Review

The Role of Bone Decortication in Enhancing the Results of Guided Bone Regeneration: A Literature Review

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Background: Bone decortication is often performed as part of a guided bone regeneration (GBR) procedure. The biologic rationale for decortication of bone is to allow progenitor cells easy access to a GBR-treated site and to facilitate prompt angiogenesis. It also may enhance the physical connection between a bone graft and a recipient site. However, the concept of decortication prior to a GBR procedure is controversial because there are no human clinical trials to support its effectiveness, and there are opposing points of view derived from animal studies regarding its usefulness.

Methods: The literature was assessed to determine whether there are enough data to validate the rationale for using decortication of bone as an integral part of GBR procedures. Eight searches were performed seeking controlled clinical trials that addressed the ability of decortication to enhance GBR.

Results: Three controlled animal clinical trials were found that supported the use of decortication prior to performing GBR. Two controlled animal clinical trials were located that indicated decortication did not improve GBR procedures. No human controlled clinical trial was identified that addressed the ability of decortication to alter GBR procedures. The literature addressing the capacity of decortication to affect onlay grafting or wound healing also provided mixed results.

Conclusion: There is conflicting information and not enough clinical trials to make a definitive determination as to the merits of bone decortication prior to GBR procedures. *J Periodontol 2009;80:175-189.*

KEY WORDS

Bone grafting; bone regeneration; decortication; ridge augmentation.

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Successful placement of a dental implant requires a recipient site with an adequate width and height of alveolar bone. Lack of bone, which could impede implant placement, can be caused by periodontitis,[1] tooth extraction,[2,3] or trauma due to long-term use of a removable prosthesis.[4] If a patient has a deficient ridge, a surgical procedure, referred to as guided bone regeneration (GBR), can be used to augment bone height and/or width.[5] Decortication of bone prior to placing a bone graft is often performed as part of a GBR procedure.[6-12] It is the intentional drilling of holes through the cortical bone into the cancellous bone or the removal of cortical bone to expose cancellous bone.[13] Sometimes, perforation of the cortical bone can be accomplished with a sharp curet.[14] Decortication is done ostensibly to enhance the healing process by promoting bleeding and allowing progenitor cells and blood vessels to reach a bone-grafted site more readily.[6-12] In addition, decortication may improve the physical bond between grafted bone and a recipient site.[15,16] However, there is controversy in the dental literature with respect to the usefulness of this procedure because its ability to accelerate or increase bone regeneration has not been substantiated in human clinical trials, and there are conflicting results derived from animal studies. Furthermore,

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decortication can have some minor negative consequences: increased operative time, additional blood loss, potentially greater postoperative pain, and some bone loss if the GBR procedure fails. Therefore, it was decided to search the literature to ascertain if there are data to support performing decortication of bone as an integral part of GBR procedures.

DATA SOURCE

This review article focuses on the ability of bone decortication to enhance GBR procedures. In addition, different issues associated with bone augmentation are discussed to provide background information. For these subjects, articles were selected from the literature to furnish general information. With regard to data pertaining to the benefits of bone decortication, a methodic review of the literature was conducted. A MEDLINE search was performed through July 2008 for studies that addressed the usefulness of bone decortication as part of GBR procedures. Searches were conducted under different headings. The reasons for the exclusion of studies for each inquiry are indicated, and the omitted papers are found in appendices correlated to each search. Cited articles were also explored for other references concerning decortication of bone.

SEARCH STRATEGIES

Search 1

The heading "decortication of bone" revealed 212 citations. The search was reduced by looking at "decortication of bone AND regeneration." This revealed 42 citations. Nineteen were eliminated because they were not in English. Of the remaining 23 papers, four articles[17-20] were included in this review; 19 studies were excluded (Appendix 1) because they did not provide a test and control group looking at bone regeneration with and without decortication of bone or the effect of bone decortication could not be determined because of confounding factors.

Search 2

The heading "cortical perforation of bone" revealed 103 references. The search was reduced by looking at "cortical perforation of bone AND regeneration." This revealed 19 citations. One was eliminated because it was not in English. The remaining 18 papers were assessed to see if they compared bone repair with and without decortication of bone. Seven studies were included in this review,[21-27] and 11 were excluded (Appendix 2).

Search 3

The heading "intramarrow penetration of bone" revealed three citations. Studies were included that compared groups with and without intramarrow penetration of bone and assessed bone regeneration. One study was included in this review;[28] two were excluded (Appendix 3) because they did not clearly provide information regarding the benefits of marrow penetration.

