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VERTEBRAL TUBERCULOSIS: MECHANICAL COMPLICATIONS OF TITANIUM CAGE VS. STRUCTURAL ALLOGRAFT SURGERY

TUBERCULOSE VERTEBRAL: COMPLICAÇÕES MECÂNICAS DA CIRURGIA COM GAIOLA DE TITÂNIO VS. ALOENXERTO ESTRUTURAL

TUBERCULOSIS VERTEBRAL: COMPLICACIONES MECÁNICAS DE LA CIRUGÍA CON JAULA DE TITANIO VS. ALOINJERTO ESTRUCTURAL

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ABSTRACT

Objective: This scientific article describes a retrospective longitudinal study that aimed to compare the outcomes and mechanical complications between patients who underwent the use of either structural allograft (SA) or titanium cage (TC) for vertebral body replacement in the management of tuberculosis in thoracic and lumbar segments. Methods: The sample consisted of 22 cases of vertebral tuberculosis surgically treated, of which 17 cases applied TC containing autograft, and five cases applied SA from a tissue bank. The median age in group A was 32.1, and in group B was 5.2. Results: The results showed no statistical difference in the number of resected vertebrae, the amount of instrumented levels, and the correction of the angular value in coronal and sagittal planes as per Cobb method. Furthermore, there were no cases of subsidence, fracture, or displacement of SA or TC until the last postoperative follow-up. However, in group A, four cases of metal rod fracture, one case of proximal junctional failure, and three cases of operative wound infection were identified, all of which improved after debridement and antibiotic therapy. Conclusion: It was concluded that both SA and TC filled with autologous bone for anterior column support and vertebral body replacement in treating tuberculosis presented similar postoperative correction outcomes with similar rates of postoperative mechanical complications. Future studies with larger samples and longer follow-up periods are necessary to evaluate the occurrence of rod fracture. ***Level of Evidence III;*** **Retrospective comparative study.**

Keywords: Tuberculosis, Spinal; Allograft; Postoperative Complications; Surgery.

RESUMO

Objetivo: Este artigo científico descreve um estudo longitudinal retrospectivo que teve como objetivo comparar os resultados e as complicações mecânicas entre pacientes que foram submetidos ao uso de aloenxerto estrutural (AE) ou gaiola de titânio (GT) para substituição do corpo vertebral no manejo da tuberculose em segmentos torácico e lombar. Métodos: A amostra foi composta por 22 casos de tuberculose vertebral tratados cirurgicamente, sendo que em 17 casos foram utilizadas GT contendo autoenxerto e em cinco casos foi utilizado AE de banco de tecidos. A mediana da idade do grupo A foi 32,1 e do grupo B foi 5,2. Resultados: Os resultados mostraram que não houve diferença estatística no número de vértebras ressecadas, quantidade de níveis instrumentados e correção do valor angular nos planos coronal e sagital pelo método de Cobb. Além disso, não houve casos de subsidência, quebra ou deslocamento do AE ou GT até o último seguimento pós-operatório. No entanto, no grupo A foram encontrados quatro casos de quebra das hastes metálicas, um caso de falha juncional proximal e três casos de infecção de ferida operatória, que evoluíram bem após desbridamento e antibioticoterapia. Conclusão: Concluiu-se que o AE e a GT preenchida com osso autólogo para o suporte anterior da coluna e substituição de corpos vertebrais no tratamento da tuberculose apresentaram resultados semelhantes na correção pós-operatória, com taxas de complicações mecânicas pós-operatórias semelhantes. Estudos futuros com maior casuística e seguimento são necessários para avaliar a quebra de hastes. ***Nível de Evidência III; Estudo retrospectivo comparativo.***

Descritores: Tuberculose da Coluna Vertebral; Aloenxertos; Complicações Pós-Operatórias; Cirurgia Geral.

