

**PRO-DENSE® INJECTABLE REGENERATIVE GRAFT:
IN VITRO AND *IN VIVO* OBSERVATIONS,
AND A PROPOSED MECHANISM OF ACTION**

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ABSTRACT

PRO-DENSE® injectable regenerative graft is a triphasic calcium salt based material that has demonstrated rapid, robust formation of dense new bone in preclinical studies and in early clinical results. A proposed mechanism of action for PRO-DENSE® Injectable Regenerative Graft is discussed. The progression of bone formation involves angiogenesis, protein binding and release, cell differentiation and proliferation, new bone formation, and bone remodeling. Preclinical studies have demonstrated that the calcium sulfate component of the PRO-DENSE® graft composite resorbs first, allowing for vascular infiltration into the calcium phosphate scaffold. *In vitro* studies of VEGF and BMP-2 have shown increased binding and release of proteins from PRO-DENSE® graft compared to calcium sulfate. The activity of VEGF released from PRO-DENSE® graft has been confirmed in an *in vitro* study of endothelial cells exposed to released VEGF. Results from ongoing studies have provided the framework for the proposed mechanism of action for PRO-DENSE® Injectable Regenerative Graft.

BACKGROUND

PRO-DENSE® Bone graft substitute is a fully synthetic composite material that is designed to be mixed intraoperatively and injected into a bony void to cure *in vivo* to form a strong ceramic. Results with PRO-DENSE® graft in three *in vivo* preclinical studies have consistently demonstrated predictable, robust bone formation. In a canine metaphyseal defect model the majority of the graft was resorbed and replaced by new bone over a period of approximately 3 months. Preliminary review of clinical cases indicates that the graft resorbs at a slower rate in humans.

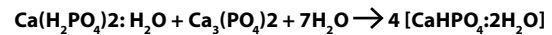
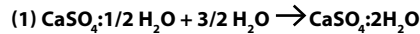
The ability of PRO-DENSE® graft to be replaced predictably with robust bone is likely attributable to the unique dissolution and protein-binding properties of the carefully engineered composite. The calcium sulfate/calcium phosphate matrix with TCP granules provides a composite containing 75% calcium sulfate and 25% calcium phosphate (brushite and granular TCP). This paper describes some *in vitro* and *in vivo* observations that may help elucidate the mechanism of the tremendous bone formation seen with PRO-DENSE® Injectable Regenerative Graft.

IN SITU REACTION

The chemistry of PRO-DENSE® graft is complex and involves two distinct reactions that occur simultaneously to produce a homogeneous combination of calcium sulfate dihydrate and calcium phosphate surrounding unreacted tricalcium phosphate (TCP) granules. The first reaction is a result of

the combination of calcium sulfate hemi-hydrate (CSH) with water to form calcium sulfate dihydrate (CSD) as shown in **EQUATION 1**.

Pure calcium sulfate has been used successfully in bone grafting for over 100 years.^{1,2} It has long been recognized, however, that in certain applications a somewhat slower resorbing material is desirable. In order to achieve this goal, in PRO-DENSE® graft the CSH has been augmented with two calcium phosphate compounds that entail the second yet simultaneous reaction to form a mineral known as “brushite” | **EQUATION 2**.



Because these reactions take place concurrently in the setting graft, the two products are intertwined on the microscopic level and are not distinguishable from one another by either light microscopy or scanning electron microscopy (SEM).

As mentioned previously, in addition to the calcium sulfate and brushite, dense granules of beta-tricalcium phosphate (β-TCP) have been incorporated into PRO-DENSE® graft. These granules are of a sufficient size and density that they are not consumed in the reaction that forms brushite. Therefore, the set graft consists of a distributed aggregate of TCP granules embedded in a matrix of intimately intertwined CSD and brushite crystallites. This is illustrated in **FIGURE 1**, which shows a polished cross-section through the middle of a 4.8 mm diameter pellet cast from PRO-DENSE® graft. The TCP granules are bright white, embedded in the light grey matrix.

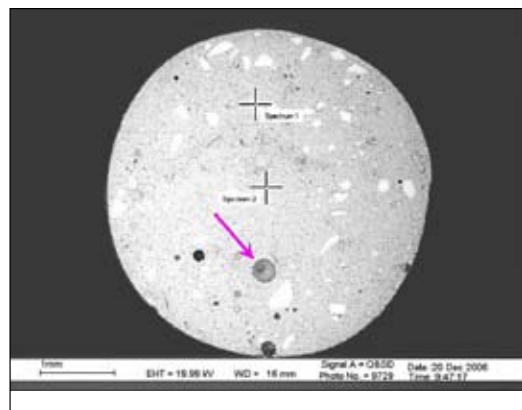


FIGURE 1 Backscattered electron image of a polished cross-section through a PRO-DENSE® pellet. The bright white particles are TCP. Several pore artifacts resulting from the sample preparation are evident in this cross-section (arrow).

