J Korean Acad Prosthodont : Volume 39, Number 6, 2001

A STUDY ON THE DIMENSIONAL ACCURACY OF MODELS USING 3-DIMENSIONAL COMPUTER TOMOGRAPHY AND 2 RAPID PROTOTYPING METHODS

Lee-Ra Cho, D.D.S., Chan-Jin Park*, D.D.S., In-Woo Park, D.D.S.**
Dept. of Prosthodontics, College of Dentistry, Kangnung National University
Dept. of Prosthodontics, College of Dentistry, Seoul National University*
Dept. of Oral and maxillofacial radiology college of Dentistry, Kangnung National University**

Statement of problem. Relatively low success rate of root analogue implant system was supposed to be due to the time duration between extraction and implant installation. The use of three-dimensional computer tomography and the reconstruction of objects using rapid prototyping methods would be helpful to shorten this time.
Purpose. This aim of this study was to evaluate the application possibility of the 3-dimensional computer tomography and the rapid prototyping to root analogue implants.
Material and methods. Ten single rooted teeth were prepared. Width and height of the teeth were measured by the marking points. This was followed by CT scanning, data conversion and rapid prototyping model fabrication. 2 methods were used; fused deposition modelling and stereolithography. Same width and height of this models were measured and compared to the original tooth.
Results. Fused deposition modelling showed an enlarged width and reduced height. The stereolithography showed more exact data compared with the fused deposition modelling. Smaller standard deviation were recorded in the stereolithographic method. Overall width error from tooth to rapid prototyping was 7.15% in fused deposition modelling and 0.2% in stereolithography. Overall height showed the tendency of reducing dimensions.
Conclusion. From the results of this study, stereolithography seems to be very predictable method of fabricating root analogue implant.

CLINICAL IMPLICATIONS

Rapid prototyping technology, especially stereolithography can be acceptable in the real clinical applications. Combining this method, root analogue implant would be successful in reducing surgical time and damage.

Replacement of lost teeth using dental implants is an acceptable treatment method and the high success rate of these implants is well documented. There were several implant installation times were suggested. Conventionally, six to nine months after tooth extraction is recommended before the implants should be inserted. However, some authors proposed the shortened healing period would be also successful. With immediate implant placement, it is possible to minimize the resorption of the alveolar bone and the soft tissues, and therefore, a better cosmetic result can be expected.[1] The major problem of immediate implant placement using cylindrical implants is the unconformity between the implants and the shape of the extraction socket. When implants fail to contact surrounding bone during the healing period, soft tissue can grow into the free space, preventing satisfactory osseointegration.

In this case, it would be advantageous if the implant used for immediate placement has the same design as the extracted tooth root. The ReImplant system (Hagen, Germany), a recently developed root analogue implant using CAD/CAM allows the immediate replacement of teeth which have to be extracted.[2,3] Several authors reported the advantages of the root analogue implant. Lundgren concluded that this system were osseointegrated with a high degree of predictability and the quality of bone-to-implant contact was high enough to function well[4].

However, long surgical time was needed in immediate replacement with this system. In case of adopting delayed immediate implantation, two surgical operation was needed. Three-dimensional imaging has been developed to gather a vast number of complex slice image[5,6]. The advent of three-dimensional imaging has not only improved data display but also promoted the development of more useful technologies to assist the dentist in diagnosis and planning[7]. Instead of the traditional implantation procedure, a CT scanning of tooth could be processed and converted into root analogue implant.[8] This was rapid prototyping technology. With rapid prototyping techniques, the surgical time can be reduced and the implant operation can be simplified.[9-12] There were various subdivisions in rapid prototyping techniques. Two methods, fused deposition modelling and stereolithography were the most frequently using techniques.[13,14] It is less clear, however, whether this was a accurate and reliable technique. Moreover, these two techniques was not compared yet.

The objectives of the present study was to compare the accuracy of the two rapid prototyping techniques, fused deposition modelling and stereolithography from the same CT scanning and converted data of natural tooth.

MATERIAL AND METHOD

Specimen preparation

Total ten extracted, single rooted teeth were used. Crown of teeth were cut at cemento-enamel junction level. To ease the measurement of the tooth, root were cut at 3mm upper at the lowest position of the tooth. Measuring points were marked at the center of the bucco-lingual and mesio-distal surface.

