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Impact of bedside percutaneous dilational and open surgical tracheostomy on intracranial pressure, pulmonary gas exchange, and hemodynamics in neurocritical care patients

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Abstract

Aim was to compare the impact of bedside percutaneous dilational tracheostomy (PDT) and open surgical technique (ST) on intracranial pressure (ICP), pulmonary gas exchange and hemodynamics.

We retrospectively analyzed data of 92 neurocritical care patients with invasive ICP monitoring during either PDT (43 patients) or ST (49 patients).

Peak ICP levels were higher during PDT (22 [17–38] mm Hg vs 19 [13–27] mm Hg, $P = .029$). Mean oxygen saturation (SpO_2) and end-tidal carbon dioxide partial pressure ($etCO_2$) did not differ. Episodes with relevant desaturation ($SpO_2 < 90\%$) or hypercapnia ($etCO_2 > 50$ mm Hg) occurred rarely (5/49 during ST vs 3/43 during PDT for $SpO_2 < 90\%$; 2/49 during ST vs 5/43 during PDT for hypercapnia). Drops in mean arterial pressure (MAP) below 60 mm Hg were seen more often during PDT (8/43 vs 2/49, $P = .026$). Mean infusion rate of norepinephrine did not differ (0.52 mg/h during ST vs 0.45 mg/h during PDT). No fatal complications were observed.

Tracheostomy can be performed as ST and PDT safely in neurocritical care patients. The impact on ICP, pulmonary gas exchange and hemodynamics remains within an unproblematic range.

Abbreviations: CBR = Ciaglia Blue Rhino tracheostomy, ENT specialist = Ear, nose and throat specialist, $etCO_2$ = end-tidal carbon dioxide partial pressure, FiO_2 = fraction of inspired oxygen, HR = heart rate, ICH = intracerebral hemorrhage, ICP = intracranial pressure, ICU = intensive care unit, IQR = interquartile range, MAP = mean arterial pressure, PDMS = patient data management system, PDT = percutaneous dilational tracheostomy, PEEP = positive end-expiratory pressure, SAH = subarachnoid hemorrhage, SBP = systolic blood pressure, SD = standard deviation, SpO_2 = oxygen saturation, ST = surgical tracheostomy, TBI = traumatic brain injury, TLT = Fantoni translaryngeal tracheostomy.

Keywords: critical care, hemodynamics, intracranial pressure, pulmonary gas exchange, tracheostomy

1. Introduction

In neurocritical care patients prolonged weaning periods are often observed and extubation attempts are regularly impeded by impaired consciousness and insufficient protective reflexes. In those patients, classical weaning criteria are often not reliable in predicting successful extubation.[1] Extubation failure can influence clinical and functional outcome in patients with traumatic brain injury (TBI)[2] and is independently predicted by prior neurosurgical treatment in intubated stroke patients.[1] Hence, tracheostomy is often required in these patients to improve secretion clearance and it provides a good option for step by step respirator weaning without need for recurrent analgosedation and reintubation. Early tracheostomy seems to be beneficial in patients with severe TBI and neurocritically ill patients compared to prolonged endotracheal intubation.[3–7] In general, however, the evidence regarding the best time for performing tracheostomy in critically ill patients is still weak.[8–10]

Bedside percutaneous dilational tracheostomy (PDT) has become a widespread method on most intensive care units (ICU) during the last two decades. PDT can be regularly

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The study was approved by and conducted according to the Ethical Committee of the University of Regensburg (approval number 18-1179-104).

Informed consent was not required due to anonymization and retrospective analysis within the setting of a non-interventional observational study.

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performed faster than open surgical tracheostomy (ST) and seems also to be a safe procedure in patients with the most common neurosurgical diseases.[11] Open ST is usually preferred in patients with proven difficult airway or coincident necessity for immobilization of the cervical spine. However, there is little evidence about the best technique for performing tracheostomy in critically ill neurosurgical patients.

To address this question, we compared an open surgical approach to two different techniques of percutaneous dilational tracheostomy with special regard on intracranial pressure (ICP) development, pulmonary gas exchange, and hemodynamics during the procedure.

2. Materials and methods

The study was approved by the Ethics Committee of the University of Regensburg (approval number 18-1179-104).