Search 4

The heading "marrow penetration/bone regeneration" revealed 11 citations. Two studies[28,29] were included that compared groups with and without intramarrow penetration of bone and assessed bone regeneration. Nine studies were excluded (Appendix 4) because they did not clearly provide information regarding the benefits of marrow penetration.

Search 5

The heading "bone regeneration/calvaria/augmentation/titanium/rabbits" revealed 20 citations. Two studies[22,29] were included that assessed the use of titanium caps to induce bone regeneration and had a test and a control group to evaluate the efficacy of decortication. Eighteen investigations were excluded (Appendix 5) because they used drugs or different bone graft materials to augment bone regeneration as opposed to using only a titanium cap for regeneration, and the benefit of decortication alone could not be determined. Studies that used decortication in the test and control groups were excluded.

Search 6

The heading "guided bone generation/cortical perforation*" revealed three citations. Two references were included[22,30] that had test and control groups with and without cortical perforations and addressed regeneration. One paper was excluded that was not pertinent to regeneration (Appendix 6).

Search 7

The heading "guided bone augmentation/decortication" revealed two citations. One reference[31] was included. The other was excluded because it did not have a test and control group to assess the impact of decortication (Appendix 7).

Search 8

The heading "bone decortication" was searched using Google, which revealed several recent controlled studies[32-34] that were not found under PubMed; these were included in this paper.

Because there were so few controlled clinical trials in the literature that addressed GBR procedures with and without decortication, it was decided to provide additional data from non-controlled studies that demonstrated GBR was possible without decortication. The headings in searches 9 through 11 were used to locate citations addressing this issue.

Search 9
The heading "bone regeneration/occlusive barriers" revealed nine citations. Four studies[30,35-37] were included. Five studies were excluded because it was not possible to tell to what extent bone regeneration was due to the topography of the bone defects (Appendix 8).

Search 10
The heading "guided bone regeneration/tuberosities" revealed two citations.[38,39] They were included in this article.

Search 11
The heading "bone regeneration/bone beyond the skeleton/animals" revealed 42 citations. Five were excluded because they were not in English. Of the remaining 37 citations, eight[22,30,40-45] were included; 29 were excluded (Appendix 9) because they did not address bone regeneration or whether the bone regeneration could be attributed to factors other than barrier protection for cell exclusion.

GBR

GBR is based on principles of guided tissue regeneration.[46-49] Melcher[46] described the concept of selective cell repopulation of defects to enhance healing. The GBR technique excludes faster growing epithelial and connective tissue cells with barriers and bone grafts to allow slower moving pluripotential and osteogenic cells to repopulate the GBR-treated site. To attain horizontal and/or vertical bone augmentation beyond the envelope of skeletal bone, four principles need to be met: exclusion of epithelium and connective tissue, space maintenance, stability of the blood clot, and primary wound closure.[50]

With respect to these facets of therapy, the following facts are important in understanding their contribution to bone regeneration. Primary closure results in a greater amount of bone deposition than healing by secondary intention after a bone graft is placed. In this regard, a recent meta-analysis by Machtei[51] confirmed that a GBR procedure without barrier exposure results in more bone formation than when a barrier becomes uncovered (3.01 mm versus 0.56 mm). A bioabsorbable or non-resorbable barrier can provide space maintenance and exclude epithelium and connective tissue cells, thereby facilitating repopulation of the GBR-treated area with progenitor cells.[9] The barrier also protects the wound and provides clot stabilization. To help maintain space, the barrier may be supported with bone grafts, implants, or tenting poles.[50] GBR procedures can be successfully performed with or without a bone graft if another technique is used to maintain space under the barrier.[5] However, bone grafts are usually used with GBR procedures. The blood clot that forms under the barrier releases growth factors (e.g., platelet-derived growth factor) and cytokines and serves as a precursor for the vascular granulation tissue that will replace it.[52,53]

ANGIOGENESIS: RELATIONSHIP OF BLOOD VESSELS AND NEW BONE FORMATION

Angiogenesis and blood supply are important for attaining GBR, and they follow a specific sequence of events.[54,55] Within the first 24 hours after a GBR procedure, the created space is filled with a blood clot. Then the clot is resorbed by neutrophils and macrophages and replaced with granulation tissue. This tissue contains numerous blood vessels, which are responsible for transporting cells and nutrients involved in osteoid formation. Osteoid is unmineralized bone; upon mineralization, it is referred to as woven bone.[55] Woven bone acts as a scaffold for additional bone deposition; subsequently, it remodels converting woven bone into lamellar bone.[56]

Development of bone is dependent on the creation of new blood vessels that provide progenitor cells and nourishment to the GBR-treated site.[54,55,57,58] The temporal relationship between vascularity and bone repair was histologically monitored by several investigators.[54,55] They reported that the creation of capillaries preceded new bone formation. Angiogenesis is a multistep process and usually proceeds from existing blood vessels.[59] Schmid et al.[55] noted that regeneration is possible after blood vessels were available, and new bone develops ~4 weeks after initiating GBR.