CT examination and three-dimensional reconstruction

Conventional CT scanning (SCT-6800TXL, Shimadzu Co., Tokyo, Japan) at 120 kV was carried out. The slice thickness of the reconstructed images was 1mm at contiguous axial scan. The original CT data were transferred from the CT workstation to a personal computer using a DICOM, version 3.0 protocol. 3-dimensional image was reconstructed on a personal computer by V-works™(Cybermed Inc., Seoul, Korea).

Data conversion to stereolithographic files and slice files

The images of the 10 specimens were saved. These files were then converted to a stereolithographic format. The stereolithographic file was sliced into a series of 0.1mm layers. The slices were stacked together into a slice file, which could be edited, added to, etc. The slice file contained all of the information needed to build the resin model, and the file was downloaded to the rapid prototyping machine.

Rapid prototyping

Two rapid prototyping(RP) techniques were used. First, in fused deposition modelling technique, RP operates on the principle of depositing material in layers or slices to build up a tooth model. The depositing material used in this study was starch. The use of CT scans allowed parts of the tooth to be serially recorded slice by slice. Similarly, an object could be reproduced slice by slice using the 3-dimensional computed STL data in conjunction with a rapid prototyping machine (RapidWorks, Cybermed lab. Inc. Seoul, Korea) (Fig. 1).

The other method was stereolithography. Stereolithography is a method of RP that uses data obtained from CT scans stored in 3-dimensional form. This data was sliced up into a series of layers, which were then traced out by a laser beam onto the surface of a vat of fluid epoxy resin. An additive in the resin solidified instantly when it was exposed to ultraviolet light from the laser. Controlling the power of the laser and its tracking speed determined the depth of the polymerization below the surface of the fluid epoxy resin. This meant that a slice of the model of a known thickness was created from the data on the top of the vat of epoxy resin. By submerging this polymerized layer below the surface of the uncured, fluid resin, a second layer could be formed and bonded into the lower layer. Slice by slice, the data was recreated in the epoxy resin until, when the final layer had been completed, the platform was elevated from the vat of liquid resin. After being removed from the stereolithographic machine (Z402, Cybermed lab. Inc. Seoul, Korea), the model was exposed to ultraviolet light for 1 to 2 hours to achieve full resin strength and completes the crosslinking process(Fig. 2).

Measurement

To measure dimension of the teeth and RP models, specimens were placed on their respective positioning jig. The mesio-distal and bucco-lingual height and width of the specimens were measured(Fig. 3). The dimension was reproduced $\times 10$ magnification using stereomicro-

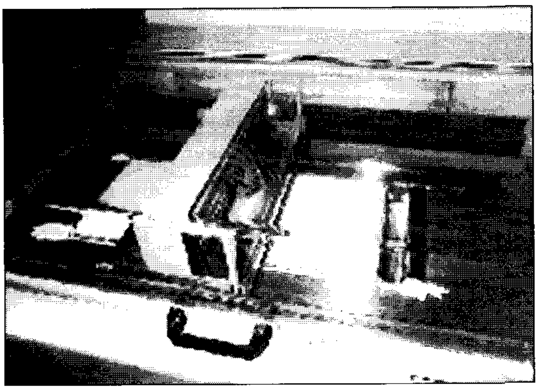

Fig. 1. Rapid prototyping machine.

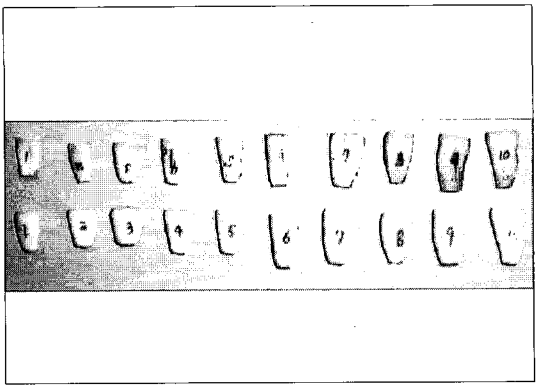

Fig. 2. Starch model from fused deposition modelling.