MECHANISM AND KINETICS OF PRO-DENSE® GRAFT RESORPTION

The kinetics of dissolution of PRO-DENSE® graft have been studied in an accelerated test in which the pellets are immersed in distilled water at 37° C. Pre-cast and weighed pellets measuring 4.8 mm diameter by 3.2 mm tall were placed in fritted glass thimbles to allow removal of pellets at test intervals without damaging the pellets. The distilled water was changed daily and the pellets (N=5) were dried and weighed to determine the percent mass remaining. Estimates based on a comparison of the percent pellet remaining in the dissolution test and radiographs from the preclinical animal model show that the *in vitro* dissolution rates are approximately six times faster than what is seen *in vivo*.

For this study pellets of pure calcium sulfate (CSD) were tested in the same fashion as a point of reference for a faster-resorbing material.

At selected times, pellets of PRO-DENSE® graft were removed from solution, dried, stabilized with ethyl cyanoacrylate, and embedded in PMMA. Ground and polished cross-sections were subjected to microscopic analysis using backscattered SEM and EDXS (energy-dispersive X-ray spectroscopy), to determine the elemental composition of each material region.

Accelerated Dissolution Results

The comparative dissolution profiles of PRO-DENSE® graft and pure CSD are shown in | **FIGURE 2**. The rate of dissolution as determined by the slope of the curves over the first four days of this accelerated test shows that the design goal of a 50% reduction in weight loss per unit time compared to pure CSD was achieved. Over time, dissolution of the calcium sulfate material in the PRO-DENSE® graft exposed a porous matrix of brushite that contained embedded TCP granules | **FIGURE 3**.

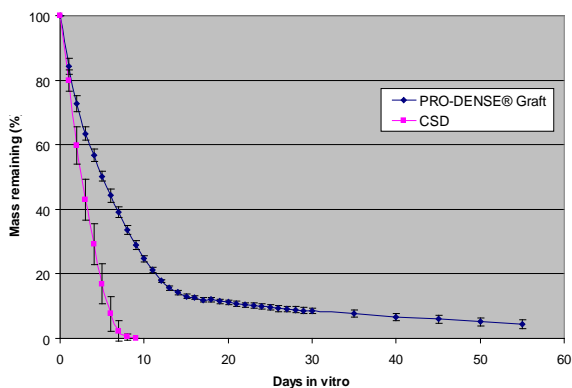


FIGURE 2 | Accelerated *in vitro* dissolution of calcium sulfate and calcium sulfate/calcium phosphate composite

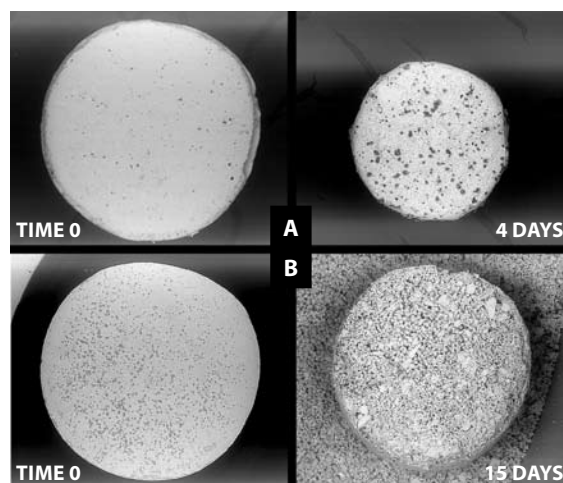


FIGURE 3 | *In vitro* dissolution of (A) calcium sulfate dihydrate pellets by four days, and of (B) PRO-DENSE® graft at 15 days (original magnification 35X). The overall size of the CSD pellet is reduced even at an early timepoint. Much of the size of the PRO-DENSE® graft is maintained, even at 15 days, but the calcium sulfate has dissolved to reveal the porous calcium phosphate structure containing TCP granules.

This difference in dissolution rate is thought to be due to the microscopic scale in which the brushite and CSD phases of PRO-DENSE® graft are distributed in the matrix of the set graft. As CSD is dissolved from the surface of the pellet, the finely dispersed brushite crystals that are left behind act to slow the diffusion of CSD dissolution products. The resulting local increase in concentration of Ca (calcium) and SO₄ (sulfate) ions slows the dissolution rate from the remaining bulk matrix. The physical progression of this process is illustrated in **FIGURES 4-6**, which show SEM images of cross sections through embedded PRO-DENSE® graft after four, eight, and twelve days of accelerated *in vitro* dissolution which has been estimated to occur about 6 times faster than *in vivo*.

