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(54) **Title**: METHODS OF TREATING OR PREVENTING PERIODONTITIS AND DISEASES ASSOCIATED WITH PERIODONTITIS

(57) **Abstract**: The present disclosure describes methods for preventing or treating periodontitis or diseases associated with periodontitis. The present disclosure also describes methods of screening for compounds that can be used to prevent or treat periodontitis or diseases associated with periodontitis.

METHODS OF TREATING OR PREVENTING PERIODONTITIS AND DISEASES ASSOCIATED WITH PERIODONTITIS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Application No. 61/662,022 filed June 20, 2012, and U.S. Application No. 13/801,096, filed on March 13, 2013.

FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

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TECHNICAL FIELD

This disclosure generally relates to periodontal disease and methods of treating or preventing periodontitis.

BACKGROUND

Periodontitis is a prevalent chronic inflammatory disease that leads to the destruction of the tissues that surround and support the teeth (periodontium). This oral disease is initiated by bacterial biofilms, which form on subgingival tooth surfaces and comprise mostly communities of gram-negative anaerobic species. The host inflammatory response to chronic microbial challenge at the dentogingival niche is implicated in inflicting damage upon the periodontium.

Although traditionally perceived as an antimicrobial enzyme system in serum, complement is now recognized as a central component of host defense impacting both innate and adaptive immunity. Not surprisingly, given its importance in fighting pathogens, complement constitutes a key target of immune evasion by microbes that cause persistent infections.

SUMMARY

The present disclosure describes methods for preventing or treating periodontitis or diseases associated with periodontitis. The present disclosure also describes methods of screening for compounds that can be used to prevent or treat periodontitis or diseases associated with periodontitis.

In one aspect, a method of treating or preventing periodontitis or diseases associated with periodontitis in an individual is provided. Such a method generally includes administering a compound to the individual that inhibits or blocks C3 expression, activity, or activation. Representative compounds include, without limitation, compstatin, analogs of compstatin, complement receptor 1-related gene/protein y (Crry), and complement activation blocker-2. Another representative compound is an antibody against C3, or, for example, a peptidomimetic antagonist of C3. Representative diseases associated with periodontitis include, without limitation, atherosclerosis, diabetes, osteoporosis, and pre-term labor.

In another aspect, a method of reducing the amount of *Porphyromonas gingivalis* and/or the inflammation caused by *P. gingivital* in an individual is provided. Such a method generally includes administering, to the individual, a compound that inhibits or blocks C3 expression, activity, or activation. Representative compounds include, without limitation, compstatin, analogs of compstatin, complement receptor 1-related gene/protein y (Crry), and complement activation blocker-2.

In still another aspect, a method of screening for compounds that treat or prevent periodontitis or diseases associated with periodontitis is provided. Such a method typically includes contacting a cell, in the presence of *P. gingivalis*, with a test compound; and evaluating the cell for expression, activity, or activation of C3. Generally, a reduction in the expression, activity, or activation of C3 in the presence of a test compound is indicative of a test compound that can be used to treat or prevent periodontitis or diseases associated with periodontitis. In some embodiments, the cell is a mammalian cell. In some embodiments, the cell is a recombinant cell comprising an exogenous nucleic acid encoding C3.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the methods and compositions of matter belong. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the methods and compositions of matter, suitable methods and materials are described below. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting. All publications, patent applications, patents, and other references mentioned herein are incorporated by reference in their entirety.

DESCRIPTION OF DRAWINGS

Figure 1 is graphs showing that C3 deficiency protects against inflammatory periodontal bone loss. Data are means ± SD (n = 5 mice). *, $P < 0.05$ and **, $P < 0.01$ vs. sham-infected WT., significant ($p < 0.01$) inhibition of bone loss or cytokine induction. Key: W-S: WT & sham-infected; W-P: WT & Pg-infected; C3-S: C3-/- & sham-infected; C3-P: C3-/- & Pg-infected.

Figure 2 is a graph showing the colonization and effects of *P. gingivalis* in the periodontium of normal or complement-deficient mice. Data are means ± SD (n = 5 mice per group). *$P < 0.01$ between the indicated groups.

Figure 3 are graphs showing bone loss measured in defleshed maxillae (Panel A) and mRNA expression of the indicated cytokines (normalized against GAPDH mRNA) and expressed as fold change in the transcript levels in the ligated site relative to those of the contralateral unligated site (assigned an average value of 1; Panel B). Data are means ± SD (n = 5 mice). Negative values indicate bone loss relative to the unligated contralateral tooth. *, $P < 0.01$ vs. WT control. •, significant ($P < 0.01$) inhibition of cytokine induction.

Figure 4 are graphs showing that Cp40 decreases inflammatory clinical parameters of NHP periodontitis. Starting 3 days after initiation of ligature-induced periodontitis, Cp40 (500 μg) was injected locally into the maxillary interdental papillae from the 1st premolar to the 2nd molar, in two animals, three times weekly. An inactive analog of Cp40 (control) was injected into the contralateral side of the mouth in the same two animals (split-mouth design). Shown are the effects of Cp40 on the indicated inflammatory clinical parameters and bone heights, determined using standardized X-ray images (taken at week 6) and Nikon Imaging System software. Specifically, the distance between the cement-enamel junction (CEJ) and alveolar bone crest (ABC) was measured at six points (1st premolar, distal; 2nd premolar mesial & distal; 1st molar, mesial & distal; 2nd molar mesial) and the data in Panel E reflect the 6-site total. The higher CEJ-ABC distance values of the controls as compared to those of Cp40 treatments signify increased bone loss in the absence of drug treatment. In all animals, the gingival margin was at the cement-enamel junction, and thus, PPD readings equaled clinical attachment loss (CAL).

Figure 5 are graphs showing that Cp40 inhibits proinflammatory cytokine production and osteoclastogenesis in NHP periodontitis. At the same timepoints that clinical exams were performed (as per Figure 4), GCF was collected from the same monkeys (treatment details in Figure 4 legend) using PerioPaper strips to assay the indicated cytokines. Total cytokine content in the eluted GCF samples was measured using Milliplex Map kits on a Bio-Plex

system. In Panel G, TRAP-positive multinucleated cells (osteoclasts) were enumerated in nine serial sections for each bone biopsy specimen taken between the 2nd premolar and 1st molar of each animal.

Figure 6 are graphs showing a significant inhibition of inflammatory clinical parameters following treatment of NHP periodontitis with Cp40. Starting 3 days after initiation of ligature-induced periodontitis, Cp40 (500 μg) or control were injected locally into the mandibular interdental papillae from the 1st premolar to the 2nd molar, three times weekly, in opposites sides of the mouth (split-mouth design). The effects of Cp40 were determined on the indicated inflammatory clinical parameters at the indicated timepoints. In all animals, the gingival margin was at the cement-enamel junction, and thus, PPD readings equaled clinical attachment loss (CAL). Data are means ± SD ($n = 4$ monkeys). *, $P < 0.05$; **, $P < 0.01$ vs. control.

Figure 7 are graphs showing decreased GCF levels of proinflammatory cytokines following treatment of NHP periodontitis with Cp40. At the same timepoints that clinical exams were performed (as per Figure 6), GCF was collected from the same monkeys (treatment details in Figure 6 legend) using PerioPaper strips to assay the indicated cytokines. Total cytokine content in the eluted GCF samples was measured using Milliplex Map kits on a Bio-Plex system. Data are means ± SD ($n = 4$ monkeys). *, $P < 0.05$; **, $P < 0.01$ vs. control.

Figure 8 are graphs showing inhibition of periodontal bone loss following treatment of NHP periodontitis with Cp40. Four monkeys were treated as described in the legend to Figure 6, and their mandibular bone heights (CEJ-ABC distance) were measured using standardized X-ray images (taken at baseline and at week 6) and Nikon Imaging System software. Measurements were made at six points (1st premolar, distal; 2nd premolar mesial & distal; 1st molar, mesial & distal; 2nd molar mesial) and the data in Panel A and Panel B reflect, respectively, the 6-site total at baseline (Panel A) and at week 6 (Panel B). For each control or Cp40 treatment, bone loss was calculated as bone height at baseline minus bone height at 6 weeks (Panel C). The difference between Cp40 and control was significant ($P < 0.05$; paired t test).

Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

Periodontitis is a set of inflammatory diseases affecting the periodontium, i.e., the tissues that surround and support the teeth. Periodontitis involves progressive loss of the

alveolar bone around the teeth, and, if left untreated, can lead to the loosening and subsequent loss of teeth. Periodontitis is caused by microorganisms that adhere to and grow on the tooth's surfaces, along with an overly aggressive immune response against these microorganisms. Periodontitis manifests as painful, red, swollen gums, with abundant plaque. Symptoms may include redness or bleeding of gums while brushing teeth, using dental floss, or biting into hard food (e.g. apples); recurrent swelling of the gum; halitosis and a persistent metallic taste in the mouth; gingival recession resulting in apparent lengthening of teeth; deep pockets between the teeth and the gums (pockets are sites where the attachment has been gradually destroyed by collagenases); and loose teeth.

In 1999, a classification system was developed for periodontal diseases and conditions, which listed seven major categories of periodontal diseases, of which the last six are termed "destructive periodontal disease" because they are essentially irreversible. In addition, terminology expressing both the extent and severity of periodontal diseases are appended to the classes to further denote the specific diagnosis. The extent of disease refers to the proportion of the dentition affected by the disease in terms of percentage of sites. Sites are defined as the positions at which probing measurements are taken around each tooth and, generally, six probing sites around each tooth are recorded to make a determination of the extent of periodontal disease. Typically, if up to 30% of sites in the mouth are affected, the manifestation is classification as localized; if more than 30% of sites in the mouth are affected, the term generalized is used. The severity of disease refers to the amount of periodontal ligament fibers that have been lost, termed clinical attachment loss, and is defined by the American Academy of Periodontology as mild (1–2 mm of attachment loss), moderate (3–4 mm of attachment loss), or severe ($\geq$ 5 mm of attachment loss).

Periodontitis also has been shown to have effects outside of the mouth. For example, periodontitis has been linked to increased inflammation as indicated by increased levels of C-reactive protein and Interleukin-6 (IL-6). In addition, periodontitis has been shown to increase the risk for a number of other diseases, including but not limited to, stroke, myocardial infarction, atherosclerosis, diabetes, osteoporosis, and pre-term labor.

The primary pathogen involved in periodontitis is *Porphyromonas gingivalis*, a gram-negative anaerobic bacterium. *P. gingivalis* inhibits the complement cascade, which usually converges at the third complement component (C3) and leads to the generation of effector molecules that mediate recruitment and activation of inflammatory cells via the anaphylatoxins, C3a and C5a, microbial opsonization and phagocytosis via opsonins such as C3b, and direct lysis of targeted microbes via the C5b-9 membrane attack complex.

Currently, there is no satisfactory adjunctive therapy in periodontitis; antimicrobials and antibiotics have largely failed in that regard. At present, perhaps the most promising approach is the use of agents that promote the resolution of inflammation (e.g., lipoxins and resolvins), although at least some of these agents appear to have stability issues (e.g., easily becomes oxidized and loses biological activity).

Methods of Treating or Preventing Periodontitis or Diseases Associated with Periodontitis

The mechanisms used by *P. gingivalis* to overcome and thwart the host's immune response as described herein can be used against the pathogen in methods of treating or preventing periodontitis or diseases associated with periodontitis. For example, blocking C3 effectively deprives *P. gingivalis* of crucial survival tactics. Thus, methods that inhibit or block C3 expression, activity or activation can be used to reduce the amount of *P. gingivalis* in an individual, thereby protecting the individual from periodontitis and associated systemic diseases like atherosclerosis. In addition, methods that inhibit the immunosuppressive signaling that occurs in the presence of C3 also can be used to reduce the amount of *P. gingivalis* in an individual, thereby protecting the individual from periodontitis and associated systemic diseases.

