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CLINICAL ARTICLE - NEUROSURGERY TRAINING

Anterior cervical discectomy and fusion: is surgical education safe?

Martin N. Stienen[1,2] · Holger Joswig[1] · Dario Jucker[1] · Gerhard Hildebrandt[1] · Karl Schaller[2] · Oliver P. Gautschi[2]

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Abstract
Background Operative skills are key to neurosurgical resident training. They should be acquired in a structured manner and preferably starting early in residency. The aim of this study was to test the hypothesis that the outcome and complication rate of anterior cervical discectomy and fusion with or without instrumentation (ACDF(I)) is not inferior for supervised residents as compared to board-certified faculty neurosurgeons (BCFN).
Methods This was a retrospective single-center study of all consecutive patients undergoing ACDF(I)-surgery between January 2011 and August 2014. All procedures were dichotomized into two groups according to the surgeon's level of experience: teaching cases (postgraduate year (PGY)-2 to PGY-6 neurosurgical residents) and non-teaching cases operated by BCFN. The primary study endpoint was patients' clinical outcome 4 weeks after surgery, categorized into a binary responder and non-responder variable. Secondary endpoints were complications, need for re-do surgery, and clinical outcome until the last follow-up.
Results After exclusion of six cases because of incomplete data, a total of 287 ACDF(I) operations were enrolled into the study, of which 82 (29.2 %) were teaching cases and 199 (70.8 %) were non-teaching cases. Teaching cases required a longer operation time (131 min (95 % confidence interval (CI) 122–141 min) vs. 102 min (95–108 min; $p<0.0001$) and were associated with a slightly higher estimated blood loss (84 ml (95 % CI 56–111 ml) vs. 57 ml (95 % CI 47–66 ml); $p=0.0017$), while there was no difference in the rate of intraoperative complications (2.4 vs. 1.5 %; $p=0.631$). Four weeks after surgery, 92.7 and 93 % of the patients had a positive response to surgery ($p=1.000$), respectively. There was no difference in the postoperative complication rate (4.9 vs. 3.0 %; $p=0.307$). Around 30 % of the study patients were followed up in outpatient clinics for more than once up until a mean period of 6.4 months (95 % CI 5.3–7.6 months). At the last follow-up, the clinical outcome was similar with a 90 % responder rate for both groups ($p=0.834$). In total, five patients from the teaching group and eight patients from the non-teaching group required re-do surgery ($p=0.602$).
Conclusions Short- and mid-term outcomes and complication rates following microscopic ACDF(I) were comparable for patients operated on by supervised neurosurgical residents or by senior surgeons. Our data thus indicate that a structured neurosurgical education of operative skills does not lead to worse outcomes or increase the complication rates after ACDF(I). Confirmation of the results by a prospective study is desired.

Keywords Anterior cervical discectomy and fusion · Surgical education · Training · Complication · Outcome

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✉ Martin N. Stienen
mnstienen@gmail.com

[1] Department of Neurosurgery, Cantonal Hospital St. Gallen, Rorschacher Str. 95, 9007 St. Gallen, Switzerland

[2] Department of Neurosurgery and Faculty of Medicine, University Hospital Geneva, Geneva, Switzerland

Introduction

Teaching of operative skills in neurosurgical resident training is fundamental. The need for a structured resident education has become even more important since the introduction of work-hour restrictions in many teaching hospitals throughout Europe [1]. Nevertheless, in many neurosurgery departments it is still common practice to introduce residents to their own surgical procedures much later in their residency. There are some ethical, technical, and political considerations that account for this practice: First, best-quality medical treatment for patients must be guaranteed and this is often prioritized over surgical training or teaching. Second, surgical trainees might prolong operation times and thereby increase time-related complications and costs. Further aspects adding to this trend may be internal patient management policies and increasing complexity and subspecialization in the field of neurosurgery.