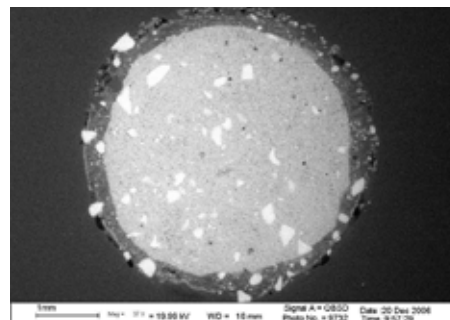


FIGURE 4 | Cross-section through a PRO-DENSE® pellet after four days of accelerated *in vitro* dissolution (which represents approximately 24 days *in vivo*). The darker region on the outer edge of the pellet represents the area in which calcium sulfate has mostly dissolved, leaving brushite and TCP particles (bright white).

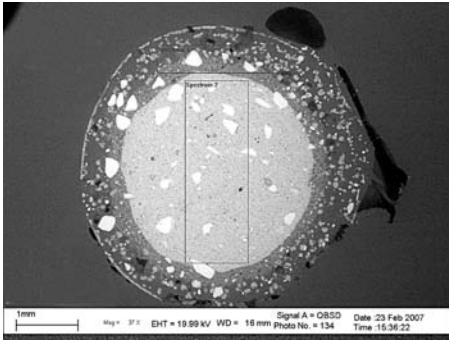


FIGURE 5 | Cross-section through a PRO-DENSE® pellet after eight days of accelerated *in vitro* dissolution (approximately 48 days *in vivo*). Dissolution of the calcium sulfate continues to progress inward.

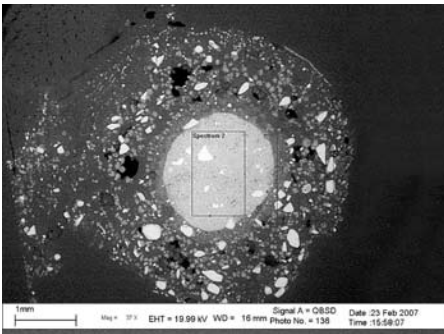


FIGURE 6 | Cross-section through a PRO-DENSE® pellet after twelve days of accelerated *in vitro* dissolution (approximately 72 days *in vivo*). The region of dissolving brushite is increasing with a subsequent decrease in the region with intact calcium sulfate.

In these images, intact matrix shows as a light grey and TCP granules as white. The brushite that is evident in the partially dissolved areas shows up as a darker grey material dispersed through the embedding media that has infiltrated into the space previously occupied by the CSD. Elemental analysis of the various regions within the cross-sections confirms the identification. Regions of intact matrix have high values for sulfur concentration while zones that are depleted of CSD show significantly lower sulfur concentrations.

The combination of mass loss data and microscopic analysis leads to the following conclusions regarding the physical-kinetic process of dissolution for PRO-DENSE® graft.

- 1| There is an initial burst of CSD dissolution from the surface of the pellet, which exposes an outer layer of fine brushite crystals and larger TCP granules.
- 2| The brushite forms a diffusion barrier that slows the rate of CSD dissolution.
- 3| As dissolution proceeds, brushite crystals on the exterior of the pellet (those that were first exposed) appear to become less dense, indicating that the brushite is also dissolving.

- 4| The relatively dense region of brushite that surrounds the intact portion of the pellet moves inward as dissolution continues.
- 5| The TCP granules form a distributed scaffold even after the majority of the CSD and brushite have dissolved. It is likely that some of the brushite remains attached to the TCP and acts to hold the granules in place.

PROPOSED MECHANISM OF ACTION OF NEW BONE FORMATION

In defects treated with PRO-DENSE® graft, triphasic resorption facilitates a maximum healing response. This effect, which has also been seen clinically, has been observed and described in a critically-sized metaphyseal defect model in the proximal humerus of dogs.³ Similar results have also been seen in a canine humerus transcortical non-critically-sized defect model. Potential contributing mechanisms have also been examined and confirmed *in vitro*.

Canine Defect Studies

PRO-DENSE® graft has been investigated in three canine studies. The first study involved the creation of non-critical size transcortical defects, (9mm diameter x 20mm long) in the proximal humerus of three mongrel dogs (data on file). Animals were sacrificed at 6 weeks and the implant sites harvested and prepared for histological examination. In this initial study, PRO-DENSE® implants were associated with progressive, robust bone growth over time as determined by radiographs. Bone formation was denser than surrounding bone at 6 weeks as observed in histological sections.

