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Anterior Cervical Corpectomy and Fusion and Anterior Cervical Discectomy and Fusion Using Titanium Mesh Cages for Treatment of Degenerative Cervical Pathologies: A Literature Review

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Anterior cervical corpectomy and fusion (ACCF) and anterior cervical discectomy and fusion (ACDF) are 2 effective and safe surgical treatments of degenerative cervical pathologies and are associated with a high percentage of excellent clinical outcomes when a graft or device must be used during the surgery, such as an allograft, autograft, nano-hydroxyapatite/polyamide cages, poly-ether-ether-ketone (PEEK) cages, and titanium mesh cages (TMCs). Although TMCs have been used in cervical surgeries for almost 2 decades, no specific reviews have been performed introducing the state of this material. Thus, in the present review, we discuss the status of using TMCs in anterior cervical surgeries.

Studies that tested the usage of TMCs in treating degenerative cervical pathologies were included in this review. The development and progress of TMCs, the biomechanical analysis of TMCs, the radiological and clinical assessment of TMCs, the advantages and disadvantages of using TMCs, and their prospects for future applications as a device of ACCF and ACDF in treating degenerative cervical pathologies are discussed.

Studies included in this review showed that TMCs can provide sufficient biomechanical stability. Furthermore, the TMCs used in anterior cervical fusion avoid the donor-site morbidity and achieve a solid bony fusion. However, there are some shortcomings. The structural characteristics and the design of TMCs cause the TMC subsidence rate to remain high, thus resulting in multiple related complications.

We believe that due to the virtues of TMCs, they are worthy of application and promotion. However, the structure of TMCs should be further optimized to reduce the TMC subsidence rate and subsidence-related complications, ultimately achieving excellent clinical results.

MeSH Keywords: **Cervical Vertebrae • Neck Pain • Patient Outcome Assessment • Spinal Cord Compression • Spinal Fusion • Titanium**

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Background

The first report on the anterior approach to the cervical spine was introduced by Robinson and Smith [1]. Due to its safety and efficacy in treating degenerative cervical pathologies, anterior cervical fusion is becoming more popular in cervical surgery and is associated with a high percentage of good clinical outcomes [2–4]. Anterior cervical corpectomy and fusion (ACCF) and anterior cervical discectomy and fusion (ACDF) are 2 effective procedures for decompression of the spinal cord in patients with serious canal stenosis and reconstruction of cervical lordosis [5–7]. When compression is limited only to the disc level, ACDF is superior to ACCF because it entails less blood loss, short hospitalization, and fewer postoperative complications. However, when the compression is extended to the vertebral body levels, ACCF is much preferred over ACDF because it can achieve satisfactory decompression at the vertebral body levels [5–7]. Many bone graft materials and devices have been developed and used for reconstruction of cervical lordosis and restoration of intervertebral height after corpectomy. Autografts, including iliac crest grafts and fibula grafts, were first introduced for vertebral body reconstruction. The autograft has been regarded as the criterion standard among bone graft materials for several decades because of its excellent bony fusion rate [8]. However, problems in the donor site can occur, such as blood loss, infection, hematoma, and donor-site pain, which restrict its widespread use [9,10]. To solve these problems, the allograft was created and used as an option for reconstruction of the vertebral body. Although it avoids donor-site complications, allograft has been found to lead to a low fusion rate and high rate of graft collapse [11]. Due to these pitfalls, some new devices, such as nano-hydroxyapatite/polyamide cages, poly-ether-ether-ketone (PEEK) cages, and titanium mesh cages (TMCs), filled with cancellous morselized bone, were developed and used as alternatives for vertebral body reconstruction. Due to the immediate load-bearing ability of TMCs, when the vertebral body is involved, resected vertebral fragments will fill into TMCs, and if the lesion is limited to disc level, a smaller quantity of autologous bone graft from the iliac crest and other autograft bone regions will be put into TMCs instead of a structural bone graft piece. To date, there are no specific reviews on the status of using TMCs in anterior cervical surgeries; thus, we will discuss the status of using TMCs in anterior cervical pathologies, including the development and progress of TMCs, the biomechanical analysis of TMCs, the radiological and clinical assessment of TMCs, the advantages and disadvantages of using TMCs, and their prospects for future applications.