RESUMEN

Objetivo: Este artículo científico describe un estudio longitudinal retrospectivo cuyo objetivo era comparar los resultados y las complicaciones mecánicas entre los pacientes que se sometieron al uso de aloinjerto estructural (AE) o jaula de titanio (JT) para la sustitución del cuerpo vertebral en el tratamiento de la tuberculosis en los segmentos torácico y lumbar. Métodos: La muestra estuvo compuesta por 22 casos de tuberculosis vertebral tratados quirúrgicamente, de los cuales 17 casos recibieron JT con autoinjerto, y cinco AE de banco de tejidos. La mediana de edad del grupo A fue de 32,1 años, y del grupo B de 5,2 años. Resultados: No hubo diferencia estadística en el número de vértebras extirpadas, la cantidad de niveles instrumentados y la corrección del valor angular en los planos coronal y sagital

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mediante el método de Cobb. Además, no hubo casos de subsidencia, rotura o desplazamiento del AE o JT hasta el último seguimiento postoperatorio. Sin embargo, en el grupo A se encontraron cuatro casos de rotura de las varillas metálicas, un caso de fallo en la unión proximal, y tres casos de infección de herida operatoria que requirieron desbridamiento y antibioticoterapia. Conclusión: El AE y las JT rellenas de hueso autólogo, para el soporte anterior de columna en sustitución de cuerpos vertebrales por tuberculosis, presentaron resultados similares en la corrección postoperatoria con tasas de complicaciones mecánicas postoperatorias similares. Se necesitan estudios futuros con una mayor casuística y seguimiento para confirmar estas conclusiones. ***Nivel de Evidencia III***; ***Estudio Retrospectivo Comparativo.***

Descriptores: *Tuberculosis de la Columna Vertebral; Aloinjertos; Complicaciones Postoperatorias; Cirugía General.*

INTRODUCTION

Tuberculosis (TB) is a pulmonary disease caused by infection by the *Mycobacterium tuberculosis* bacillus, whose existence dates back to 9000 BC, according to evidence of infection found in mummies from Egypt and Peru. Extrapulmonary TB is approximately 3%, of which 10% correspond to musculoskeletal TB, with the spine being the most affected site (50% of cases).[1,2] In its regard, spinal tuberculosis (STB) mainly occurs in the thoracolumbar region, following the bacillus spread from a primary site through Batson's paravertebral venous plexus or through arterial or lymphatic routes. Such disease usually originates in the subchondral cancellous bone, which holds an abundant vascular network, favoring contamination.[1,2]

Percivall Pott was the first to describe the vertebral attack of tuberculosis in 1779, observing the clinical triad of the disease's complications, namely: neurological deficit, occurring in 23% to 76% of patients; kyphotic deformity of the spine, in 29%; and paravertebral abscess, which might be the initial appearance of this disease.[3-6]

One of the first to propose surgical treatment for STB was Ménard[7] in 1894, using costotransversectomy to decompress the spinal cord to avoid violating the posterior ligaments. Despite temporarily improving symptoms due to abscess drainage, the lack of association with anterior column reconstruction for structural support resulted in symptom recurrence, with sequent progression of kyphosis. Later on, in 1960, Hodgson published the concept of radical anterior debridement followed by reconstruction using rib structural graft, known as the Hong Kong procedure.[6–8] With the later advent of antituberculosis chemotherapy, the clinical outcomes for patients with STB have shown substantial improvement (82%-95%),[9] leaving surgical treatment for patients with severe deformity, instability, intractable pain, or progressive neurological deficit.[1,9,10]

Among the various surgical approaches, posterior (PA) or combined approaches have been effective options in treating STB, although vertebrectomies might be necessary in cases of worsening deformity. Since Suk et al. first presented posterior-only vertebrectomy, it is a safe technique with lower morbidity when compared to the combined approach,[11,12] enabling circumferential decompression of the spinal cord and anterior column reconstruction using structural autografts or allografts (SA) as well as titanium mesh cages (TC). However, few studies have compared complications related to the adopted reconstruction methods.[10] This study compares results and mechanical complications among patients undergoing SA and TC use for vertebral body replacement to manage tuberculosis in thoracic and lumbar segments.