A structured training program was established at our institution (see supplementary table 1), whereby continuous theoretical and practical training have been implemented in order to teach residents neurosurgical procedures early in their training. During all surgical procedures, residents are assisted by a board-certified faculty neurosurgeon (BCFN). Although surgeons' experience has recently been found to influence the rate of complications and clinical outcome in bariatric surgery [2], this has not been demonstrated in spinal surgery thus far [3, 4]. In a previous study, we found that the likelihood of a favorable outcome was equal for patients receiving microscopic lumbar disc surgery by a resident surgeon under supervision and by a BCFN. Moreover, no serious complications were recorded up to 1-year follow-up, indicating that surgical treatment by resident surgeons is safe [5]. However, it has not been answered whether the same holds true for other spinal procedures such as anterior cervical discectomy and fusion with or without instrumentation (ACDF(I)).

The aim of the present study is to test the hypothesis that the postoperative outcome and complication rates after ACDF(I)-surgery performed by neurosurgery residents in training under supervision are equal to those cases of experienced BCFN.

Methods

Study design and patient identification

This was a retrospective single-center study of a consecutive patient cohort receiving ACDF(I)-surgery. Patient charts from 01/2011 to 08/2014 were reviewed and all patients with complete relevant clinical and radiological data were included.

Study groups and education program

All cases were dichotomized into two groups according to the surgeon's experience level: teaching cases (postgraduate year (PGY)-2 to PGY-6) and non-teaching cases (patients operated on by a BCFN) [5]. Residents would have had the experience of assisting a minimum of 15 ACDF(I) procedures and had completed 24 months of training (Supplementary Table 1). All patients of the teaching group were informed that a resident would perform the operation with the help of a BCFN. For every case performed by a resident, there was supervision by a BCFN. The supervising BCFN intervened only when the resident experienced difficulties, e.g., with difficult anatomy, hemostasis or in case of intraoperative complications such as dural tears, for example. It is important to note that the BCFN was declared primary surgeon whenever key parts of the surgery (e.g., discectomy, foraminal decompression, removal of posterior osteophytes or the posterior longitudinal ligament, cage insertion or plate fixation) were handed over. This was also respected by the study protocol.

Patients requiring ACDF(I) surgery were assigned to the study groups as follows: As a general rule, at our institution, residents recruit surgical candidates from outpatient clinics or from the emergency department. Patient management and recommendation for surgery are overseen by the BCFN in charge, who would later assist the resident at the corresponding surgery. Privately insured patients are exempted from residents' care. No other factors (e.g., age, severity of disease, previous surgeries) influenced the decision whether the patient undergoing ACDF(I) would be assigned to a resident or a BCFN (Supplementary Table 1).

Preoperative factors

The preoperative clinical status as well as radiological features were recorded for the baseline-stratification of the study groups. Instability was defined as segmental degenerative hypermobility; no cervical trauma cases were included in the study. As severely degenerated segments may be more difficult to operate, the degree of cervical disc degeneration was recorded on preoperative magnetic resonance imaging (MRI). To account for degree of degeneration, we applied a classification similar to the Pfirrmann classification (grades A–E) to preoperative cervical MRI, despite the fact that this classification was originally developed for lumbar disc degeneration [6]. Cervical disc height and radiological signs of myelopathy were also recorded.

Surgical technique

A right-sided anterolateral retropharyngeal approach was used and the correct level was verified using intraoperative fluoroscopy. Discectomy was performed under slight distraction by a

Caspar vertebral dissector and using the operation microscope 'Leica M525 F50' (Leica Microsystems, Wetzlar, Germany). Posterior osteophytes and the posterior longitudinal ligament were removed using Kerrison punches and/or a high-speed microdrill. Any dural tears were fixed with Spongostan® (Ethicon, Germany) and fibrin glue patches (EVICEL®, Ethicon, Germany). After foraminal decompression, a PEEK cage (Cornerstone-SR®, Medtronic, USA) filled with allogenic bone matrix (Grafton DBM®, Biohorizons, USA) was fitted into the intervertebral disc space (ACDF). Because of the significant pain at the donor site, [7] we refrain from using bone grafts. An anterior plate (Venture®, Medtronic) was added at the discretion of the surgeon (ACDFI). Indications for the latter traditionally included segmental instability, myelopathy and multiple level surgery more than two segments and when restoration of the cervical alignment was aimed at. In view of the current literature indicating a superior outcome after additional cervical plating as compared to insertion of stand-alone cages, plate insertion was openly discussed with every patient prior to surgery from 2013 onwards [8]. As an alternative to the fusion material above, an anchored cage (Zero-P®, Synthes) was used in 20 patients [9].

