Neurosurg Rev (2018) 41:285–290
DOI 10.1007/s10143-017-0854-8

ORIGINAL ARTICLE

Retrospective analysis of cervical corpectomies: implant-related complications of one- and two-level corpectomies in 45 patients

Sebastian Hartmann[1] · P. Kavakebi[1] · C. Wipplinger[1] · A. Tschugg[1] · P. P. Girod[1] · S. Lener[1] · C. Thomé[1]

Received: 1 December 2016 / Revised: 20 March 2017 / Accepted: 4 April 2017 / Published online: 17 April 2017

Abstract Cervical corpectomies are increasingly used to treat degenerative, metastatic, inflammatory and traumatic multisegmental diseases. The postoperative results are thought to correlate mainly with the number of resected vertebral bodies. Thus, the aim of the study was to analyse complications and early outcome of these procedures to document the implant-related complications in order to set up a prospective clinical trial. Forty-five patients, who were treated in our department from 2011 to 2014 and who were available for a minimum follow-up of 1 year, were consecutively included in this retrospective evaluation. The median age was 61 (±11) years with a female to male sex ratio of 19 to 26, respectively. In these patients, cervical corpectomies (one-, two- and three-level procedures) were performed. The average number of resected levels was 1.2 levels. The intraoperative loss of blood (LOB), the red cell transfusions (rcT), the length of operation (LOO) and the usage of drains were investigated and correlated with intra- and postoperative complications. The mean LOO was 244 min (±68) with a mean LOB of 511 ml (±531). The overall complication rate was 22.9% (10 patients). Six patients (13.3%) had implant-related complications due to loosening and toggling of the screws and/or cage subsidence. Two patients (4.4%) had a postoperative haematoma and another two patients (4.4%) suffered from neurological deterioration due to an ongoing and severe myelopathic syndrome. All these patients received revision surgery. The average time from the first to revision surgery was 90 days. Cervical corpectomies still remain procedures with a high complication rate mainly represented by implant-related failures. These implant-related complications range from screw/plate loosening or toggling to graft dislocation with subsidence and might be associated with constructs extended to the C7 vertebral body. In our study population, the rate of implant failure was comparable to the literature, but not obviously correlated with the number of vertebral bodies resected. This may be attributed to the different disease entities. Thus, our results support the use of circumferential approaches for selected instability scenarios (metastatic or inflammatory diseases, kyphosis, osteoporosis, etc.) of one- and two-level corpectomies.

Keywords Cervical corpectomy · Implant complications · Circumferential instrumentation · Degenerative · Metastatic lesion

Introduction

Cervical corpectomies represent a common technique to treat a wide range of different spinal disorders including degenerative, metastatic, inflammatory and traumatic diseases. In some cases, lengthy compression of neural structures may lead to clinical signs of cervical myelopathy, making decompressive surgery inevitable. A bundle of different graft techniques varying from titanium mesh cage reconstructions to the use of expandable cages or autologous bone are available with the advantages of immediate anterior column stability till bony fusion occurs.

Despite new implant developments in the last years, the failure rate in anterior-only corpectomies is still high and especially depending on the number of levels resected, so that

Sebastian Hartmann and P. Kavakebi contributed equally.

✉ Sebastian Hartmann
sebastian.hartmann@i-med.ac.at

[1] Department of Neurosurgery, Medical University of Innsbruck, Anichstrasse 35, 6020 Innsbruck, Austria

the use of an additional dorsal instrumentation might be beneficial in selected cases (Table 1) [1, 2, 4, 6, 7, 9–13].

Especially two-level approaches represent an intermediate state of instability between one- and three-level procedures, so that an anterior-only instrumentation often seems to be sufficient except in patients with poor bone quality or other diseases [14].

With the aim to optimize future interventions and to allow planning of a prospective trial, we performed a retrospective data analysis of cervical corpectomies at our department between 2011 and 2014 with a major focus on implant-related complications.