MATERIALS AND METHODS

Patient Data

The present study, approved by the Research Ethics Committee under protocol 44355820.2.0000.5273, was based on the retrospective evaluation of patient records admitted to a quaternary service in consecutive convenience sampling between November 2012 and July 2021, with surgeries performed by the same team. Inclusion criteria were: diagnosis of thoracic and lumbar spinal tuberculosis, confirmed by histopathological examination, in children and adults, with a single posterior approach or combined approach, followed by debridement, instrumentation, and anterior column reconstruction using TC or SA. Exclusion criteria were active pulmonary tuberculosis, cancer, non-contiguous spinal tuberculosis, and traumatic fracture.

The diagnoses were based on the results of histopathological examinations and radiological findings, including spinal radiography, computed tomography (CT), and magnetic resonance imaging to evaluate the destruction of the vertebral body and the presence of abscesses. This study comprises 22 surgically treated thoracolumbar STB patients, of which 17 used TC-containing autograft (group A), while 5 used SA from tissue banks (group B). Local kyphotic deformities were measured by Cobb angle between the superior and inferior endplates of the collapsed vertebral levels before and after surgery through lateral panoramic radiographs of the spine.

Preoperative Management

Whenever possible, patients underwent chemotherapy with antituberculosis drugs (IRPE) for at least 2 to 4 weeks before surgery. However, patients with significant neurological deficits were subjected to immediate spinal cord decompression, abdicating the time for antibiotic therapy. Surgical planning was elaborated according to the focus of infection, the involved spinal segment, radiographs, CT, and MRI. Two vertebrae above and below the involved segment were fused in patients with evident vertebral lesions.

Surgical procedure

After the induction of general anesthesia and neuromonitoring, patients subjected to the single posterior approach were placed in the prone position. Intraoperative fluoroscopy was used for marking the implicated vertebrae. A midline incision was made, exposing the spinous process, bilateral lamina, facet joints, transverse process, and part of the ribs that would be resected. Transpedicular screws were placed in the vertebrae according to the preoperative planning. Before vertebrectomy, a pre-molded temporary rod was placed to prevent movement during debridement. After the excision of part of the transverse process and ribs, the collapsed vertebrae, necrotic disc, and paravertebral abscesses were completely removed. The thoracic nerve roots were cut out in patients who underwent rib excision. After preparing the vertebral endplates, either SA or suited TC filled with autogenous rib and lamina bone were inserted at the projected site for reconstructing stability after visual macroscopic evaluation. Intraoperative fluoroscopy was used to confirm the position of the TC or SA. The temporary rod was replaced with 2 to 4 new rods.

In cases of combined approach, a retroperitoneal approach to the spine was used to perform massive debridement, endplate preparation, and placement of the anterior support device, followed by posterior instrumentation.

A subcutaneous drain was placed before suturing the incision. Excised vertebrae and necrotic tissues were sent for histopathological examination.

Postoperative Management

The drain was removed when the drainage flow remained lower than 100ml for 24 hours. All patients were treated with antituberculosis medication identical to the ones administered preoperatively for 12 to 18 months. Whenever possible, continuous use of thoracolumbar brace was prescribed for at least six months postoperatively. In all cases, physical examination, radiography, and CT were used to evaluate the conservation of curvature correction and the presence of mechanical complications such as SA or TC subsidence or migration, graft breakage, or resorption.

Statistical Analysis

Descriptive analyses for quantitative data were presented as means, followed by their respective standard deviations (±SD), medians, interquartile range (IQR), and minimum and maximum values. Categorical variables were expressed as frequencies and percentages.

Furthermore, t-Student, ANOVA, and Mann-Whitney tests were used to compare quantitative variables. Categorical variables were analyzed using Chi-Square or Fisher's Exact tests when necessary.