Postoperatively, patients had relative bed rest until the next morning in order to minimize the risk of re-bleeding or anesthesia-related falls. No collars were applied. On postoperative day one, nurses and physiotherapists assisted the patients with mobilization using a standardized protocol. Cervical spine X-rays (anterior posterior and lateral views) were performed on postoperative day one or two. Given an uneventful in-hospital course, patients were usually discharged home on postoperative day two or three. Elderly patients were discharged between postoperative day four to six. Planning of subsequent in-hospital rehabilitation, whenever deemed necessary, often prolonged hospitalization time.

Data collection

Operation time, estimated blood loss (EBL) and intraoperative complications such as incidental durotomy, vascular or esophageal injury were recorded. Wrong level exposure was defined as exposure of the wrong cervical disc identified by intraoperative fluoroscopy before discectomy was undertaken. Early postoperative complications, new neurological deficit, recurrent laryngeal nerve palsy, wound infections and symptomatic postoperative bleeding, managed either surgically or not, were assessed. Absolute and relative pre-vertebral swelling were measured as proxy to estimate the dissection quality and identify pre-vertebral surgical site hematomas as follows: the distance from the posterior wall of the trachea to a perpendicular line connecting the anterior endplates of the adjacent vertebrae was measured in postoperative lateral X-rays (Fig. 1). For multi-level surgeries, the segment with the greatest distance was chosen. Relative pre-vertebral swelling was calculated by subtracting the anatomical distance "anterior vertebral body - trachea" determined on the preoperative MRI from the distance measured on the postoperative X-rays.

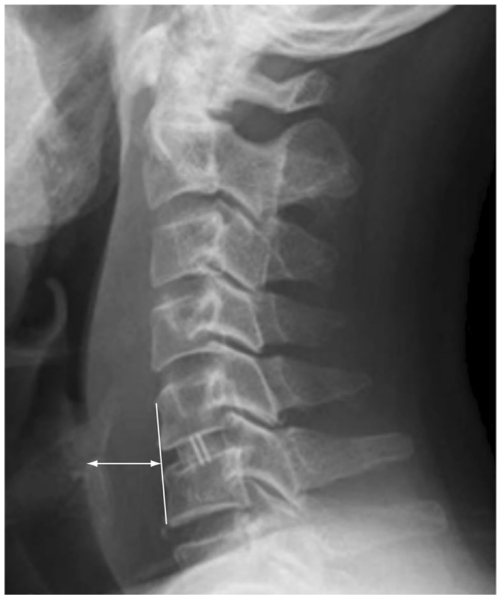

Fig. 1 The distance (*arrows*) from the posterior wall of the trachea to a perpendicular line connecting the anterior endplates of the adjacent vertebrae was measured in postoperative lateral X-rays as proxy to estimate the dissection quality and identify pre-vertebral surgical site hematomas

All patients had a 4-week follow-up (FU), which represented the final FU at the same time when they fared well. Therefore, the number of FUs may be an indicator for or suggestion of a prolonged postoperative course and even treatment failure or a complication. Concerning the complication analysis, those that may be transient in nature (e.g., recurrent laryngeal nerve palsy, new neurological deficit, wound infection) were analyzed for each point in time separately (at discharge, at 4 weeks, at the time of last FU). Analysis of re-do surgeries at each point in time comprised of the sum of all re-do surgeries up until then (at discharge, at 4 weeks and at time of last FU).

