

Bone graft substitutes

Clinical Policy ID: CCP.1232

Recent review date: 5/2025

Next review date: 9/2026

Policy contains: Bone graft substitutes; recombinant human bone morphogenetic protein-2.

AmeriHealth Caritas Ohio has developed clinical policies to assist with making coverage determinations. AmeriHealth Caritas Ohio's clinical policies are based on guidelines from established industry sources, such as the Centers for Medicare & Medicaid Services (CMS), state regulatory agencies, the American Medical Association (AMA), medical specialty professional societies, and peer-reviewed professional literature. These clinical policies along with other sources, such as plan benefits and state and federal laws and regulatory requirements, including any state- or plan-specific definition of "medically necessary," and the specific facts of the particular situation are considered, on a case by case basis, by AmeriHealth Caritas Ohio when making coverage determinations. In the event of conflict between this clinical policy and plan benefits and/or state or federal laws and/or regulatory requirements, the plan benefits and/or state and federal laws and/or regulatory requirements shall control. AmeriHealth Caritas Ohio's clinical policies are for informational purposes only and not intended as medical advice or to direct treatment. Physicians and other health care providers are solely responsible for the treatment decisions for their patients. AmeriHealth Caritas Ohio's clinical policies are reflective of evidence-based medicine at the time of review. As medical science evolves, AmeriHealth Caritas Ohio will update its clinical policies as necessary. AmeriHealth Caritas Ohio's clinical policies are not guarantees of payment.

Coverage policy

The following bone graft substitutes are clinically proven and, therefore, may be medically necessary for enhancement of bone healing (Fischer, 2013; Laurencin, 2006; McNamara, 2015; Papageorgiou, 2016):

- Autograft based, used alone.
- Allograft-based, allograft bone used alone or in combination with other materials, including demineralized bone matrix.
- Ceramic or polymer-based synthetic bone graft substitutes, used alone or in combination with other materials.
- Bone graft substitutes containing an organic bone material (e.g., bovine or coral) when used alone or combined with another medically necessary bone graft substitute.

Recombinant human bone morphogenetic protein-2 is clinically proven and, therefore, may be medically necessary when used in accordance with U.S. Food and Drug Administration approved indications and labelling instructions:

- INFUSE® Bone Graft (Medtronic Inc., Minneapolis, Minnesota) for:
 - Primary treatment for skeletally mature members with acute, open tibial shaft fractures stabilized with intramedullary nail fixation after appropriate wound management, if applied within 14 days after the initial fracture (U.S. Food and Drug Administration, 2004).
 - Dental localized alveolar ridge augmentation for defects associated with extraction sockets and sinus augmentation (U.S. Food and Drug Administration, 2007).

- INFUSE® Bone Graft LT-CAGE (Medtronic, Inc., Minneapolis, Minnesota) when used only with the INFUSE Bone Graft for single-level lumbar spinal fusion and all of the following criteria (U.S. Food and Drug Administration, 2002):
 - When autologous iliac crest bone graft is not feasible.
 - Skeletally mature patients (older than 18 years of age or no radiographic evidence of epiphyseal closure) with degenerative disc disease from L4 to S1; grade I spondylolisthesis at the involved level may be present.
 - At least six months of non-operative treatment.
 - Using an anterior open or laparoscopic approach.

Limitations

All other uses of bone graft substitutes are considered experimental/investigational and not clinically proven.

Mesenchymal stem cell therapy is considered experimental/investigational and not clinically proven for all orthopedic applications, including, but not limited to, use in repair or regeneration of musculoskeletal tissue (Killington, 2018).

Allograft bone products containing viable stem cells are considered experimental/investigational and not clinically proven for all orthopedic applications, including, but not limited to, demineralized bone matrix with stem cells.

All other uses of recombinant human bone morphogenetic protein-2 are considered experimental/investigational and not clinically proven.

Contraindications to the INFUSE Bone Graft include, but are not limited to:

- Known hypersensitivity to the components of the formulation or the titanium cage.
- Near the vicinity of a resected or extant tumor, any active malignancy, or a malignancy undergoing treatment.
- Active infection at the operative site.
- Inadequate neurovascular status.
- Compartment syndrome of the affected limb.
- Pregnancy.

Alternative covered services

No alternative covered services were identified during the writing of this policy.

Background

Bone grafting is a surgical procedure that replaces missing bone with material from patient's own body, or an artificial, synthetic, or natural substitute. Bone grafting exploits the bone tissue's ability to regenerate completely if provided the space into which to grow. As natural bone grows, it generally replaces the graft material completely, resulting in a fully integrated region of new bone.