Such methods (e.g., methods of inhibiting or blocking C3 expression, activity or activation) typically include administering a compound to the individual that inhibits or blocks C3 expression, activity or activation. By way of example, there are a number of compounds that are known to inhibit or block C3 expression, activity, or activation (e.g., C3 antagonists). For example, compstatin or analogs of compstatin, complement receptor 1-related gene/protein y (Crry), and complement activation blocker-2 are inhibitors of C3 that are known in the art. See, for example, Sahu et al., 2000, "Complement Inhibitors Targeting C3, C4, and C5", in *Contemporary Immunology: Therapeutic Interventions in the Complement System*, pp. 75-112, Lambris and Holers, Eds., Humana Press Inc., Totowa, NJ; and Qu et al., 2012, "New analogs of the clinical complement inhibitor compstatin with subnanomolar affinity and enhanced pharmacokinetic properties," Immunobiology, 218:496-505.

An antibody against C3 also can be used to inhibit or block C3 expression, activity, or activation. Antibodies against C3 are known and are commercially available from, for example, Creative BioMart (Shirley, NY), ABCAM (Cambridge, MA), and Acris Antibodies (San Diego, CA). In addition, RNA interference ("RNAi") can be used to specifically target the nucleic acid encoding C3. RNAi is a process that is used to induce specific post-

translational gene silencing. RNAi involves introduction of RNA with partial or fully double-stranded character into the cell or into the extracellular environment. The portion of the target gene used to make RNAi can encompass exons but also can include untranslated regions (UTRs) as well as introns. See, for example, Kim et al., 2008, *Biotechniques*, 44:613-6 as well as Lares et al., 2010, *Trends Biotechnol.*, 28:570-9; and Pfeifer et al., 2010, *Pharmacol. Ther.*, 126:217-27. See, also, Ricklin & Lambris, 2007, *Nature Biotechnol.*, 25:1265-75.

In certain embodiments, one or more inhibitors of complement can be administered to an individual and used to prevent or treat periodontitis (or diseases associated with periodontitis) via the role of complement, as described herein, in the formation of periodontitis and, specifically, in the establishment of *P. gingivalis*. Representative complement inhibitors include, without limitation, sCR1, C1 Inhibitor (C1inh), Membrane Cofactor Protein (MCP), Decay Accelerating Factor (DAF), MCP-DAF fusion protein (CAB-2), C4bp, Factor H, Factor I, Carboxypeptidase N, vitronectin (S Protein), clusterin, CD59, compstatin and its functional analogs, Clq inhibitors or anti-Clq antibodies, Cl inhibitors or anti-Cl antibodies, Clr inhibitors or anti-Clr antibodies, Cls inhibitors or anti-Cls antibodies, MSP inhibitors or anti-MASP antibodies, MBL inhibitors or anti-MBL antibodies, C2 inhibitors or anti-C2 antibodies, C4 inhibitors or anti-C4 antibodies, C4a inhibitors or anti-C4a antibodies, C5 inhibitors or anti-C5 antibodies, C5a inhibitors or anti-C5a antibodies, C5aR inhibitors or anti-C5aR antibodies, C5b inhibitors or anti-C5b antibodies, C3a inhibitors or anti-C3a antibodies, C3aR inhibitors or anti-C3aR antibodies, C6 inhibitors or anti-C6 antibodies, C7 inhibitors or anti-C7 antibodies, C8 inhibitors or anti-C8 antibodies, C9 inhibitors or anti-C9 antibodies, properdin inhibitors or anti-properdin antibodies, Factor B inhibitors or anti-Factor B antibodies, or Factor D inhibitors or anti-Factor D antibodies.

Compounds that inhibit or block C3 expression, activity, or activation can be administered to an individual via any number of routes, which typically depends on the particular compound and its features. Compounds can be incorporated into pharmaceutical compositions suitable for administration to an individual. Such compositions typically include, at least, the compound and a pharmaceutically acceptable carrier. As used herein, "pharmaceutically acceptable carrier" is intended to include any and all solvents, dispersion media, coatings, antibacterial and anti-fungal agents, isotonic and absorption delaying agents, and the like, compatible with pharmaceutical administration. The use of such media and agents for pharmaceutically active substances is well known in the art. Except insofar as any conventional media or agent is incompatible with the active compound, use thereof in the

compositions is contemplated. Additional or secondary active compounds also can be incorporated into the compositions described herein.

A pharmaceutical composition as described herein is formulated to be compatible with its intended route of administration. Examples of routes of administration include parenteral, e.g., intravenous, intradermal, subcutaneous, oral (e.g., ingestion or inhalation), transdermal (topical), transmucosal, and rectal administration. In addition, local administration into the periodontal pocket (e.g., via direct injection, or via, for example, a Perio Chip) also is a route of administration that may be employed in the methods described herein. Solutions or suspensions used for parenteral, intradermal, or subcutaneous application can include the following components: a sterile diluent such as water for injection, saline solution (e.g., phosphate buffered saline (PBS)), fixed oils, a polyol (for example, glycerol, propylene glycol, and liquid polyetheylene glycol, and the like), glycerine, or other synthetic solvents; antibacterial and/or antifungal agents such as parabens, chlorobutanol, phenol, ascorbic acid, thimerosal, and the like; antioxidants such as ascorbic acid or sodium bisulfite; chelating agents such as ethylenediaminetetraacetic acid; buffers such as acetates, citrates or phosphates and agents for the adjustment of tonicity such as sodium chloride or dextrose. The proper fluidity can be maintained, for example, by the use of a coating such as lecithin, by the maintenance of the required particle size in the case of dispersion and/or by the use of surfactants. In many cases, it will be preferable to include isotonic agents, for example, sugars, polyalcohols such as mannitol or sorbitol, and sodium chloride in the composition. Prolonged administration of an injectable composition can be brought about by including an agent that delays absorption. Such agents include, for example, aluminum monostearate and gelatin. A parenteral preparation can be enclosed in ampoules, disposable syringes or multiple dose vials made of glass or plastic.

Oral compositions generally include an inert diluent or an edible carrier. Oral compositions can be liquid, or can be enclosed in gelatin capsules or compressed into tablets. Pharmaceutically compatible binding agents, and/or adjuvant materials can be included as part of an oral composition. Tablets, pills, capsules, troches and the like can contain any of the following ingredients, or compounds of a similar nature: a binder such as microcrystalline cellulose, gum tragacanth or gelatin; an excipient such as starch or lactose; a disintegrating agent such as alginic acid, Primogel, or corn starch; a lubricant such as magnesium stearate or Sterotes; a glidant such as colloidal silicon dioxide; a sweetening agent such as sucrose or saccharin; and/or a flavoring agent such as peppermint, methyl salicylate, or orange flavoring. Transmucosal administration can be accomplished through the use of nasal sprays

or suppositories. For transdermal administration, the active compounds typically are formulated into ointments, salves, gels, or creams as generally known in the art.

It is especially advantageous to formulate oral or parenteral compositions in dosage unit form for ease of administration and uniformity of dosage. Dosage unit form as used herein refers to physically discrete units suited as unitary dosages for an individual to receive; each unit containing a predetermined quantity of active compound calculated to produce the desired therapeutic effect in association with the required pharmaceutical carrier. The dosage units themselves are dependent upon the amount of compound to be delivered. The amount of a compound necessary to inhibit or block C3 expression, activity or activation can be formulated in a single dose, or can be formulated in multiple dosage units. Treatment of an individual with a compound that inhibits or blocks C3 expression, activity or activation may require a one-time dose, or may require repeated or multiple doses.

Screening for Compounds that Can Be Used to Treat or Prevent Periodontitis or Diseases Associated with Periodontitis

The results described herein regarding complement component C3 and *P. gingivalis* also can be used to screen for therapeutic compounds (i.e., compounds that inhibit the expression, activity, or activation of C3). For example, a nucleic acid molecule can be produced that includes a promoter operably linked to nucleic acid encoding a C3 polypeptide. Promoters that drive expression of a DNA sequence are well known in the art. Promoters suitable for expressing a nucleic acid encoding C3 are known to those skilled in the art and include, for example, constitutive or inducible promoters. Many constitutive and inducible promoters are known in the art. As used herein, "operably linked" means that a promoter and/or other regulatory element(s) are positioned in a vector relative to a nucleic acid encoding C3 in such a way as to direct or regulate expression of the nucleic acid. Such a nucleic acid molecule can be introduced into host cells (e.g., *E. coli*, yeast) using routine methods (e.g., electroporation, lipid-based delivery systems, nanoparticle delivery systems, and viral-based delivery systems), and the host cells can be contacted with a test compound. A vector as described herein also may include sequences such as those encoding a selectable marker (e.g., an antibiotic resistance gene).

Methods of evaluating whether or not a test compound inhibits the expression of C3 are well known in the art. For example, RT-PCR or Northern blotting methods can be used to determine the amount of C3 mRNA in the presence and absence of the test compound. In

addition, methods that can be used to evaluate whether or not a test compound inhibits the activity or the activation of C3 are known in the art.

Methods of making recombinant host cells (e.g., recombinant mammalian host cells) are discussed herein and are well known in the art. In addition, virtually any type of compound can be used as a test compound in the screening methods described herein. Test compounds can include, for example and without limitation, nucleic acids, peptides, proteins, non-peptide compounds, synthetic compounds, peptidomimetics, antibodies, small molecules, fermentation products, or extracts (e.g., cell extracts, plant extracts, or animal tissue extracts).

In accordance with the present disclosure, there may be employed conventional molecular biology, microbiology, biochemical, and recombinant DNA techniques within the skill of the art. Such techniques are explained fully in the literature. The discovery will be further described in the following examples, which do not limit the scope of the methods and compositions of matter described in the claims.

EXAMPLES

Example 1—Mice Lacking C3 are Protected Against *P. gingivalis*-Induced Bone Loss

CS7BL/6 wild-type (WT) mice or mice deficient in C3 ($C3^{-/-}$) were orally infected or not with *P. gingivalis* (Pg) and assessed for induction of periodontal bone loss using defleshed maxillae (Figure 1A). Buccal and lingual gingiva around the six maxilary molars were dissected from the same mice and processed for real-time PCR to determine mRNA expression levels for the indicated cytokines (normalized against GAPDH mRNA and expressed as fold induction relative to the sham-infected WT group) (Figure 1B). Similar experiments were performed in which gingiva were homogenized and soluble extracts were used to determine cytokine levels using Luminex-100 technology (Figure 1C).

It was found that mice lacking the central complement component C3 ($C3^{-/-}$ mice) are protected against *Porphyromonas gingivalis*-induced bone loss relative to wild-type controls (Figure 1). Inhibition of bone loss (Figure 1A) correlated with diminished expression of inflammatory and bone resorptive cytokines (IL-1β, TNF-α, IL-6, and IL-17) at the mRNA (Figure 1B) and protein (Figure 1C) levels. These data conclusively implicate C3 in destructive periodontal inflammation.

Example 2—Colonization and Effects of *P. gingivalis* in the Periodontium of Normal or Complement-Deficient Mice

Wild-type (WT) mice or mice deficient in C3 or C5aR were orally inoculated with *P. gingivalis* (Pg) or vehicle only (Sham) and were sacrificed 7 days later. The numbers of *P. gingivalis* and of total bacteria in the periodontal tissue were determined using quantitative real-time PCR of the *ISPg1* gene (*P. gingivalis*) or the 16S rRNA gene (total bacteria).