The Development and Progress of TMCs

The use of TMCs was first introduced in 1986 [12]. Since then, TMCs have been used widely for spinal reconstruction. TMCs are fixed cylindrical devices that can be filled with autologous bone to provide structural support for the anterior column and reconstruct the natural alignment of the spine. In 2001, Kandziora et al. [13] introduced some designs of titanium cages, including screw-design titanium cages, box-design titanium cages, and cylinder titanium mesh cages. By comparing their biomechanical characteristics in a sheep model after ACDF, they suggested that cylinder-design TMCs were able to contain extension and lateral bending more effectively than cages with other designs [13]. The traditional cylinder-design TMCs are still used widely in cervical surgery [14–19]. Besides these traditional TMCs, more kinds of TMCs were introduced to be used in degenerative cervical diseases. To increase the contact area with the adjacent endplate, an end ring or endcaps have been added to traditional TMCs [20–24], the design of endcaps was to prevent telescoping in order that to increase the titanium mesh cage (TMC)'s maximum load-bearing ability but not affect the device's stiffness [25]. However, the clinical outcomes prove that the subsidence rate of the TMCs with endcaps design remains high because the endcaps are flat and are not in accordance with the endplate [26]. In addition, by using electron-beam melting technique, Wu et al. [26] developed a new porous titanium cage to reduce its elastic modulus and compared its spinal fusion rate with a PEEK cage in a sheep cervical model. The titanium cage eliminates the need for bone grafting to stuff the cage, which greatly simplifies the surgical procedure and makes it very suitable for patients with inadequate autografts [26]. Yang et al. [27] fabricated a novel artificial vertebral body by electron-beam melting for cervical vertebral body replacement in a sheep model. They constructed a new 3D-printed porous TMC and showed that this new type of TMC could maintain the cervical stability of sheep. Although these porous TMCs have not been applied in human surgery, they have great potential in clinical applications. Recently, a new type of TMC was introduced to replace the traditional TMCs. Yu et al. [28] designed a new type of TMC which fully matches the adjacent endplate morphology, consisting of a hollow reticular cylinder body with 2 endcaps; however, in contrast to the previously introduced endcaps design, the superior endcap of the new TMC is curved at both ends, its inferior endcap has an oblique angle parallel to the superior endplate of the adjacent vertebral, and the ring border of both side endcaps exceeds the edge of the cylindrical body to increase the contact area between cages and endplates. To eliminate the complications associated with the traditional TMCs, Liu et al. [23] designed a new type of TMC and compared the efficacy and safety with traditional TMCs in the treatment of continuous 3-level cervical spondylotic myelopathy. The new TMC has 2 unique characteristics: one is that the superior endcap is curved to fit the inferior endplate and has paralleled grooves to prevent displacement backward, and the other is that the inferior endcap is designed with an angle that tilts upward and backward to fit the superior endplate.

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Lu et al. [24] evaluated radiological and clinical outcomes of using a new 3D-printed anatomy-adaptive titanium mesh cage (AA-TMC) for single-level ACCF in patients with degenerative cervical diseases. Their new type of TMC includes several notable features: its superior end has a fornix shape; the inferior end of the AA-TMC has an oblique shape with an angle upward and backward; a supporting end ring is added to the end of the AA-TMC; and in the axial plane, the dorsal and bilateral sides of the AA-TMC are flat and heart-shaped. In addition, there are several sizes of AA-TMC with different heights and widths available, so the surgeon can choose the most suitable cages instead of trimming the TMC, which can cause cage subsidence. With these new types of TMCs, the design is becoming more precise to fit the adjacent vertebral bodies, and its efficacy and safety will be verified in more clinical cases.