DECORTICATION

Many clinical studies[6,9-12] and case reports[7,8] used decortication as part of a GBR protocol and demonstrated successful results. Conversely, other investigations[2,30,31,35-45] conducted in animals indicated that bone regeneration occurred without decortication. Therefore, it is questionable whether decortication of bone is necessary to attain extraskeletal bone augmentation or if it enhances results (Figs. 1 and 2).

Before discussing studies that quantified the benefits of decortication, it is advantageous to address various aspects and potential benefits that may be derived from bone decortication: increased bleeding, access for progenitor cells and blood vessels, interlocking of bone, and spatial relationships of decortications.

Drilling holes through cortical bone into more vascular cancellous bone induces bleeding that immerses the GBR site in blood.[6,31,54,55] As the clot organizes, it releases cytokines and growth factors to attract progenitor cells, osteoblasts, and blood vessels.[52,53,60,61] Decortication of bone is frequently

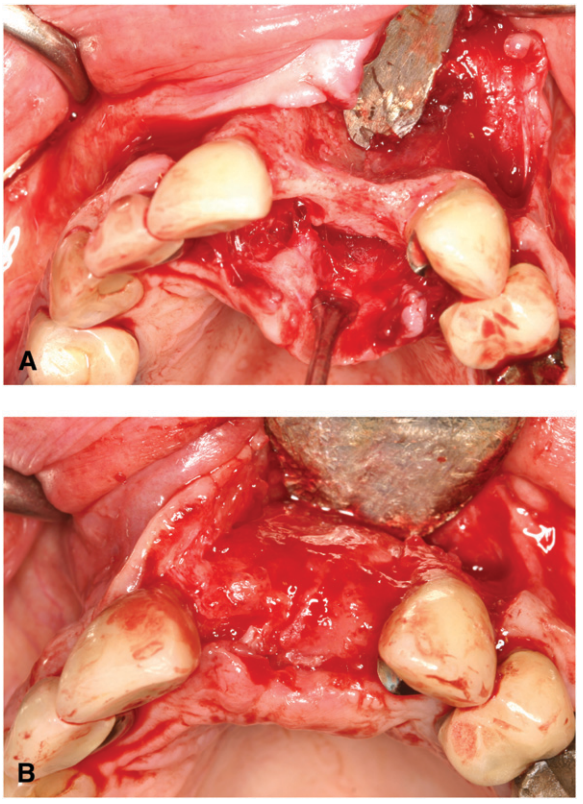

Figure 1.
A) *GBR at teeth #9 and #10. Decortication was done prior to bone grafting.* ***B)*** *Healing after 6 months.*

performed as part of a ridge-augmentation procedure,[7,8,10-12] but it is not often performed when doing a socket preservation. After an extraction, bleeding from foramina in the cribriform plate usually precludes the need to induce hemorrhage. However, if a socket is not bleeding after a tooth is extracted, it has been advocated to decorticate the socket walls to provoke hemorrhaging to ensure a clot fills the alveolus.[62] In addition, bone decortication is not usually done during the treatment of intrabony defects. Relevantly, no controlled studies were found during the literature searches on decortication that compared the treatment of intrabony defects with and without decortication of bone as an adjunctive therapy.

Decortication of bone may provide passageways for blood vessels and progenitor cells to have rapid access to a GBR-treated site.[6,31,55] It is believed that creating perforations in the bone mimics what occurs during bone remodeling when osteoclastic cutting cones radially penetrate the bone.[63] Ultimately, the bone needs to resorb and create blood vessel channels or remodel around Volkmann's vascular canals to allow access for new blood vessels.[30] This facilitates capillary ingrowth that precedes bone deposition.[54,55,57,58]

