The effectiveness of element downsizing on finite element domains of infinite/finite element analysis in an implant-bone system

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Purpose: The aim of this study is to investigate the effectiveness of element downsizing on finite element (FE) domains of infinite/finite element (IE/FE) analysis in an implant-bone system.
Materials and Methods: A 2-dimentional implant-bone system was studied by FE analysis and IE/FE analysis respectively. Different element sizes of 3.0, 2.0, 1.0, and 0.5 mm were applied in FE domains respectively.
Results: In IE/FE analysis, element size of 2.0 mm is suggested to be effective. While, in FE analysis, that is 0.5 mm.
Conclusion: Larger element size can be applied in IE/FE analysis than that in FE analysis only.
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Clinical Significance: IE/FE analysis will be a more effective method than FE analysis in dental biomechanical study.
Key Words: element analysis, element size, implant, infinite element analysis.

Introduction

In 1977, Weinstein[1] was the first to use finite element (FE) analysis in implant dentistry. Subsequently, FE analysis was rapidly applied in many other aspects of implant dentistry. Vertical and transverse loads from mastication induce axial forces and bending moments and result in stress gradients in the implant as well as in the bone. A key factor for the success or failure of a dental implant is the manner in which stresses are transferred to the surrounding bone. Load transfer from implants to surrounding bone depends on the type of loading, the bone-implant interface, the length and diameter of the implants, the shape and characteristics of the implant surface, the prosthesis type and the quantity and quality of the surrounding bone. FE analysis allows researchers to predict stress distribution in the contact area of the implants with cortical bone and around the apex of the implants in trabecular bone.

Infinite element (IE) analysis is a combination of an infinite partition technique and finite element analysis.[2] The first paper on this combination was by Thatcher.[2] Infinite element analysis, as its name indicates, can divide the domain into infinitely many pieces, causes more accuracy in computation of local domains, especially stress concentration domains.[3]

For a given problem, if it is sufficient to use FE analysis, then, the conventional approach was used. Otherwise, infinite element analysis was used to get higher precise. Different problem are treated differently. To complex problems, infinite element analysis is only used in stress concentration domains and finite element analysis is still used in other domains. That is infinite/finite element (IE/FE) analysis.

As Sato et al.[4] mentioned, the element sizes were important for the validity of FE analysis. This study is to investigate the proper element size in IE/FE analysis in an implant-bone system and compare with that in FE analysis only.

Materials and Methods

Huang et al.[5] modeled an endodontic endosseous implant in trabecular bone. The 2-dimentional dental implant system was constructed based on a geometric and radiographic analysis of a section of incision residual root with endodontic endosseous implant in place. A vertical 100 N loading was applied at the top of implant. The elastic properties of responding materials in the model were shown in Table 1.

Table 1. Material parameters used in the implant-bone system.

Material	Elastic modulus (Pa)	Poisson's Ratio	Author, Year	Reference number
Implant pure Ti	117×10^3	0.30	Ronald, 1995	6
Dentin	1.86×10^4	0.31	Reinhardt, 1984	7
Periodontal membrane	6.9	0.45	Farah, 1989	8
Cortical bone	1.34×10^4	0.30	Cook, 1982	9
Trabecular bone	1.37×10^3	0.31	Borchers, 1983	10

For FE analysis, four different element sizes of 3.0, 2.0, 1.0, and 0.5 mm were conducted in the implant-bone system. These were termed models F30, F20, F10, and F05. The FE analysis was taken under the software of Super-SAP5 (1991, Algorithm Corp., Pittsburgh, PA, USA).

For IE/FE analysis, four different element sizes of 3.0, 2.0, 1.0, and 0.5 mm were also conducted in the implant-bone system except IE domains. Here, IE domains are the stress concentration domains around right-hand apical foramen of Huang's model. These were termed models I/F30, I/F20, I/F10, and I/F05. Dirichlet-Neumann method was applied to conjunct IE and FE domains. The varies of displacements in the boundary was treated as the target function and the similar boundary condition was obtained by iterative computation of the displacements outputted by FE analysis and the stresses outputted by IE analysis.

Results

Some key nodes in the implant model were calculated. Values of displacement induced with the downsizing element at the nodes near stress concentration point. Displacement in the model F10, I/F30 was higher than that in the model F05, I/F20. However, there was no clear difference of displacement values among the model F05, I/F20, I/F10, I/F05 (Fig. 1).

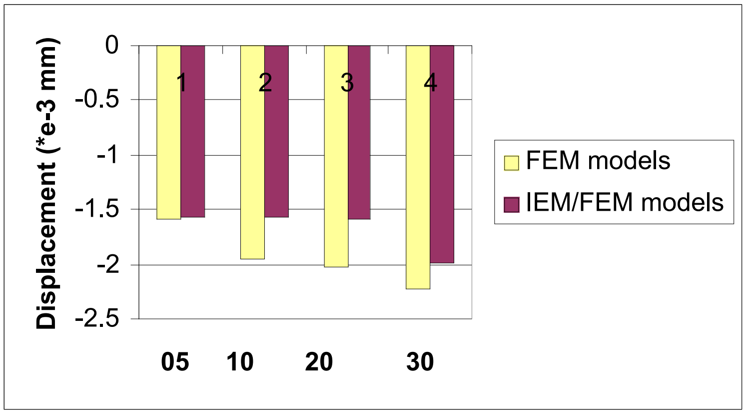

Fig. 1. Values of displacement at one of respective notes in IE/FE and FE models.

Discussion

The maximum stress and responding displacement are at the node of stress concentration point. Therefore, some key nodes near stress concentration point were selected to measure the effectiveness of downsizing element. That is because mechanical quantities vary violently at these points and more significant changes could be found with downsizing element.

IE/FE analysis is a new method in calculation mechanics. It is the combination of IE analysis and FE analysis. Effectiveness of downsizing element showed that it is significant from 3.0 to 2.0 in IE/FE analysis, while, from 1.0 to 0.5 in FE analysis. That means the proper element size is recommended to be 2.0 mm in IE/FE analysis while less 0.5 mm in FE analysis. Larger element size will save computer memory and calculation time. Therefore, IE/FE analysis is a more effective method in dental implant biomechanical study.

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