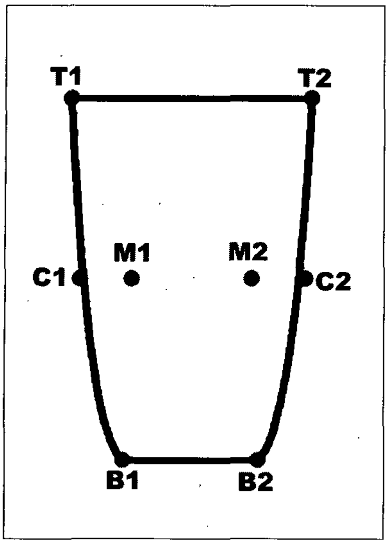

Fig. 3. Marking points for measuring the dimension of rapid prototyping models and tooth.

scope (Olympus, USA) and the image captured with CCD camera. Then, a video image of the dimension was blindly examined using image analysis soft ware at 10 measuring point around each specimen. Measurement error was ±5㎛.

Statistical analysis

Data on the width and height of RP model were compared to the original teeth and were recorded as percentile(%). All data was analyzed using one-way ANOVA to determine whether significant differences in each dimension existed at the 95% confidence level. When differences were significant, multiple comparison test was done by Scheffe' s method (α<0.05).

RESULTS

The results of the mean width (%) of starch model made from fused deposition modelling and epoxy model made from stereolithography are shown in Table Ⅰ and Figure 4 to 7. Rapid prototyping technique processed the model with similar dimension of the natural tooth. However, the proportion of width/height was different to that of the natural tooth.

The starch model made from fused deposition modeling showed enlarged width mesio-distally and bucco-lingually. There was no regular pattern of enlarging width. The height of the starch model showed slightly reduced shape. Combining the factor that shortening was happened in CT data acquisition process, the real model made from fused deposition technique was sup-

Table Ⅰ Relative mean width (%) of model profile to original tooth (Mean±S.D)

	Starch model		Epoxy model	
Site	Mesio-Distal	Bucco-Lingual	Mesio-Distal	Bucco-Lingual
Top	99.3 ± 4.6	104.6 ± 7.1	99.9 ± 0.80	100.0 ± 0.25
Center	110.3 ± 4.6	110.7 ± 6.1	100.2 ± 0.51	100.1 ± 0.25
Bottom	114.2 ± 12.0	103.7 ± 10.9	100.6 ± 1.87	100.2 ± 0.60
Total	108.0 ± 4.7	106.3 ± 7.1	100.3 ± 1.20	100.1 ± 0.49

Table Ⅱ Relative mean height (%) of model profile to original tooth (Mean±S.D)

	Starch model		Epoxy model	
Site	Mesio-Distal	Bucco-Lingual	Mesio-Distal	Bucco-Lingual
Right	99.1 ± 3.9	100.6 ± 3.9	99.6 ± 0.31	100.0 ± 0.05
Left	100.1 ± 4.7	99.6 ± 4.7	100.0 ± 0.28	100.1 ± 0.25
Total	99.6 ± 3.4	100.1 ± 3.5	99.8 ± 0.35	100.0 ± 0.18

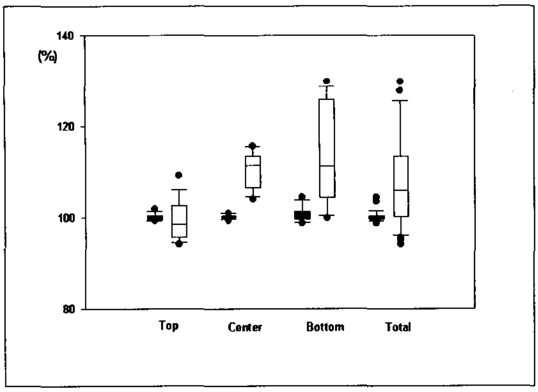

Fig. 4. Relative mesio-distal width of model profile to original tooth.

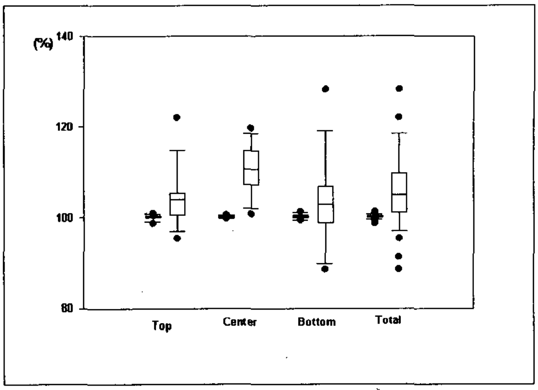

Fig. 5. Relative mesio-distal width of model profile to original tooth.