Materials and methods

A retrospective analysis of 45 consecutive patients treated by an anterior cervical corpectomy and graft reconstruction with plating between 2011 and 2014 was performed (Table 2). The mean age was 60 (±11) years, with a female to male sex ratio of 19 to 26, respectively (Table 2). Due to the retrospective character of the present study, a minimum follow-up for all patients of 12 months to a maximum follow-up of 55 months (±24 months) could be established. The majority of the disease entities was represented by degenerative spinal canal stenosis with myelopathy in 34 patients followed by nine patients with metastatic lesions and consecutive fractures (Table 2). The remaining patients suffered from cervical spondylodiscitis and one patient was admitted with a cervical burst fracture (Table 2). Patients with insufficient follow-up due to death (in metastatic disease) or non-Austrian residency were excluded. Surgery was performed after conservative options had failed for more than 3 months or the urgency of the (primary) disease required an immediate or emergency operation. The majority of the patients were treated with a titanium mesh cage system (TMC; Synmesh™ Vertebral Body Replacement System, Depuy Synthes©); all other intervertebral devices used are illustrated in Table 3. A semi-constrained screw/plate system with self-drilling screws of up to 20° angulation (Skyline™ Anterior Cervical Plate System, Depuy Synthes©) was applied after corpectomy.

Three surgeons performed all surgical procedures. The corpectomies were accomplished by removing the median half of the vertebral corpus and the remaining disc material including the annulus to perform a clinical “median box-type corpectomy”. The subchondral bone of the adjacent cranial and caudal vertebrae was fully removed to sustain a flat surface for the intervertebral body device. The posterior longitudinal ligament (PLL) was completely resected and the bony structures were laterally undercut to achieve a full decompression of the spinal cord. Grafting was accomplished with approximately 2 mm of distraction by using the “Caspar” distractor system. Postoperatively, none of the patients wore a collar.

Finally, we assessed the length of operation (LOO; min), the intraoperative loss of blood (LOB; ml) and the required use of blood transfusions (rcT). Special attention was paid to the postoperative implant-related complications involving cage subsidence, rod breakage and screw toggling or loosening (Table 4). General postoperative complications including haematomas and neurological deterioration which required revision surgeries were evaluated. For statistical analysis, the Student’s t test and the Fisher exact test were used. The level of significance was set to $p < 0.05$.

Results

Thirty-seven patients (82%) were treated with a one-level corpectomy, seven patients (16%) received a two-level procedure and one patient required a three-level corpectomy (2%) (1.2 levels on average; Table 2). Three patients have been initially treated by a circumferential instrumentation; two patients out of these three were treated by a one-level corpectomy due to a metastatic lesion of the cervical spine. The remaining patient received a two-level corpectomy due to degenerative changes with clinical myelopathy and severe kyphosis.

The mean intraoperative loss of blood (iLOB) was 511 ml (±531) combined with an average use of 0.7 (±1.5) blood transfusions (rcT). The mean LOO revealed to be 244 min (±68). There was no statistically significant relationship between iLOB, LOO, the number of levels resected and the postoperative failures ($p < 0.05$).

Ten patients (22.2%) experienced a postoperative complication (Table 4). Two patients (4.4%) had a postoperative haematoma and another two patients (4.4%) suffered from neurological deterioration due to ongoing and severe myelopathic symptoms. All four patients received revision surgery including evacuation of the haematoma or further decompression of neural structures. The remaining six patients had a construct failure within the first weeks after surgery (mean 90 days after surgery), so that an overall implant-related complication rate of 13.3% could be observed. All of the six patients with implant-related failures were treated with an anterior-only procedure. There was isolated loosening or toggling of the anterior lower screws in three patients (50%) (Table 4). Another three patients (50%) suffered from cage subsidence into the caudal vertebral body (one patient) and graft displacement with kicking out of the graft/plate anteriorly (two patients) due to caudal/lower screw pull-out (Table 4). The implant-related complications were comparable between two-level corpectomies (one out of seven; 14.3%) and one-level procedures (five out of 37; 13.5%) ($p > 0.05$). The implant-related failures were observed in degenerative (five;