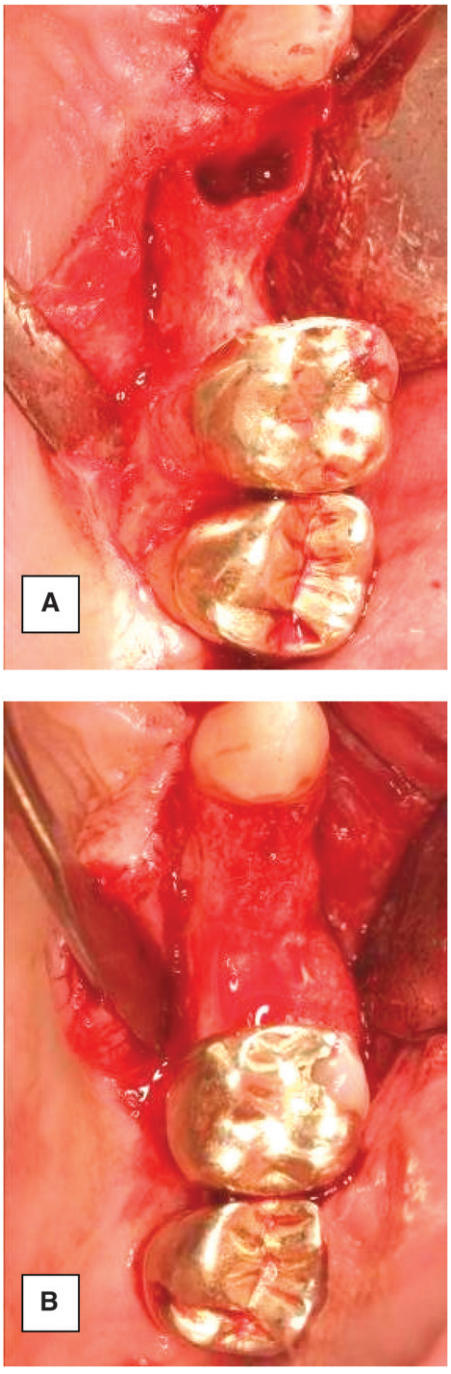

Figure 2.
A) *GBR at teeth #12 and #13. Decortication was not done prior to bone grafting.* ***B)*** *Healing after 6 months.*

It is recognized that osteoblasts are responsible for new bone formation and are derived from the periosteum, endosteum, and undifferentiated pluripotential mesenchymal cells in the bone marrow.[61] However, during a GBR procedure, the periosteum is elevated with the flap, and a barrier is placed over the grafted bone, thereby excluding any contribution of osteoblasts from the periosteum. In addition, the cortical

bone upon which a bone graft was initially placed may impede undifferentiated pluripotential mesenchymal cells from the endosteum and bone marrow from reaching the GBR-treated site. Therefore, it was theorized that decortication of intact bone may speed up the process of getting blood vessels, osteoblasts, and pluripotential cells to grafted sites.[6-12]

Perforating the bony cortex also may increase the mechanical interlocking of a bone graft and a recipient site, which may improve its stability and provide firm linking for newly regenerated bone.[15,16] Concerning monocortical bone blocks, it usually takes 4 to 5 months for them to bond with native bone.[64] However, clinicians have noted that when bone blocks are presumed healed, they can fracture off along the interface of the bone graft and native bone as an implant is placed.[64] This finding suggests that block grafts may be interlocked with native bone and not fully fused to it.

With respect to the spacing of bone perforations to attain the maximum benefit, this subject has never been addressed in the literature (Fig. 3). However, it is prudent to avoid over decortication when placing bone blocks because they need to be immobilized, and solid bone is needed for the lag screws that retain the bone graft.

REGIONAL ACCELERATORY PHENOMENON

Frost[65] described a phenomenon referred to as regional acceleratory phenomenon. It denotes that there is a local exuberant response to noxious stimuli, which accelerates the normal healing process. Relevantly, decortication can be considered a noxious stimulus; Winet[66] noted that vascularity peaked after trauma to the bone and declined to normal levels after healing was completed. Application of this concept is being used as a method to facilitate rapid orthodontic movement.[34,67] In particular, selective alveolar decortication is used to initiate local tissue repair and release of osteoprogenitor cells and osteoinductive agents.[67]

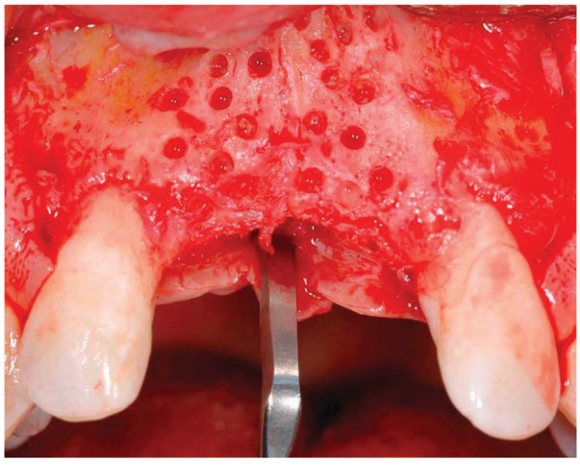

Figure 3.
An example of arbitrarily spaced decortications in buccal plate of the premaxilla.