In the second and third studies, critically-sized defects were created in the proximal humerus of mongrel dogs. The cylindrical, longitudinal defects were created by drilling a 13mm diameter x 50mm long hole adjacent to the greater trochanter.³ In the second study, one defect was filled with PRO-DENSE® graft in each of ten dogs. At 13 and 26 weeks, the animals were sacrificed and the defect sites harvested for contact radiographs, histology, and mechanical testing. In the third study, six dogs were implanted. Each canine was sacrificed at an early timepoint (2, 3, 4, 6, 8, or 10 weeks) and contact radiographs and histological specimens were prepared. The results were compared to data for autograft and normal bone collected in similar but unrelated studies.

The radiographs and histology from both of these studies clearly illustrated an efficient and constant progression of material resorption and bone growth over time. The PRO-DENSE® graft was also associated with the growth of dense new bone in early time points and a significant increase in compressive strength of the healed bone compared to normal bone at the earliest timepoint that mechanical testing was employed, 13 weeks.

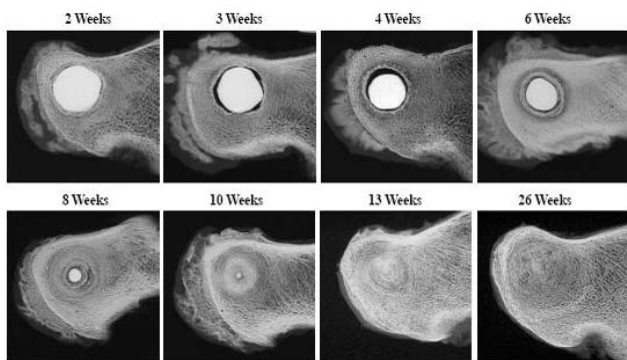


FIGURE 7 | Representative contact radiograph images showing the degradation of PRO-DENSE® graft and infill of new bone over time.

Representative contact radiographs taken at each timepoint are shown in **FIGURE 7**. As early as the first time point, 2 weeks, the material showed resorption and the remaining bolus was surrounded by a thin region devoid of calcified components which was immediately adjacent to a region of particularly dense new bone. By 8 weeks, less than 50% of the material remained and the front of new bone had continued to move inward. By 13 weeks, the bolus of material had almost completely resorbed and was replaced with new bone. By 26 weeks, the new bone in the defect had remodeled to resemble normal bone.

Examination of the histology images and histomorphometric analysis at each time point as well as compressive strength measurements taken at 13 and 26 weeks support the progression seen in the contact radiographs. Histomorphometry data of PRO-DENSE® implants were compared to data from autograft implants collected in unrelated studies.

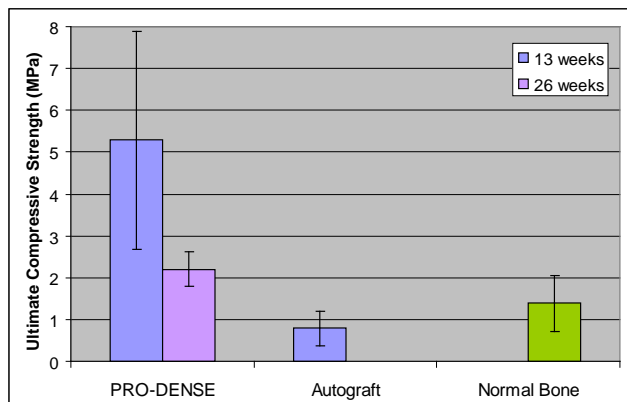


FIGURE 8 | Compressive strength of new bone in defect sites treated with PRO-DENSE®. Data for autograft-treated sites and normal bone were collected in similar, unrelated studies. Data was not available for autograft at 26 weeks.

Prior to 8 weeks, the percent area of new bone in the PRO-DENSE® graft-treated sites was lower than in autograft-treated sites or normal bone due to the presence of a significant amount of residual graft. By 8 weeks, however, a majority of the graft had resorbed, and the percentage of new bone surpassed that of the autograft group. At 13 and 26 weeks, the amount of new bone in PRO-DENSE®graft-filled sites compared with autograft-treated sites showed a similar profile as mechanical strength indicative of remodeling to normal bone.³ **FIGURE 8**. At 13 weeks, the compressive strength of new bone in sites receiving PRO-DENSE® graft was greater than six times (6.7X) that of sites receiving autograft (in an unrelated study) and greater than three times (3.9X) that of normal bone taken from a similar anatomical site. As most of the implant had resorbed by 13 weeks (>90%), the increase in strength can primarily be attributed to increased strength of the healing bone as further confirmed by the dense bone and minimal residual graft seen in histological specimens. By 26 weeks, new bone had remodeled and exhibited mechanical properties only slightly higher than those of normal bone.

