ATC = around the clock; BMI = body mass index; MITLIF = minimally invasive transforaminal lumbar interbody fusion; PRN = as needed; TLIF = transforaminal lumbar interbody fusion; UCSF = University of California, San Francisco; VAS = visual analog scale.

differentiating the MITLIF and open TLIF techniques. In particular, early postoperative mobilization and function correlate with fewer complications, improved patient satisfaction, and shorter length of stay.^{1,19,23} Similarly, narcotics usage is a surrogate measure for pain, and adequate control of pain has been associated with better outcomes.^{4,6}

Methods

Patients

This study was approved by the UCSF Committee on Human Research. In total, 75 consecutive patients who underwent either single-level open TLIF or MITLIF at the UCSF between 2006 and 2011 were included in this retrospective, chart-review study. Fifty patients underwent MITLIF and 25 open TLIF by 2 primary surgeons (D.C. and P.V.M.): Dr. Chou performed 9 MITLIF and 14 open TLIF surgeries, and Dr. Mummaneni performed 41 MITLIF and 11 open TLIF surgeries.

Outcome Measures

Primary outcome measures included the amount of morphine-equivalent pain medication administered postoperatively and functional performance using the standardized physical therapy inpatient assessment. Morphine-equivalent dosing of narcotics was calculated using the standardized conversion formulas from the American Pain Society Guidelines (<http://www.americanpainsociety.org>). Information was obtained from medical records and from the most recent medication history prior to surgery. Postoperative pain medication usage was calculated starting with administration in the recovery room and tabulated for the entire inpatient stay on the basis of medication administration records kept by nurses. Accessory medications were defined as muscle relaxants, antidepressants, and anti-anxiety medications and were recorded qualitatively as use only, because of the varying medications administered and the lack of equivalent dosing calculations.

Functional ability was assessed using the standardized physical therapy inpatient assessment on postoperative Day 1. This included measures of rising from the supine to the sitting position and from the sitting to the standing position, chair transfer, and ambulatory status and distance ambulated, along with assistive devices used. Each measure was graded on a 4-point scale (1 = independent, 2 = minimal assistance required, 3 = moderate assistance required, and 4 = maximum assistance required or unable to complete) except for distance ambulated, which was recorded in feet. Assist devices included a 4-wheel walker or an intravenous pole.

Fusion rates were graded for all patients on a 4-point scale and the latest postoperative radiograph with flexion/extension views. The 4 grades were as follows: I = solid bony fusion, II = partial bony trabeculation, III = instrumentation lucency at 1 level or movement on dynamic imaging, and IV = instrumentation lucency at both levels and movement on dynamic imaging. Grades I and II were considered to represent good fusions.¹⁶ Patients with follow-up imaging of less than 6 months or for whom only

plain radiographs were available were excluded from the fusion analysis.

The VAS scores were obtained preoperatively and at the last follow-up. Differences in VAS scores between these time points were calculated and compared between MITLIF and open TLIF patients.

Secondary outcome measures included operative characteristics (estimated blood loss, length of the surgical procedure, and complications), length of stay, discharge location, home equipment, and cost of inpatient hospitalization. Cost differences were based on the average cost of 1 day on an acute care inpatient ward in Northern California (\$2590).

Statistical Analysis

All statistical analyses were performed with Prism (GraphPad Software) using the Student t-test for parametric data and chi-square analyses for nominal data. Statistical significance was defined as $p < 0.05$. Mean values are presented $\pm$ SD.

Results

In total, 75 patients underwent either single-level open TLIF or MITLIF at UCSF between 2006 and 2011. Of these patients, 50 (67%) underwent MITLIF and 25 (33%) received open TLIF. The average follow-up for all patients was 5.05 ± 1.4 years. A summary of the basic demographic data of these patients and their medical histories is shown in Table 1. Average age, sex, BMI, and history of prior lumbar surgery did not differ between the surgery groups. The 2 groups did differ in the history of tobacco use: a history of greater than 1 pack/year was reported by 12 (48%) of the TLIF patients and 6 (12%) of the MITLIF patients ($p < 0.002$). None of the patients reported using tobacco at the time of the surgery. Lumbar level, surgical indication, and presence of radicular pain also did not differ between the 2 groups. Both groups combined had 41 patients with spondylolisthesis: 39 of whom had low-grade (Grades I and II) and 2 of whom (in the open TLIF group) had high-grade (Grades III and IV) spondylolisthesis. Representative pre- and postoperative radiographs for 2 cases of low-grade spondylolisthesis are shown in Fig. 1.