Statistical methods and study endpoints

The primary endpoint of this study was the patients' clinical outcome 4 weeks after surgery, categorized into five-tier categories and then transformed into a binary responder (excellent relief, good relief and some relief) and non-responder variable (unchanged, worsened) [10]. Secondary endpoints were patients' clinical outcome at their last FU, operation time in minutes (min), estimated blood loss (EBL) in milliliters (ml), rate or severity of intraoperative complications (wrong level exposure, incidental durotomy with or without cerebrospinal fluid (CSF) leak, vascular injury, esophageal injury), postoperative complications classified as major (re-do surgery, new neurological deficit, recurrent laryngeal nerve

palsy) and minor complications (wound-infection necessitating antibiotic treatment, minor surgical site hematoma not requiring re-do surgery), postoperative radiological imaging findings (optimal or suboptimal placement of fusion material, absolute and relative pre-vertebral swelling) as well as duration of hospital stay.

Analysis was performed using GraphPad Prism 5.0c for Mac. The two-tailed *t*-test, two-tailed Fisher's exact test, two-tailed Mann–Whitney test or Chi-square test were used as appropriate; the selection of the test is indicated in each of the Tables 1, 2, 3, 4 and 5.

Results

Baseline demographics

A total of 287 ACDF(I) operations eligible for analysis were performed between January 2011 and August 2014 at the Department of Neurosurgery, Cantonal Hospital St. Gallen. Six cases were excluded from analysis because of incomplete data. In total, 281 patients were enrolled into the study of which 82 (29.2 %) were teaching cases (operated on by a resident in training) and 199 (70.8 %) were non-teaching cases (operated on by a BCFN). Baseline patient data, distribution of possible confounding factors and the preoperative status are displayed in Table 1. Patients of the teaching group were about 5 years younger on average and had predominantly soft discal compression. All other baseline parameters were equally distributed. Of note, the percentage of cases demonstrating clinical and radiological signs of myelopathy was equal for both groups. All other surgery-related factors were equally distributed between the study groups (Table 2).

Complications and in-hospital course

Teaching cases generally took about 30 min longer and these were associated with slightly higher EBL (mean of 25 ml, Table 2). Incidence and type of intraoperative complications were equally low in both groups. Notably, any wrong level

Table 1 Basic demographic parameters and preoperative status of study group patients. Teaching group patients were about 5 years younger, showed predominantly soft discal compression and less osteochondrosis. *mm* millimeters; *MRI* magnetic resonance imaging; *CI* confidence interval. *preoperative MRI was available for analysis in 44 resident (54 %) and 68 BCFN (34 %) cases

	Teaching cases		Non-teaching cases		*p* value
Age (in years; mean, 95 % CI)	52.6, 50.2–55.0		57.1, 55.5–58.7		0.006[X]
Sex					
Male	45	55 %	111	56 %	0.895[Y]
Female	37	45 %	88	44 %	
BMI (in kg/m^2; mean, 95 % CI)	25.4, 24.1–26.6		25.7, 24.9–26.4		0.725[Z]
Diagnosis					
Cervical disc herniation	67	82 %	103	52 %	0.004[+]
Foraminal stenosis	19	23 %	59	30 %	
Osteochondrosis	34	41 %	110	55 %	
Instability	5	6 %	23	12 %	
Preoperative status					
Motor deficit	43	52 %	86	43 %	0.788[+]
Sensory deficit	50	61 %	110	55 %	
Radicular pain	76	93 %	191	96 %	
Myelopathy	12	15 %	27	14 %	
Preoperative MRI features*					
Degree of degeneration					
A	–	–	–	–	0.979[+]
B	2	4 %	2	3 %	
C	13	30 %	19	28 %	
D	23	52 %	36	53 %	
E	6	14 %	11	16 %	
Distance skin – anterior vertebral body (in mm; mean, 95 % CI)	43.0, 40.2–45.8		44.1, 42.5–45.7		0.261[Z]
Cervical disc height (in mm; mean, 95 % CI)	4.8, 4.5–5.2		4.7, 4.5–5.0		0.434[Z]
Myelopathy signal	7	15.9 %	10	14.7 %	1.000[Y]
Total patients	*n*=82	100 %	*n*=199	100 %	