The Biomechanical Analysis of TMC Use

The normal spinal angle has a lordotic alignment in cervical and lumbar vertebra and a kyphotic alignment in thoracic and sacral vertebra. Normal movement of the spine includes extension, flexion, lateral bending, and axial rotation. Thus, to maintain the lordosis of the cervical vertebra and intervertebral disc height after ACCF or ACDF, an interbody fusion cage must be used. As for TMCs, biomechanical studies of human and other animals should be performed to verify the feasibility for keeping the normal motion of the cervical vertebra. Zdeblick et al. [29] introduced a cervical interbody fusion cage in an animal model, analyzing the use of an intervertebral fusion device after anterior cervical discectomy in the goat cervical spine. Biomechanical testing was done to compare the biomechanical stiffness among TMCs, hydroxyapatite-coated BAK cages, and recombinant human bone morphogenetic protein-2-filled cages, showing no significant differences in the mean biomechanical stiffness data in axial compression, torsion, flexion, extension, and lateral bending among 3 groups. In 2001, Kandziora et al. [30] conducted an *in vitro* biomechanical comparison of cervical fusion cages having various structures in a sheep model after ACDF. They concluded that compared with the intact motion segment, the TMCs with cylinder-design had significantly better flexion, extension, and rotation stiffness, and the rotation stiffness of the cages increased with the endplate-implant contact area. In comparison with bone grafts, all TMCs with cylindrical designs had significantly lower flexion stiffness and the bending stiffness was significantly greater, but the extension stiffness was not different. They also are more effective than titanium cages with a screw design. As it was an *in vitro* study in a sheep model, Kandziora et al. [31] conducted an *in vivo* study comparing the different designs of cages after ACDF in a sheep model. The mean stiffness value in axial rotation and lateral bending was significantly higher in cylinder-design TMCs filled with autologous iliac crest bone graft than with autologous tricortical iliac crest bone graft and box-design titanium cages filled with autologous iliac crest bone graft, and the range of motion (ROM) in rotation was significantly lower in cylinder-design TMCs than in the other groups. However, these *in vivo* results are in crucial contrast to *in vitro* results obtained by them. In their previous *in vitro* study [30], they demonstrated significantly higher stiffness for box-design cages than for the cylinder-design cages, suggesting that biomechanical *in vitro* studies have poor ability to predict the *in vivo* effect of interbody fusion cages. In attempts to overcome the technical problems associated with nonexpandable cages, a new expandable cage has been introduced for vertebral body replacement in the cervical spine. Kandziora et al. [32] compared the biomechanical properties of expandable and nonexpendable TMCs in the human cervical spine, demonstrating that in comparison with the intact motion segment, all implants significantly increased stiffness in flexion and bending, but decreased stiffness in extension, which was in accordance with their previous studies [30,31], and there were no biomechanical differences between the nonexpandable and expandable TMCs. Additional anterior plating significantly increased biomechanical stiffness in all test modes, which was recommended in cervical vertebral body replacement [32,33]. Pflugmacher et al. [33] found no significant difference in ROM and segmental stiffness between the tricortical iliac crest bone graft and TMCs, which is consistent with another study [32]. In 2011, Zhou et al. [34] compared 3 types of stabilization techniques after cervical discectomy and fusion in goats, showing that in all loading modes, the ROM values were lower in TMCs filled with autologous cancellous bone graft and multi-amino acid copolymer/α-tricalcium phosphate interbody fusion cages filled with autologous cancellous bone graft than that in autologous tricortical iliac crest bone grafts. In 2013, due to the traditional titanium cage's greater elastic modulus than natural bone, Wu et al. [26] developed a porous titanium cage to reduce its elastic modulus and compared it with a PEEK cage in a sheep anterior cervical fusion model. The results demonstrated that the porous titanium cages promoted significantly higher mechanical stability than the conventional PEEK cage. Several biomechanical studies have been performed to analyze the biomechanical factors related to TMC subsidence [35–44]. Lu et al. [41] concluded that there are 3 biomechanical factors associated with TMC subsidence: the condition of the endplate, the bone mineral density (BMD), and the TMC-endplate interface. When the endplate is completely removed from the adjacent vertebral body, the maximum load is much lower than that of an intact vertebra [35,37–39,43], and the maximum load decreased with decreased BMD, which caused the TMC more easily penetrate the vertebral body [35,36,40]. In addition, a TMC with a larger diameter is advocated because of the benefits of relying on a larger TMC-endplate interface contact area and a larger volume for bone grafting [36,38,40].