Table 1 Implant-related and overall complication rates according to the number of levels resected as stated in the literature

	Type of study	One-level corpectomy (IRC)	IRC in %	Two-level corpectomy (IRC)	IRC in %	≥ three-level corpectomy (IRC)	IRC in %	Total IRC	OAC (%)	Diagnosis
Boakye et al. [1]	Retrospective analyses	1205 (20)	1.7	300 (4)	1.3	55 (3)	5.5	27	18	n.a.
Wang et al. [2]		95 (4)	4.2	76 (4)	5.3	77 (8)	10.4	16	6	n.a.
Özgen et al. [3]		37 (n.a.)	–	35 (n.a.)	–	–	–	10	21	D, M, T, I
Ayran et al. [4]		47 (n.a.)	–	6 (n.a.)	–	–	–	1	24	D, M, T, I
Current study		37 (5)	13.5	7 (1)	14.3	1	–	6	13	D, M, T, I
Kristof et al. [5]		–	–	42 (7)	16.7	–	–	7	40	n.a.
Vaccaro et al. [6]		–	–	33 (3)	9.1	12 (6)	50	9	20	D, M, T
Sasso et al. [7]		–	–	33 (5)	15.2	7 (2)	28.6	7	23	D
Thalgott et al. [8]		19 (n.a.)	–	7 (n.a.)	–	–	–	4	23	D
Daubs et al. [9]		15 (1)	6.7	6 (4)	66.7	2 (2)	100	7	30	T, I

OAC overall complication rate, *IRC* implant-related complications, *D* degenerative diseases, *M* metastatic diseases, *T* cervical vertebral fracture, *I* infectious diseases, *n.a.* not available

Table 2 Patient characteristics (intraoperative loss of blood (LOB, ml), length of operation (LOO, min), degenerative diseases (D), infectious diseases (I))

	Total	Percent
Demographics		
Number of patients	45	
Age (years; ±SD)	61 (±11)	
Gender		
Female	19	42.2
Male	26	57.8
Anterior-only	42	93.3
Circumferential	3	6.7
Levels resected		
One-level corpectomies	37	82.2
Two-level corpectomies	7	15.6
Three-level corpectomies	1	2.2
LOO (min; ±SD)	244 (±68)	
LOB (ml; ±SD)	511 (±531)	
Diseases		
Degenerative	32	71.1
Metastatic	8	17.8
Infectious	3	6.7
Vertebral fractures	2	4.4
Implant-related complications		
One-level corpectomies (all D)	5	11.1
Two-level corpectomies (I)	1	2.2

all one-level corpectomy) and infectious diseases (one; two-level corpectomy) (Tables 2 and 5). All patients with implant-related complications needed revision surgery including anterior re-instrumentation with an additional dorsal support. No further implant-related complications after revision surgery were noted.

Discussion

The present study represents one of the largest single-centre analyses of cervical corpectomies including degenerative, metastatic as well as inflammatory and traumatic disease. These diseases can lead to lengthy compression of the cervical

Table 3 Cage devices used in the different types of diseases

Cage devices used	D	M	I	T
Synmesh™ (Depuy Synthes©)	29	5	3	1
ECD™ (Depuy Synthes©)	2	2		
Trabis™ (coLigne©)	1	1		1

D degenerative diseases, *M* metastatic diseases, *I* infectious diseases, *T* cervical vertebral fracture

Table 4 Postoperative complications; all patients needed revision surgery

Complications	Total	Percent
Haematoma	2	4.2
Neurological deterioration	2	4.2
Implant-related failure	6	13.3
Screw toggling	3	6.7
Cage subsidence	3	6.7

spinal cord with resulting severe myelopathic symptoms. Decompression surgery is often required. The use of different anterior approaches including anterior cervical discectomy and cage implantation (ACDF), anterior corpectomy and fusion with graft reconstruction (ACCF) or hybrid variations (skip corpectomies) is available. Especially multilevel corpectomy procedures without the use of circumferential instrumentations have been associated with postoperative instability. As a result, implant failure might occur [1, 4, 7, 15]. Two-level corpectomies may compose an intermediate state of instability between one- and three-level options, so that an additional dorsal instrumentation might indicate "over-treatment" in some cases.