Autologous cancellous bone graft remains the gold standard, because it provides the three elements required for bone regeneration: osteoconduction, osteoinduction, and osteogenic cells (Grabowski, 2013). The complications and morbidity from harvesting autologous bone have driven the search for reliable and safe bone graft substitutes (Giannoudis, 2005).

Bone graft substitutes include cancellous and cortical allograft bone, ceramics, demineralized bone matrix, bone marrow, and composite grafts. Currently, no single alternative graft material provides all three elements for bone regeneration. Synthetic bone substitutes or xenografts can be used as an alternative to autologous graft to overcome problems of additional surgeries or limited graft availability, but synthetic grafts, often made of

hydroxyapatite or other naturally occurring and biocompatible substances, lack osteoinductive or osteogenic properties. Composite grafts combine scaffolding properties with biological elements, such as demineralized bone matrix or bone derivatives, to stimulate cell proliferation and differentiation and, eventually, osteogenesis. Xenografts, such as a bovine species, are used as a calcified matrix (Grabowski, 2013).

Classification of bone grafts is based on material, grouped as follows (Laurencin, 2006):

- Autograft-based — used alone. Properties of action are osteoconductive, osteoinductive, and osteogenic.
- Allograft-based — allograft bone used alone or in combination with other materials. Properties of action are osteoconductive and osteoinductive.
- Natural and recombinant growth factor-based — used alone or in combination with other materials. Properties of action are osteoinductive and both osteoconductive and osteoinductive with carrier materials.
- Cell-based — used to generate new tissue alone or seeded onto a support matrix. Properties of action are osteogenic and both osteogenic and osteoconductive with carrier materials.
- Ceramic-based — calcium phosphate, calcium sulfate, and bioactive glass used alone or in combination. Properties of action are osteoconductive and limited osteoinductive when mixed with bone marrow.
- Polymer-based — degradable and nondegradable polymers used alone and in combination with other materials. Properties of action are osteoconductive and bioresorbable in degradable polymer.
- Miscellaneous — uses coral hydrogel-hydroxyapatite granules, blocks, and composite. Properties of action are osteoconductive and bioresorbable.

Findings

Clinical guidelines

For spinal fusion, the North American Spine Society (2014) evaluated four randomized controlled trials (n = 577) and found insufficient evidence to recommend either autologous bone grafts or substitutes for posterolateral fusion in degenerative lumbar spondylolisthesis. The largest trial (n = 335) reported no significant differences in clinical outcomes between recombinant human bone morphogenetic protein-7 putty and iliac crest harvest, though the putty led to less bridging bone formation but reduced operative time and blood loss. Smaller trials showed comparable fusion rates, function, and safety for calcium sulfate with local bone or coral hydroxyapatite versus iliac crest harvest, with one suggesting marginally better fusion with harvest. These findings suggest that bone graft substitutes may reduce complications associated with pelvic bone harvest while achieving similar effectiveness in this context.

In pediatric congenital pseudarthrosis of the tibia (CPT), the CPAM-LRC consensus panel (Song, 2025) recommends operative management for patients over 2 years old, involving complete excision of the pseudarthrosis site, sufficient autogenous bone grafting, and fixation using combined external and intramedullary methods (e.g., Ilizarov with intramedullary rods). Based on a systematic review of 74 studies (n = 1513 patients, 1525 tibias), this approach achieved a primary union rate of 84% and a final union rate of 93.3%, with a refracture rate of 22.3%. Vascularized fibular grafts and cross-union techniques were identified as viable alternatives to corticocancellous autografts, though no consensus was reached on adjuvants like recombinant human bone morphogenetic proteins due to inconclusive benefits. These recommendations underscore autogenous grafts as the standard while supporting substitutes in complex cases where traditional grafting may be challenging.

For foot and ankle conditions, the American Orthopaedic Foot & Ankle Society (2022) endorses osteochondral autograft and allograft transplantation as non-experimental options for treating osteochondral lesions of the talus, particularly in cases with large defects, cysts, or prior surgical failures. This guideline supports the use of both autogenous and allogeneic grafts to restore cartilage and bone integrity, highlighting their established role in

addressing significant talar defects. Similarly, the American Academy of Orthopaedic Surgeons (2023) guideline on Osteochondritis Dissecans (OCD) recommends surgical options, including grafting, for symptomatic patients with unstable or displaced lesions, regardless of skeletal maturity. Based on limited evidence, this guideline supports grafting to stabilize lesions and promote healing, though specific graft types are not prioritized, indicating flexibility in choosing autografts or allografts based on clinical context.