Progression of New Bone Formation

The formation of new bone is described as a progression of five steps which repeat as the graft is resorbed until the entire graft site is filled with new, remodeled bone.

1| ANGIOGENESIS

As with all healing, angiogenesis is a key early event in the repair of injured bone. Immediately following an injury, growth factors and other proteins flood the region to attract and stimulate cells to initiate the healing process, including enabling the formation of new blood vessels. As demonstrated *in vitro*, the calcium sulfate component is the first phase of the PRO-DENSE® implant material to be resorbed. As the calcium sulfate is resorbed *in vivo* by one or more mechanisms including dissolution and osteoclastic resorption **FIGURE 9** |,⁴ the calcium phosphate (i.e., brushite and TCP) scaffold with interconnected pores is revealed, allowing for infiltration into the implant by newly formed blood vessels | **FIGURE 10**.

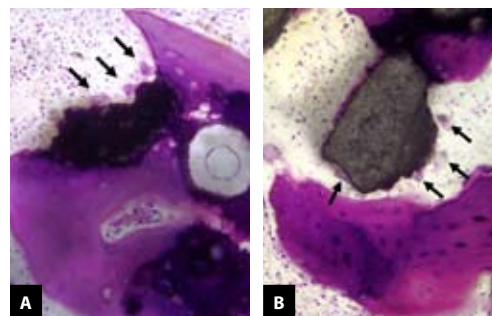


FIGURE 9 | Osteoclasts (arrows) resorbing (a) calcium sulfate/brushite material, and (b) β-TCP granules, in a canine proximal humerus defect site treated with PRO-DENSE® graft, 13 weeks post-implantation. (Basic fuschin and toluidine blue, 300X)

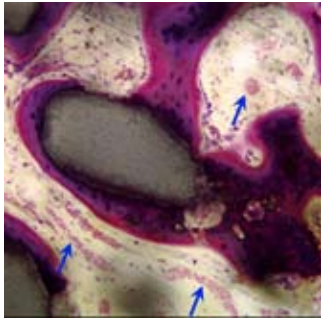


FIGURE 10 | New blood vessels (arrows) adjacent to PRO-DENSE® graft in a canine proximal humerus defect site implanted with PRO-DENSE® graft, 6 weeks post-implantation. (Basic fuchsin and toluidine blue, 300X)

2 | PROTEIN BINDING AND RELEASE

As new blood vessels infiltrate the defect region and the calcium phosphate scaffold, cytokines and growth factors are transported into the implant/defect interface region. Angiogenic factors such as VEGF (vascular endothelial growth factor) and FGF (fibroblast growth factor) play a key role in the development of new blood vessels, including the chemoattraction and induction of proliferation of endothelial cells.^{5,6}

An *in vitro* study of PRO-DENSE® graft specimens exposed to radiolabelled VEGF or radiolabelled BMP-2 (bone morphogenetic protein-2) has shown that the proteins preferentially bind to PRO-DENSE® graft compared to pure calcium sulfate.⁷ Briefly, PRO-DENSE® graft and calcium sulfate pellets were incubated in PBS with 20 ug/mL VEGF or BMP-2 at 37°C for 1 hour (4 replicates for VEGF; 6 replicates for BMP-2). After rinsing to remove loosely adhered proteins, pellets were placed in tubes and the radioactivity, indicative of adhered proteins, was measured with a gamma counter. There was a trend towards higher adsorption of VEGF on PRO-DENSE® graft although the difference was not significant | **FIGURE 11**. Significantly greater binding of BMP-2 was measured from PRO-DENSE® graft compared to CSD (p=0.026) | **FIGURE 11**.

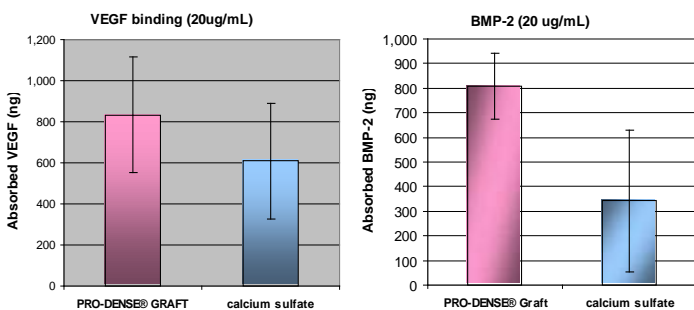


FIGURE 11 | Proteins adhered to pellets soaked in 20 µg/mL VEGF (a) or BMP-2 (b). Bars represent standard deviations.