Nevertheless, the occurrence of graft migration seems to be related to the number of cervical levels involved and the length of the corpectomy defect created. In a one-level corpectomy with the lowest incidence of graft migration reported, we found an implant-related complication rate of approximately 14%. The incidence in two-level cases did not increase significantly in the present study, so that a considerable effect on graft destabilization is lacking. This might be related to the small number of two-level corpectomies and the variety of the diseases presented in this retrospective analysis.

Table 5 Patient characteristics of degenerative cases (intraoperative loss of blood (LOB, ml), length of operation (LOO, min))

	Total	%
Degenerative cases		
Alter (years; ±SD)	61 (±9)	
Gender		
Female	13	40.6
Male	19	59.4
Anterior-only instrumentation	31	96.9
Circumferential instrumentation	1	3.1
Levels resected		
One-level corpectomies	29	90.6
Two-level corpectomies	3	9.4
Three-level corpectomies	0	0
LOO (min; ±SD)	241 (±54)	
LOB (ml; ±SD)	306 (±170)	
Implant-related complications	5	15.6
One-level corpectomies	5	15.6
Two-level corpectomies	0	0
Cage devices used		
Synmesh™ (Depuy Synthes©)	29	90.6
ECD™ (Depuy Synthes©)	1	3.1
Trabis™ (coLigne©)	2	6.3

Extending a one- to a two-level corpectomy was recently shown to decrease stability in a biomechanical investigation with a significantly increased range of motion (ROM) [16]. In contrast to the anterior-only procedures, circumferential instrumentations in two-level corpectomies revealed the same ROM as the one-level construct with antero-posterior support. A similar effect has been shown in other biomechanical and clinical studies, so that an increased stability with the use of an additional dorsal support was observed [4, 12, 13].

Moreover, a significant association between an increased incidence of implant-related failures and constructs ending at the C7 cervical body was reported [2]. The junctional change of the cervical lordosis into the thoracic kyphosis may be a reason for the increased incidence of implant-related failures, especially in two-level corpectomies [2]. Three patients with implant-related failures in our study had constructs ending at C7 (one patient with a one-level corpectomy and two patients with a two-level corpectomy). Additionally, Panjabi et al. observed excessive residual motions at the lower screw-vertebra conjunction of corpectomy constructs. This effect occurred especially after biomechanically applied cyclic loading of long-segment instrumentations [10]. These excessive residual motions combined with constructs extending to the C7 vertebral body might describe the observed failures of the present study at the lower end of the constructs (all screws fatigued at the lower screw-vertebra conjunction) [2, 10].

All TMC systems (Synmesh cage system; Depuy Synthes©) were implanted without the use of end rings/caps. Of 38 patients treated with TMC systems, six patients experienced implant-related failures. The surgeons believed to gain a better surface area for promoting bony fusion without the use of these end rings/caps. These end rings ensure a greater surface on vertebral endplates and may prevent endplates of pressure peaks, so that the occurrence of TMC subsidence might be reduced [17]. Appropriately, a higher incidence of graft subsidence with the use of TMCs was observed in the study of Chen et al. An association with the amount of cage subsidence combined with a decreased physical recovery rate was found to be highly associated with the number of levels involved [18]. Consequently, the preparation of the endplates represents an important part of the procedure to confirm a durable surface of the lower vertebral body for the implanted graft to resist fractures and to allow a robust inferior fixation [2].