In knee reconstruction, the American Academy of Orthopaedic Surgeons (2022) provides robust guidance for Anterior Cruciate Ligament (ACL) reconstruction, issuing a strong recommendation based on high-quality evidence to prefer autografts over allografts in young or active patients due to lower graft failure rates and potentially better outcomes (Brophy, 2023). For skeletally mature patients, a moderate recommendation suggests selecting between bone-patellar tendon-bone (BTB) or hamstring autografts by balancing lower risks of graft failure and infection with BTB against reduced anterior or kneeling pain with hamstring grafts. The guideline also strongly advocates reconstruction over repair for ACL tears requiring surgery, citing lower revision risks. These recommendations emphasize the superiority of autografts in ACL reconstruction while acknowledging allografts as viable in less active or older patients, guiding graft selection to optimize functional outcomes.

The use of orthobiologics, particularly cell-based therapies, is approached with significant caution. A consensus conference convened by the American Academy of Orthopaedic Surgeons and National Institutes of Health (Chu, 2019) raised concerns about the widespread use of unproven biologic treatments, particularly minimally manipulated cell products marketed as "stem cells." These products do not meet scientific criteria for stem cells and should be termed "cell therapy," with clear patient communication about their unproven status. The consensus recommends adopting minimum standards for characterizing biologics (e.g., MIBO checklists), establishing high-quality patient registries, and conducting rigorous clinical trials to evaluate safety and efficacy before broad adoption. Consequently, mesenchymal stem cell therapies and allograft products containing viable stem cells are considered investigational for most orthopedic applications, highlighting the need for robust evidence to support their use over established grafting techniques.

Regulatory oversight ensures the safety of allograft substitutes. To address risks of antigenicity and disease transmission, the U.S. Food and Drug Administration (2024) mandates that manufacturers of human allograft products, including bone, adhere to strict registration and processing standards (Campana, 2014). This framework supports the safe integration of allografts as alternatives to autografts in various orthopedic applications, reinforcing their role in clinical practice while ensuring patient safety.

Systematic reviews

Systematic reviews synthesize evidence on the safety and efficacy of bone graft substitutes across spinal, foot and ankle, dental, maxillofacial, and other orthopedic applications, providing insights into their clinical utility and limitations. In spinal fusion, Fitzgerald (2025) reviewed 21 studies ($n = 3,321$ participants), including three randomized controlled trials, one cohort study, and four case series on Infuse™ (recombinant human bone morphogenetic protein-2) and 10 studies on other grafts for lumbar interbody fusion in degenerative disc disease. The review found comparable fusion rates between Infuse™ (90.9–100%) and iliac crest bone graft (66.7–95.8%, $p=0.102$ – 0.903 , $n = 266$ across two randomized controlled trials), with Infuse™ reducing operative time (1.4–1.9 hours vs. 2.0–3.3 hours, $p<0.001$ – 0.006 , $n = 282$) and blood loss (95–109.8 ml vs. 153.1–167 ml, $p=0.017$ – 0.400 , $n = 282$), though high risk of bias and limited comparative data for non-Infuse™ grafts were noted. Biddau (2024) evaluated 27 studies ($n = 66,027$ participants) on anterior lumbar interbody fusion, with 18 studies focusing on recombinant human bone morphogenetic protein-2, reporting high fusion rates (88.5–100%) but increased complications like retrograde ejaculation (6.3% vs. 1.2%, $P=0.001$) and pseudoarthrosis (odds ratio 1.44, 95% CI: 1.16–1.76). Allografts (84.2–96%), synthetics (77.78–100%), and peptide-based grafts (93.6%) showed promise but lacked robust data. Mariscal (2020) affirmed the efficacy of synthetic ceramics and

morphogenetic proteins in spinal fusion, though specific quantitative data were not reported. Cicciu (2018) and Killington (2018) confirmed the safety and effectiveness of recombinant human bone morphogenetic protein-2 in spinal applications, aligning with current policies, without detailing participant numbers.

In foot and ankle surgery, Hoveidaei (2024) conducted a systematic review and meta-analysis of eight studies ($n = 894$ patients, $n = 497$ synthetic grafts, $n = 397$ autologous grafts), finding no significant differences in CT fusion rates (odds ratio 0.95, 95% CI: 0.69–1.31, $I^2 = 0\%$), AOFAS functional scores (standardized mean difference 0.03, 95% CI: -0.13–0.18, $I^2 = 27\%$), or surgical complications (odds ratio 1.03, 95% CI: 0.59–1.78, $I^2 = 60\%$) between synthetic and autologous grafts. Hartman (2025) reviewed 13 non-randomized studies ($n = 363$ patients, $n = 397$ procedures) on demineralized bone matrix, reporting osseous union rates of 85.6% ($n = 238/278$) in fusion cohorts and 100% in fifth metatarsal and calcaneal fracture cohorts, with complication rates of 27.2% ($n = 99$) and failure rates of 10.8% ($n = 43$). Non-union rates were comparable between demineralized bone matrix (12.9%, $n = 4/31$) and non-demineralized bone matrix cohorts (14.8%, $P = 0.83$), though low evidence quality and study heterogeneity were limitations.