Criteria for being included into this study were age above 18 years, presence of a severe brain injury such as TBI, subarachnoid hemorrhage (SAH), intracerebral hemorrhage (ICH) or severe cerebral infection with the need for continuous ICP monitoring and prolonged mechanical ventilation resulting in tracheostomy which had to be performed bedside on the ICU. Accordingly, exclusion criteria were an age below 18 years, pregnancy and a lacking ICP monitoring.

The database of the patient data management system (PDMS, MetaVision Suite™, iMDsoft, Tel Aviv, Israel) on the neurosurgical ICU and a mixed surgical ICU at the University Hospital Regensburg was screened retrospectively between 2003 and 2014 for the key words "presence of a tracheostoma" and "presence of an ICP-measurement". Patients who met both queries were screened for inclusion and exclusion criteria and the data sets were checked for integrity. If all selectional criteria could be fulfilled, the patient was enrolled into the study (see Flow Chart, Supplemental Digital Content, which illustrates study selection, http://links.lww.com/MD/D208).

Tracheostomy was performed either by a surgical (surgical tracheostomy, ST) or a percutaneous dilational technique (percutaneous dilational tracheostomy, PDT). All open surgeries were performed by an ear, nose, and throat (ENT) specialist. For dilational tracheostomy, two different techniques were used depending by whom the tracheostomy was carried out. For dilational tracheostomies performed by an ENT specialist the technique described by Fantoni (Fantoni translaryngeal tracheostomy, TLT,[12]) was used. Tracheostomies conducted by the team of the ICU without support of the ENT department were performed using the Ciaglia Blue Rhino (CBR) technique.[13]

The decision for tracheostomy and the choice of the appropriate technique were made by the attending ICU physicians according to each patient's constitution and estimated time of required respiratory therapy. A specific weaning protocol did not exist.

For every included patient parameters regarding ventilation and pulmonary gas exchange (fraction of inspired oxygen, FiO_2; oxygen saturation, SpO_2; end-tidal carbon dioxide partial pressure, $etCO_2$; positive end-expiratory pressure, PEEP), hemodynamic situation (heart rate, HR; mean arterial pressure, MAP; systolic blood pressure, SBP), use of vasopressors (infusion rate of norepinephrine) and the dosage of narcotics and opioids (infusion rate and bolus injection of propofol, midazolam, ketamine and sufentanil) as well as the course of ICP including interventions for lowering an elevated ICP were extracted from the PDMS within a period from 24 hours before until 24 hours after tracheostomy. In addition, peri- and post-procedural complications, as well as infections probably associated with tracheostomy were recorded (see Table, Supplemental Digital Content, which provides all raw data recorded for the study, http://links.lww.com/MD/D208).

Tracheostomy was performed under intravenous anesthesia in all cases with additional local anesthesia given on top in almost all cases.

Statistical analysis was performed using IBM SPSS Statistics™ 25 (IBM, Armonk, NY). Categorical data were presented as absolute and relative frequencies and were compared between ST and PDT using a Chi-square-test of independence. Continuous data were presented as mean ± SD or as median [interquartile range (IQR)] depending on the underlying distribution. Study groups were compared using Student's *t* test for normal distributed and Mann-Whitney *U* test for non-normal distributed data. Level of significance was set to $P < .05$. In this retrospective, exploratory study, no a priori sample size calculation was performed. Instead, all available patients in a pre-defined period were included to maximize the power.

3. Results

After eliminating all patients whose data sets were incomplete or who had any kind of exclusion criteria, 92 patients (27 female, 65 male) could be enrolled in the present study. ST was performed in 49 cases and PDT in 43 cases (39 TLT, 4 CBR), respectively. The underlying cerebral disorders of the included patients are listed in Table 1.

The number of failed extubation attempts preceding tracheostomy did not differ significantly between both groups (four patients, 8.2% in PDT group vs six patients, 14.0% in ST group, $P = .373$). Tracheostomy was performed earlier in the ST group (day 10 [8–14] after admission to ICU vs day 14 [11–18] in PDT group, $P < .001$). There was no statistically significant difference in the required total days with mechanical ventilation on ICU (25.7 ± 9.4 day in ST group vs 27.7 ± 11.5 days in PDT group, $P = .373$) and remaining days after tracheostomy with demand for respiratory therapy (15.3 ± 7.7 days in ST group vs 14.0 ± 8.3 days in PDT group, $P = .454$). Length of ICU stay did not differ between both groups (28 ± 10 days in ST group vs 32 ± 12 days in PDT group, $P = .090$). Procedure time for PDT was significantly shorter (50 [40–60] minutes for ST vs 30 [25–40] minutes for PDT, $P < .001$).