[X] two-tailed *t* test; [Y] two-tailed Fisher's exact test; [Z] two-tailed Mann–Whitney test; [+] Chi-square test

Table 2 Surgical case variables of teaching and non-teaching cases. Operation time and estimated blood loss were significantly higher in the teaching group, while the rate of intraoperative complications was equal. *C* cervical; *CI* confidence interval; *ml* milliliters

	Teaching cases		Non-teaching cases		*p* value
Operated segments					
C3-4	6	7 %	16	8 %	0.683[+]
C4-5	22	27 %	62	31 %	
C5-6	60	73 %	133	67 %	
C6-7	41	50 %	106	53 %	
C7-Th1	2	2 %	12	6 %	
No. of operated segments					
Single segment	42	51 %	98	49 %	0.793[Y]
Multiple segments	40	49 %	101	51 %	
Number of segments (mean, 95 % CI)	1.59, 1.44–1.75		1.64, 1.54–1.74		0.614[Z]
Fusion material used					
Cage	42	51.2 %	104	52.3 %	0.293[+]
Cage and plate	37	45.1 %	78	39.2 %	
Zero-P®	3	3.7 %	17	8.5 %	
Intraoperative complications					
None	80	97.6 %	196	98.5 %	0.631[Y]
Yes	2	2.4 %	3	1.5 %	
Incidental durotomy	2	2.4 %	3	1.5 %	
Vascular injury	–	0 %	–	0 %	
Esophageal injury	–	0 %	–	0 %	
Other	–	0 %	–	0 %	
Other surgery parameters					
Operation time in minutes (mean, 95 % CI)	131, 122–141		102, 95–108		<0.0001[Z]
Estimated blood loss in ml (mean, 95 % CI)	83.6, 56.4–110.7		56.7, 47.1–66.4		0.0017[Z]
Wrong level exposure	3	3.6 %	5	2.5 %	0.695[Y]
Total	*n*=82	100 %	*n*=199	100 %	

[Y] two-tailed Fisher's exact test; [Z] two-tailed Mann–Whitney test; [+] Chi-square test

exposure never resulted in surgery of the wrong level as the level was corrected each time before discectomy was commenced. Incidental durotomy was recorded in 2.4 % of the teaching and 1.5 % of the non-teaching group (Table 2), while arachnoid opening and CSF leakage were only seen once in each group respectively.

Postoperative complication rates were equal between the study groups and are outlined in Table 3. Two patients from each group underwent re-do surgery before discharge for 1) CSF-fistula and 2) loosening of a plate screw (teaching group) as well as for 1) CSF-fistula and 2) incomplete decompression necessitating posterior foraminotomy (non-teaching group). New neurological deficits were seen in three patients: one patient developed new motor deficit of 3/5 on the British Medical Research Council (BMRC) grading scale [11] for shoulder abduction after a C3 to C5 decompression with cages and plate application (teaching group). The other two patients (teaching and non-teaching group) suffered from spinal cord ischemia, most likely secondary to hyperextension of the cervical spine during positioning (positioning was done by the primary surgeon in both cases). Three patients in the non-teaching group developed recurrent laryngeal nerve palsy. Positioning of fusion material in the postoperative imaging revealed no differences between the two study groups. Prevertebral swelling was equal between both groups. Neither wound infections nor symptomatic postoperative bleeding were noted in both groups. Length of hospitalization was comparable for both groups. An equal percentage of patients from both groups were discharged to a in-hospital rehabilitation program; all others received outpatient physiotherapy (Table 3).

Postoperative clinical outcome and complications at 4-week follow-up

Overall, the majority of patients experienced clinically meaningful improvement from surgery, as it is evident from the responder rates of 93 % for both groups (Table 4). The rate of complications was equal (Table 4).