Whereas *P. gingivalis* cannot colonize the periodontium of CSaR-deficient mice ($C5ar^{-/-}$), it can colonize the periodontium of $C3^{-/-}$ mice and instigate an increase in the total bacterial counts, as it does in wild-type mice (Figure 2). Taken together with the data shown in Figure 1, these findings suggest that, whereas dysbiosis is necessary for inflammatory bone loss, it is not sufficient by itself. Rather, the dysbiotic microbiota requires the presence of C3 to induce maximum inflammation and bone loss.

Example 3—$C3^{-/-}$ Mice are Protected Against Ligature-Induced Periodontal Bone Loss

Bone loss was induced through the use of a 5-0 silk ligature tied around the maxillary second molar (L); the contralateral molar tooth in each mouse was left unligated as baseline control (UC or WT).

This results in a *P. gingivalis*-independent model of periodontitis, resulting in massive local accumulation of bacteria and rapid inflammatory bone loss. C3-/- mice were protected in this model based on bone loss (Figure 3A) and mRNA expression of the indicated cytokines (Figure 3B). Therefore, C3 is heavily involved in inflammatory bone loss suggesting that C3 inhibitors (e.g., compstatin) could find therapeutic application in periodontitis.

Example 4—Non-Human Primate Studies

The immune system and periodontal anatomy of ***the*** cynomolgus monkey is very similar to that of humans, and ligature-induced periodontitis in this NHP model displays bacteriological, immunohistological and clinical features that are most similar to those observed in human periodontitis. The cynomolgus monkey model is therefore considerably more predictive of drug efficacy in human periodontitis as compared to other, widely used preclinical animal models such as rodents. Moreover, the cynomolgus model of ligature-induced periodontitis allows longitudinal examination of the disease in a way that cannot be performed in humans.

Silk ligatures were placed around maxillary posterior teeth (2nd premolar and 1st molar) on both halves of the mouth for a split-mouth experimental design, i.e., one side was treated with active drug (Cp40, the current lead version of compstatin) and the other with inactive analog (control). Thus, each animal served as its own control. An initial study with a 6-week duration was conducted using two animals. Treatment with compstatin resulted in decreased clinical inflammation and bone loss (Figure 4), as well as reduced levels of proinflammatory cytokines in the gingival crevicular fluid (GCF) and lower numbers of osteoclasts in bone biopsy specimens (Figure 5), as compared to control treatments. Importantly, the decreased bone loss in sites treated with Cp40 (revealed radiographically by greater bone heights, i.e., CEJ-ABC distances; Figure 4E) was consistent not only with decreased osteoclastogenesis (Figure 5G) but also with decreased GCF levels of RANKL (Figure 5E), a key osteoclasto-genic factor. Moreover, the GCF levels of osteoprotegerin (OPG), a natural inhibitor of RANKL, were maintained at higher levels in Cp40-treated sites than control sites during the course of the study (Figure 5F).

In a second NHP study, ligature-induced periodontitis was induced by placing ligatures around the mandibular posterior teeth (i.e., in the lower jaw) of the same two animals plus in two additional animals (total of four monkeys). The results obtained (Figures 6, 7, and 8) confirmed the results of the original study. Moreover, the presence of four animals allowed the possibility for statistical analysis. The protective effects of Cp40 with regard to certain clinical parameters (PPD and GI, Figure 6A and B) and most cytokine responses (Figure 7) reached statistical significance. Importantly, Cp40 caused a significant inhibition of bone loss (Figure 8C), consistent with its effects on molecules regulating osteoclastogenesis (decreased RANKL and increased OPG levels vs. control treatment; Figure 7H and I, respectively).

This is the first time, for any disease, that complement inhibition has been shown to inhibit inflammatory processes that lead to osteoclastogenesis and bone loss in NHP. Moreover, these data strongly support the therapeutic potential of Cp40 in human periodontitis.

OTHER EMBODIMENTS

It is to be understood that, while the methods and compositions of matter have been described herein in conjunction with a number of different aspects, the foregoing description of the various aspects is intended to illustrate and not limit the scope of the methods and

compositions of matter. Other aspects, advantages, and modifications are within the scope of the following claims.

Disclosed are methods and compositions that can be used for, can be used in conjunction with, can be used in preparation for, or are products of the disclosed methods and compositions. These and other materials are disclosed herein, and it is understood that combinations, subsets, interactions, groups, etc. of these methods and compositions are disclosed. That is, while specific reference to each various individual and collective combinations and permutations of these compositions and methods may not be explicitly disclosed, each is specifically contemplated and described herein. For example, if a particular composition of matter or a particular method is disclosed and discussed and a number of compositions or methods are discussed, each and every combination and permutation of the compositions and the methods are specifically contemplated unless specifically indicated to the contrary. Likewise, any subset or combination of these is also specifically contemplated and disclosed.

WHAT IS CLAIMED IS:

1. A method of treating or preventing periodontitis or diseases associated with periodontitis in an individual, comprising:

administering a compound to said individual that inhibits or blocks C3 expression, activity, or activation.

2. The method of claim 1, wherein said compound is selected from the group consisting of compstatin, analogs of compstatin, complement receptor 1-related gene/protein y (Crry), and complement activation blocker-2.

3. The method of claim 1, wherein said compound is an antibody against C3.

4. The method of claim 1, wherein said compound is a peptidomimetic antagonist of C3.

5. The method of claim 1, wherein said diseases associated with periodontitis are selected from the group consisting of atherosclerosis, diabetes, osteoporosis, and pre-term labor.

6. A method of reducing the amount of *Porphyromonas gingivalis* and/or the inflammation caused by *P. gingivital* in an individual, comprising:

administering, to said individual, a compound that inhibits or blocks C3 expression, activity, or activation.

7. The method of claim 6, wherein said compound is selected from the group consisting of compstatin, analogs of compstatin, complement receptor 1-related gene/protein y (Crry), and complement activation blocker-2.

8. A method of screening for compounds that treat or prevent periodontitis or diseases associated with periodontitis, comprising:

contacting a cell, in the presence of *P. gingivalis*, with a test compound; and

evaluating said cell for expression, activity, or activation of C3,

wherein a reduction in the expression, activity, or activation of C3 in the presence of a test compound is indicative of a test compound that can be used to treat or prevent periodontitis or diseases associated with periodontitis.

9. The method of claim 8, wherein said cell is a mammalian cell.

10. The method of claim 8, wherein said cell is a recombinant cell comprising an exogenous nucleic acid encoding C3.

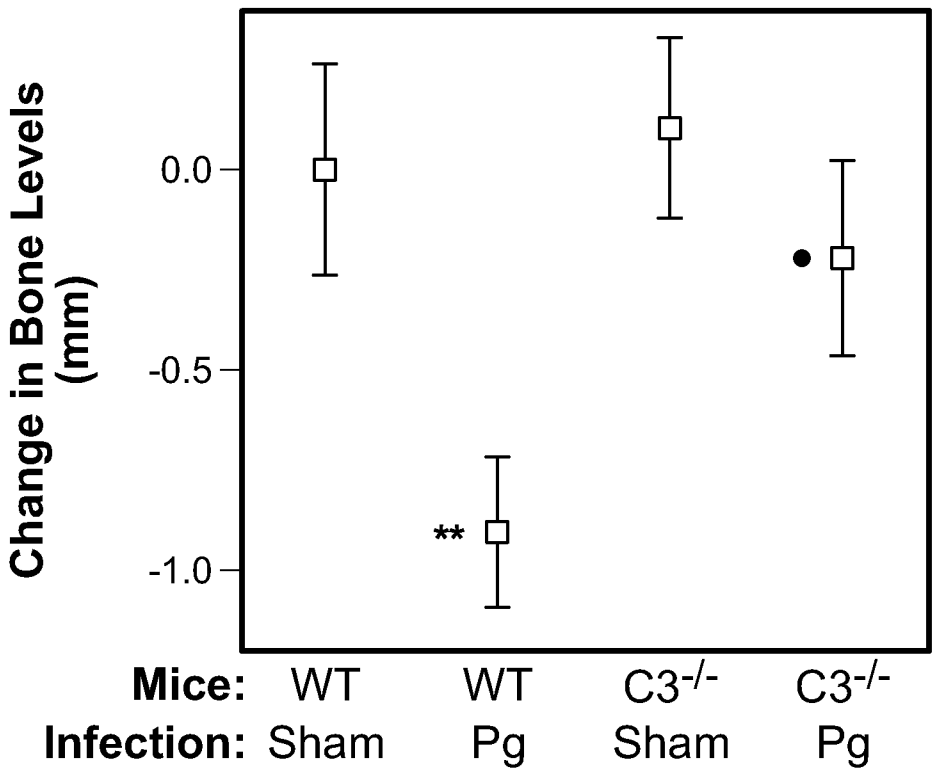
Change in Bone Levels (mm)
0.0
-0.5
-1.0
**
Mice: WT WT C3-/- C3-/-
Infection: Sham Pg Sham Pg

FIG. 1A

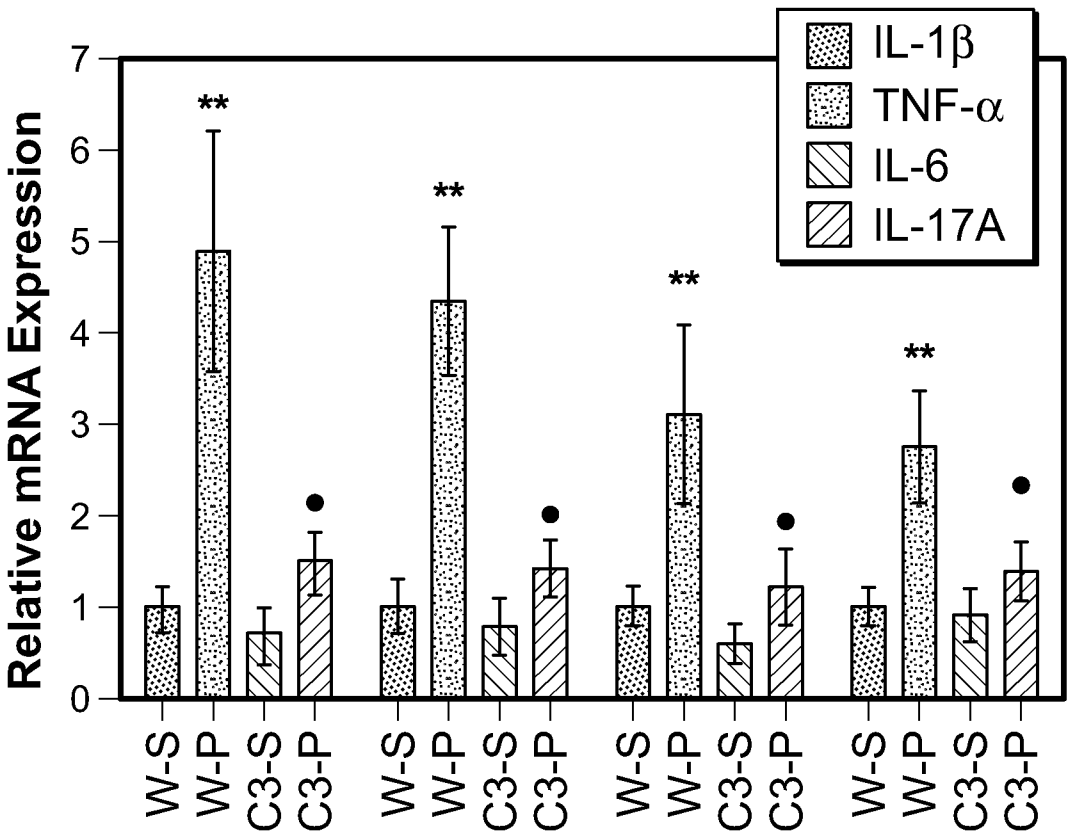
Relative mRNA Expression
0
1
2
3
4
5
6
7
IL-1β
TNF-α
IL-6
IL-17A
**
W-S W-P C3-S C3-P W-S W-P C3-S C3-P W-S W-P C3-S C3-P W-S W-P C3-S C3-P