The course of ICP values from 24 hours before until 24 hours after tracheostomy is shown in Table 2. Mean ICP values did not differ during the whole periprocedural period except at 2 hours

Table 1

Cerebral disorder of included patients.

	ST	PDT	*P* value
Number of patients	49	43	
Cerebral disorder			
TBI	22 (44.9%)	17 (39.5%)	.608
ICH	12 (24.5%)	7 (16.2%)	.332
SAH	12 (24.5%)	15 (34.9%)	.283
Cerebral infarction	2 (4.1%)	2 (4.7%)	.896
Cerebral infection	1 (2.0%)	2 (4.7%)	.499

ST = surgical tracheostomy, PDT = percutaneous dilational tracheostomy, TBI = traumatic brain injury, ICH = intracerebral hemorrhage, SAH = subarachnoid hemorrhage.

Table 2

Course of intracranial pressure (ICP) during tracheostomy (TS) and periprocedural. Data are presented as mean ± standard deviation (SD) when normally distributed, and as median [interquartile range (IQR)] when non-normally distributed.

	ST (n = 49)	PDT (n = 43)	*P* value
ICP 24 h before TS (mm Hg)	10.4 ± 4.2	10.6 ± 3.6	.817
ICP 2 h before TS (mm Hg)	11.5 ± 5.2	10.7 ± 4.2	.764
Time with ICP > 20 mmHg in the period 24 h before TS (min)	12 [0–57]	9 [0–45]	.959
ICP during TS (mm Hg)	15.6 ± 5.5	15.4 ± 6.7	.887
Highest ICP level during TS (mm Hg)	19 [13–27]	22 [17–38]	.029
Time with ICP > 20 mmHg during TS (min)	0 [0–15]	3 [0–10]	.927
ICP 2 h after TS (mm Hg)	11.0 ± 5.2	8.8 ± 4.0	.029
ICP 24 h after TS (mm Hg)	10.9 ± 4.7	10.6 ± 3.6	.688
Time with ICP > 20 mmHg in the period 24 h after TS (min)	13 [1–95]	6 [0–36]	.178

after tracheostomy when the mean ICP value was higher in the ST group (11.0 ± 5.2 minutes vs 8.8 ± 4.0 minutes, $P = .029$). On the other hand, the median peak ICP level during tracheostomy was higher in the PDT group than in the ST group (22 [17–38] mm Hg vs 19 [13–27] mm Hg, $P = .029$). During tracheostomy procedure at least 1 measured ICP value above 20 mm Hg was recognized in 28 patients of the PDT group and in 23 patients of the ST group, respectively (65.1% vs 46.9%, $P = .080$).

Medical treatment for ICP control during tracheostomy was necessary in seven patients of the ST group (17.3%) and in 12 patients of the PDT group (27.9%, $P = .107$). The frequency of specific measures is listed in Table 3.

Respiratory and ventilation parameters are listed in Table 4. FiO_2 values were significantly lower in the PDT group 24 and two hours before and 24 hours after tracheostomy. Accordingly, the mean PEEP was lower in the PDT group 24 and two hours before and 2 and 24 hours after tracheostomy. SpO_2 and $etCO_2$ did not differ between both groups in the time period 24 hours before until 24 hours after tracheostomy. The number of patients with at least 1 measured drop of SpO_2 below 90% during tracheostomy did not differ between both groups (5 patients, 10.2% in ST group vs 3 patients, 7.0% in PDT group, $P = .584$). At least 1 episode with an elevation of $etCO_2$ above 50 mm Hg during tracheostomy was observed in 2 patients (4.1%) in ST group vs 5 patients (11.6%) in PDT group, not reaching statistical significance ($P = .173$).