All analyses were performed using Sigma Plot software for Windows with a significance level of $\alpha=0.05$.

RESULTS

Ten male and twelve female patients were analyzed. The median age at the time of surgery was 32.11 (IQR 8.78-58.65) in group A (TC) and 5.19 (IQR 3.89-11.19) in group B (SA) (Table 1). The disease affected spinal segments: 8 cases in the thoracic segment, 11 cases in the thoracolumbar junction, and 3 cases in the lumbar segment. The postoperative follow-up time was similar in both groups. (Table 1)

Regarding perioperative data, the Cobb angles of the pre- and postoperative segmental kyphosis in group A were 51.5° and 17.2°, respectively, and in group B, were 50° and 15°, respectively (Table 2). The amount of metal rods used in the construct was divided into subgroups of 2, 3, and 4 rods to ensure greater similarity between the analyzed groups, as well as the number of excised vertebrae, divided into less than six and greater than or equal to 6 (Table 2). Operative time was similar in both groups.

As presented in Table 3, surgical complications were divided into clinical and mechanical complications. Dural tears occurred in one patient, pleural effusion in seven patients; and surgical site infection in three patients. Among the mechanical complications, one patient presented proximal junctional failure, and four presented rod breakage. There was no SA subsidence, breakage, resorption, or SA or TC migration in the postoperative follow-up in any of the evaluated groups. Computed tomography was used to analyze the bone graft consolidation to the adjacent terminal vertebral plates according to the Bridwell classification.[13] Complete graft consolidation (type 1) was observed in all patients.

Table 1. Demographic data and follow-up time of patients from the "Titanium Cage" group and "Structural Allograft" group.

	TC (n = 17)	SA (n = 5)	P
Age (years)	32.11 (iqr 9.50-58.66)	5.19 (iqr 2.81-25.89)	0.072
Gender			
Female	9 (52.94%)	3 (60.00%)	1.000
Male	8 (47.06%)	2 (40.00%)	
Follow-up (months)	40.69 (sd=36.45)	57.43 (sd=30.32)	0.390

IQR: Interquartile Range; SD: Standard deviation.

Table 2. Perioperative data from patients in the "Titanium Cage" group and "Structural Allograft" group.

	TC (N = 17)	SA (N = 5)	P
preoperative cobb	51.53 (sd ± 27.67)	50.00 (sd ± 55.20)	0.960
postoperative cobb	17.29 (sd ± 16.47)	15.00 (sd ± 17.56)	0.803
rods			
2	13	4	0.675
3	2	1	
4	2	0	
vcr			
<4	15	2	0.055
≥4	2	3	
instrumented levels			
<6	3	3	0.100
≥6	14	2	
pRBCs			
≤2	11	5	0.278
>2	6	0	
operative time (minutes)	409.69 (sd±115.51)	390.00 (sd±133.84)	0.777

SD: Standard Deviation; VCR: *vertebral column resection;* pRBCs: Packed red blood cells.

Table 3. Postoperative complications of patients from the "Titanium Cage" group and "Structural Allograft" group.

	TC (n = 17)	SA (n = 5)	P
Clinical Complications			
Dural Tear	0	1	1.000
Pleural Effusion	5	2	
Infection	3	0	
Total	8	3	
mechanical complications			
PJK	0	1	1.000
Rods Breakage	4	0	
Total	4	1	

PJK: Proximal Junctional Kyphosis.

DISCUSSION

Certain developing countries still show a high prevalence of spinal tuberculosis in children and adults.[10,14] The pathogen causes bone destruction with damage to the vertebral body, which doesn't necessarily affect the posterior bone structure. In pediatric patients, the potential growth of the anterior region is compromised. In contrast, posterior growth remains normal, predisposing to the appearance of a kyphotic deformity, especially during the rapid growth and development period of a child.[14] An early diagnosis is essential to initiate antituberculosis chemotherapy and minimize sequelae, improving the clinical outcomes.