FIG. 1B

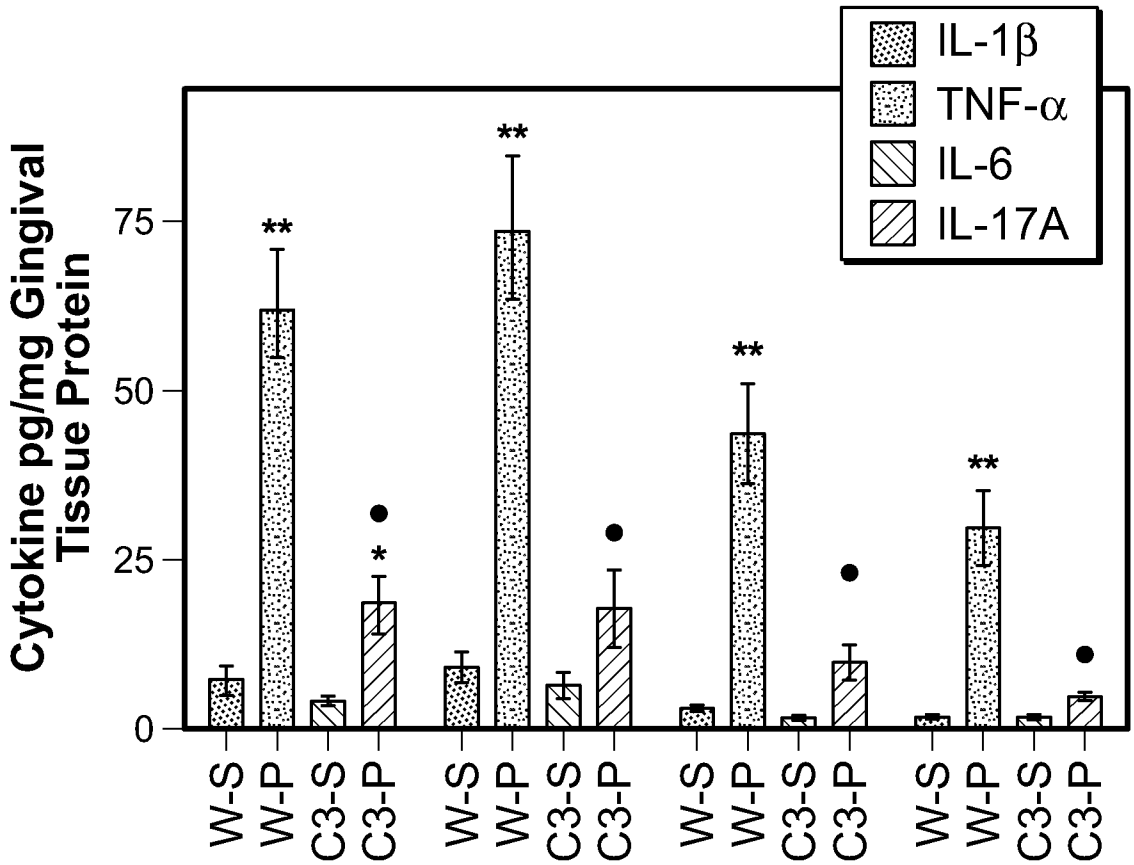
IL-1β
TNF-α
IL-6
IL-17A
Cytokine pg/mg Gingival Tissue Protein
0
25
50
75
**
*
W-S
W-P
C3-S
C3-P

FIG. 1C

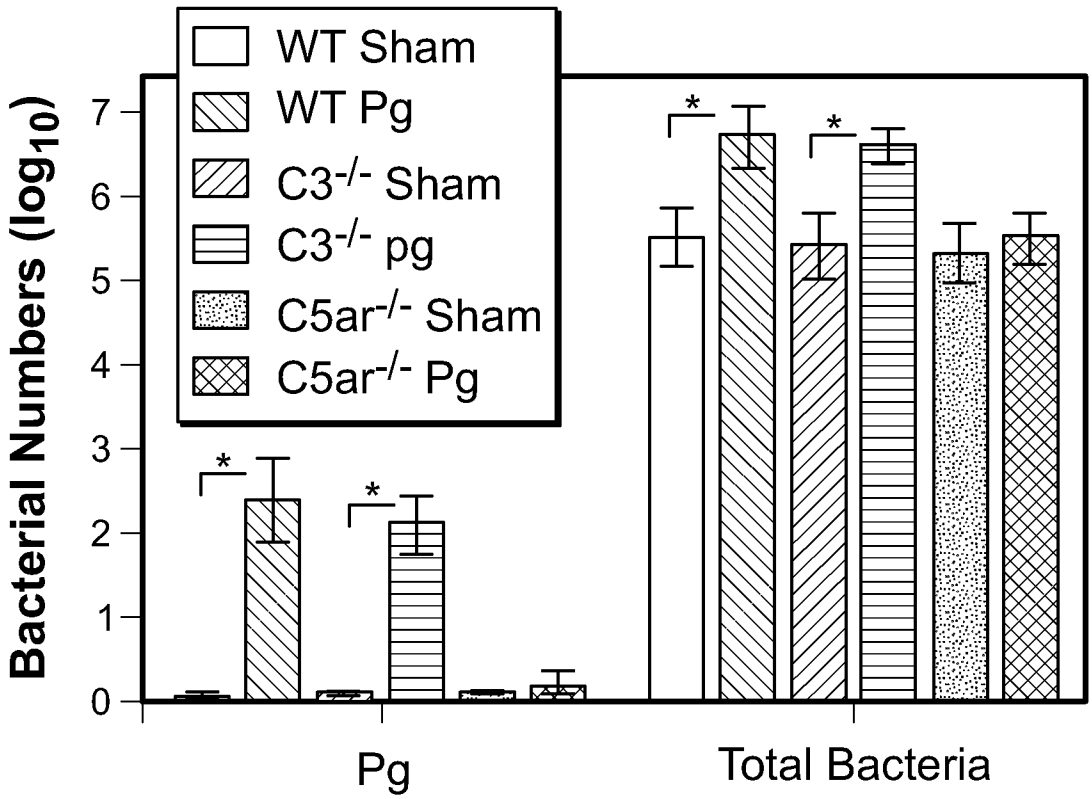
WT Sham
WT Pg
C3-/- Sham
C3-/- pg
C5ar-/- Sham
C5ar-/- Pg
Bacterial Numbers (log10)
0
1
2
3
4
5
6
7
*
Pg
Total Bacteria