Regarding hemodynamic parameters, we focused on HR and MAP throughout the procedure (Table 5). None of the patients' HR fell below 45/min, the highest HR measured was 134/min in the ST group and 117/min in the PDT group, respectively. During tracheostomy neither mean HR nor mean MAP differed

Table 3

Number of patients requiring medication for lowering an elevated intracranial pressure (ICP) during tracheostomy (TS).

	ST (n = 49)	PDT (n = 43)	*P* value
Thiopental	4 (9.3%)	9 (18.4%)	.079
Mannitol 20%	5 (11.6%)	4 (8.2%)	.885
Sodium chloride 20%	1 (2.3%)	2 (4.1%)	.482
Trometamol	1 (2.3%)	0	.346

Table 4

Respiratory and ventilation parameters during tracheostomy (TS) and periprocedural. FiO_2, fraction of inspired oxygen; PEEP, positive end-expiratory pressure; SpO_2, oxygen saturation; $etCO_2$, end-tidal carbon dioxide partial pressure. Data are presented as mean ± standard deviation (SD) when normally distributed, and as median [interquartile range (IQR)] when non-normally distributed.

	ST (n = 49)	PDT (n = 43)	*P* value
FiO_2 24 h before TS (%)	40 [36–45]	36 [31–40]	.002
FiO_2 2 h before TS (%)	42 [37–51]	38 [35–44]	.001
FiO_2 during TS (%)	100 [100–100]	100 [100–100]	.248
FiO_2 2 h after TS (%)	44 [40–50]	40 [35–50]	.196
FiO_2 24 h after TS (%)	41 [38–49]	37 [34–43]	.001
PEEP 24 h before TS (mbar)	9.4 ± 2.8	7.4 ± 1.8	<.001
PEEP 2 h before TS (mbar)	9 [7–11]	7 [6–8]	<.001
PEEP 2 h after TS (mbar)	9 [7–11]	7 [6–8]	<.001
PEEP 24 h after TS (mbar)	9.1 ± 2.7	7.3 ± 1.8	<.001
SpO_2 24 h before TS (%)	99 [98–100]	99 [98–100]	.325
SpO_2 2 h before TS (%)	99 [98–100]	99 [98–100]	.354
SpO_2 during TS (%)	100 [99–100]	100 [99–100]	.944
SpO_2 2 h after TS (%)	99 [98–100]	99 [98–100]	.435
SpO_2 24 h after TS (%)	99 [98–99]	99 [98–100]	.246
$etCO_2$ 24 h before TS (mmHg)	37.0 ± 5.1	37.7 ± 5.3	.577
$etCO_2$ 2 h before TS (mmHg)	36.7 ± 5.5	37.3 ± 6.8	.677
$etCO_2$ during TS (mmHg)	34.7 ± 5.0	35.7 ± 7.0	.508
$etCO_2$ 2 h after TS (mmHg)	34.7 ± 5.0	36.1 ± 5.3	.264
$etCO_2$ 24 h after TS (mmHg)	36.2 ± 4.7	36.7 ± 5.5	.729

significantly between both groups (79/min ± 15/min in ST group vs 85/min ± 14/min in PDT group, $P = .070$; 93 ± 11 mm Hg in ST group vs 94 ± 12 mm Hg in PDT group, $P = .632$). The cumulative time with a MAP lower than 60 mm Hg during tracheostomy was less than 1 minute in both groups. Hemodynamic support with norepinephrine during tracheostomy was required in 42 patients in the ST group and 34 patients in the PDT group (85.7% vs 79.1%, $P = .402$). The infusion rate of norepinephrine during tracheostomy did not differ between both groups (0.4 [0.1–0.7] mg/h in ST group vs 0.3 [0.1–0.6] mg/h in PDT group, $P = .496$). The number of patients with at least 1 episode of a drop of the MAP below 60 mm Hg was higher in the PDT group (8 patients, 18.6% in PDT group vs 2 patients, 4.1% in PDT group, $P = .026$).

Table 5

Heart rate (HR) and mean arterial pressure (MAP) during tracheostomy (TS). Data are presented as mean ± standard deviation (SD) when normally distributed, and as median [interquartile range (IQR)] when non-normally distributed.