Table 2 shows a summary of preoperative medication usage. There were trends toward increased usage of narcotic pain medication around the clock and as needed in the TLIF group that were not statistically significant ($p = 0.08$ and $p = 0.23$, respectively). The use of accessory medications, including muscle relaxants ($p = 0.22$), antidepressants ($p = 0.33$), and anti-anxiety medications ($p = 0.21$), did not significantly differ between the 2 groups.

Details on the surgical procedures are reported in Table 3. Comparisons between the MITLIF and TLIF patients indicated that the MITLIF procedure significantly reduced the length of the operation (245 vs 279 minutes, respectively, $p = 0.046$) and blood loss (392 vs 535 ml, respectively, $p = 0.03$) and also decreased the frequency of dural rents (0 vs 3, respectively, $p = 0.01$). Reoperation was performed in 3 (12%) of the TLIF patients and 5 (10%) of the MITLIF patients. Reasons for reoperation included infection (2 patients), malpositioned screw (1 pa-

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TABLE 1: Demographic characteristics of the 75 patients in this study

Characteristic	Open TLIF (n = 25)	MITLIF (n = 50)	p Value
age (yrs)*	54.3 ± 11.1	53.7 ± 11.5	0.320
sex ratio (M/F)	14:11	27:23	0.510
BMI*	28.2 ± 5.5	28.5 ± 4.7	0.280
prior lumbar surgery, no. (%)†	8 (32)	7 (14)	0.080
history of tobacco use, no. (%)‡	12 (48)	6 (12)	0.002
radicular pain, no. (%)	10 (40)	12 (24)	0.150
surgery level			0.340
L1–2	0	1	
L2–3	0	1	
L3–4	3	5	
L4–5	12	33	
L5–S1	10	10	
surgical indications, no. (%)			
spondylosis	12 (48)	28 (56)	0.350
spondylolisthesis	14 (56)	27 (54)	0.810
Grades I & II (low)§	12 (86)	27 (100)	0.360
Grades III & IV (high)§	2 (14)	0 (0)	
foraminal stenosis	10 (40)	25 (50)	0.200

* Mean values are presented ± SD.

† One open TLIF patient underwent prior fusion at an adjacent level. All remaining patients had undergone either laminectomy or discectomy.

‡ All smokers had stopped smoking more than 30 days before undergoing the operation.

§ Percentages in these categories are calculated on the basis of the total number of patients with spondylolisthesis in each group.

tient), and adjacent-segment disease (5 patients). Furthermore, the MITLIF procedure shortened the overall length of hospitalization by 1.25 inpatient days, resulting in estimated direct cost savings of \$3885 per MITLIF patient.

All of the patients underwent functional assessment by physical therapists on postoperative Day 1 and status was graded on a 4-point scale using the standardized inpatient physical therapy assessment. Performance was graded as independent (1) or requiring minimal (2), moderate (3), or maximal (4) assistance. Satisfactory performance was defined as being independent or requiring minimum assistance in this assessment. In Table 4, TLIF and MITLIF patients did not differ in their performance changing from the supine to the sitting position, with 15 (60%) of the open TLIF group and 36 (72%) of the MITLIF group showing a satisfactory performance ($p = 0.55$). In the sitting to standing task, only 12 (60%) of the TLIF patients could perform the task, whereas 46 (98%) of the MITLIF group achieved satisfactory performance ($p = 0.0002$). Such differences were also observed for the more challenging ambulation task, where 17 (74%) of the open TLIF group and 43 (86%) of the MITLIF group successfully ambulated with any level of assistance ($p = 0.033$). Of those patients able to ambulate, the patients in the MITLIF group again performed better, being able to walk on average for a length of 91 feet compared with 31 feet for the open TLIF patients ($p = 0.002$). The use of an assistive device (a 4-wheel walker or intravenous pole) did not differ between the 2 groups (48% vs 60% for TLIF and MITLIF, respectively, $p = 0.43$).