EFFECT OF DECORTICATION ON INCORPORATION OF ONLAY BONE GRAFTS OR WOUND HEALING: MEDICAL AND DENTAL LITERATURE

This section addresses the use of decortication to enhance the incorporation of onlay bone grafts and wound healing.[16-20,23-27,32,33,68-74] It does not address the intentional regeneration of bone outside the skeletal structures, which is covered in a subsequent segment of the text. The information for the medical and dental literature is presented separately to make it easier to follow the available data.

Medical Literature Related to Onlay Bone Grafting and Wound Healing

In medicine, GBR procedures are not usually performed to develop bone outside the skeletal envelope of bone. However, investigations have assessed the benefits of decortication to enhance the fusion of vertebrae[17,18,33] and the incorporation of bone grafts to mend non-union of fractured clavicles[68] and humeruses.[69] Therefore, data from the medical literature that referred to bone decortication were reviewed to determine whether it could provide additional information with respect to the benefits of bone decortication.

In 1924, the concept of denuding bone or creating a decortication facet was described as a method to accelerate arthrodesis (spinal fusion).[70] Subsequently, clinicians conducted controlled studies[16-18,20,33,71,72] in animals to decide if cortical bone perforations enhanced the incorporation of onlay bone grafts (Table 1). These studies were succinctly outlined because their methodologies and results were diverse. Gordh et al.[16] conducted a controlled clinical trial in a rat model (N = 22) that lasted 20 weeks. Tibial or femoral grafts were placed on tibial bones that were or were not perforated. The investigators noted that there was migration of marrow components through the cortical perforations to the grafted region and increased lamellar bone apposition compared to the non-decorticated grafts. These data were descriptive in nature and did not provide quantification of monitored parameters.

Decortication of bone has also been used extensively as part of spinal fusions. Canto et al.[17] found that decortication of rat vertebrae (N = 72) before grafting resulted in a larger percentage of bone formation compared to sites that were not decorticated. At 9 weeks, new bone formation ranged from 25.93% to

Table 1.

Decortication of Bone to Enhance Survival of Bone Grafts: Controlled Clinical Trials

Investigators	Animal	Time	Result
Gordh et al.[16]	22 rats	20 weeks	Decorticated grafts increased lamellar apposition of bone compared to non-decorticated graft sites.*
Canto et al.[17]	72 rats	9 weeks	Statistically significant increase in the percentage formation of bone during spinal fusion was due to decortication of bone.*
Boden et al.[20]	60 rabbits	10 weeks	Spinal fusion was not attained in any control animals when decortication and bone grafting were omitted.*
de Carvalho et al.[74]	6 dogs	90 days	The autogenous bone grafts were incorporated with the receptor bed, mainly in the perforated and decorticated groups.*
Sandhu et al.[18]	20 dogs	3 months	There were no statistically significant differences in clinical and radiographic spinal fusion rates between decorticated and non-decorticated sites treated with recombinant human BMP-2.
Huebsch et al.[19]	10 dogs	10 weeks	After intentional wounding of the mandible, there was no appreciable histologic difference in healing with and without prior decortication.
Conti et al.[33]	15 dogs	3 months	Six months after spinal fusion there was no benefit if decortication was performed. Initially, 1 to 3 months, the grafts were better integrated with decortication.
Ishikawa et al.[72]	52 rabbits	6 weeks	The inclusion of decortication to autologous iliac grafting for spinal fusion significantly improved fusion rates in non-instrumented spines, but in instrumented spines, it did not provide a statistically significant improvement.
Adeyemo et al.[23]	12 sheep	16 weeks	Decortication provided no benefit compared to non-decorticated sites receiving mandibular onlay bone grafts.

* Better results reported with decortication were not necessarily statistically significantly better. If they were, it was stated. Otherwise, the investigators did not quantify the results and provided their interpretation of the data that decortication was beneficial.

30.6% for decorticated sites and 16.4% to 18.73% in the control group. Similarly, Boden et al.[20] used a rabbit model to assess the properties of the intertransverse spinal fusion healing process using autogenous iliac bone graft. Sixty rabbits were assessed after 10 weeks using different treatment methods. It was concluded that spinal fusion was not achieved in any control animals when there was omission of decortication or bone grafting. In contrast, Conti et al.[33] demonstrated in a dog model (N = 15) that decortication of vertebrae that were bone grafted resulted in better bone integration within 1 to 3 months compared to sites that were not decorticated. However, by 6 months there was no benefit with respect to the non-decorticated sites. Similarly, Ishikawa et al.[72] noted that when spinal instrumentation and decortication were performed together in rabbits (N = 52), decortication did not provide any benefit with regard to spinal fusion rates.