FIG. 2

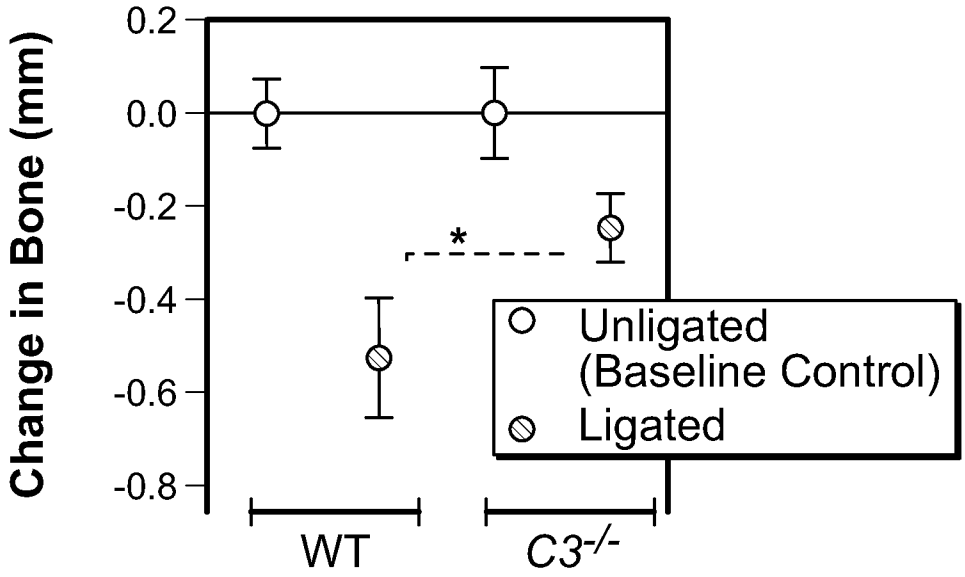

FIG. 3A

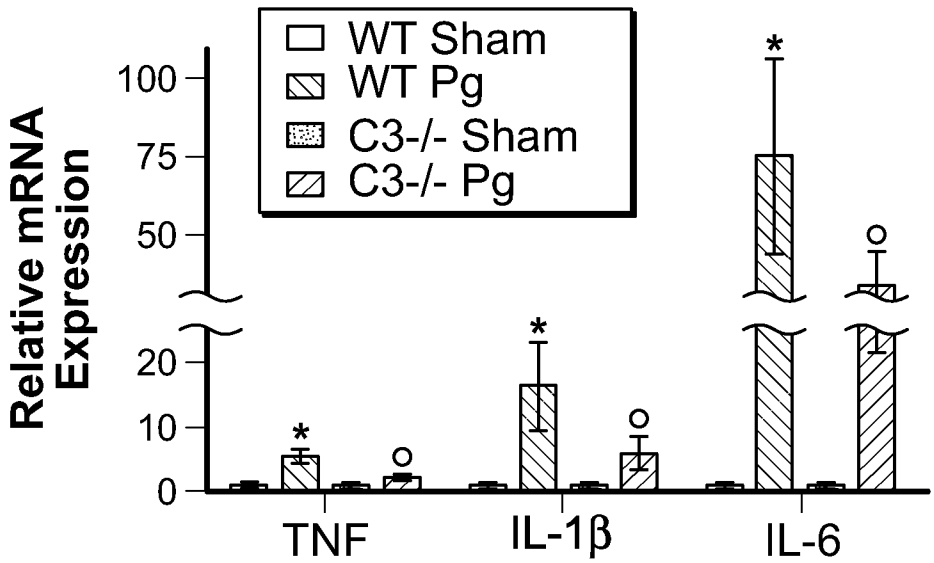

FIG. 3B

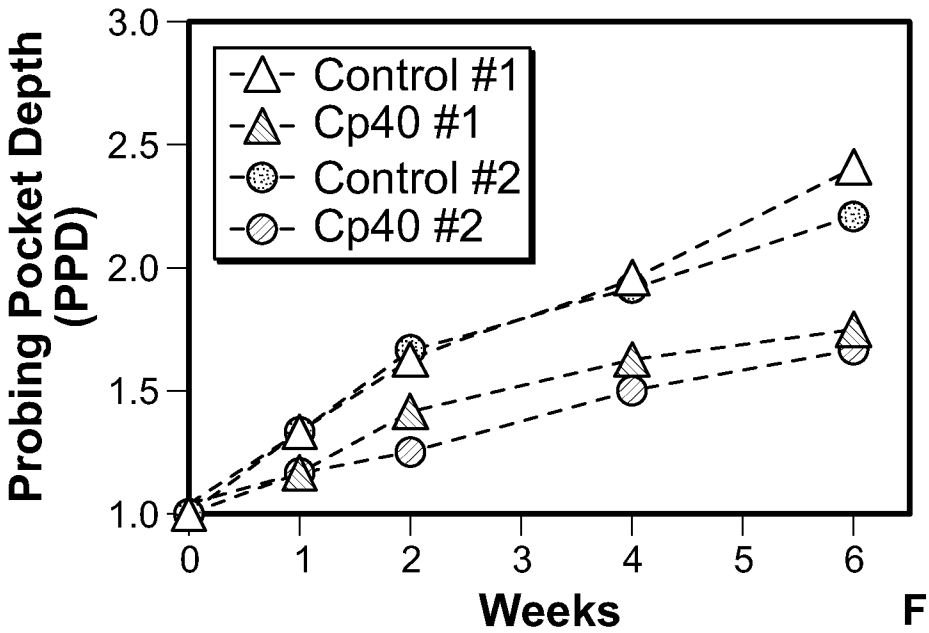

FIG. 4A

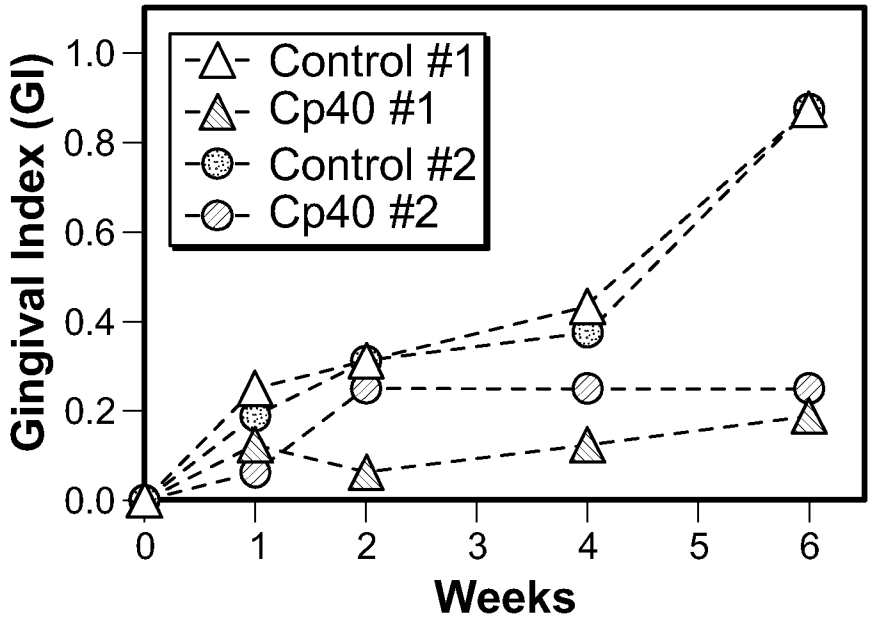

FIG. 4B

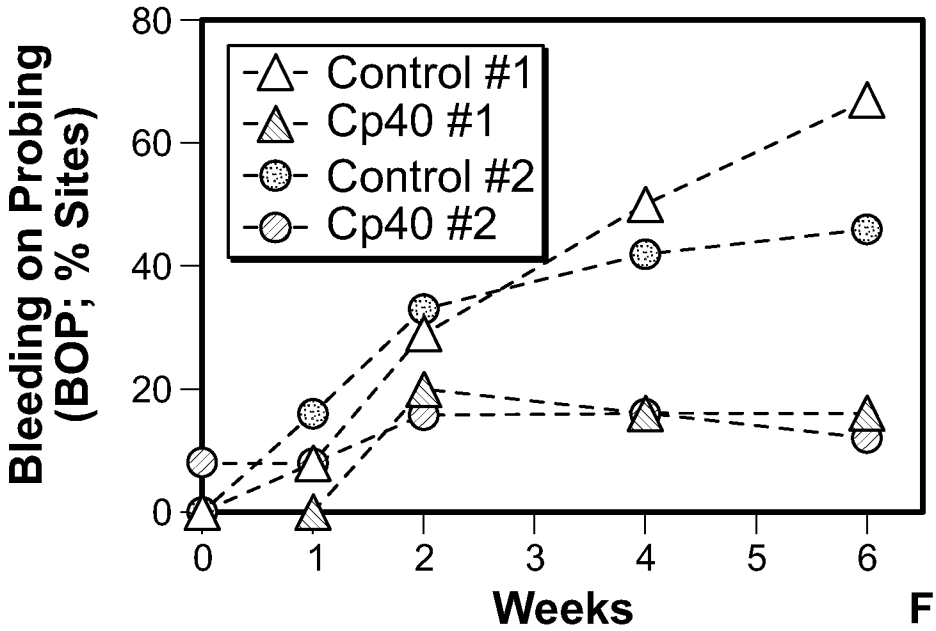

FIG. 4C

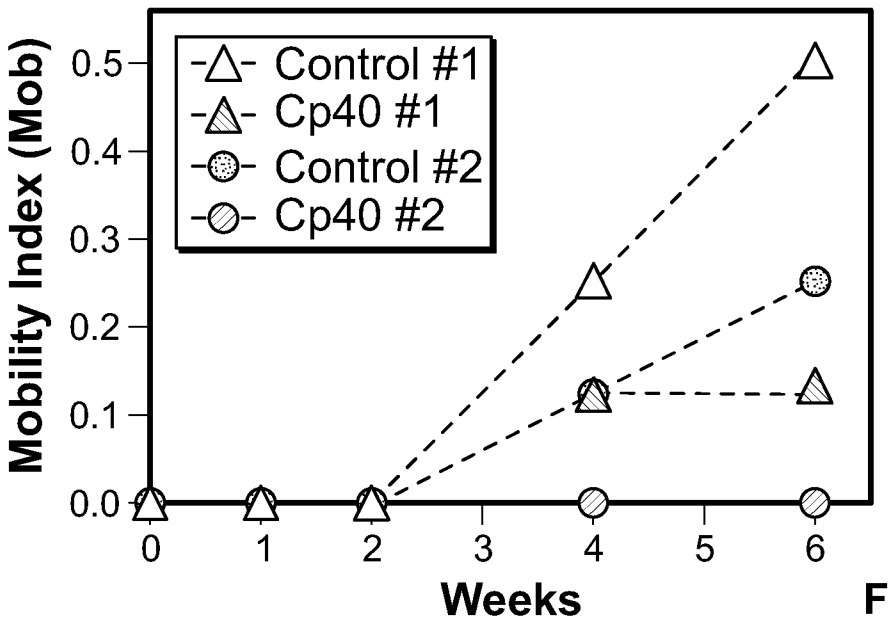

FIG. 4D

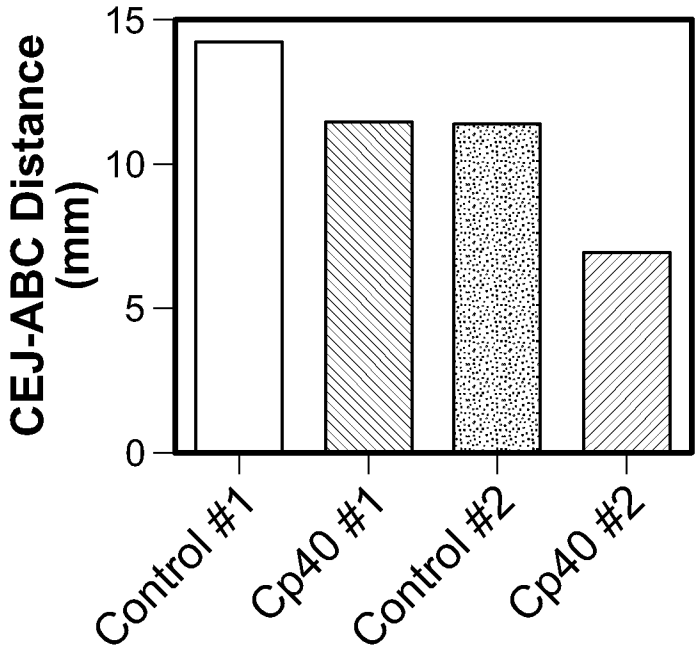

FIG. 4E

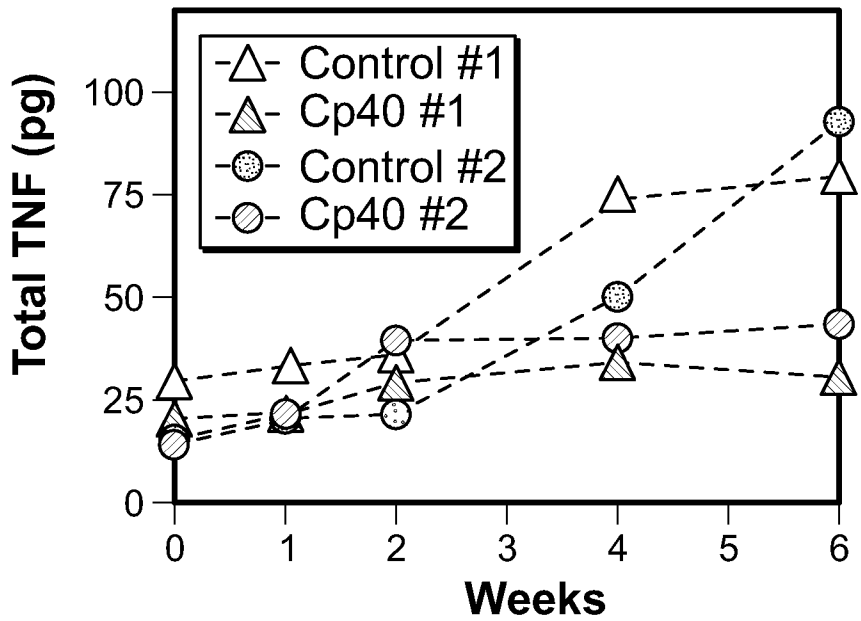

FIG. 5A

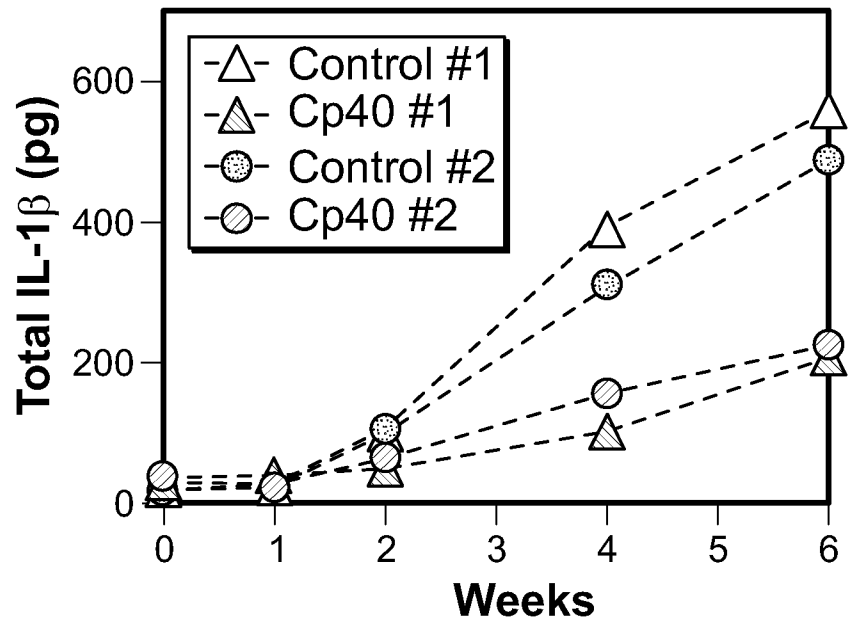

FIG. 5B

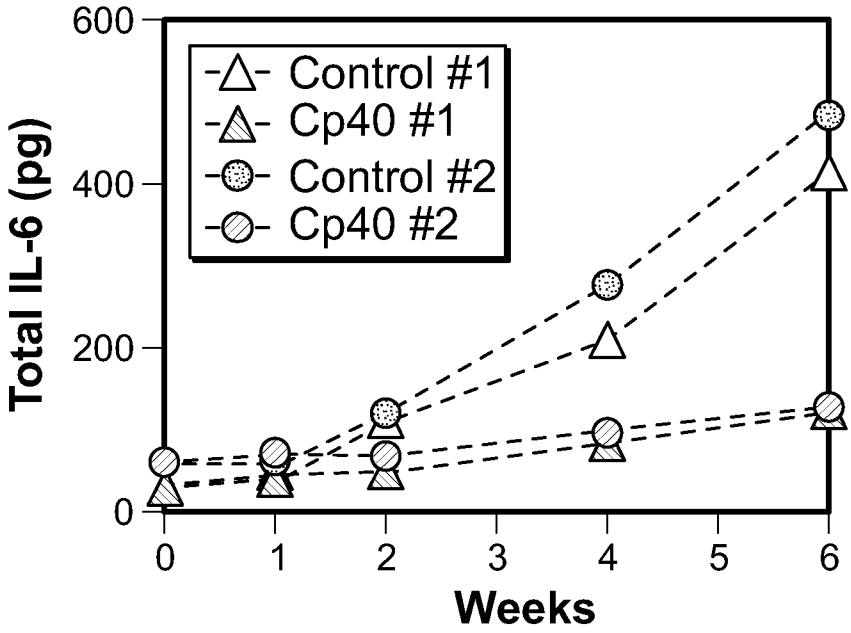

FIG. 5C

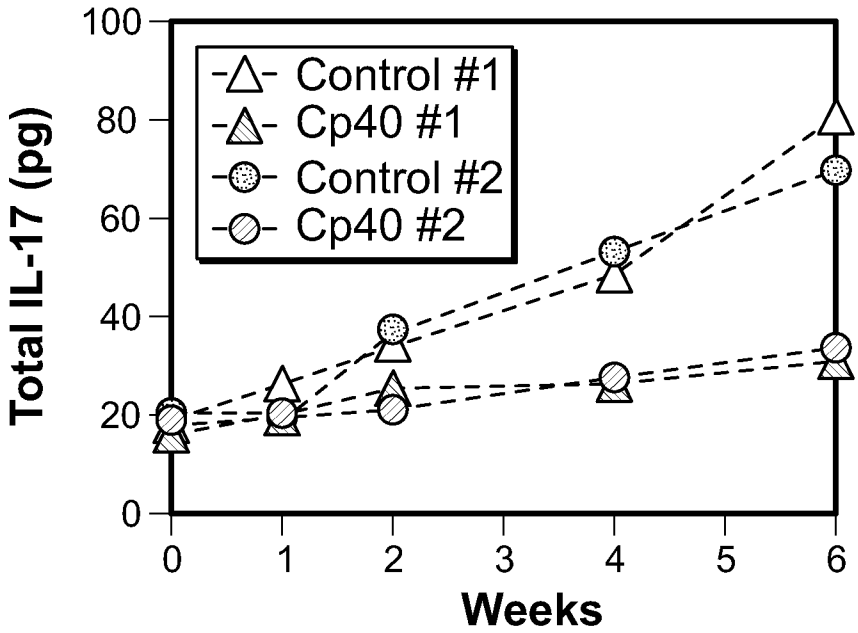

FIG. 5D

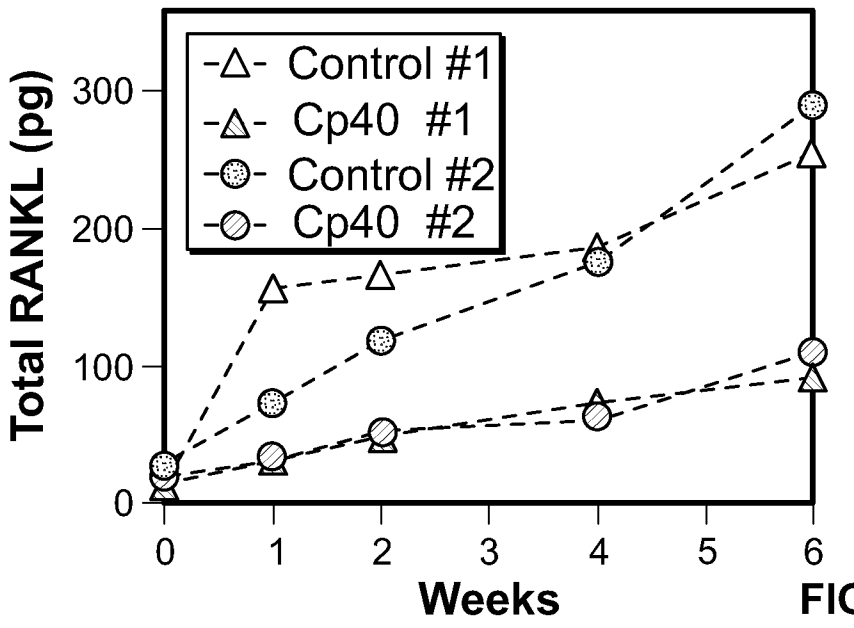

FIG. 5E

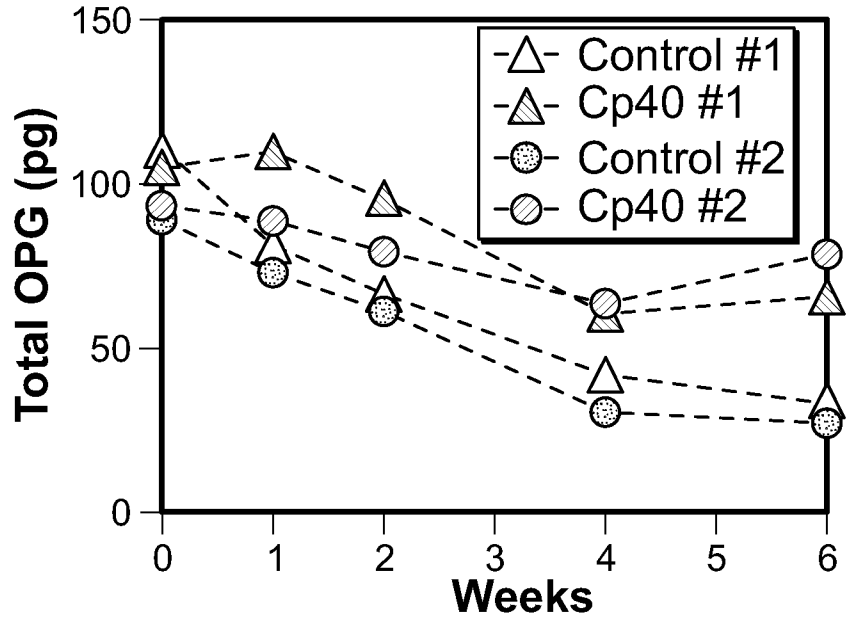

FIG. 5F

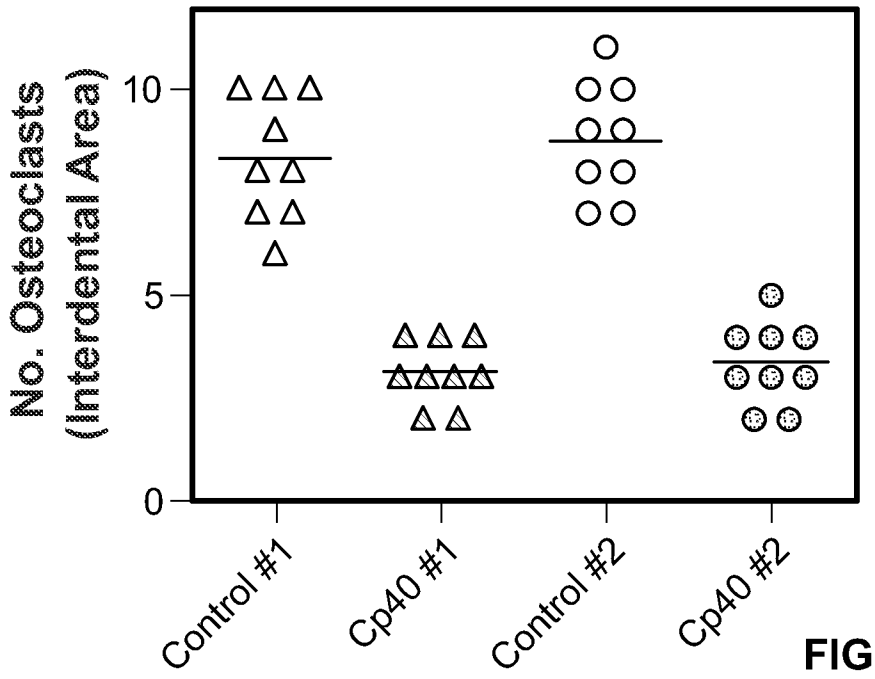

FIG. 5G

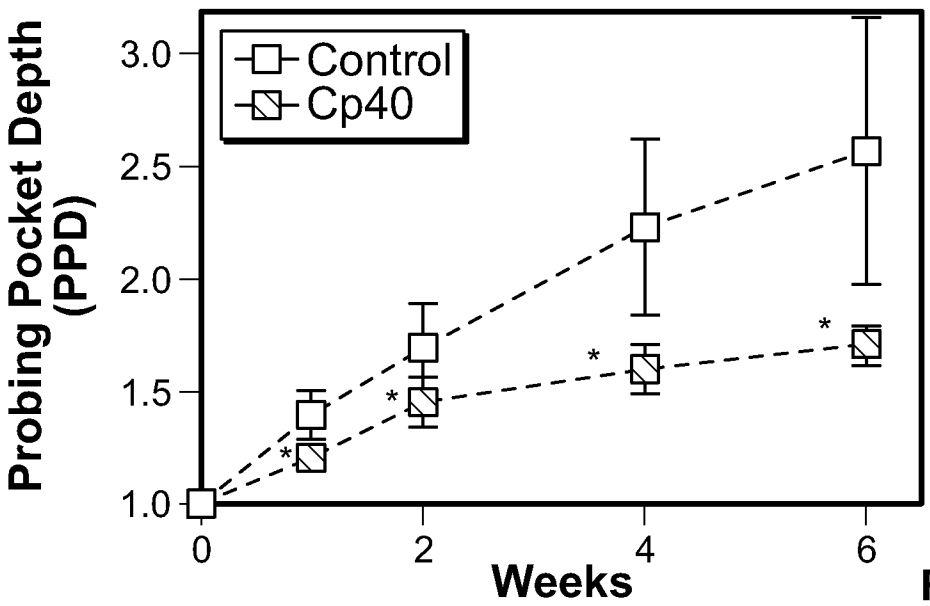

FIG. 6A

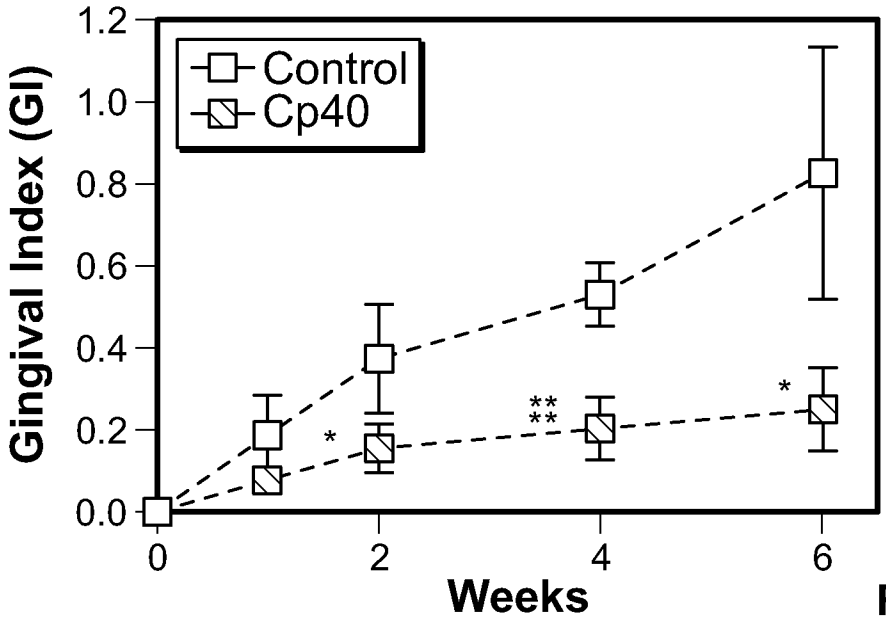

FIG. 6B

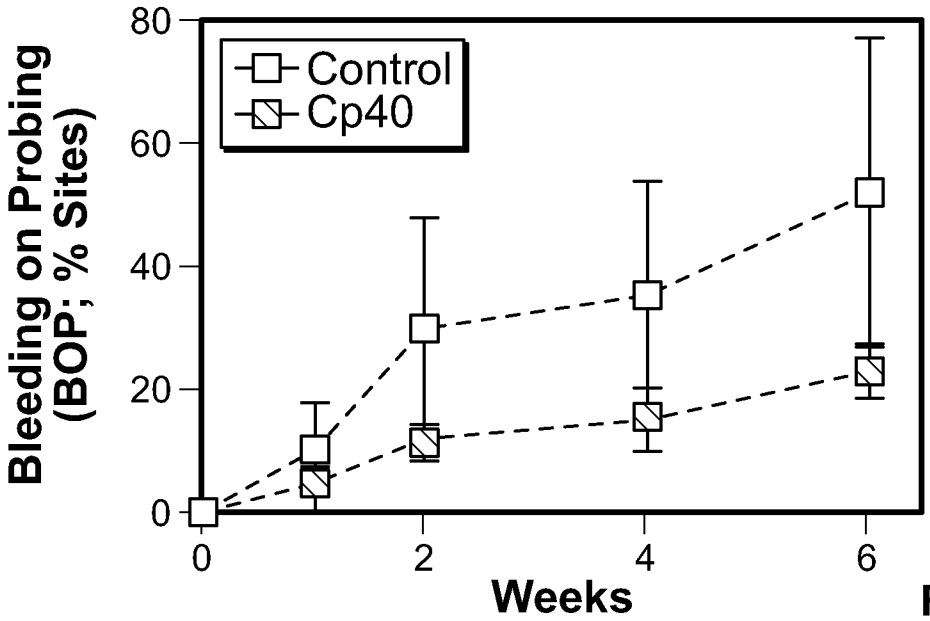

FIG. 6C

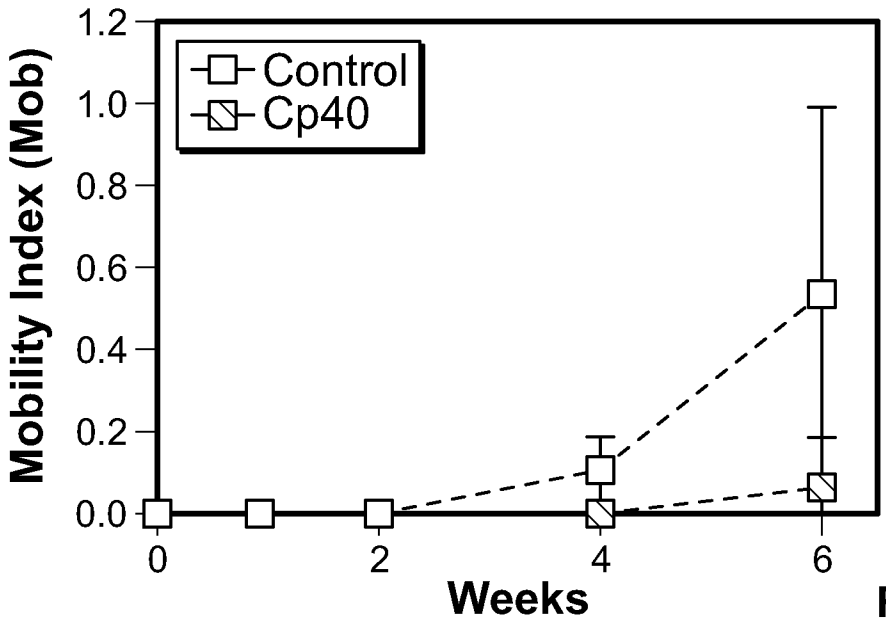

FIG. 6D