Table 5 shows the usage of postoperative pain and accessory medications and a comparison with their preoperative dosage and frequency of use. Note that even though the as-needed (PRN) narcotic usage did not significantly differ between the MITLIF and TLIF groups (140.5 vs 153.9 mg/day, respectively, $p = 0.37$), the usage of narcotics ATC by the MITLIF patients (66.5 mg/day) was significantly lower than that of the open TLIF patients (201.5 mg/day, $p = 0.019$). The use of muscle relaxants ($p = 0.51$), antidepressants ($p = 0.28$), and antianxiety medications ($p = 0.38$) in the immediate postoperative period did not significantly differ between the groups. Compared with preoperative levels, after MITLIF, ATC narcotics usage was reduced by 30.9 mg/day, and after TLIF, it was reduced by 109.3 mg/day ($p = 0.02$).

For all patients, preoperative VAS scores were compared with those at the last follow-up (Table 6). Preoperatively, MITLIF patients had an average VAS score of 7.1 and TLIF patients had one of 7.6 ($p = 0.26$). At the last follow-up, MITLIF patients reported a VAS score of 2.9 and TLIF patients of 3.5 ($p = 0.25$). There was also no significant difference in the degree change in the VAS score between the 2 groups ($p = 0.44$).

Patients with less than 6 months of postoperative imaging or absence of dynamic films were excluded from the analysis of fusion rates, resulting in the exclusion of 5 TLIF patients from this analysis. Table 7 shows the fusion rates and their grades (I–IV). A solid fusion was defined as Grade I or II, and long-term fusion rates were 92% in the MITLIF group and 100% in the open TLIF group; no

FIG. 1. Radiographs of patients who underwent open TLIF or MITLIF. Lateral radiographs of a representative patient taken preoperatively (**A**) and after open TLIF (**B**). Lateral radiographs of a representative patient taken preoperatively (**C**) and after MITLIF (**D**).

statistically significant differences were detected in the quality of fusion between the 2 groups ($p = 0.09$).

Discussion

Open TLIF is a well-studied procedure and has been the mainstay for posterior lumbar interbody fusion for many years.^{9,10,17} Advantages of this open surgical approach include high fusion rates, an increase in foraminal height, and good patient outcomes.^{8,17,18} An alternative to open surgery is the development of minimally invasive approaches for operating on the lumbar spine with the goal of reducing morbidity while preserving outcomes. To date, several studies have reported on the advantages of MITLIF over TLIF. In the hands of an experienced surgeon, the MITLIF approach is associated with shorter operation times, lower blood loss, and a shorter period of hospitalization.^{20,21,24} These findings are consistent with

our study, but some authors have proposed that selection bias may contribute to these results. Although such bias cannot be excluded, most patient characteristics, including spondylolisthesis grade, BMI, and history of prior lumbar surgery, did not differ between the MITLIF and TLIF groups in the present study. Published long-term outcomes of MITLIF including fusion rates are comparable to open TLIF, and 1 study reported no difference in overall health state (assessed as EuroQol Group-5 scores) at the 2-year follow-up between the MITLIF and TLIF groups.^{2,13}

However, MITLIF procedures have some disadvantages, including an initial learning curve for the surgeon that can lead to increased complication rates. Several groups have reported that MITLIF is associated with an increase in the number of neurological deficits, incidence of CSF leakage, and screw/cage complications.^{19,22} On the other hand, TLIF surgery has been reported to result in more wound infections and medical complications such as urinary tract infections.⁵ With experience, the incidence of complications in both groups decreases, and in our small study, none of the MITLIF patients experienced new neurological deficits, dural tears, or screw/cage misplacement. The successful placement of instrumentation, however, requires fluoroscopy, and concerns have been raised regarding the increased radiation exposure associated with this visualization technique to the patient, surgeon, and operating room staff. Several studies have reported longer radiation exposure of MITLIF patients, and 1 study found that this exposure did not decrease with the surgeon's level of experience.^{16,24} To date, the long-term effects of increased radiation exposure are poorly studied and remain an important question for future investigation.