Finally, recommendations on the use of an additional dorsal support in patients with different instability scenarios due to kyphosis, metastatic diseases associated with insufficient

posterior elements or reduced bone quality are lacking. The present study includes degenerative cases as well as metastatic lesions and inflammatory or traumatic cases (Table 2). Nevertheless, the majority of the published studies included a number of disease entities potentially hindering the comparability between each other.

Three patients of the present study received a circumferential instrumentation. They were treated with a one-level corpectomy due to a metastatic lesion of the cervical spine (cancer of unknown primary {CUP}, adenocarcinoma of the lung {SCLC} and non-small cell lung carcinoma {NSCLC}). Due to the lack of evidence-based data, the surgeons performed intuitively a circumferential approach in these patients despite a one-level corpectomy. None of these patients exhibited implant-related complications.

Implant-related failures after cervical corpectomies will become a more and more important problem due to the increasing number of elderly patients suffering from mainly degenerative diseases (Table 5). These elderly and mostly comorbid patients are exposed to an increased perioperative complication rate with a second dorsal approach, so that any stability-increasing technique of a single anterior approach would be favourable [1, 19]. Additionally, Boakye et al. revealed that patients suffering from type 1 diabetes have a fourfold higher mortality rate compared to patients with no history of diabetes [1]. Matched to the study of Boakye et al., we did not find any relationship between type 1 diabetes, age or smoking status and an increased complication rate. This may be due to the limited patient number. A small number of studies of anterior-only techniques to increase biomechanical stability are available. Koller et al. investigated biomechanically the use of an anterior transpedicular screw (ATS) placement technique in two-level corpectomies with encouraging results compared to the intact model as well as to the conventional anterior-only screw placement [20, 21]. Beside the ATS technique, anterior cement-augmented techniques of the cervical spine were described in only a small series of patients [19, 22, 23]. These techniques are uncommon but may increase screw fixation, especially in two-level corpectomies, in which a dorsal support can indicate "over-treatment" as described above. In the recently published prospective observational study of Waschke et al., cement augmentation of the anterior screws in one- and two-level corpectomies was performed with good clinical results. The group included metastatic disease as well as osteoporotic fractures of the cervical spine. The patient population might be comparable to the current investigation. Hartmann et al. evaluated cement-augmented two-level corpectomy constructs compared to conventional anterior screw placement biomechanically [24]. A two-level corpectomy with cement augmentation of the anterior screws resulted in a significantly reduced ROM compared to the conventional anterior screw-and-plate fixation, so that cement-augmentation techniques might be a treatment option in cases with reduced bone mineral density avoiding an additional dorsal instrumentation [24].

In the present case series, none of the patients wore a collar postoperatively according to the lack of evidence-based data. Despite the use of collars in other studies, the postoperative complication rate did not differ substantially in the present data collection. Some surgeons use collars in the postoperative course for an interval of 6 to 12 weeks [2, 9, 11, 15]. Consequently, the use of any kind of collar might neither be discouraged nor recommended, so that the practice is based on surgeons' experience and patients' pre-existing disorders. Further prospective research of cervical corpectomies should be undertaken to ensure a safe clinical use of these technically demanding procedures.

Limitations

The study is limited by its retrospective nature, its patient number and the short follow-up period (12 months). Consequently, the level of evidence is considered "level 4" and the available clinical data is limited. Long-term data on recovery of patients exhibiting implant-related complications is therefore lacking. Finally, the patient population (including degenerative, metastatic and inflammatory) is heterogeneous. A subgroup analysis was performed for the degenerative cases (Table 5); however, a subgroup analysis for all disease entities would require a larger study population. Nevertheless, the main purpose of the present study was focused on implant-related complications after cervical corpectomies in a real-world setting, so that the comparability to other published series should be given (Table 1). Finally, three surgeons with different years of surgical experience performed all spine procedures and residents and fellows were involved in the cases at our academic centre, which may also have had an influence on surgical outcome.