The objectives of surgical treatment for spinal tuberculosis include removal of the focus of infection, complete neural decompression, reduction of vertebral deformity; and reconstruction of spinal stability.[14,15] To reconstruct the stability compromised by anterior bone loss and aggressive debridement, it is imperative to interpose structural support that reestablishes the spine integrity, which can be done with autologous or homologous structural grafts or with the use of titanium mesh cages. Ukunda et al. analyzed 24 patients diagnosed with thoracolumbar tuberculosis who underwent anterior spine reconstruction with interposition of structural allograft and obtained a satisfactory clinical and radiological outcome.[16] In summary, structural allografts have greater applicability when in difficulty of obtaining sufficient autograft from a donor site.[17-19] structural allografts for anterior column support have been reported since the 1950s when Cloward[20] described his series of 67 patients subjected to anterior spinal fusion using wedged allografts from the iliac crest. The benefits of this technique include immediate restoration of anterior support, elimination of donor site morbidity, reduction of operative time and blood loss, and rigid biological fixation. The disadvantages include longer fusion time, lower vascular penetration, and risk of transmitting diseases.[17,18,21]

Since developed by Jürgen Harms and Dieter Stoltze in 1987, titanium mesh cages filled with autologous or morselized and impacted allograft have been additional options to the use of structural grafts in vertebral body defects. They can replace intervertebral discs as well as one or more vertebrae. It fulfills the basic mechanical principles of resistance to anterior compressive loads, lateral flexion, axial rotation, and support for maximum static load without plastic deformation.[22,23] Zhang et al. evaluated the use of titanium cages in the surgical treatment of 28 adult patients with thoracolumbar tuberculosis through a posterior approach, proving the effectiveness and safety of both the technique and the intersomatic device, with improvement in pain levels as per the Oswestry Disability Index (ODI) and in the correction of segmental kyphosis, with no subsidence or instrumentation failure reported.[24] Similar results were found when evaluating adult patients with lumbar or lumbosacral tuberculosis who underwent the use of titanium cages and posterior fusion.[25,26]

The present study compares complication rates between the use of structural allograft versus a non-expandable titanium cage filled with autograft in the reconstruction of the anterior column through a single posterior or combined approach for treating spinal TB. Despite showing no significant differences in mechanical complications such as proximal junctional failure, it evidences higher rod failure rates in the allograft group (with no statistically significant difference) despite having comparable additional rods in both groups. With the same objective, another study that analyzed patients with spinal tuberculosis who underwent reconstructive surgery for a minimum of five years concluded that although both methods were effective, the titanium cage could provide superior postoperative clinical outcomes when more than two spine segments were resected.[10] This comparison between allograft and titanium cage was previously performed by Cardenas et al. in a cadaveric biomechanical model, showing similar fibular graft stiffness to that of metal devices.[27]

Most patients in the present study underwent vertebral body replacement through a single posterior approach. Despite being a more demanding technique with greater neurological risks,[12] is more common, generally avoiding the need for an additional surgeon for the associated anterior approach.

It is worth noting some clinical experiences with effective results regarding the single posterior approach for the surgical treatment of thoracic or thoracolumbar tuberculosis, such as those published by Wang et al.[15] after analyzing 32 patients who underwent titanium cage filled with allograft. Similarly, Zhang et al.[24] presented a case series with 28 patients treated through a single posterior approach with titanium mesh cages filled with auto or allograft, with a four-year follow-up period, proving it to be an effective and safe method, capable of preserving sagittal balance throughout follow-up. Nonetheless, a study by Assaghir et al.[28] comparing anterior versus posterior approaches for single-level thoracic tuberculosis concluded that both approaches provide rigid consolidation and conservation of kyphosis correction.