	ST (n = 49)	PDT (n = 43)	*P* value
HR 1 h before TS (/min)	77 ± 14	83 ± 14	.057
HR during TS (/min)	79 ± 15	85 ± 14	.070
Cumulative time with HR<45/min during TS (min)	0 [0–0]	0 [0–0]	1.000
Cumulative time with HR > 120/min during TS (min)	0 [0–0]	0.4 [0–0]	.064
MAP 1 h before TS (mm Hg)	92 ± 12	92 ± 12	.933
MAP during TS (mm Hg)	93 ± 11	94 ± 12	.632
Cumulative time with MAP<60 mm Hg during TS (min)	0 [0–0]	0 [0–0]	.099
Cumulative time with MAP > 100 mm Hg during TS (min)	9 [0–20]	6 [2–12]	.308

Table 6

Mean infusion rate and bolus injection of sedatives and opioids during tracheostomy (TS). Data are presented as mean ± standard deviation (SD) when normally distributed, and as median [interquartile range (IQR)] when non-normally distributed.

	ST (n = 49)	PDT (n = 43)	*P* value
Infusion rate of propofol during TS (mg/h)	200 [60–240]	200 [0–300]	.183
Bolus injection of propofol during TS (mg)	0 [0–45]	0 [0–80]	.443
Infusion rate of midazolam during TS (mg/h)	0 [0–14]	0 [0–20]	.728
Bolus injection of midazolam during TS (mg)	0 [0–0]	0 [0–0]	.626
Infusion rate of ketamine during TS (mg/h)	0 [0–175]	0 [0–150]	.524
Bolus injection of ketamine during TS (mg)	0 [0–0]	0 [0–0]	.415
Infusion rate of sufentanil during TS (μg/h)	80 [33–100]	40 [0–80]	.013
Bolus injection of sufentanil during TS (μg)	0 [0–40]	0 [0–30]	.931

The required dosages of sedatives and opioids during tracheostomy were similar in both groups except a remarkably higher infusion rate for sufentanil in the PDT group (Table 6).

In 3 cases, relevant complications during ST were documented in the PDMS. Two times a serious bleeding occurred, in 1 case difficulties during insertion of the tracheal cannula leaded to a relevant drop of SpO_2. In the further course of ICU treatment, in 1 case of ST operative revision was required due to impaired wound healing. In another case, a serious infection of the tracheostoma occurred. During PDT reintubation was required in two cases because the insertion of the tracheal cannula was not possible. One patient of the PDT group required the replacement of the tracheal cannula within 24 hours after tracheostomy due to cuff leakage.

CRP values just before tracheostomy did not differ significantly between both groups (112.8 ± 70.7 mg/L in ST group vs 94.7 ± 64.2 mg/L in PDT group, $P = .212$). During the 7 days following tracheostomy, a relevant increase in CRP value did not occur in either group. On the day of tracheostomy most of the patients in both groups required antibiotic therapy (83.7% in ST group vs 70.0% in PDT group, $P = .113$). After tracheostomy a remarkably high percentage of patients in the PDT group required a new antibiotic therapy or the escalation of the preceding regime (46.5% in PDT group vs 24.5% in ST group, $P = .008$).

4. Discussion

In the present study, we compared different tracheostomy methods (ST and PDT) in critically ill neurosurgical patients with regard to procedure duration and the course of ICP values and vital parameters.

The finding that the median procedure time for ST was 50 minutes vs 30 minutes for PDT could be a considerable argument for preferring PDT in neurointensive care patients as a shorter surgical time for tracheostomy is assumed to be a crucial factor to avoid ICP increases during the procedure in the literature.[11] However, the median duration of 30 minutes for PDT in the present study seems to be considerably longer compared to a mean duration for PDT of only 13.1 minutes reported in a meta-analysis published in 2014.[14] A possible explanation for this difference could be divergent definitions of the start and end point of the procedure. In addition, the duration of a procedure like PDT is mainly dependent on experience. At university medical centers, procedures like tracheostomy are often performed by young colleagues under supervision of an experienced instructor understandably leading to a longer duration.

In the present study, ST was performed significantly earlier than PDT (median day 10 after admission to the ICU vs day 14). A possible explanation could be that ST is preferred in patients with a difficult airway when PDT is contraindicated. In these cases, extubation attempts are often estimated to be too dangerous as reintubation is expected to be challenging leading to a priori tracheostomy. However, failed tracheostomy-preceding extubation attempts were not observed more often in patients finally receiving PDT.