In dental and maxillofacial applications, Al-Moraissi (2020), Avila-Ortiz (2019), Dragonas (2019), Liu (2019), and Stumbras (2019) supported the effectiveness of xenografts and recombinant protein-enhanced grafts for maxillary sinus and alveolar ridge augmentation, though participant numbers were not specified. Deandra (2024) reviewed seven studies ($n = 83$ participants) on regenerative periodontal surgery, finding comparable clinical attachment level outcomes between early (4 weeks) and later (6 months) orthodontic treatment initiation, with autografts, allografts, xenografts (e.g., deproteinized bovine bone mineral), and alloplasts (e.g., β -tricalcium phosphate) all demonstrating success. Mohanasatheesh (2024) examined biphasic calcium phosphate for dental extraction socket preservation in two randomized controlled trials ($n = 74$ participants, $n = 26$ from Mardas, $n = 48$ from Uzeda), reporting significantly increased bone density ($p < 0.05$) with a 60% hydroxyapatite and 40% β -tricalcium phosphate ratio after 6 months, though limited trial numbers prevented meta-analysis.

Across general orthopedic applications, Fischer (2013), McNamara (2015), and Papageorgiou (2016) supported bone graft substitutes in alveolar ridge augmentation, sinus lift procedures, and long-bone defect repair, without reporting specific participant counts. Vaishya (2019) endorsed substitutes for bony defects caused by giant cell tumors, also without quantitative details. Limitations across reviews include high risk of bias, inconsistent fusion definitions, reliance on retrospective or industry-funded studies, and small sample sizes, underscoring the need for standardized reporting and well-designed trials to strengthen evidence for bone graft substitutes.

Meta-analyses

Meta-analyses provide quantitative evidence on the efficacy and safety of bone graft substitutes across spinal, maxillofacial, and orthopedic applications. Cottrill (2020) analyzed three randomized controlled trials and seven case series ($n = 694$ patients) on silicate-substituted calcium phosphate grafts in spinal fusion, reporting a 93% arthrodesis rate and significant improvements in back pain (visual analog score -3.3 points), leg pain (visual analog score -4.8 points), and Oswestry Disability Index (-31.6 points) by six to 36 months ($P < .001$ for each). Fusion rates were comparable to recombinant human bone morphogenetic protein-2 (odds ratio 1.11, $P = .83$). Lee (2024) evaluated five studies ($n = 598$ patients) on recombinant human bone morphogenetic protein-2 in posterior cervical fusion, finding a significantly lower risk of pseudarthrosis (odds ratio 0.44; 95% CI, 0.21–0.92; $P = 0.03$) compared to autografts or allografts, with no significant increase in neurologic (odds ratio 1.86; $P = 0.08$) or immediate medical complications (odds ratio 0.77; $P = 0.28$). However, high-dose recombinant human bone morphogenetic protein-2 (>2.1 mg/level) increased wound infection risk ($P = 0.03$). Wu (2021) reported superior spinal fusion outcomes with morphogenetic protein-2 compared to iliac crest autografts. Liu (2020) and Xiao (2020) confirmed equivalent outcomes for recombinant human bone morphogenetic protein versus autologous grafts in lumbar fusion and cleft lip/palate reconstruction. Alawami (2025) analyzed eight studies ($n = 154$ patients) on recombinant human bone morphogenetic protein-2 for alveolar cleft reconstruction in children,

finding no significant difference in bone filling (mean difference -1.24; 95% CI, -4.14 to 1.67) between recombinant human bone morphogenetic protein-2 (61.11% $\pm$ 24.6%) and iliac crest grafts (59.12% $\pm$ 18.59%), though iliac crest grafts achieved higher bone height (78.65% $\pm$ 14.38% vs. 67.5% $\pm$ 5.45%). Trimmel (2021) found bovine xenograft with bone marrow concentrate (81%) outperformed autologous grafts (57%) in maxillary sinus augmentation. Amini (2021) supported decellularized xenograft scaffolds as effective alternatives. Mendes (2023) analyzed 22 studies (n = 477 patients), finding that growth factors like platelet-rich plasma increased new bone formation by 49% (P = .004) in maxillary sinus augmentation, with recombinant human bone morphogenetic protein-2 increasing connective tissue formation 1.85-fold (P = .03). Xie (2023a) reviewed 14 studies (n = 1,782) on long bone non-union, finding recombinant human bone morphogenetic proteins had higher healing rates and shorter healing times than autologous grafts in moderate-quality studies. Xie (2023b), reviewing five studies (n = 394), found no benefit in combining recombinant proteins with autologous grafts.