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The Radiological and Clinical Assessment of TMCs

In addition to biomechanical analysis of TMCs, the radiological and clinical outcomes of using TMCs after ACCF or ACDF should be assessed preoperatively, immediately after surgery, and at next follow-up. Radiological evaluations, including the static and dynamic lateral radiographs and computed tomographic (CT) scans, are used to estimate the bony fusion status. We also need to use dynamic lateral radiographs to evaluate the cervical alignment changes and the relationship between the TMC and adjacent endplates. There are also other parameters used to assess the radiological outcomes after using TMCs. The coronal angle and the sagittal angle were assessed to evaluate the radiological stability of TMCs [25], and the sagittal displacement ratio was assessed to estimate the morbidities of graft collapse, extrusion, and segmental kyphosis [45]. Narotam et al. [25] and Chuang et al. [45] found that after using TMCs, no patients experienced significant instability of coronal and sagittal angles, and there was minimal change in sagittal displacement, which means the stability of the cervical segment after using TMCs remains good. The symptoms before surgery, such as neck and arm pain, and other neurological deficits improved in almost all of the patients after surgery [14,23,24,45–47]. For clinical outcomes, the Japanese Orthopedic Association (JOA) scoring system is used to assess the improvement rate of relevant segmental function, and the visual analog scale (VAS) and the neck disability index (NDI) are used to compare the degree of pain before and after surgery. Numerous studies have demonstrated an overall improvement in criteria scores immediately after surgery and at next follow-up, accompanied by disappearance of neurological symptoms [14,23,24,28,45,48–50]. TMC subsidence is another phenomenon frequently observed in the postoperative period. A study of TMC subsidence compared a mild group (1~3 mm) with a severe group (>3 mm), showing that the mild group did not have significantly different clinical outcomes, but the severe group was correlated with risky neurological outcomes [20]. Multiple studies have confirmed that TMC subsidence is very high (up to 90%) and leads to subsidence-related complications such as neck pain, neurological deterioration, and instrument failures [20,22,28,45,49,51,52]. In several recent studies, the new type of TMCs showed a lower rate of subsidence [23,24,28] than with traditional TMCs. Yu et al. [28] compared the efficacy and safety of a new type of TMC versus the traditional TMC for single-level ACCF. With respect to TMC subsidence, they found that there was a significantly lower rate of subsidence with the new type of TMC (4%) than with the traditional TMC (17%), and postoperative neck pain was worse when using the traditional TMC. In addition, subsidence was reported to be strongly correlated with neck pain, but the exact correlation between them remained unclear [20,28]. Severe subsidence can lead to multiplex complications. Cervical alignment changed to kyphosis after severe subsidence [7]. In addition, it led to the buckling of the ligamentum flavum and stenosis of the neural foramen, which results in recompression to the nerve roots and spinal cord [20,22,28]. Subsidence also puts more stress load on the anterior plate and screws, which can result in instrument failure such as plate breakage and screw back-out [16,47,53]. For bone fusion, most studies have shown that almost all patients using TMCs achieved solid bone fusion at their final follow-up [14,20,23–25,28,45,51,54–56]. Furthermore, the mean time to achieve solid fusion was 5~7 months [20,50,57,58].

The Advantages and Disadvantages of Using TMCs

The first advantage of using TMCs is a reduction in donor-site morbidity. Autografts such as the iliac crest, fibula, and ribs can result in multiple complications, including blood loss, infection, hematoma, and donor-site pain [9,10]. TMCs provide structural support to the anterior column without an autograft harvesting. Alternatively, grafts from resected vertebral bodies after corpectomy and a lower-quantity autografts from the iliac crest or fibula after discectomy can be filled into and around the TMC. It not only utilizes the resected vertebral fragments to regrow inside and around the TMC to promote bony fusion, but also reduces excessive damage to the autograft Many published studies have reported that almost all patients receiving TMCs achieved a solid fusion at their final follow-up [45–47]. In a meta-analysis, Seaman [59] compared TMCs and PEEK interbody fusion, showing that TMC and PEEK cages have comparably high fusion rates. In addition, Yang et al. [49] compared the anterior cervical fusion by TMC and nano-hydroxyapatite/polyamide cage following single-level corpectomy and found that at 4-year follow-up, the fusion rates of both groups were similarly high. Due to the superior corrosion resistance and low density of TMCs, as well as the ability to enhance cell adhesion and osseointegration, a TMC is more likely to be recommended for use in anterior cervical fusion [59,60]. Finally, TMCs provide immediate restoration of cervical alignment, enlargement of a stenotic neural foramen, and stabilization of degenerative pathologies [51,54,61].