From a different perspective, Sandhu et al.[18] demonstrated no statistically significant difference in spinal fusion rates (N = 20 dogs) when decortication versus applications of bone morphogenetic protein (BMP) to bone surfaces was performed before spinal fusion. Relevantly, Hsu and Wang[73] recently reviewed the literature to assess the use of BMPs to improve spinal fusion. They concluded that multiple commercially available recombinant BMPs demonstrate clinical success in spinal fusions, but they are too expensive to be routinely used. Therefore, it seems that the selection of a method to enhance spinal fusion is at the discretion of the clinician. One additional note concerning the use of BMPs, Issa et al.[32] recently reported that combining decortication with

recombinant human BMP type 2 resulted in more bone formation in rats (N = 56) after 6 weeks than when used alone at non-decorticated sites (the evaluation was based on a radiographic densitometry technique). This concept needs further study.

Other preliminary investigations assessed if perforations of large grafts as opposed to the recipient bed would enhance the healing process. Lewandrowski et al.[24-26] used lasers to perforate and demineralize bone grafts before transplanting them into rats and sheep. These studies demonstrated that osteogenesis in cortical bone grafts can be fostered through the process of partial demineralization and laser perforation. The investigators concluded that the processing of cortical bone allografts by the combination of perforation and partial demineralization resulted in better healing of transplanted bones compared to processing by partial demineralization alone. Delloye et al.[27] also found that perforating a bone graft itself (cortical bone) substantially improved the amount of new bone formed by the host compared to using a non-perforated bone graft.

Dental Literature Related to Onlay Bone Grafting and Wound Healing

The dental literature provided mixed results with regard to the ability of decortication to enhance the incorporation of onlay grafts or improve wound healing (Table 1).[19,23,74] de Carvalho et al.[74] concluded after assessing the healing in six dogs after 90 days that autogenous monocortical bone grafts placed on the mandible demonstrated better healing at sites that were initially decorticated as opposed to sites that did not have initial bed preparation. The data were descriptive in nature, and the results were not quantified.

In contrast, other studies found that decortication did not enhance the incorporation of bone grafts or bone repair after intentional wounding. Adeyemo et al.[23] assessed the influence of decortication on the incorporation of onlay mandibular bone grafts in 12 sheep. After 16 weeks they noted that decortication of the recipient sites provided no advantages over non-perforated beds with respect to the rate of healing or integration of bone grafts. In another study,[19] a dog model (N = 10) was used to assess healing after decortication. The investigators made a bilateral cut from the sigmoid notch to the angular process of the mandible. On one side, the fragments were decorticated and wired together. On the opposite side, the fragments were not decorticated but were overlapped and wired together. After 10 weeks, there was no appreciable histologic difference between the two sides with respect to bone healing.

In conclusion, it seems that decortication of bone is frequently used in the medical literature to enhance the incorporation of onlay bone grafts during various therapeutic procedures. However, there are animal studies in the medical and dental literature that did not corroborate that decortication enhanced onlay grafting or the repair of intentional wounds.

ASSESSING THE EFFECT OF DECORTICATION ON REGENERATION OF BONE OUTSIDE THE SKELETAL HOUSING: ANIMAL AND HISTOLOGIC STUDIES IN THE DENTAL LITERATURE

In general, there are limited and conflicting data derived from controlled clinical trials[22,28-31] in animal models with respect to the affects of decortications on GBR. The available data are difficult to compare because investigations used different animal models, reevaluated sites at different time intervals, attempted to regenerate different heights and widths of bone, and the results were reported as an overall percentage gain of bone, which did not differentiate between the width and height of bone. A short review of data from histologic trials pertaining to the benefits of decortication is outlined in the following sections to provide clinicians with the available information they need to make clinical decisions.

Controlled Clinical Trials in Animals: The Effect of Decortication Versus No Decortication on Bone Regeneration

Statistically significant improvement of bone regeneration after decortication. Data confirming that decortication enhanced bone regeneration has been ascertained in three studies[28-30] conducted in rabbit and rat animal models (Table 2). Majzoub et al.[28] demonstrated in rabbits (N = 16) that 2 months after GBR the percentage of bone development in experimental titanium domes (cell occlusive barriers) placed adjacent to the calvaria was significantly greater than at sites where decortication was not performed (71.72% versus 53.58%). Similarly, Min et al.[29] conducted a controlled study in rabbits (N = 10). Two titanium domes were placed over the calvarium of each rabbit. Decortication was done beneath one dome, and the cortical bone was left intact under the other. At 3 months, there were more osteoblast-like cells at sites under the titanium domes that underwent decortication compared to controls (27.7 ± 3.6 versus 17.3 ± 3.6). In addition, these sites manifested a higher percentage of newly generated tissue (78.9% versus 69.8%) and a higher percentage of mineralized bone (24% versus 16.4%) at 3 months. Furthermore, in a rat model (N = 30), Rompen et al.[30] noted that after 4 months there was increased augmentation of bone at sites within titanium chambers that were decorticated compared to locations that were left unaltered (172.8% versus 141%, this refers to bone width with respect to thickness of the calvarium).