Gaining a better understanding of the above issues is important to the ongoing debate over the relative benefits and shortcomings of the MITLIF and TLIF approaches. Our study aims to better evaluate 2 understudied components—early postoperative function and in-hospital narcotics usage. Physical function was assessed with the standardized inpatient physical therapy evaluation on postoperative Day 1. This assessment provided an objective, standardized, and blinded examination of the functional performance of each patient on the 1st hospital day postoperation. As shown in Table 4, most patients were able to progress from the supine to the sitting position with some help, and the patients in the MITLIF and TLIF groups did not show any significant differences in this task ($p = 0.55$). However, a significant difference was detected between the 2 groups in changing from the sitting

TABLE 2: Preoperative daily morphine-equivalent pain reliever and accessory medication usage

Medication	Open TLIF (n = 25)	MITLIF (n = 50)	p Value
narcotics ATC (mg/day)*	92.2 ± 32.2	35.6 ± 11.2	0.08
narcotics PRN (mg/day)*	96.6 ± 48.3	53.7 ± 10.6	0.23
muscle relaxants, no. (%)	4 (16)	14 (28)	0.22
antidepressants, no. (%)	10 (40)	17 (34)	0.33
anxiety medications, no. (%)	10 (40)	15 (30)	0.21

* Mean values are presented ± SD.

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TABLE 3: Surgery details, complications, and length of stay in the hospital

Variable	Open TLIF (n = 25)	MITLIF (n = 50)	p Value
length of op (mins)*	278.8 ± 14.5	244.6 ± 73.0	0.046
blood loss (ml)*†	535.5 ± 324.0	392.5 ± 284.0	0.030
graft material, no. (%)			0.370
BMP‡	14 (56)	21 (42)	
iliac crest	11 (44)	29 (58)	
dural rent, no. (%)	3 (12)	0 (0)	0.010
reop, no. (%)	3 (12)	5 (10)	0.860
length of stay (days)*§	6.05 ± 1.8	4.8 ± 1.8	0.006

* Mean values are presented ± SD.

† Includes blood loss from harvest of iliac crest bone.

‡ Use of bone morphogenetic protein (BMP) in TLIF has been discontinued because of cost considerations.

§ Includes the day of the surgery.

TABLE 4: Physical therapy standardized assessment on postoperative Day 1*

Assessed Skill	Open TLIF	MITLIF	p Value
supine to sitting position, no. (%)	(n = 25)	(n = 50)	0.5500
independently	7 (28)	15 (30)	
w/ minimal assistance	8 (32)	21 (42)	
w/ moderate assistance	7 (28)	13 (26)	
w/ maximal assistance	3 (12)	1 (2)	
sitting to standing position, no. (%)	(n = 20)	(n = 47)	0.0002
independently	8 (40)	21 (45)	
w/ minimal assistance	4 (20)	25 (53)	
w/ moderate assistance	6 (30)	1 (2)	
w/ maximal assistance	2 (10)	0 (0)	
gait assessment, no. (%)	(n = 23)	(n = 50)	
ambulatory (any level of assistance)	17 (74)	43 (86)	0.0330
assistance device (FWW or IV pole)	11 (48)	30 (60)	0.4300
mean distance walked ± SD (ft)	31 ± 12	91 ± 17	0.0020

* The p values for differences in the performance of the positional-change tasks refer only to comparisons of the numbers of TLIF and MITLIF patients showing satisfactory performance (being independent or requiring minimal assistance to change positions). FWW = four-wheel walker; IV = intravenous.

TABLE 5: Postoperative daily use of morphine-equivalent pain reliever and accessory medication use at the time of discharge and in comparison to preoperative use

Medication Use	Open TLIF (n = 25)	MITLIF (n = 50)	p Value
postop medication use			
narcotics ATC (mg/day)*	201.5 ± 61.2	66.5 ± 21.9	0.019
narcotics PRN (mg/day)*	153.9 ± 50.1	140.5 ± 15.0	0.370
muscle relaxants, no. (%)	20 (80)	38 (76)	0.510
antidepressants, no. (%)	10 (40)	15 (30)	0.280
anxiety medications, no. (%)	8 (32)	14 (28)	0.380
postop vs preop medication use			
Δ narcotics ATC (mg/day)	-109.3	-30.9	0.020
Δ narcotics PRN (mg/day)	-57.3	-86.8	0.200
Δ muscle relaxants	-16	+24	0.240
Δ antidepressants	no change	+2	0.280
Δ anxiety medications	-2	-1	0.280

TABLE 6: VAS scores preoperatively and at the time of the last follow-up (3–6 years)*

VAS Score	Open TLIF (n = 25)	MITLIF (n = 50)	p Value
preop	7.6 ± 0.5	7.1 ± 0.7	0.26
at last follow-up	3.5 ± 0.5	2.9 ± 0.3	0.25
VAS change	4.3 ± 0.8	4.1 ± 0.5	0.44