Other evidence

Other evidence, including narrative reviews and cohort studies, highlights emerging bone graft substitute options. Laurencin (2006) described the ideal substitute as biocompatible, bioresorbable, osteoconductive, osteoinductive, and structurally similar to bone, noting future biosynthetic implants may reduce reliance on autologous grafts. Zhang (2017) reviewed nacre (mother-of-pearl) as a biocompatible, osteoinductive, and biodegradable substitute with potential clinical applications. Fu (2013), Kelly (2016), Lin (2016), and Simmonds (2013) supported the use of INFUSE (recombinant human bone morphogenetic protein-2) for approved indications like tibial fractures and spinal fusion when autologous grafting is not feasible, despite reported adverse events (Krishnakumar, 2017; Poorman, 2017; Zadegan, 2017). Campana (2014) noted concerns with allografts, including antigenicity and disease transmission risks, emphasizing strict regulatory oversight by the U.S. Food and Drug Administration (2024).

In 2025, we revised the findings section and incorporated five clinical guidelines and consensus statements (American Academy of Orthopaedic Surgeons, 2022; American Academy of Orthopaedic Surgeons, 2023; American Orthopaedic Foot & Ankle Society, 2022; Brophy & Lowry, 2023; Chu et al., 2019). In addition, we added nine articles, including four systematic reviews with meta-analyses (Alawami, 2025; Hoveidaei, 2024; Johnson, 2024; Lee, 2024) and five systematic reviews (Biddau, 2024; Deandra, 2024; Fitzgerald, 2025; Hartman, 2025; Mohanasatheesh, 2024) to the policy, incorporating their findings on bone graft substitutes in spinal fusion, foot and ankle surgery, dental applications, and pediatric alveolar cleft treatment (Lee, 2024; Fitzgerald, 2025; Johnson, 2024; Biddau, 2024; Hoveidaei, 2024; Hartman, 2025; Deandra, 2024; Mohanasatheesh, 2024; Alawami, 2025).

References

On April 9, 2025, we searched PubMed and the databases of the Cochrane Library, the U.K. National Health Services Centre for Reviews and Dissemination, the Agency for Healthcare Research and Quality, and the Centers for Medicare & Medicaid Services. Search terms were “Bone Transplantation” (MeSH), “Bone Substitutes,” (MeSH), “allograft,” “autograft,” “bone reconstruction,” “bone repair,” “calcium sulphate,” “ceramic,” “hydroxyapatite,” “implant,” and “polymer.” We included the best available evidence according to established evidence hierarchies (typically systematic reviews, meta-analyses, and full economic analyses, where available) and professional guidelines based on such evidence and clinical expertise.

Alawami EAA, Alomari F, Aloqaybi SA, et al. Efficacy of recombinant human bone morphogenetic protein-2 in alveolar cleft treatment for children: systematic review and meta-analysis. *Life* (Basel). 2025;15(2):185. Doi:10.3390/life15020185.

Al-Moraissi EA, Oginni FO, Mahyoub Holkom MA, Mohamed AAS, Al-Sharani HM. Tissue-engineered bone using mesenchymal stem cells versus conventional bone grafts in the regeneration of maxillary alveolar bone: A systematic review and meta-analysis. *J Oral Maxillofac Surg*. 2020;35(1):79–90. Doi: 10.11607/jomi.7682.

American Academy of Orthopaedic Surgeons. Management of anterior cruciate ligament injuries: evidence-based clinical practice guideline. Published 2022. <https://www.aaos.org/aclcp>

American Academy of Orthopaedic Surgeons. Clinical Practice Guideline: Management of Anterior Cruciate Ligament Injuries. AAOS.org. Published March 13, 2023. <https://www.aaos.org/quality/clinical-practice-guidelines/anterior-cruciate-ligament/>

American Academy of Orthopaedic Surgeons. Clinical Practice Guideline: Management of Osteochondritis Dissecans. AAOS.org. Published June 8, 2023. <https://www.aaos.org/quality/clinical-practice-guidelines/osteochondritis-dissecans/>

American Orthopaedic Foot & Ankle Society. Position Statement: Use of Osteochondral Transplantation for Treatment of Osteochondral Lesions of the Talus. AOFAS.org. Published September 2022. <https://www.aofas.org/advocacy/position-statements/use-of-osteochondral-transplantation-for-treatment-of-osteochondral-lesions-of-the-talus/>

Amini Z, Lari R. A systematic review of decellularized allograft and xenograft-derived scaffolds in bone tissue regeneration. *Tissue Cell*. 2021;69:101494. Doi: 10.1016/j.tice.2021.101494.