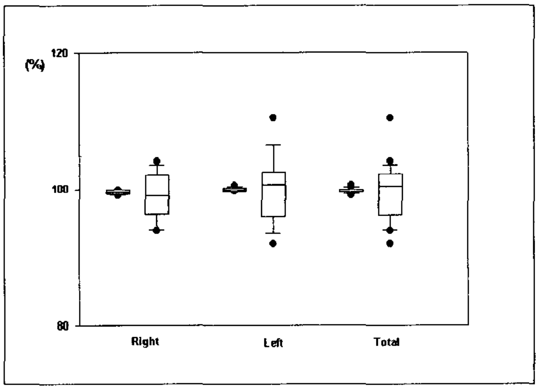

Fig. 6. Relative mesio-distal height of model profile to original tooth.

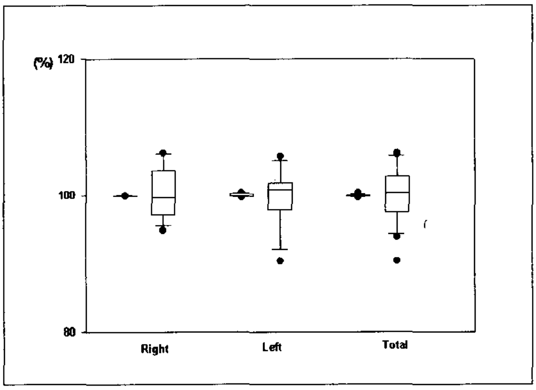

Fig. 7. Relative bucco-lingual height of model profile to original tooth.

posed to be slightly enlarged dimension.

Stereolithography seemed to be more accurate rapid prototyping technique than fused deposition modeling. The epoxy model made from stereolithography had very similar height and width to the natural tooth. Moreover, Smaller standard deviation were recorded in the stereolithographic method.

Overall width error from tooth to rapid prototyping was 7.15% in fused deposition modelling and 0.2% in stereolithography. Overall height showed the tendency of reducing dimensions.

DISCUSSION

The advantage of the immediate implantation with ReImplant system is the preservation of soft and hard tissues; the implants resemble the tooth at soft tissue level, allowing retention of the biologic contour of the soft tissue and the interdental papilla. No sophisticated surgical techniques are needed and an esthetic result can be achieved without numerous soft and hard tissue management procedure. Despite these advantages, gingival and bony recession during the healing period in some cases were reported. One suggested solution might be the two times protocol of first implant surgery. However, the patient were suffered from the two time operation.

Some authors reported the several cases of implantation with custom made root analogue titanium implants placed into extraction sockets[2,15]. Excluding the patient with extensive periodontal disease, Re-Implant system allows the immediate replacement of teeth even in molar areas. This system is composed of a titanium milling unit with an integrated laser and computer control station. The data obtained by laser scanning of extracted tooth was transferred to the computer unit. And then, with the software program, it is possible to change the dimensions and the surface characteristics of the final implant. It had superior primary stability and larger surface area and simplicity. With the experimental animal study, Lundgren et al.[4] and Kohal et al.[15] reported the good osseointegration results. Despite of these theoretical merits, long term results showed that lower clinical success rate than conventional screw type implant. Possible reasons of it were seemed to the long surgical time and deficient soft tissue coverage. From this point of view, the need for making implant with rapid prototyping would be arose.

Computer applications in radiology are evolving rapidly, tied to incremental improvements in hardware, software, and methods. The use of three-dimensional digitizers to perform localization of real three-dimensional points in conjunction with images and the rendering of objects using rapid prototyping methods, such as stereolithography and material deposition techniques. With this techniques, custom implants could be made before the first implant surgery and shorten the surgical time.

The great majority of early applications of rapid prototyping were in the field of craniomaxillofacial surgery.[16,17] Making skull models would be advantageous to the surgical planning.[18-20] Custom made implantable object in cranioplasty has been attempted in many medical and dental areas. Expected advantages of pre-manufacture of implants were: improved aesthetic results and reduction in post operative complications. This was attributed to the accuracy of fit of the rapid prototyping implant, and the importance of this to extraction socket integrity.