3 | CELL PROLIFERATION AND DIFFERENTIATION

Following injury and implantation of biocompatible materials, active proteins such as TGF-β (transforming growth factor beta) attract regenerative cells to the defect/implant interface region.⁷ Released proteins and other proteins in the surrounding area also incite cell proliferation and induce differentiation of stem cells to osteoblast progenitors and then to osteoblasts. Factors which enhance proliferation of osteoblastic stem cells, osteoblast precursors, and/or osteoblasts include TGF- β, PDGF (platelet derived growth factor), and IGF-I and IGF-II (insulin-like growth factor-I and -II).^{8,9,10,11,12,13} Bone morphogenetic proteins (BMPs), also referred to as osteoinductive factors, play a critical role in the differentiation of stem cells to preosteoblastic and osteoblastic cells.^{14,15,16}

In vitro results have indicated that proteins released from the PRO-DENSE® scaffold are active and stimulatory.⁷ In the demonstrative study, PRO-DENSE® disks were soaked in a 20 µg/mL VEGF solution for 1 hour and then rinsed to remove loosely adhered proteins. Disks were then incubated in PBS solution and eluates were drawn at 24, 48, and 72 hours, with replenishment of the PBS solution after each eluate aspiration. Human umbilical vascular endothelial cells (HUVEC) were seeded onto transwell inserts (pore size 8 µm) which were placed in media dosed with the eluates for 4 hours. Following incubation, cells that had migrated from the inserts to the bottom of the wells were trypsinized and counted.

There was a trend toward an increase in cellular migration in wells treated with PRO-DENSE®/VEGF eluates vs. control eluates (i.e., PRO-DENSE® graft / PBS alone) | **FIGURE 9**, indicating that the released protein was active and stimulatory. Additionally, the number of migrated cells was relatively consistent at the three timepoints (24, 48, 72 hours) supporting a pattern of sustained release of the protein from the PRO-DENSE® graft specimens.

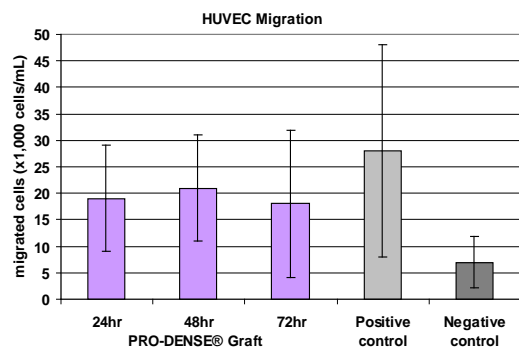


FIGURE 12 | HUVEC cells migrated over time in response to VEGF absorbed and then eluted from PRO-DENSE® graft samples. The positive and negative controls were PBS with 40 ng/mL VEGF and PBS alone, respectively. Bars represent standard deviations.

4 | NEW BONE FORMATION

In the canine models discussed, new bone formed directly adjacent to PRO-DENSE® graft. Osteoblasts recruited to the area formed the new bone via intramembranous ossification. Although new bone growth in long bones is typically formed via endochondral ossification (i.e., the inclusion of an intermediary cartilage scaffold), osteoblasts adjacent to PRO-DENSE® graft directly laid down osteoid tissue which was then mineralized to form new bone | **FIGURE 13**. Osteoblasts continued to regenerate new bone, eventually surrounding residual PRO-DENSE® materials | **FIGURE 14**. Over time, the remainder of the PRO-DENSE® graft was resorbed, again due in part to osteoclastic resorption.

This progression of new bone formation is consistent with the theory presented regarding resorption shown by *in vitro* dissolution studies. As seen histologically, new bone formation starts at the edge of the defect, presumably following new blood vessels into the porous brushite/TCP matrix. As resorption of the calcium sulfate and calcium phosphate progresses inward toward the center of the original PRO-DENSE® graft bolus, new bone growth follows until the majority of the implant material is gone.