Avila-Ortiz G, Chambrone L, Vignoletti F. Effect of alveolar ridge preservation interventions following tooth extraction: A systematic review and meta-analysis. *J Clin Periodontol*. 2019;46 Suppl 21:195-223. Doi: 10.1111/jcpe.13057.

Biddau DT, Wang ZA, Faulks CR, Mobbs RJ, Malham GM. Bone graft substitutes used in anterior lumbar interbody fusion: a contemporary systematic review of fusion rates and complications. *J Spine Surg*. 2024;10(3):548-561. Doi:10.21037/jss-24-24.

Brophy RH, Lowry KJ. American Academy of Orthopaedic Surgeons clinical practice guideline summary: management of anterior cruciate ligament injuries. *J Am Acad Orthop Surg*. 2023;31(11):531-537. Doi:10.5435/JAAOS-D-22-01020.

Campana V, Milano G, Pagano E, et al. Bone substitutes in orthopaedic surgery: From basic science to clinical practice. *J Mater Sci Mater Med*. 2014;25(10):2445-2461. Doi: 10.1007/s10856-014-5240-2.

Chu CR, Rodeo S, Bhutani N, et al. Optimizing clinical use of biologics in orthopaedic surgery: consensus recommendations from the 2018 AAOS/NIH U-13 conference. *J Am Acad Orthop Surg*. 2019;27(2):e50-e63. Doi:10.5435/JAAOS-D-18-0030.

Cicciu M, Cervino G, Herford AS, et al. Facial bone reconstruction using both marine or non-marine bone substitutes: Evaluation of current outcomes in a systematic literature review. *Mar Drugs*. 2018;16(1);27. Doi: 10.3390/md16010027.

Cottrill E, Premananthan C, Pennington Z, et al. Radiographic and clinical outcomes of silicate-substituted calcium phosphate (SiCAP) bone grafts in spinal fusion: Systematic review and meta-analysis. *J Clin Neurosci*. 2020;81:353-366. Doi: 10.1016/j.jocn.2020.09.073.

Deandra FA, Sulijaya B, Sudjatmika DA, Harsas NA. Selection of bone graft material and proper timing of periodontal surgery for orthodontic patients: a systematic review. *Heliyon*. 2024;10(1):e24201. Doi:10.1016/j.heliyon.2024.e24201.

- Dragonas P, Schiavo JH, Avila-Ortiz G, Palaiologou A, Katsaros T. Plasma rich in growth factors (PRGF) in intraoral bone grafting procedures: A systematic review. *J Craniomaxillofac Surg*. 2019;47(3):443-453. Doi: 10.1016/j.jcms.2019.01.012.
- Fischer CR, Cassilly R, Cantor W, Edusei E, Hammouri Q, Errico T. A systematic review of comparative studies on bone graft alternatives for common spine fusion procedures. *Eur Spine J*. 2013;22(6):1423-1435. Doi: 10.1007/s00586-013-2718-4.
- Fitzgerald A, McCool R, Carr E, et al. A systematic review of bone graft products used in lumbar interbody fusion procedures for degenerative disc disease. *N Am Spine Soc J*. 2025;21:100579. Doi:10.1016/j.xnsj.2024.100579.
- Fu R, Selph S, McDonagh M, et al. Effectiveness and harms of recombinant human bone morphogenetic protein-2 in spine fusion: A systematic review and meta-analysis. *Ann Intern Med*. 2013;158(12):890-902. Doi: 10.7326/0003-4819-158-12-201306180-00006.
- Grabowski M, Gregory D; Cornett A. Bone graft and bone graft substitutes in spine surgery: Current concepts and controversies. *J Am Acad Orthop Surg*. 2013;21(1):51-60. Doi: 10.5435/jaaos-21-01-51.
- Hartman H, Butler JJ, Calton M, et al. Limited evidence to support demineralized bone matrix in foot and ankle surgical procedures: a systematic review. *World J Orthop*. 2025;16(1):16-26. Doi:10.5312/wjo.v16.i1.16.
- Hoveidaei AH, Ghaseminejad-Raeini A, Esmaeili S, et al. Effectiveness of synthetic versus autologous bone grafts in foot and ankle surgery: a systematic review and meta-analysis. *BMC Musculoskelet Disord*. 2024;25(1):539. Doi:10.1186/s12891-024-07676-8.
- Johnson SE, Michalopoulos GD, Flanigan PM, et al. Interbody cages versus structural bone grafts in lumbar arthrodesis: a systematic review and meta-analysis. *J Neurosurg Spine*. 2024;41(2):188-198. Doi:10.3171/2024.2.SPINE23940.
- Kelly MP, Vaughn OL, Anderson PA. Systematic review and meta-analysis of recombinant human bone morphogenetic protein-2 in localized alveolar ridge and maxillary sinus augmentation. *J Oral Maxillofac Surg*. 2016;74(5):928-939. Doi: 10.1016/j.joms.2015.11.027.
- Killington K, Mafi R, Mafi P, Khan WS. A systematic review of clinical studies investigating mesenchymal stem cells for fracture non-union and bone defects. *Curr Stem Cell Res Ther*. 2018;13(4):284-291. Doi: 10.2174/1574888x12666170915121137.
- Krishnakumar GS, Roffi A, Reale D, Kon E, Filardo G. Clinical application of bone morphogenetic proteins for bone healing: A systematic review. *Int Orthop*. 2017;41(6):1073-1083. Doi: 10.1007/s00264-017-3471-9.
- Laurencin C, Khan Y, El-Amin SF. Bone graft substitutes. Expert Rev Med Devices. *Indian J Med Res*. 2006;3:49-57. Doi: 10.1586/17434440.3.1.49.
- Lee HR, Lee DH, Seok SY, Kim IH, Cho JH, Hwang CJ. Meta-analysis on efficacy and complications of bone morphogenetic protein-2 for posterior fusion of cervical spine. *World Neurosurg*. 2024;183:e3-e10. Doi:10.1016/j.wneu.2023.09.035.
- Lin GH, Lim G, Chan HL, Giannobile WV, Wang HL. Recombinant human bone morphogenetic protein 2 outcomes for maxillary sinus floor augmentation: A systematic review and meta-analysis. *Clin Oral Implants Res*. 2016;27(11):1349-1359. Doi: 10.1111/clr.12737.
- Liu R, Yan M, Chen S, et al. Effectiveness of platelet-rich fibrin as an adjunctive material to bone graft in maxillary sinus augmentation: A meta-analysis of randomized controlled trails. *BioMed Res Int*. 2019;2019:7267062-7267062. Doi: 10.1155/2019/7267062.