Since neurocritical care patients often show fairly controlled ICP levels over a longer period of time, external stimuli like invasive procedures such as PDT or ST may lead to significant increases in ICP. The timing of tracheostomy, however, seems not to influence ICP.[15] Patients in both groups of the present study had well controlled ICP values within the last 24 hours before tracheostomy was performed. Throughout the surgery, a slight increase in middle ICP levels within both groups was seen reflecting the general impact of the intervention. Remarkably, peak ICP levels were higher in the PDT group indicating a higher impact of PDT technique on ICP compared to ST. Regarding the number of patients with at least 1 episode of a measured ICP value above 20 mm Hg there was a trend towards a higher frequency in the PDT group, but medicamentous intervention for lowering ICP was not necessary more often. Data regarding ICP levels during tracheostomy are rare. Kuechler et al reported on a temporarily elevated ICP during PDT in 24% of the cases.[11] In this study, severe hypercapnia occurred only in 15% suggesting that this seems not to be the only reason for causing ICP elevation during tracheostomy. Milanchi et al did only measure a temporary slight and statistically non-significant increase in ICP during PDT and concluded that PDT is safe in neurosurgical patients.[16] This is in accordance with our data since we also found an increase in ICP which stayed within acceptable ranges and the rate of severe hypercapnia during tracheostomy was low. Kleffmann et al reported on a significant rise of ICP during PDT procedure. The mean ICP values, however, remained below 20 mm Hg.[17] Stocchetti et al compared ST and PDT regarding the effect on ICP and found a significant increase of ICP regardless of which technique was performed. Intracranial hypertension with ICP above 20 mm Hg, however, occurred more often in PDT group.[18] Kuechler et al reported on a temporarily rising ICP during PDT in 24% of the cases without affecting cerebral perfusion pressure (CPP). Surgery time and hypercapnia were identified to be risk factors for intraoperative ICP elevation.[11]

More patients in the PDT group had at least 1 episode with MAP falling below 60 mm Hg. However, the infusion rate of norepinephrine did not differ between both groups. Kleffmann et al reported on rising MAP to mean values above 100 mm Hg during PDT.[17] This, however, should be avoidable when sufficiently deep anesthesia during tracheostomy is ensured. Episodes with arterial hypotension during PDT in brain-injured patients occurred in only 3 of 289 cases in the study mentioned above.[11] This is in line with our findings where relevant drops in MAP could be avoided in all cases.

Severe complications rarely occurred in both groups which is in line with prior findings in neurological[11] and unselected ICU patients.[19] The rate of lethal complications is about 0.65% for both techniques.[20] A large meta-analysis comparing ST and percutaneous tracheostomy revealed a higher rate of

wound infection after ST in unselected critically ill adult patients.[14] In an older meta-analysis a trend toward fewer complications in percutaneous techniques was reported.[21] Delaney et al found a lower incidence of wound infection and reduced clinical relevant bleeding when PDT is performed compared to ST.[22]

The main limitation of our study is its retrospective design. Retrospective database researches are often limited due to data quality. In addition, continuous measurement of ICP during tracheostomy was required for being included in the present study. Obviously, in many cases the probe for measuring ICP had been removed prior to performance of tracheostomy leading to a relatively small sample size. In addition, the fact that FiO_2 and PEEP were lower in the PDT group 24 and 2 hours before and 24 hours after tracheostomy indicates that ST was preferably performed in patients with pulmonary problems due to safety reasons. This could have led to a certain bias with patients with a poorer condition being overrepresented in the ST group. Finally, it has to be clarified that the decision for tracheostomy was not based on a weaning protocol but was according to the estimation of the attending ICU physicians in the particular case.

In summary, we can conclude that tracheostomy in critically ill neurointensive care patients is safe irrespective of which technique is used. During tracheostomy increased ICP levels are observed but remain within acceptable ranges. PDT seems to have a higher impact on ICP than ST although PDT can be performed faster than ST. A problematic drop in SpO_2, severe hypercapnia and arterial hypotension during tracheostomy rarely occur irrespectively of the tracheostomy technique used.

Author contributions

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