* Mean values are presented ± SD.

to the standing position, with more MITLIF than TLIF patients being able to stand independently or with minimal assistance ($p = 0.0002$). A similarly significant difference was noted for ambulation, where both ambulatory status and distance walked were significantly increased in MITLIF patients relative to the performance of the TLIF patients in these 2 tasks ($p = 0.033$ and $p = 0.002$, respectively). As shown in previous studies, early ambulation and mobility reduces medical complications including deep venous thrombosis, aspiration pneumonia, and urinary tract infections.^{15,21} Early mobility is also associated with shorter hospitalization, and our findings support the notion that the benefits of MITLIF approaches are realized early in the postoperative period, which is consistent with previous findings.¹⁴

The second component of our study, inpatient narcotic use, provides a quantitative assessment of pain by using actual medication administration as a surrogate measure of pain. Previous studies have used VAS, a subjective measure, to assess pain, and these studies have shown improvements in VAS scores with MITLIF compared with open TLIF. In our series, VAS scores did not differ between the MITLIF and open TLIF patients preoperatively ($p = 0.26$) or at the last follow-up ($p = 0.25$). To date, none of the previous studies has reported morphine-equivalent dosing during hospitalization and correlated such dosing with the procedure performed. The MITLIF patients required significantly less narcotic medication ATC than the open TLIF patients ($p = 0.019$), whereas the PRN requirement did not differ between the 2 groups ($p = 0.37$). On average, MITLIF patients used approximately one-third of the daily ATC dose compared with the TLIF patients (66.5 vs 201.5 mg/day, respectively, $p = 0.019$). We distinguished ATC from PRN administration to better define baseline pain, which likely represents a more accurate measure of postsurgical pain. In contrast, PRN

TABLE 7: Fusion rates at the last follow-up (0.5–2 years postoperatively)

Fusion Grade*	No. of Patients		p Value
	Open TLIF (n = 20)†	MITLIF (n = 50)	
I	9	9	0.09
II	11	37	
III	0	4	
IV	0	0	

* See text for delineation of grades.

† Five patients were excluded from this group because of lack of dynamic postoperative imaging.

medications are frequently requested after painful episodes, such as before or after physical therapy and after using the restroom and are less connected with the surgical procedure. Furthermore, accessory medication usage was also recorded and analyzed to determine whether there were significant differences between the 2 groups, and no such differences were detected for antidepressant, antianxiety, or muscle relaxant use. The latter is particularly surprising given the increased muscle and soft tissue trauma associated with an open TLIF procedure, although this result may also reflect prescribing practices.

Long-term outcomes were evaluated by comparing fusion (range 0.5–2 years) and reoperation rates between the MITLIF and open TLIF patients. As shown in Table 6, these outcomes did not differ between the 2 groups. Lastly, hospital costs remain an important concern for all medical centers nationwide. At UCSF, the MITLIF patients stayed 1.25 fewer days in the hospital than the open TLIF patients, resulting in an average estimated direct cost saving of \$3885/patient calculated on the basis of the reported hospital cost data in Northern California.⁷ We propose that improved physical function and decreased usage of narcotics medication both contributed to this cost saving, making MITLIF a viable alternative to open TLIF in the vast majority of patients with degenerative lumbar disc disease.

Conclusions

Compared with open TLIF, MITLIF improves short-term functional mobility and decreases postoperative pain medication usage and achieves similar long-term fusion rates and reductions in VAS pain scores.

Disclosure

Dr. Mummaneni reports receiving honoraria and royalties from DePuy Spine, royalties from Quality Medical Publishing, royalties from Thieme Publishers, and honoraria from Globus. Dr. Chou reports consulting for Globus, and nonfinancial relations with Medtronic, DePuy, and Orthofix.

Author contributions to the study and manuscript preparation include the following. Conception and design: Cheng, Chou, Mummaneni. Acquisition of data: Cheng, Park, Le, Reisner. Analysis and interpretation of data: Cheng, Reisner. Drafting the article: Cheng. Critically revising the article: Cheng, Park, Chou, Mummaneni. Reviewed submitted version of manuscript: Cheng, Park, Reisner, Chou, Mummaneni. Approved the final version of the manuscript on behalf of all authors: Cheng. Statistical analysis: Cheng. Study supervision: Chou, Mummaneni.

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