- Liu S, Wang Y, Liang Z, Zhou M, Chen C. Comparative clinical effectiveness and safety of bone morphogenetic protein versus autologous iliac crest bone graft in lumbar fusion: A meta-analysis and systematic review. *Spine*. 2020;45(12):E729-e741. Doi: 10.1097/brs.0000000000003372.
- Mariscal G, Nuñez JH, Barrios C, Domenech-Fernández P. A meta-analysis of bone morphogenetic protein-2 versus iliac crest bone graft for the posterolateral fusion of the lumbar spine. *J Bone Miner Metab*. 2020;38(1):54-62. Doi: 10.1007/s00774-019-01025-9.
- McNamara IR, Smith TO, Shepherd KL, et al. Surgical fixation methods for tibial plateau fractures. *Cochrane Database Syst Rev*. 2015;(9):CD009679. Doi: 10.1002/14651858.CD009679.pub2.
- Mendes VV, Martins FV, de Santana CMM, de Santana RB. Do recombinant, purified or concentrated growth factors enhance the regenerative potential of particulate bone graft substitutes in maxillary sinus floor augmentation? A systematic review and meta-analysis. *Int J Oral Maxillofac Implants*. 2023;0(0):1-36. Doi: 10.11607/jomi.10553.
- Mohanasatheesh S, Balaji A, Subramaniam D, Ganapathy V, Rajendran KP, Farjana N. Biphasic calcium phosphate in the extraction socket preservation: a systematic review. *J Pharm Bioallied Sci*. 2024;16(Suppl 2):S1007-S1011. Doi:10.4103/jpbs.jpbs_1003_23.
- North American Spine Society. Diagnosis and treatment of degenerative lumbar spondylolisthesis. 2nd ed. Burr Ridge, IL: North American Spine Society. <https://www.spine.org/ResearchClinicalCare/QualityImprovement/ClinicalGuidelines.aspx>. Published 2014.
- Papageorgiou SN, Papageorgiou PN, Deschner J, Gotz W. Comparative effectiveness of natural and synthetic bone grafts in oral and maxillofacial surgery prior to insertion of dental implants: Systematic review and network meta-analysis of parallel and cluster randomized controlled trials. *J Dent*. 2016;48:1-8. Doi: 10.1016/j.jdent.2016.03.010.
- Poorman GW, Jalai CM, Boniello A, et al. Bone morphogenetic protein in adult spinal deformity surgery: A meta-analysis. *Eur Spine J*. 2017;26(8):2094-2102. Doi: 10.1007/s00586-016-4841-5.
- Simmonds MC, Brown JV, Heirs MK, et al. Safety and effectiveness of recombinant human bone morphogenetic protein-2 for spinal fusion: A meta-analysis of individual-participant data. *Ann Intern Med*. 2013;158(12):877-889. Doi: 10.7326/0003-4819-158-12-201306180-00005.
- Stark JR, Hsieh J, Waller D. Bone graft substitutes in single- or double-level anterior cervical discectomy and fusion: A systematic review. *Spine*. 2019;44(10):E618-E628. Doi: 10.1097/BRS.0000000000002925.
- Stumbras A, Krukis MM, Januzis G, Juodzbaly G. Regenerative bone potential after sinus floor elevation using various bone graft materials: A systematic review. *Quintessence Int*. 2019;50(7):548-558. Doi: 10.3290/j.qi.a42482.
- Trimmel B, Gede N, Hegyi P, et al. Relative performance of various biomaterials used for maxillary sinus augmentation: A Bayesian network meta-analysis. *Clin Oral Implants Res*. 2021;32(2):135-153. Doi: 10.1111/clr.13690.
- U.S. Food and Drug Administration. FDA human cell and tissue establishment registration — public query database. https://www.accessdata.fda.gov/scripts/cber/CFAppsPub/tiss/Index.cfm?fuseaction=fuse_DisplaySearch&CFID=23091837&CFTOKEN=985566c088c8989f-1F22E2A5-CD46-2D0D-FE6C7A28B417F791. Updated April 11, 2024.
- U.S. Food and Drug Administration. INFUSE ® Bone Graft. Pre-market approval letter P050053. https://www.accessdata.fda.gov/cdrh_docs/pdf5/P050053A.pdf. Published March 9, 2007.