Another application field of rapid prototyping would be the combined techniques of stereolithography and eletroforming.[22] Schmitt et al.[8] reported a process used to create implant-retained restorations without conventional casting. They said this method had many advantages such as making many restorations at the same time, increasing efficiency and cost-effectiveness. From previous research and technical development of rapid prototyping, we plan to apply rapid prototyping technique to the dental implant.

The evolution rapid prototyping allowed layered formation of object. The creation of a solid object from a series of layers or slices of finite depth is relatively easy to visualize. Layering methods falls into three basic types, liquid based, solid based and powder based systems, resulting in final models made from a variety of materials ranging from paper to various polymers, to metals. It is clear that some methods will have advantages over others in certain applications or where material choice is important.

Although stereolithography is by far the most established, other techniques also have expanded and available. Stereolithography is well known accurate rapid prototyping techniques.[22,23] In our results, epoxy model made from the stereolithography showed superior accuracy than the starch model from material depositing technique, powder based method. Moreover, the standard deviations of the epoxy model were recorded one tenth of that of the starch model. It means that the epoxy model seems to be accurate, reproducible and reliable method of rapid prototyping techniques.

Fused deposition modelling was newly adopted methods in medical field. Some authors reported the durability of the models from this techniques. Main advantages of this method were the simplicity and the direct production of models. However, from the results of our study, this technique produced the wider model. It might bring about some problems in implantation procedure. Enlarged implant could not be embedded easily in extraction socket. Moreover, most frequent complication of Re Implant system was thin buccal bone fracture. Therefore, this type of rapid prototyping was not recommended.

In our study, we used the three dimensional CT imaging for gathering the information of the natural tooth. However, the image format with CT data might give some problems which would be the main source of tooth structure.[24] The slice thickness from CT we used was in the order of 1mm. Therefore, maximum 1 mm of tooth structure could not be captured with three dimensional CT. It means that the .STL file had the shortened data compared to the natural tooth. However, the results of the vertical height of rapid prototyping showed very slightly shortened images. From this results, it was supposed that the processing model from .STL data might lead to enlarged object.

When compared with achievable thicknesses on rapid prototyping machines of typically 0.1mm, or better, it is clear that the potential resolution of CT-derived data was poorer than that of the rapid prototyping machine. Considering this limitations on materials and tooling, this resolution would be a major part been overcome.

All the rapid prototyping techniques rely on a software interface which takes computer-aided design (CAD) information, and converts it to a .STL file format. In ReImplant system, implant could not be processed with this .STL file. This was pointed as the one problem needed future upgrade.

One limitation of our study is that the accuracy of ReImplant model were not directly compared to the tooth. Although one implant made with rapid prototyping model showed very similar to the original tooth. Scientific comparison could not be done due to the technical problems. Therefore, indirect comparison only could be possible. However, the results of this study was very encouraging to the application of rapid prototyping in the dental implant field.

CONCLUSIONS

Within the limits of this study, the following conclusions were drawn:

1. Rapid prototyping technique processed the model with similar dimension of the natural tooth.
2. The starch model made from fused deposition modeling showed enlarged width and slightly shortened height.
3. The epoxy model made from stereolithography had very similar height and width to the natural tooth.
4. Stereolithography seemed to be more accurate rapid prototyping technique than fused deposition modeling.

Acknowledgements

The author wishes to acknowledge the financial support of the Kangnung National University research program year of 2001.

REFERENCES

1. Heydecke G, Kohal R, Glaser R. Optimal esthetics in single-tooth replacement with the Re-Implant system: A case report. Int J Prosthodont 1999;12:184-9.
2. Kohal RJ, Heydecke G, Mota LF, Klaus G, Caffesse RG, Strub JR. Custom made root analogue titanium implants placed into extraction sockets. Clin Oral Impl Res 1997;8:386-92.
3. Strub JR, Kohal R, Klaus G, Ferraresso F. The Re Implant system for immediate implant placement. J Esthet Dent 1997;9:187-96.