Finally, it should be noted that the present study has limitations that must be acknowledged to ensure proper interpretation. First, the low statistical population of the study does not allow for subanalyses, even when comparing a specific disease. Additionally, the titanium cage group had a higher number of instrumented vertebrae when compared to the allograft group, which provided additional support for anterior column reconstruction. This difference, however, was not statistically significant, possibly due to the reduced number of treated patients. Lastly, additional comparison between structural autograft versus structural allograft and non-structural autograft versus non-structural allograft filling the titanium cage may be advisable to avoid possible clinical biases.

CONCLUSION

The use of structural allograft and titanium cages for anterior column support and vertebral body replacement in treating tuberculosis demonstrated similar rates of postoperative mechanical complications ($p = 1.0$). Future studies with larger samples and follow-up periods are needed to evaluate the emergence of complications.

All authors declare no potential conflict of interest related to this article.

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REFERENCES

1. Ali A, Musbahi O, White VLC, Montgomery AS. Spinal Tuberculosis: A Literature Review. JBJS Rev. 2019;7(1):e9.
2. Rajasekaran S, Soundararajan DCR, Shetty AP, Kanna RM. Spinal Tuberculosis: Current Concepts. Glob Spine J. 2018;8(4 Suppl):96S-108S.
3. Tuli SM. Historical aspects of Pott's disease (spinal tuberculosis) management. Eur Spine J. 2013;22(Suppl 4):529-38.
4. Chen CH, Chen YM, Lee CW, Chang YJ, Cheng CY, Hung JK. Early diagnosis of spinal tuberculosis. J Formos Med Assoc. 2016;115(10):825-36.
5. Alavi SM, Sharifi M. Tuberculous spondylitis: Risk factors and clinical/paraclinical aspects in the south west of Iran. J Infect Public Health. 2010;3(4):196-200.
6. Rajasekaran S, Kanna RM, Shetty AP. History of spine surgery for tuberculous spondylodiscitis. Unfallchirurg. 2015;118(Suppl 1):19-27.
7. Ménard VA. Causes of paraplegia in Pott's disease, its surgical treatment by direct opening of the vertebras [Article in French]. Orthop Rev (Pavia). 1984.
8. Hodgson AR, Stock FE. Anterior Spine Fusion for the Treatment of Tuberculosis of the Spine. J Bone Jt Surg. 1960;42(2):p 295-310. doi:10.2106/00004623-196042020-00009.
9. Gao Y, Ou Y, Deng Q, He B, Du X, Li J. Comparison between titanium mesh and autogenous iliac bone graft to restore vertebral height through posterior approach for the treatment of thoracic and lumbar spinal tuberculosis. PLoS One. 2017;12(4):e0175567.
10. Zhang HQ, Li M, Wang YX, Tang MX, Guo CF, Liu SH, et al. Minimum 5-Year Follow-Up Outcomes for Comparison Between Titanium Mesh Cage and Allogeneic Bone Graft to Reconstruct Anterior Column Through Posterior Approach for the Surgical treatment of Thoracolumbar Spinal Tuberculosis with Kyphosis. World Neurosurg. 2019;127:e407-15.
11. Suk SI, Kim JH, Kim WJ, Lee SM, Chung ER, Nah KH. Posterior Vertebral Column Resection for Severe Spinal Deformities. Spine (Phila Pa 1976). 2002;27(21):2374-82.
12. Garcia PBL, Silva LECT da, Barros AGC de, Almeida LEPCA de. Posterior Vertebral Column Resection (Pvcr): A Safe and Effective Option to Treat Kyphosis from Spinal Tuberculosis. Coluna/Columna. 2021;20(1):42-6.