Table 3 Postoperative in-patient follow-up and radiological imaging features of teaching and non-teaching cases. Note that no significant differences between the study groups exist. *mm* millimeters; *CI* confidence interval. * prevertebral swelling was determined in 44 teaching (54 %) and 68 non-teaching cases (34 %) where preoperative MRI was available for comparative analysis (see Table 1)

	Teaching cases		Non-teaching cases		*p* value
Postoperative complications (until hospital discharge)					
None	78	95.1 %	192	97.0 %	0.735[Y]
Major complications	4	4.8 %	6	3.0 %	0.735[Y]
Re-do surgery	2		2		
New neurological deficit	2		1		
Recurrence nerve palsy	0		3		
Minor complications	–	0 %	–	0 %	–
Wound infection	–		–		
Surgical site hematoma	–		–		
Postoperative radiological features					
Fusion material placed correctly	80	97.6 %	186	93.5 %	0.244[Y]
Fusion material placed suboptimally	2	2.4 %	13	6.5 %	
Distance anterior vertebral body – trachea (in mm; mean, 95 % CI)	20.4, 19.5–21.3		20.6, 19.9–21.2		0.873[Z]
Relative prevertebral swelling (in mm; mean, 95 % CI) *	7.9, 7.2–8.8		8.1, 6.9–9.2		0.454[Z]
X-ray on postoperative day (mean, 95 % CI)	1.3, 1.1–1.5		1.5, 1.4–1.6		0.120[Z]
Discharge					
Length of postoperative hospitalization (in days; mean, 95 % CI)	4.6, 3.9–5.3		4.6, 4.3–5.0		0.896[Z]
Home	74	90.2 %	176	88.4 %	1.000[Y]
Stationary rehabilitation / peripheral hospital	8	9.8 %	21	11.6 %	
Total patients	*n*=82	100 %	*n*=199	100 %	

[Y] two-tailed Fisher's exact test; [Z] two-tailed Mann–Whitney test

Table 4 Four-week complication rates and outcome after teaching- and non-teaching surgical procedures. Clinical outcome as determined by patient response (excellent relief, good relief and some relief) or non-response to surgery (unchanged, worsened), as well as complication rates were similar. *SD* standard deviation. * since the index surgery

	Teaching cases		Non-teaching cases		*p* value
Postoperative clinical outcome after 4 weeks					
Non-responders	6	7.3 %	14	7.0 %	1.000[Y]
Unchanged	4		11		
Worse	2		3		
Responders	76	92.7 %	185	93.0 %	
Some relief	13		29		
Good relief	54		125		
Excellent relief	9		31		
Postoperative complications after 4 weeks					
None	78	95.1 %	193	97.0 %	0.307[Y]
Major complication	3	3.7 %	6	3.0 %	0.484[Y]
Re-do surgery*	2		2		
New neurological deficit	1		1		
Recurrence nerve palsy	–		3		
Minor complication	1	1.2 %	–	0 %	0.292[Y]
Superficial wound infection	1		–		
Total patients	*n*=82	100 %	*n*=199	100 %	

[Y] two-tailed Fisher's exact test; [Z] two-tailed Mann–Whitney test

Table 5 Final follow-up outcome and complication rates following teaching and non-teaching surgical procedures. At final follow-up, about 90 % of patients from both groups were considered responders to treatment with a similar complication rate. *CI* confidence interval. * since the index surgery

	Teaching cases		Non-teaching cases		*p* value
Long-term follow-up					
No additional consultation	56	68.3 %	146	73.4 %	0.465[Y]
Additional consultation	26	31.7 %	53	26.6 %	
Interval to last follow-up in days after index surgery (mean, 95 % CI)	199, 146–252		191, 145–235		0.424[Z]
Clinical outcome at last follow-up					
Non-responders	8	9.7 %	22	11.1 %	0.834[Y]
Unchanged	3		13		
Worse	5		9		
Responders	74	90.3 %	177	89.9 %	
Some relief	15		23		
Good relief	47		122		
Excellent relief	12		32		
Complications at last follow-up					
None	74	90.2 %	187	93.9 %	0.308[Y]
Major complication	7	8.5 %	12	6.0 %	0.602[Y]
Re-do surgery*	5		8		
New neurological deficit	2		1		
Recurrence nerve palsy	–		3		
Minor complication	1	1.2 %	0	0 %	0.291[Y]
Superficial wound infection	1		–		
Total patients	*n*=82	100 %	*n*=199	100 %	