Conclusion

The present study observed a high complication rate in cervical corpectomies. The most common problems are associated with implant-related failures, which were not correlated with the number of levels resected. The additional dorsal support represented the "salvage approach" to treat implant-related complications and might also be used primarily for selected cases (metastatic or inflammatory diseases, kyphosis, osteoporosis, construct ending at C7, etc.). Despite the different disease entities included, the complication rate is comparable with the literature. This study was aimed to analyse the implant-related complication rate to set up a prospective clinical trial.

Compliance with ethical standards

Funding The study did not receive any external funding.

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval According to the local institutional review board, for this type of retrospective study, ethics approval is not required.

Informed consent According to the local institutional review board, for this type of retrospective study, informed consent is not required.

References

1. Boakye M, Patil CG, Ho C, Lad SP (2008): Cervical corpectomy: complications and outcomes. Neurosurgery 63:295–301; **discussion 301-2**. doi:10.1227/01.NEU.0000327028.45886.2E
2. Wang JC, Hart RA, Emery SE, Bohlman HH (2003): Graft migration or displacement after multilevel cervical corpectomy and strut grafting. Spine (Phila Pa 1976) 28:1016–1021; **discussion 1021-2**. doi:10.1097/01.BRS.0000061998.62204.D7
3. Ozgen S, Naderi S, Ozek MM, Pamir MN (2004): A retrospective review of cervical corpectomy: indications, complications and outcome. Acta Neurochir 146:1099–1105; **discussion 1105**. doi:10.1007/s00701-004-0327-z
4. Aryan HE, Sanchez-Mejia RO, Ben-Haim S, Ames CP (2007) Successful treatment of cervical myelopathy with minimal morbidity by circumferential decompression and fusion. Eur Spine J 16: 1401–1409. doi:10.1007/s00586-006-0291-9
5. Kristof RA, Kiefer T, Thudium M, Ringel F, Stoffel M, Kovacs A, Mueller CA (2009) Comparison of ventral corpectomy and plate-screw-instrumented fusion with dorsal laminectomy and rod-screw-instrumented fusion for treatment of at least two vertebral-level spondylotic cervical myelopathy. Eur Spine J 18:1951–1956. doi:10.1007/s00586-009-1110-x
6. Vaccaro AR, Falatyn SP, Scuderi GJ, Eismont FJ, McGuire RA, Singh K, Garfin SR (1998) Early failure of long segment anterior cervical plate fixation. J Spinal Disord 11:410–415
7. Sasso RC, Ruggiero RA, Reilly TM, Hall PV (2003) Early reconstruction failures after multilevel cervical corpectomy. Spine (Phila Pa 1976) 28:140–142. doi:10.1097/01.BRS.0000041590.90290.56
8. Thalgott JS, Xiongsheng C, Giuffre JM (2003) Single stage anterior cervical reconstruction with titanium mesh cages, local bone graft, and anterior plating. Spine J 3:294–300
9. Daubs MD (2005) Early failures following cervical corpectomy reconstruction with titanium mesh cages and anterior plating. Spine (Phila Pa 1976) 30:1402–1406
10. Panjabi MM, Isomi T, Wang JL (1999) Loosening at the screw-vertebra junction in multilevel anterior cervical plate constructs. Spine (Phila Pa 1976) 24:2383–2388
11. Sevki K, Mehmet T, Ufuk T, Azmi H, Mercan S, Erkal B (2004) Results of surgical treatment for degenerative cervical myelopathy: anterior cervical corpectomy and stabilization. Spine (Phila Pa 1976) 29:2493–2500