4. Lundgren D, Rylander H, Andersson M, Johansson C, Albrektsson T. Healing-in of root analogue titanium implants placed in extraction sockets; An experimental study in the beagle dog. Clin Oral Impl Res 1992;3:136-44.
5. Wang G. Spiral CT, 3D Visualization in Medicine. ACM SIGGRAPH 98, 1998; Course 23, 168-73.
6. Lill W, Solar P, Ulm C, Watzek G, Blahout R, Matejka M. Reproducibility of 3-dimensional CT-assisted model production in the maxillofacial area. Br J Oral Maxillofac Surg 1992;30(4):233-6.
7. Winder J, Cooker RS, Gray J, Fannin T, Fegan T. Medical rapid prototyping and 3D CT in the manufacture of custom made cranial titanium plates. 1999;26-8.
8. Schmitt SM, Chance DA. Fabrication of titanium implant-retained restorations with nontraditional machining techniques. Int J Prosthodont 1995;8:332-6.
9. Bill JS, Reuther JF, Dittmann W, Kubler N, Meier JL, Pistner H, Wittenberg G. Stereolithography in oral and maxillofacial operation planning. Int J Oral Maxillofac Surg 1995;24(1 Pt 2):98-103.
10. Andrews JC, Mankovich NJ, Anzai Y, Lufkin RB. Stereolithographic model construction from CT for assessment and surgical planning in congenital aural atresia. Am J Otol 1994;15(3):335-9.
11. D' Urso PS, Barker TM, Earwaker WJ, Bruce LJ, Atkinson RL, Lanigan MW, Arvier JF, Effeney DJ. Stereolithographic biomodelling in craniomaxillofacial surgery: a prospective trial. J Craniomaxillofac Surg 1999;27:30-7.
12. Girod S, Teschner M, Schrell U, Kevekordes B, Girod B. Computer aided 3-D simulation and prediction of craniofacial surgery: a new approach. J Craniomaxillofac Surg 2001;29:156-8.
13. Barker TM, Earwaker WJ, Lisle DA. Accuracy of stereolithographic models of human anatomy. Australas Radiol 1994;38(2):106-11.
14. Webb PA. A review of rapid prototyping techniques in the medical and biomedical sector. J Med Eng Tech 2000;24:149-53.
15. Kohal RJ, Hurzeler MB, Mota LF, Klaus G, Caffesse RG, Strub JR. Custom-made root analogue titanium implants placed into extraction sockets. An experimental study in monkeys. Clin Oral Impl Res 1997;8:386-92.
16. Sailer HF, Haers PE, Zollikofer CP, Warnke T, Carls FR, Stucki P. The value of stereolithographic models for preoperative diagnosis of craniofacial deformities and planning of surgical corrections. Int J Oral Maxillofac Surg 1998;27(5):327-33.
17. Heissler E, Fischer FS, Bolouri S, Lehmann T, Mathar W, Gebhardt A, Lanksch W, Bier J. Custom-made cast titanium implants produced with CAD/CAM for the reconstruction of cranium defects. Int J Oral Maxillofac Surg 1998;27(5):334-8.
18. Wang Z, Wang X, Liu S. Research on improving rapid prototyping, Proceedings of 1998 IEEE International Conference on Robotics and Automation . 1998;1:314-17.
19. Santler G, Karcher H, Ruda C. Indications and limitations of three-dimensional models in cranio-maxillofacial surgery. J Craniomaxillofac Surg 1998;26(1):11-6.
20. Klein HM, Schneider W, Alzen G, Voy ED, Gunther RW. Pediatric craniofacial surgery: comparison of milling and stereolithography for 3D model manufacturing. Pediatr Radiol 1992;22(6):458-60.
21. Wu M, Tinschert J, Augthun M, Wagner I, Schaldilich-Stubernrauch J, Sahm PR, Spiekermann H. Application of laser measuring, numerical simulation and rapid prototyping to titanium dental castings. Dent Mater 2001;17:102-8.
22. Kragskov J, Sindet-Pedersen S, Gyldensted C, Jensen KL. A comparison of 3-dimensional CT scans and stereolithographic models for evaluation of craniofacial anomalies. J Oral Maxillofac Surg 1996;54(4):402-11.
23. Santler G, Karcher H, Kern R. Stereolithography model vs. milled 3D models. Production, indications, accuracy. Mund Kiefer Gesichtschir 1998;2(2):91-5.
24. Vannier MW. Computer applications in radiology. Current Opinion Rad 1991;3:258-66.

Reprint requests to:
Dr. Lee-Ra Cho
Dept. of Prosthodontics, Kangnung National University
Chibyun-Dong 123, Kangnung, Kangwon-Do, Korea
E-mail : lila@kangnung.ac.kr