[Y] two-tailed Fisher's exact test; [Z] two-tailed Mann–Whitney test

Postoperative clinical outcome and complications at time of last follow-up

About one-third of the patients from each group attended more than one FU until a mean of 6.4 months (95 % CI 5.3–7.6 months). The final outcome was similar between the two study groups with a responder rate of about 90 % (p=0.308; Table 5). Since the initial surgery, five patients from the teaching group and eight patients from the non-teaching group underwent additional cervical spine surgery (p=0.602). Two patients in the teaching group and one patient in the non-teaching group still suffered from a neurological deficit secondary to the first operation.

Discussion

Short- and mid-term outcome after microscopic anterior cervical discectomy and fusion with or without instrumentation were equal between patients operated on either by a supervised neurosurgical resident in training or by an experienced BCFN. Likewise, intraoperative and postoperative complication rates were comparable. As discussed in our previous report, [5] the fact that every teaching case was supervised by an experienced senior surgeon and key steps or management of complications were handed over if necessary, represents a strong bias with respect to surgical result for resident procedures. Accordingly, the reader must not conclude that residents and BCFNs have similar operative skills. Our data merely indicate that a structured neurosurgical operative education does not lead to worse outcomes or harm the patients after ACDF(I).

The study groups were well balanced for most baseline demographics and surgical confounding factors (Tables 1 and 2) except that patients in the teaching group were about 5 years younger and had predominantly soft disc compression. Large-scale studies have demonstrated that higher age was associated with a less favorable postoperative course [12]. For example, the odds ratio for perioperative mortality after cervical spine surgery was estimated to be 3.0 (95 % CI 2.1–4.5, p<0.0005) for patients older than 65 years old. The difference in mortality, however, was more attributed to comorbidities and systemic complications rather than factors directly related to surgery [13]. The postoperative clinical outcomes are usually equally good in older patients [14, 15]. As most patients in our study were older than 65 years old and the study focused on surgical complications as well as on the postoperative outcome, the mean age difference of 5 years between the study groups is very unlikely to have influenced our primary or secondary endpoints. It is important to note that teaching cases were by no means pre-selected to be easy cases as they included cervical cord compression and multilevel

pathologies, which are generally perceived more difficult to operate on [12, 13].

Mean operation times were relatively long in both groups owing to a 50 % rate of multi-level surgeries in our cohort (Table 2) [16–18]. While operation times and EBL were comparable in our previous report for microscopic lumbar disc surgery for teaching and non-teaching cases, [5] our present data indicates that resident operations took 30 min longer on average and were associated with a slightly higher EBL of about 25 ml (Table 3). It is a general conception that surgical procedures carried out by residents are slower because they are less target-oriented and more subject to technical difficulties, especially when dealing with intraoperative complications. Still, this finding might likewise reflect the cautious operating technique, as residents are apprehensive of important anatomical structures such as the carotid and vertebral arteries, trachea, esophagus, and the spinal cord in the operative field. A somewhat higher rate of additional instrumentation in the teaching group may have added to the longer operation time of the residents (45.1 vs. 39.2 %, $p=0.423$). In any case, the difference of 30 min falls within the variations of operation time reported in previous studies on ACDF(I) (mean 88.43 min, 95 % CI 70.7–106.2 min) [19]. Therefore, we consider this difference in operation time acceptable. The mean EBL of our whole cohort was lower or comparable to previously published results with a range of 41.1 to 150.2 ml in prospective series [19–21]. Concerning the study groups, we noticed a small but significantly higher mean blood loss of 25 ml in the teaching group that we regard as clinically irrelevant in otherwise healthy patients. In patients with anemia for example, this issue, however, should be kept in mind when a resident is chosen as the primary surgeon.