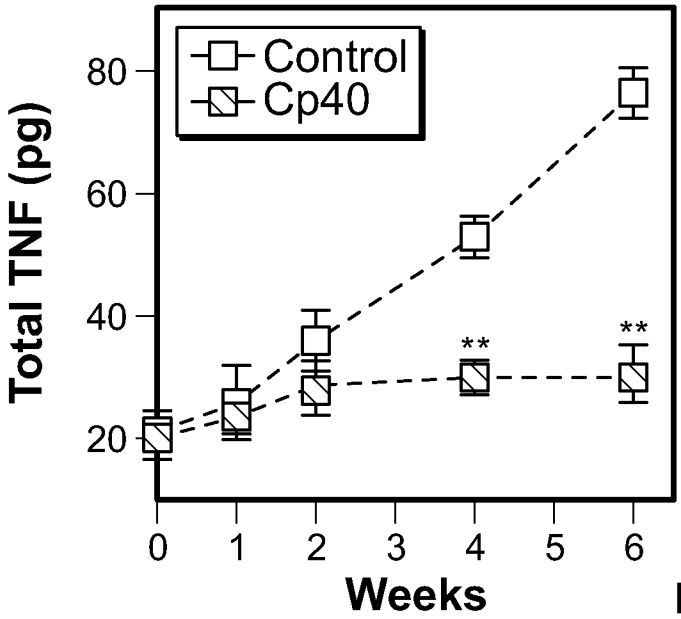

FIG. 7A

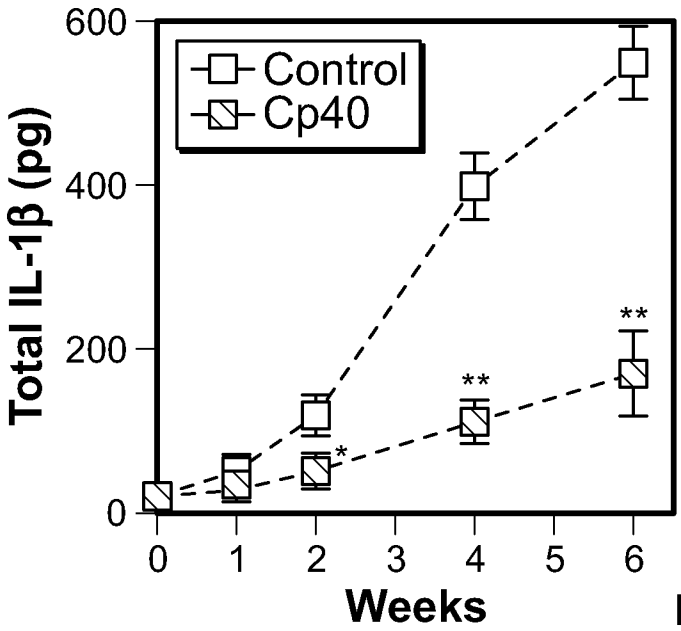

FIG. 7B

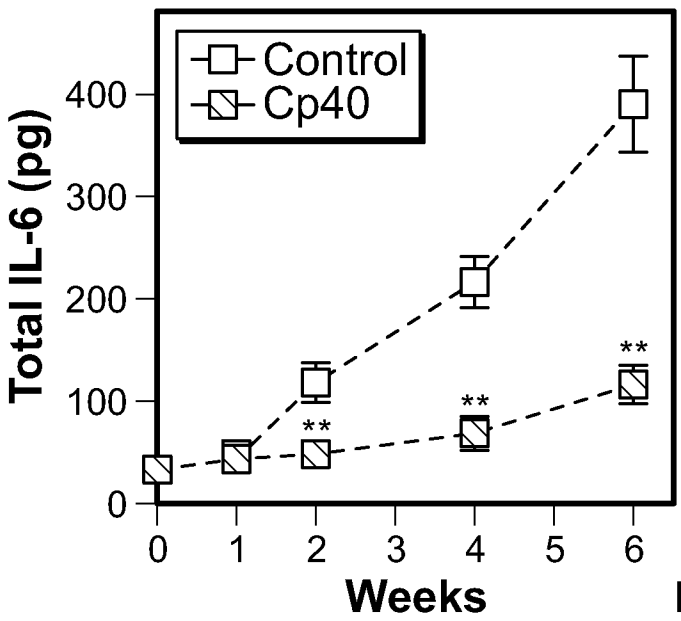

FIG. 7C

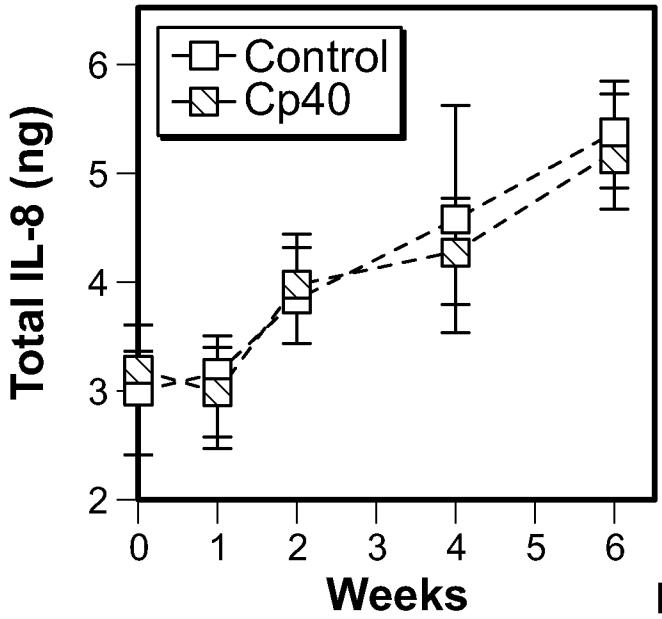

FIG. 7D

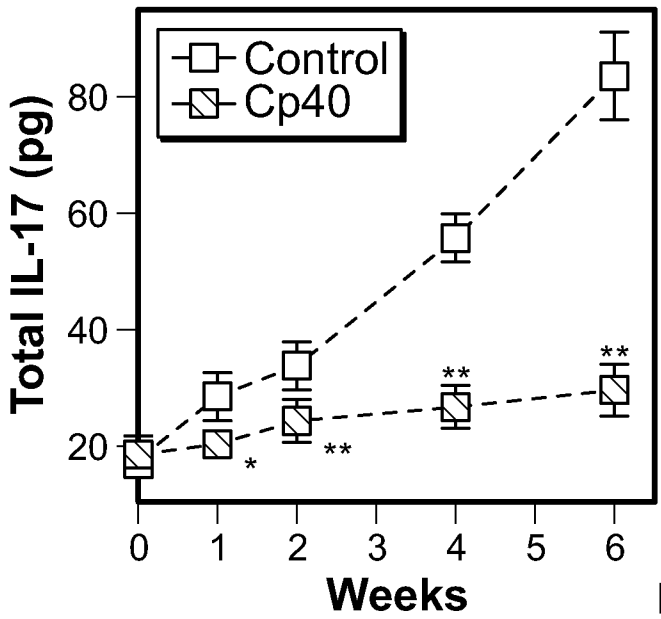

FIG. 7E

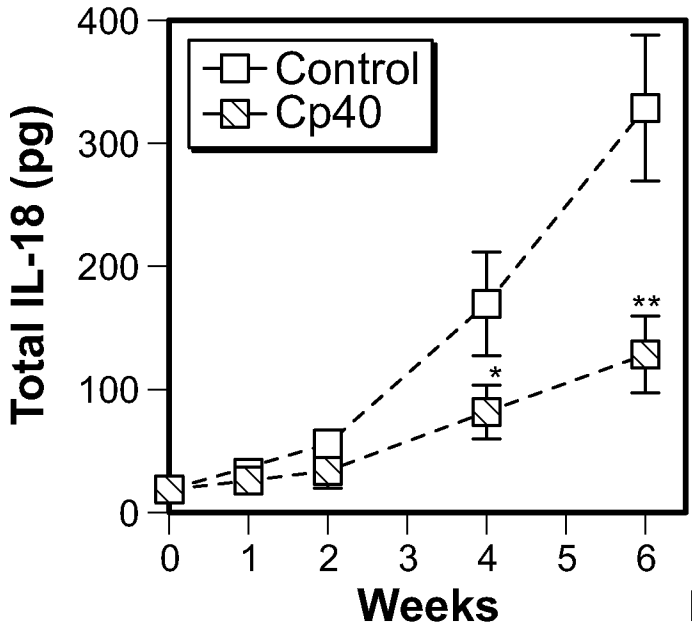

FIG. 7F

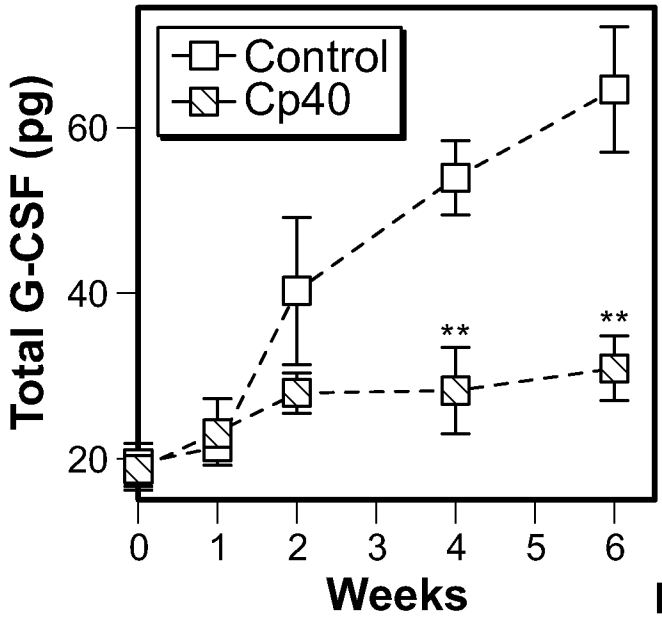

FIG. 7G

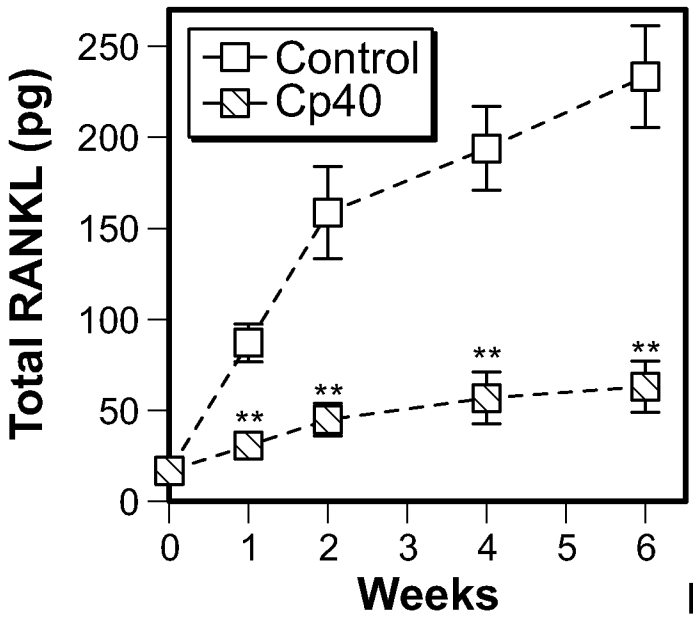

FIG. 7H

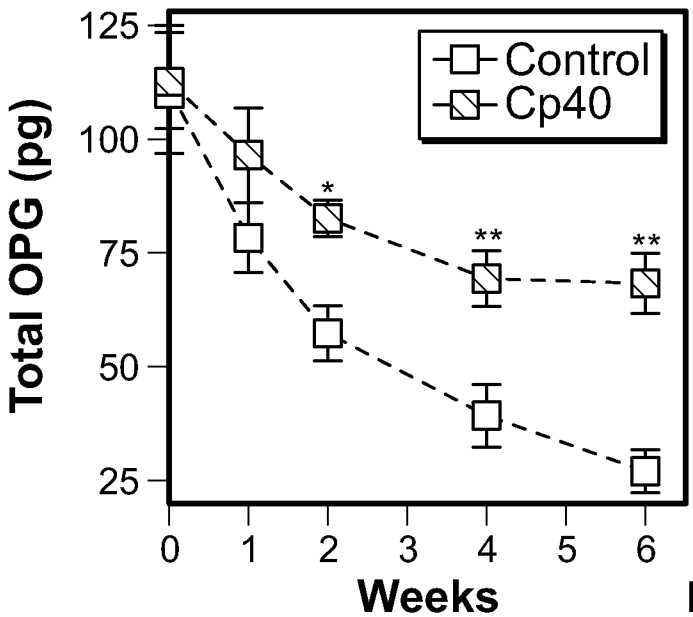

FIG. 7I

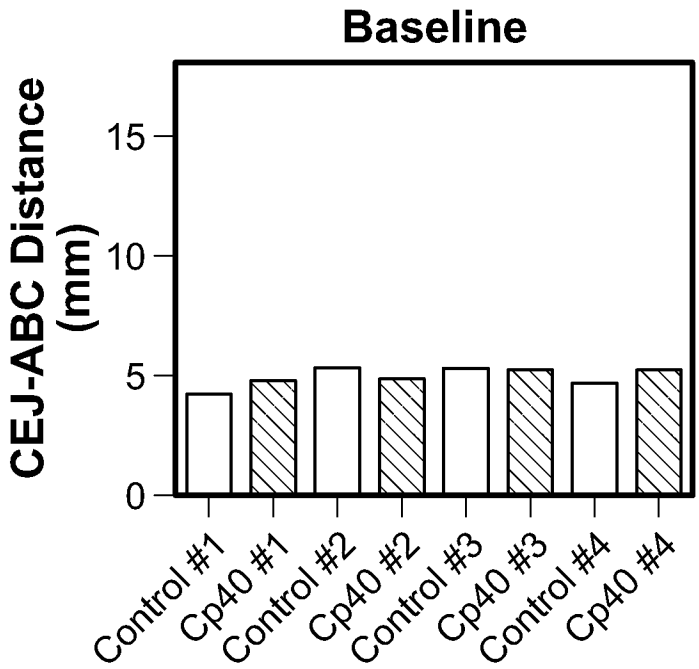

FIG. 8A

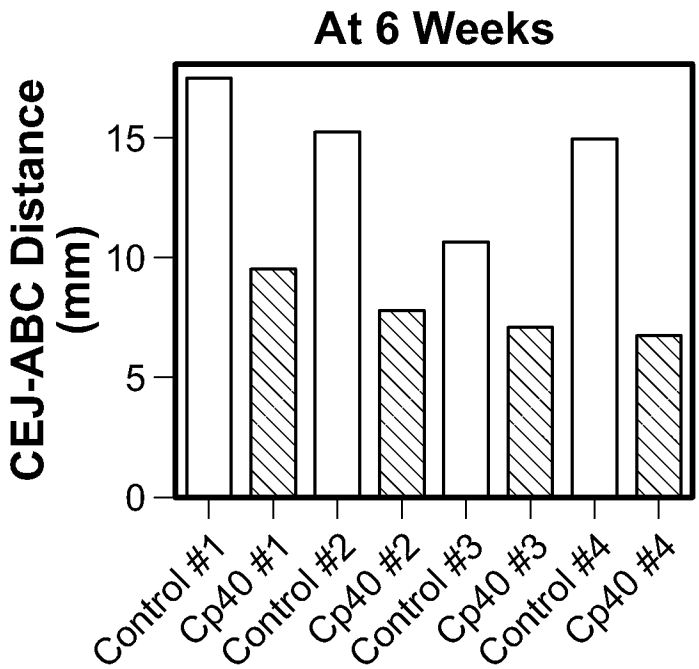

FIG. 8B

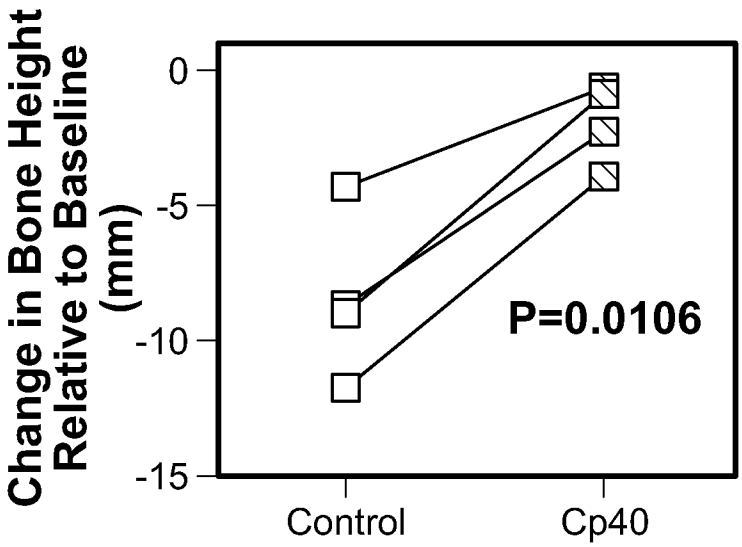

FIG. 8C

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/046599

A. CLASSIFICATION OF SUBJECT MATTER

A61K 39/395(2006.01)i, A61P 1/02(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61K 39/395; A61K 39/00; A61K 39/295; A61P 1/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: periodontitis, Porphyromonas gingivalis, complement