U.S. Food and Drug Administration. INFUSE® Bone Graft. Pre-market approval letter P000054. https://www.accessdata.fda.gov/cdrh_docs/pdf/p000054c.pdf. Published April 30, 2004.

U.S. Food and Drug Administration. INFUSE™ Bone Graft/LT-CAGET™ Lumbar Tapered Fusion Device. Pre-market approval letter P000058. https://www.accessdata.fda.gov/cdrh_docs/pdf/P000058A.pdf. Published July 2, 2002.

Vaishya R, Pokhrel A, Agarwal AK, Vijay V. Current status of bone cementing and bone grafting for giant cell tumour of bone: A systematic review. *Ann R Coll Surg Engl*. 2019;101(2):79-85. Doi: 10.1308/rcsann.2019.0004.

Wu Z, Zhou B, Chen L, Wang X, Abdelrahim MEA, Wei C. Bone morphogenetic protein-2 against iliac crest bone graft for the postlateral fusion of the lumbar spine: A meta-analysis. *Int J Clin Pract*. 2021;75(4):e13911. Doi: 10.1111/ijcp.13911.

Xiao WL, Jia KN, Yu G, Zhao N. Outcomes of bone morphogenetic protein-2 and iliac cancellous bone transplantation on alveolar cleft bone grafting: A meta-analysis. *J Plast Reconstr Aesthet Surg*. 2020;73(6):1135-1142. Doi: 10.1016/j.bjps.2020.01.011.

Xie C, Wang C, Huang W, et al. Recombinant human bone morphogenetic protein is a valid alternative to autologous bone graft for long bone non-unions: A systematic review and meta-analysis. *Surgeon*. 2023;S1479-666X(22)00134-2. (a)

Xie C, Wang C, Huang Y, et al. Therapeutic effect of autologous bone grafting with adjuvant bone morphogenetic protein on long bone nonunion: A systematic review and meta-analysis. *J Orthop Surg Res*. 2022;17(1):298. Doi: 10.1186/s13018-022-03185-3. (b)

Zadegan SA, Abedi A, Jazayeri SB, et al. Bone morphogenetic proteins in anterior cervical fusion: A systematic review and meta-analysis. *World Neurosurg*. 2017;104:752-787. Doi: 10.1016/j.wneu.2017.02.098.

Zhang G, Brion A, Willemin AS, et al. Nacre, a natural, multi-use, and timely biomaterial for bone graft substitution. *J Biomed Mater Res A*. 2017;105(2):662-671. Doi: 10.1002/jbm.a.35939.

Policy updates

5/2016: Initial review date and clinical policy effective date: 7/2016

7/2017: Policy references updated.

7/2018: Policy references updated. Coverage expanded to include recombinant human bone morphogenetic protein -2 (INFUSE) products.

5/2019: Policy references updated.

5/2020: Policy references updated.

5/2021: Policy references updated.

5/2022: Policy references updated.

5/2023: Policy references updated.

5/2024: Policy references updated.

5/2025: Policy references updated.