Patients of both study groups benefited equally from ACDF(I) in our outcome analysis ($p=1.000$). A good outcome results from a good indication for surgery in the first place as well as from a thorough execution of the procedure. Besides radicular arm pain as the principal symptom in most of the patients, the indications for surgery included (painless) progressive or severe motor deficit or myelopathy in 14 patients of the teaching and 35 in the non-teaching group. These 49 patients with another principal symptom other than radicular arm pain are much less likely to show a detectable improvement in the short-term [22]. Thus, at the 4 week FU, the patient's perceived benefit from surgery might be underrated, affecting both study groups in equal measures. With this in mind, true therapy failures can best be determined by the rate of "worsening" at final FU, which was also equal between the study groups (6.1 vs. 4.5 %; $p=0.763$). Long-term FU is not regularly performed at our institution and is generally reserved for those patients who reported incomplete relief or new symptoms. Therefore, length of FU may suggest a prolonged postoperative course and even represent an indicator of treatment failure and complications. This phenomenon of negative selection most probably explains why the positive response rate was slightly inferior at the time of last FU (likewise no differences between the study groups ($p=0.834$)) compared to FU at 4 weeks (Table 5)).

Neurosurgical resident education usually takes place in teaching hospitals. Comparing their outcomes to non-teaching hospitals has stimulated an interesting debate in the health care community. Teaching hospitals play a major role in the health care systems worldwide by educating the next generation of surgeons and physicians, advancing healthcare technologies and providing highly specialized services for complex patients. There is a controversy regarding mortality and morbidity rates between teaching and nonteaching hospitals [23–25]. Some studies indicated that teaching hospitals were superior for complex surgical procedures, while the quality of care was similar for more common and less complex procedures [24, 26, 27]. A recent large scale epidemiological Northern-American study on 212,385 cervical spine operations identified subtle, yet significant differences: Patients treated in teaching facilities were more likely to undergo more complex procedures and therefore had increased complication rates and mortality, longer hospitalization times and higher costs [13]. It can be concluded that every hospital has its unique and critical role in the health care system [28]. The degree of surgical experience was not addressed in the cited studies. Our results added valuable information, indicating that patient outcomes are not negatively affected by residents performing ACDF(I).

Concerning the limitations of our study, one has to appreciate for retrospective data acquisition which may result in underreporting adverse events associated with ACDF(I) in both study groups alike. This issue has been highlighted in previous works on spine surgery [29, 30]. It would thus be desirable to repeat this study using a prospective study design, which likewise records the number of patients crossing over from the teaching group to the BCFN-group due to intraoperative difficulties, as this may impact the final results. Alternatively, high-quality data challenging our findings could be derived from prospective multi-centre spine registries that are increasingly being established (e.g., British Spine Registry, Spine Tango, or NASS Spine Registry), if a parameter "teaching case" was included. Group sizes differed as they represent the typical distribution of patients recruited for the given indication by residents and BCFNs in our institution. Further bias may have resulted from insurance status (all patients with private insurance were operated on by BCFN), as well as from baseline difference in age and underlying pathology that were in favor of the resident group (Table 1).

Conclusions

Short- and mid-term outcome and complication rates following microscopic ACDF(I) were comparable for patients

operated on by a supervised neurosurgical resident in training or by an experienced senior surgeon. Our data thus indicate that a structured neurosurgical education of operative skills, where residents are encouraged to operate their own cases, is safe for ACDF(I). In view of some methodological weaknesses of this study (retrospective data acquisition of a limited number of patients), confirmation of our results by a prospective study is desired.

Conflict of interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Informed patient consent Informed consent was obtained from each patient (or, if necessary, next of kin/guardian) that was included in the study.

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