Table 2.

Mean Percentage of Bone Regeneration With and Without Bone Decortication: Controlled Clinical Trials

Investigators	Animal	Time Period (months)	Increased Bone With Decortication (%)	Increased Bone With No Decortication (%)	Comment
Majzoub et al.[28]	16 rabbits	2	71.72*	53.58	Titanium domes had a height of 3 mm and a diameter of 4.8 mm.
Min et al.[29]	10 rabbits	3	78.9*	69.8	Titanium domes had a height of 4 mm and a diameter of 8 mm.
Rompen et al.[30]	30 rats	4	172.8*	141	Titanium chambers had a length of 5 mm, width of 4 mm, and height of 3 mm. Results evaluated with regard to the skull thickness.
Lundgren et al.[31]	8 rabbits	3	75.5	71.2	Titanium cylinder with an inner diameter of 6 mm and inner height of 4.5 mm.
Slotte and Lundgren[22]	8 rabbits	3	64.4	64.9	Titanium cylinder with an inner diameter of 6 mm and inner height of 4.5 mm.

* Statistically significantly different compared to no decortication.

Non-significant improvements of bone regeneration after decortication. Data from clinical trials found that decortication did not enhance bone healing (Table 2).[22,31] Lundgren et al.[31] assessed whether removal of the outer cortical plate enhanced bone regeneration under titanium cylinders. Two cylinders were placed in eight rabbits. On one side the cortical bone was removed, whereas on the other side it was left intact. After 3 months, there was no difference in the amount of augmented bone in relation to the total experimental area at test versus control sites (75.5% versus 71.2%). The investigators concluded that removal of the outer cortical plate of bone did not enhance regeneration in a secluded space. However, the investigators mentioned two possible explanations for this finding: surgery on both sides to place the dome may have stimulated healing, and removal of the cortical plate at test sites required these locations to produce more bone than control sites to end up with a similar amount of bone. Thus, they conducted an additional study to reassess the benefits of decortication. Slotte and Lundgren[22] placed two titanium cylinders in eight rabbits. The bone under one cylinder served as the test site and was perforated seven times, whereas the control site was not decorticated. After 3 months, it was found that cortical perforations did not enhance the percentage of bone augmentation (64.45% versus 64.9%). However, test sites demonstrated increased bone density.

Bone Regeneration in Animal Models When Bone Decortication Was Not Used as Part of the Surgical Protocol: Animal Clinical Trials

Many experimental animal studies[22,31,35-45] examined different facets of GBR procedures without comparing the benefits of decortication versus no decortication. They demonstrated that GBR procedures could be successful without decortication of bone. Several representative investigations were selected to illustrate the efficacy of GBR procedures without decortication.

In a rabbit model, Lundgren et al.[45] placed four titanium domes (two on each side of the skull) in three rabbit calvaria to create a secluded space, with bone being the only adjoining tissue to the dome. After 3 months, histologic assessments revealed complete bone fill in all 12 domes.

In a rat model, Kostopoulos et al.[39] (N = 30) used a rigid polytetrafluoroethylene occlusive capsule to develop tuberosities on their rami. One side of the mandible served as the test site (periosteum left over the bone), and the other side was the control site (periosteum was removed). After 120 days, the

mean bone fill was 56% versus 52% at the test sites versus the control sites. In the same rat model (N = 30), Lioubavina et al.[38] assessed the long-term stability of regenerated bone. The new bone level was stable after 6 months, and the mean bone fill of capsules was 98.6% on radiographs. In another study (N = 18 rats), Kostopoulos and Karring[75] compared bone formation with and without a bioabsorbable membrane. On one side of the mandible a membrane was supported by an implant to maintain space; an implant was placed on the other side, but no membrane was used. When the barriers were removed after 6 months, the spaces under the barriers were usually filled with bone, whereas there was negligible bone formation if barriers were not placed. From a different perspective, Rasmusson et al.[44] confirmed in a rat model that GBR without decortication was able to regenerate bone around exposed implant threads. In general, it can be concluded that the above experimental animal studies demonstrated that GBR procedures were successful to different degrees without decortication. However, these investigations did not include comparisons to sites that were decorticated; therefore, they did not answer the question about whether decortication provides a benefit.