13. Bridwell KH, Lenke LG, McEnery KW, Baldus C, Blanke K. Anterior fresh frozen structural allografts in the thoracic and lumbar spine. Do they work if combined with posterior fusion and instrumentation in adult patients with kyphosis or anterior column defects?. Spine. 1995;20(12):1410-8.
14. Zhang H, Guo Q, Wang Y, Guo C, Tang M. The efficiency of the posterior-only approach using shaped titanium mesh cage for the surgical treatment of spine tuberculosis in children: A preliminary study. J Orthop Surg (Hong Kong). 2018;26(3):2309499018806684.
15. Wang B, Hua W, Ke W, Zhang Y, Zeng X, Yang C. The efficacy of allograft bone using titanium mesh in the posterior-only surgical treatment of thoracic and thoracolumbar spinal tuberculosis. BMC Surg. 2020;20(1):133.
16. Ukunda UNF, Lukhele MM. The posterior-only surgical approach in the treatment of tuberculosis of the spine: outcomes using cortical bone allografts. Bone Joint J. 2018;100-B(9):1208-13.
17. Ehrler DM, Vaccaro AR. The use of allograft bone in lumbar spine surgery. Clin Orthop Relat Res. 2000;(371):38-45. doi:10.1097/00003086-200002000-00005.
18. Vaccaro AR, Cirello J. The use of allograft bone and cages in fractures of the cervical, thoracic, and lumbar spine. Clin Orthop Relat Res. 2002;(394)19-26. doi:10.1097/00003086-200201000-00003.
19. Buttermann GR, Glazer PA, Bradford DS. The use of bone allografts in the spine. Clin Orthop Relat Res. 1996;(324):75-85 doi:10.1097/00003086-199603000-00010.
20. Cloward RB. The Treatment of Ruptured Lumbar Intervertebral Disc by Vertebral Body Fusion: III. Method of Use of Banked Bone. Ann Surg. 1952;136(6):987-92. doi:10.1097/00000658-195212000-00011.
21. Singh K, DeWald CJ, Hammerberg KW, DeWald RL. Long structural allografts in the treatment of anterior spinal column defects. Clin Orthop Relat Res. 2002;(394):121-9. doi:10.1097/00003086-200201000-00014.
22. Pitzen T, Jeszenszky D, Stoltze KD, Ostrowski G, Ruf M. A passion for the spine: Tribute to Jürgen Harms on his 75th birthday. Orthopade. 2019;48(12):1048-56.
23. Abdeen K. Efficacy of Titanium Mesh Cages for Anterior Column Reconstruction after Thoracolumbar Corpectomy. Asian Spine J. 2016;10(1):85-92.
24. Zhang H, Zeng K, Yin X, Huang J, Tang M, Guo C. Debridement, internal fixation, and reconstruction using titanium mesh for the surgical treatment of thoracic and lumbar spinal tuberculosis via a posterior-only approach: a 4-year follow-up of 28 patients. J Orthop Surg Res. 2015;10:150.
25. Guo CF, Zhang HQ, Gao Q, Liu JY, Wu JH. [Debridement, internal fixation, and reconstruction with titanium mesh for the surgical treatment of lumbar tuberculosis via a posterior-only approach in adults]. Zhongguo Gu Shang China J Orthop Traumatol. 2017;30(5):406-10.
26. Wang YX, Zhang HQ, Liao W, Tang MX, Guo CF, Deng A, et al. One-stage posterior focus debridement, interbody graft using titanium mesh cages, posterior instrumentation and fusion in the surgical treatment of lumbo-sacral spinal tuberculosis in the aged. Int Orthop. 2016;40(6):1117-24.
27. Cardenas RJ, Javalkar V, Patil S, Gonzalez-Cruz J, Ogden A, Mukherjee D, et al. Comparison of allograft bone and titanium cages for vertebral body replacement in the thoracolumbar spine: a biomechanical study. Neurosurgery. 2010;66(6 Suppl Operative):314-8.
28. Assaghir YM, Refae HH, Alam-Eddin M. Anterior versus posterior debridement fusion for single-level dorsal tuberculosis: the role of graft-type and level of fixation on determining the outcome. Eur Spine J. 2016;25(12):3884-93.