12. Setzer M, Eleraky M, Johnson WM, Aghayev K, Tran ND, Vrionis FD (2012) Biomechanical comparison of anterior cervical spine instrumentation techniques with and without supplemental posterior fusion after different corpectomy and discectomy combinations: laboratory investigation. J Neurosurg Spine 16:579–584. doi:10.3171/2012.2.SPINE11611
13. Acosta FL, Aryan HE, Chou D, Ames CP (2008) Long-term biomechanical stability and clinical improvement after extended multilevel corpectomy and circumferential reconstruction of the cervical spine using titanium mesh cages. J Spinal Disord Tech 21:165–174. doi:10.1097/BSD.0b013e3180654205
14. Yan D, Wang Z, Deng S, Li J, Soo C (2011) Anterior corpectomy and reconstruction with titanium mesh cage and dynamic cervical plate for cervical spondylotic myelopathy in elderly osteoporosis patients. Arch Orthop Trauma Surg 131:1369–1374. doi:10.1007/s00402-011-1317-2
15. Eleraky MA, Llanos C, Sonntag VK (1999) Cervical corpectomy: report of 185 cases and review of the literature. J Neurosurg 90:35–41
16. Hartmann S, Thomé C, Keiler A, Fritsch H, Hegewald AA, Schmölz W (2015) Biomechanical testing of circumferential instrumentation after cervical multilevel corpectomy. Eur Spine J 24: 2788–2798. doi:10.1007/s00586-015-4167-8
17. Yamagata T, Takami T, Uda T, Ikeda H, Nagata T, Sakamoto S et al (2012) Outcomes of contemporary use of rectangular titanium stand-alone cages in anterior cervical discectomy and fusion: cage subsidence and cervical alignment. J Clin Neurosci 19:1673–1678. doi:10.1016/j.jocn.2011.11.043
18. Chen Y, Chen D, Guo Y, Wang X, Lu X, He Z, Yuan W (2008) Subsidence of titanium mesh cage: a study based on 300 cases. J Spinal Disord Tech 21:489–492. doi:10.1097/BSD.0b013e318158de22
19. Waschke A, Walter J, Duenisch P, Kalff R, Ewald C (2013) Anterior cervical intercorporal fusion in patients with osteoporotic or tumorous fractures using a cement augmented cervical plate system: first results of a prospective single-center study. J Spinal Disord Tech 26: E112–E117. doi:10.1097/BSD.0b013e3182764b37
20. Koller H, Schmidt R, Mayer M, Hitzl W, Zenner J, Midderhoff S et al (2010) The stabilizing potential of anterior, posterior and combined techniques for the reconstruction of a 2-level cervical corpectomy model: biomechanical study and first results of ATPS prototyping. Eur Spine J 19:2137–2148. doi:10.1007/s00586-010-1503-x
21. Koller H, Schmoelz W, Zenner J, Auffarth A, Resch H, Hitzl W et al (2015) Construct stability of an instrumented 2-level cervical corpectomy model following fatigue testing: biomechanical comparison of circumferential antero-posterior instrumentation versus a novel anterior-only transpedicular screw-plate fixation technique. Eur Spine J 24:2848–2856. doi:10.1007/s00586-015-3770-z
22. Yukawa Y, Kato F, Ito K, Nakashima H, Machino M (2009) Anterior cervical pedicle screw and plate fixation using fluoroscope-assisted pedicle axis view imaging: a preliminary report of a new cervical reconstruction technique. Eur Spine J 18: 911–916. doi:10.1007/s00586-009-0949-1
23. Aramomi M, Masaki Y, Koshizuka S, Kadota R, Okawa A, Koda M, Yamazaki M (2008): Anterior pedicle screw fixation for multilevel cervical corpectomy and spinal fusion. Acta Neurochir 150: 575–582; **discussion 582**. doi:10.1007/s00701-008-1574-1
24. Hartmann S, Thomé C, Tschugg A, Paesold J, Kavakebi P, Schmölz W (2017) Cement-augmented screws in a cervical two-level corpectomy with anterior titanium mesh cage reconstruction: a biomechanical study. Eur Spine J. doi:10.1007/s00586-017-4951-8