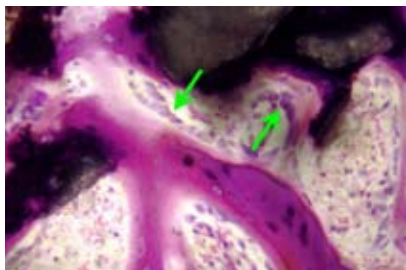


FIGURE 13 | Osteoblasts (arrows) adjacent to the osteoid (very light pink) and calcified new bone (darker pink) laid upon residual PRO-DENSE® material, in a canine transcortical defect at 6 weeks. (Basic fuschin and toluidine blue, 300X)

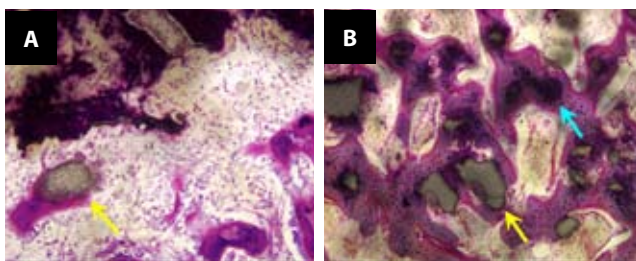


FIGURE 14 | Newly formed bone (dark pink) adjacent to residual PRO-DENSE® material at (a) 2 weeks (154X), and (b) at 6 weeks (75X) in a proximal humerus defect and transcortical defect, respectively, in dogs. TCP granules are light grey (yellow arrow) and brushite or calcium sulfate are dark material. (blue arrow). (Basic fuschin and toluidine blue, 75X)

5 | BONE REMODELING

Following formation of newly woven bone, remodeling occurs in response to mechanical loading (Wolff’s Law). Over time, new bone in the defect site remodels to resemble normal bone | **FIGURE 15**.

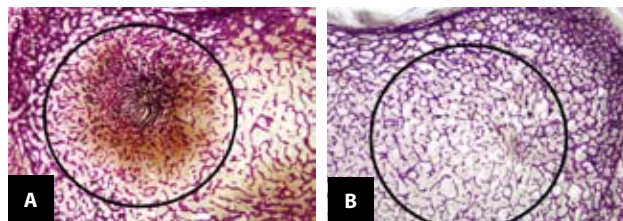


FIGURE 15 | Newly formed bone in the proximal humerus of dogs at: (a) 13 weeks, and (b) 26 weeks. The circles approximate the original defects. At 13 weeks, there is still some residual implant material, and the bone formation around the implant material is particularly dense. By 26 weeks, the material is mostly resorbed and the bone is continuing to remodel toward normal bone architecture. (Basic fuschin and toluidine blue, 10X)

EARLY CLINICAL OBSERVATIONS

In early case studies, PRO-DENSE® Injectable Regenerative Graft has been associated with consistent material resorption, accompanied by predictable, robust new bone formation. The region of protein absorption, protein release, and new bone formation surrounds the implant material | **FIGURE 16**. Computed tomography (CT) scans have typically shown a thin, translucent layer which is believed to represent the layer of new, unmineralized osteoid | **FIGURE 17**. This thin region advances inward as graft resorption and healing progress. CT scans also show a layer of denser bone adjacent to the healing defect site at early timepoints which decreased over time, that is consistent with radiographic results of healing defects in the canine studies.³



FIGURE 16 | Radiographs of a painful benign bone cyst in the tibia of a 16-year old male: (A) Pre-operative, (B) 1 month post-op, (C) 3 months post-op, and (D) 9 months post-op. Note the dense new bone surrounding the remaining implant at 3 months. By 9 months, all material is resorbed and the bone continues to remodel toward normal bone architecture. *Images courtesy of Mike Neel, MD, OrthoMemphis, Memphis, TN.*

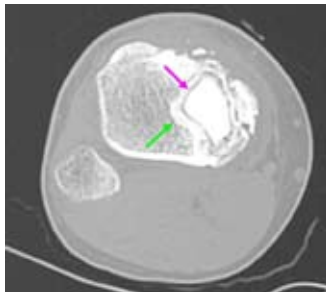


FIGURE 17 | CT scan at 3 months from the mid-region of the tibial bone cyst. The thin, translucent osteoid layer (pink arrow) is surrounded by especially dense new bone formation (green arrow). Image courtesy of Mike Neel, MD, OrthoMemphis, Memphis, TN.

Radiographic results in a prospective, uncontrolled, multi-center trial of displaced tibial plateau fractures treated with PRO-DENSE® graft have also been consistent with those observed in the canine studies. Defects in thirty-four patients with closed (32) or open (2) fractures were treated with PRO-DENSE® Injectable Regenerative Graft.¹⁷ Evaluation of CT scans from the 18 patients who have reached the 24 week timepoint revealed a progression in bone density toward normal bone between 12 and 24 weeks. This progression in density toward that of normal bone is consistent with results of the canine studies. Functional outcome assessments pre-operatively and at 12 and 24 weeks using the short-form musculoskeletal function assessment (SMFA) reflected increasing function over time.