Although there are benefits in using TMCs, pitfalls still exist. First, the cost of anterior cervical fusion using TMCs is much higher than with autografts and allografts, and Majd et al. [62] reported that surgery using a TMC is much more expensive than with a fibular allograft. Rieger [14] reported that the price of TMCs is higher than with conventional techniques harvesting from a second donor site. Second, TMC is a metallic material that can cause metallic artifacts in follow-up CT and MRI scans [14,25], so it is more difficult to evaluate the efficacy of decompression of the spinal cord postoperatively.

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Third, although the fusion rate is high, the radiological determination of solid fusion remains difficult because the TMC is not radiolucent and sometimes cannot be distinguished from the solid fusion on plain radiography. A solid bony fusion is diagnosed on the basic of these radiological evidence: the appearance of bridging trabecular bone at the interface between the TMC and adjacent endplates, the absence of lucencies between TMC and endplate; no movement between TMC and endplate, and the absence of anterior plate breakage and screw dropout [12,24,45,52,58]. If the fusion status is doubtful, CT scans are further performed to verify the fusion status. To solve this problem, the authors placed additional cancellous bone graft anterior and posterior to the TMC in the operation because it is easier to estimate fusion status in these areas outside the TMCs [63,64]. Fourth, the TMC subsidence rate is reported to be high. In most TMC fusion cases, the inferior cage-endplate contact was limited at the posterior rim of the TMC, which induces subsidence in the upper endplates of the caudal vertebral bodies [20]. TMC is more likely to occur at the posterior area of the caudal body because the TMC was placed in the anterior two-thirds of the endplates, which causes the posterior rim of the TMC to be in direct contact with the central region of the caudal endplate, which the weakest region of the vertebral body [7,38,40]. Another reason is that cervical lordosis and superior endplate is oblique whereas the inferior part of TMC is flat, and the mismatch between them results in a small contact area and a large stress concentration [20,22]. Fifth, the elastic modulus of titanium is 110GPa is much higher than that of natural bone (0.05~30GPa) [65], causing the stress-shielding effect. The stress shielding allows the TMC to sustain load-bearing after cervical fusion, consequently leading to bone resorption of the adjacent vertebral body [26].

Future Directions

Due to the potential donor-site complications of autografts [9,10] and low bony fusion rate and graft collapse of allografts [11], the alternative devices such as nano-hydroxyapatite/polyamide cages, PEEK cages, and TMCs were introduced for anterior cervical reconstruction. Many previous studies have reported on the efficacy and safety of traditional TMCs used in treating degenerative cervical diseases [45,47,53,54,57,66]. Although it avoids the donor-site morbidities and achieves a solid bony fusion, complications such as TMC subsidence still occur at follow-up [20,22,66]. In recent years, a new type of TMC was designed to reduce the subsidence rate of TMCs [23,24,28]. Although these new types of TMCs differ from each other, the first principle is to match the anatomy of the TMC design with the adjacent endplates and increase the contact area between them. Yu et al. [28] and Liu et al. [23] compared the radiological and clinical outcomes of new types of TMCs and traditional TMCs, showing the subsidence rate is significantly lower in new-type TMCs. The new TMCs exist have several drawbacks. For example, excessive distraction of adjacent vertebral bodies needs to be done during the implantation of new-type TMCs, which may cause destruction of the vertebra. Moreover, if the anterior surface of the new-type TMC is flat, is it possible to change the flat surface into a curved surface in accordance with the normal alignment of the cervical vertebra? We believe that in the near future, a more suitable type of TMC will be designed and used for treating anterior cervical fusion.

Conclusions

Considering the sufficient biomechanical stability of TMCs and advantages of the TMCs in avoiding donor-site complications and achieving a high fusion rate, TMCs are worth promoting for use in degenerative cervical pathologies. However, new anatomy-adaptive TMCs should be designed to reduce the TMC subsidence rate and associated complications, leading to improved clinical prognosis.

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