Controlled Clinical Trials in Animals: The Effect of the Size of Decortications on Regeneration of Bone

Only one controlled study was found that addressed the impact of the size of decortications on bone regeneration. Nishimura et al.[21] evaluated whether the size of the openings through the cortex altered the outcome. Titanium mesh–reinforced expanded polytetrafluoroethylene barriers were used to create cell-occlusive domes in a rabbit model (N = 16). They created bone defects in two sizes (slits in bone): 1×15 mm and 3×15 mm. Initially, the larger slits were associated with faster and more new bone formation compared to the smaller perforations.[21] However, no difference was noted in the amount of bone regenerated 12 weeks after therapy (12.75 mm^2 versus 9.70 mm^2). To the best of our knowledge, no other animal study has been conducted to determine whether large perforations resulted in more new bone formation than smaller decortications.

EXTRAPOLATING ANIMAL STUDIES TO HUMANS

Rats and rabbits are often used because they are easy to anesthetize, inexpensive to buy, easy to maintain, and require little space for caging.[76] The disadvantage is that they belong to low-order phylogenetic species with a characteristically high potential for osteogenesis. The rate of osseous formation seems to vary inversely with the species' position on the phylogenetic scale.[76] Therefore, it is difficult to extrapolate experimental results relative to the rate and amount of bone regeneration from animal models to humans. Nevertheless, the fundamental physiology of bone repair and regeneration is similar in these animals and humans. Accordingly, it may be reasonable to suggest that the positive effects of decortication in accelerating healing or enhancing the volume of bone regeneration in experimental animal models can be obtained in humans.

ADDITIONAL LIMITATIONS OF REVIEWED STUDIES

Many experimental investigations assessing GBR procedures were done on the calvarium of rat and rabbit models. The cranial vault of these animals seems to be a reasonable experimental area for investigations regarding bone regeneration. However, outcomes in calvarial bone models may not reflect results attained with other membranous bones.

It was noted that animal studies and clinical trials that assessed the efficacy of decortication and GBR procedures did not provide information with respect to different results that may be expected in the mandible versus the maxilla. In addition, no conclusions could be drawn about how the size of the bone marrow would affect the decision to decorticate prior to performing a GBR procedure. Furthermore, no data were found that addressed how the size of the bone marrow might affect the regenerative results.

Another major limitation of the reviewed studies may pertain to the time when healing was assessed. It is possible that decortication may provide early benefits with regard to regeneration; however, these benefits cannot be clearly delineated over time. In this respect, studies that assessed histologic specimens at an earlier time point would provide additional information. Conversely, if the results are the same after 3 or 6 months, this might be interpreted to indicate that decortication is not necessary.

CONCLUSIONS

The data in the literature do not provide a clear answer about the usefulness of performing decortication to enhance GBR. However, the following conclusions can be drawn:

No human clinical trial has been done to determine whether decortication enhances ridge augmentation.

GBR using a barrier with and without decortication may result in bone regeneration.

Decortication may provide a quicker healing response; however, the data are limited to support this contention.

Decortication may facilitate regenerating more bone, as per several controlled clinical trials in animals. However, there are other investigations that

noted there was no benefit. Furthermore, successful results can be attained without decortication. Therefore, conflicting information precludes making a definitive statement that decortication results in improved outcomes.

There does not seem to be a detrimental healing effect as a result of decortication.

Decortication may help to physically interlock new bone and remaining graft material to the recipient site.

Animal models may provide information. However, healing rates are faster in animal models, and the healing response may not be the same in humans.

There is no guidance in the literature with regard to the size of holes that should be made in bone, their spatial configuration, or the amount of area that should be decorticated in relation to the size of the GBR treated site.

Growth factors and BMPs applied to grafted sites may obviate decortication procedures. However, this idea needs further testing. Additional studies also need to address the potential benefits of bone decortication done in conjunction with growth factors.

Additional controlled clinical trials (human and animal) are needed to determine whether decortication should be an integral part of GBR procedures.

The finding that decortication may have some benefits without any serious negative impact suggests that the decision to use decortication is really at the discretion of the clinician.

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APPENDIX 1. ARTICLES EXCLUDED UNDER SEARCH DECORTICATION OF BONE AND REGENERATION

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APPENDIX 2: ARTICLES EXCLUDED UNDER SEARCH CORTICAL PERFORATION OF BONE AND REGENERATION

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APPENDIX 3: ARTICLES EXCLUDED UNDER SEARCH INTRAMARROW PENETRATION OF BONE

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