CONCLUSIONS

Ongoing preclinical *in vivo* and *in vitro* studies offer insight into the possible mechanism of action that makes PRO-DENSE® Injectable Regenerative Graft a powerful graft for healing bone defects. Studies thus far have shown that the graft provides unique dissolution properties and the ability to bind and release proteins at the implant/defect interface. This provides an ideal environment for the direct deposition of bone resulting in a slow-resorbing matrix that propagates healing across the defect. This may explain the predictable, robust bone formation seen in the animal models and in early clinical experience.

REFERENCES

1. Bahn SL. "Plaster: a bone substitute." *Oral Surgery Oral Medicine and Oral Pathology*, 21(5): 672-681, 1966.
2. Peltier LF. "The use of Plaster of Paris to fill defects in bone." *Clinical Orthopedics and Related Research*, 21:1-31, 1961.
3. Urban RM, Turner TM, Hall DJ, Inoue N, Gitelis S, "Increased bone formation using a calcium sulfate and calcium phosphate composite graft," *Clinical Orthopedics and Related Research*, 459: 110-117, 2007.
4. Bloemers FW, Blokhuis TJ, Patka P, Bakker FC, Wiperman BW, Haarman HJTM, "Autologous bone versus calcium-phosphate ceramics in treatment of experimental bone defects," *Journal of Biomedical Materials Research Part B: Applied Biomaterials*, 66B: 526-531, 2003.
5. Lakey LA, Akella R, Janieri JP. "Angiogenesis: Implications for tissue repair," Ch. 11 in *Bone Engineering*, ed. by Davies JE, em squared inc., Toronto, Canada, 2000.
6. Marie PJ, Lomri A, Debais F, Lemonnier J, "Fibroblast growth factors and osteogenesis," ch. 12 in *Skeletal Growth Factors*, ed. by Canalis E, Lippincott William and Wilkins, Philadelphia, PA, 2000.
7. McCanless J, Chesnutt B, Slack S, Bumgardner, Haggard W. "Comparison of bone graft substitutes through protein adsorption and cellular response." *Transactions of the Orthopedic Research Society*, 33: 99, 2008.
8. Janssens K, ten Dijke P, Janssens S, Van Hul W, "Transforming growth factor-β1 to the bone," *Endocrine Reviews*, 26(6): 743-774, 2005.
9. Bolander ME, "Regulation of fracture repair by growth factors," Proceedings of the Society for Experimental Biology and Medicine, 200(2):165-70, 1992.
10. Erlebacher A, Filvaroff EH, Ye J-Q, Derynck R, "Osteoblastic responses to TGF-β during bone remodeling," *Molecular Biology of the Cell*, 9: 1903-1918, 1998.
11. Conover CA, "Insulin-like growth factors and the skeleton," ch. 7 in *Skeletal Growth Factors*, ed. by Canalis E, Lippincott William and Wilkins, Philadelphia, PA, 2000.
12. Canalis E and Ornitz DM, "Platelet-derived growth factor: Skeletal actions and regulation," ch. 10 in *Skeletal Growth Factors*, ed. by Canalis E, Lippincott William and Wilkins, Philadelphia, PA, 2000.
13. Balooch G, Balooch M, Nalla RK, Schilling S, Filvaroff EH, Marshall GW, Marshall SJ, Ritchie RO, Derynck R, Alliston T, "TGF-βeta regulates the mechanical properties and composition of bone matrix," Proceedings of the National Academy of Sciences of the United States of America, 102(52):18813-18818, 2005.
14. Choi IH, Chung CY, Cho T-J, Yoo WJ, "Angiogenesis and mineralization during distraction osteogenesis," *Journal of Korean Medical Science*, 17: 435-447, 2002.
15. Canalis E, Economides AN, Gazzerro E, "Bone morphogenetic proteins, their antagonists, and the skeleton," *Endocrine Reviews*, 24(2): 218-235, 2003.
16. Cheng H, Jiang W, Phillips FM, Haydon RC, Peng Y, Zhou L, Luu HH, An N, Breyer B, Vanichakarn P, Szatkowski JP, Park JY, He T-C, "Osteogenic activity of the fourteen types of bone morphogenetic proteins," *Journal of Bone and Joint Surgery*, 85-A(8): 1544-1552, 2003.
17. Ricci W, Watson JT, Borrelli J, Weber T, Choplin R, Persohn S, White R, "A prospective functional and CT analysis of a calcium sulfate/ calcium phosphate composite graft for the treatment of tibial plateau fractures," *Transactions of the International Society for Fracture Repair (ISFR)*, 2008.



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