component 3 (C3)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	HAJISHENGALLIS, G. `Complement and periodontitis`, Biochemical Pharmacology, 2010, Vol. 80, pages 1992-2001 See abstract, page 1995.	8-10
X	BEIKLER, T. et al. `Gene expression in periodontal tissues following treatment`, BMC Medical Genomics, 2008, Vol. 1, Article Number 30 See abstract and the 6th page.	8-10
A	BOSTANCI, N. et al. `Porphyromonas gingivalis: an invasive and evasive opportunistic oral pathogen`, FEMS Microbiology Letters, 28 May 2012 (E-pub.), Vol. 333, pages 1-9 See abstract, page 2.	8-10
A	WO 2011-091366 A2 (UNIVERSITY OF LOUISVILLE RESEARCH FOUNDATION, INC. et al.) 28 July 2011 See abstract, claims 9-11.	8-10

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 September 2013 (30.09.2013)	**30 September 2013 (30.09.2013)**

Name and mailing address of the ISA/KR
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701, Republic of Korea
Facsimile No. +82-42-472-7140

Authorized officer
CHOI Sung Hee
Telephone No. +82-42-481-8740

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/046599

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☒ Claims Nos.: 1-7
because they relate to subject matter not required to be searched by this Authority, namely:
Claims 1-7 are directed to a treatment method of the human body by therapy and thus relate to a subject matter which this International Searching Authority is not required to search under Article 17(2)(a)(i) of the PCT and Rule 39.1(iv) of the Regulations under the PCT.

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required addtional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2013/046599

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2011-091366 A2	28/07/2011	AU 2011-207441 A1	09/08/2012
		EP 2525814 A2	28/11/2012
		US 2013-0034568 A1	07/02/2013
		WO 2011-091366 A3	29/12/2011