Title	Development of automatic dental implant identification systems using deep learning and artificial images generated from STL data of dental implants
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Citation	大阪大学, 2023, 博士論文
Version Type	
URL	https://hdl.handle.net/11094/91851
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様式３

論　文　内　容　の　要　旨

氏　名　（　王　　展越　）	
論文題名	Development of automatic dental implant identification systems using deep learning and artificial images generated from STL data of dental implants （歯科インプラントのSTLデータから生成した人工画像と深層学習を応用した歯科インプラント自動識別システムの開発）

Introduction

Dental implant therapy has become a widespread prosthetic alternative for missing teeth. There are currently more than 500 implant manufacturers worldwide, with more than 4,000 implant systems on the market. Some implants are challenging to distinguish between types due to their similar morphology in X-ray images. Knowing the type of implant is a prerequisite for maintenance and retreatment. Due to patient transfer or clinic closure, it is common for information to need clarification. Therefore, it is difficult for dentists to identify unfamiliar implants. Deep learning, a subfield of artificial intelligence, has been applied to implant automatic identification. Deep learning uses artificial neural networks to "learn" features from the training images, then conducts classification automatically. Largely annotated training images are needed to gain a high feature extraction ability. At present, actual implant radiographs were collected and used as training datasets. However, this method is cumbersome and time-consuming due to ethical concerns. Furthermore, rarely used implant radiographs are challenging to collect. As a solution to the data collection problems and to contribute to rare-implant identification, with the development of computational capabilities and the help of image rendering technique, a novel method was devised in this research, which is to generate artificial images from the stereolithography (STL) data of the implants.

Experiment 1. Artificial image dataset construction

1-1. Purpose

Experiment 1 is to generate artificial implant images from the STL data of the implant.

1-2. Materials and Methods

Eighty-three STL files of different dental implants (Institut Straumann AG, Basel, Switzerland) belonging to three dental implant systems, Straumann bone level (BL, n = 12), Straumann bone level tapered (BLT, n = 18), and Straumann tissue level (TL, n = 53) were chosen for image generation.

STL models were resized to the same scale in the open-source computer graphics software Blender (www.blender.org, Blender Foundation, Amsterdam, Netherlands). To generate artificial images, STL models were put into the open-source image processing renderer Mitsuba 2 (https://github.com/mitsuba-renderer/mitsuba2). This process is conducted in a 13-inch 2 GHz quad-core Intel Core i5 laptop computer (MacBook Pro laptop, Apple Inc., Los Altos, CA, USA). All implant STL models were placed in the center with the implant-abutment junction up and the tip down, letting the long axis of implants coincide with the z-axis. Then the following parameters were defined. The tilt of the x/z-plane and the y/z-plane were chosen randomly between the range of -20° ~ +20°, -5° ~ +5°, respectively. The rotation of the z-axis was 0° ~ 360°. The value range for the extinction coefficient was set to 0.4 ~ 2.0 mm^{-1}, and the radiant intensity was 40 ~ 200 $W\cdot sr^{-1}$. Their combination at different values results in synthetic images with various transparency and brightness characteristics. Afterward, 116 panoramic images publicly disclosed were used to provide background diversity for implants. Finally, images were cropped to rectangles and resized to the same height of 256 pixels.

1-3. Results and Discussion

Artificial images of implants were generated successfully from STL models of implants and publicly available X-ray images. It took about 7 to 21 seconds to generate an artificial image. This experiment generated 22,896 images for BL, BLT, and TL implant systems, with 68,688 images in total.

Implants in the artificial images contained different positions, transparencies, and brightness levels and were surrounded by various backgrounds. It is believed that this image processing method can produce any number of artificial images without ethical issues.

Experiment 2. Automatic identification systems for dental implants

2-1. Purpose

Experiment 2 is to build identification systems for dental implants using the artificial image datasets constructed in Experiment 1 for deep learning and evaluate the performance of these identification systems.

2-2. Materials and Methods

Artificial images generated in Experiment 1 (n=68,688) for BL, BLT, and TL systems were randomly divided into two datasets: the training dataset (n=61,819, 90%) and the validation dataset (n=6,869, 10%). Three artificial neural network architectures with increasing complexity: LeNet, Midsize, and Google Inception v3, were used to develop three automatic identification systems in this experiment. All these three identification systems were developed and evaluated by NVIDIA V100 Tensor Core Graphics Processing Unit (GPU), 32 gigabytes (GB) memory (Nvidia Corporation, Santa Clara, CA, USA).

After these systems were developed, 295 actual periapical radiographs containing three desired implant systems were collected and preprocessed to evaluate the performances of these identification systems. The use of patients' X-ray images was approved by the ethics committee of Osaka University (approval number: R3-E14, October. 20, 2021). Regardless of the haziness, distortion, or blur, implants would be included in this research if they were complete. An ablation study was conducted using the Google Inception v3 network to explore how the number of training images affects model performance. Three dentists from the Department of Fixed Prosthodontics, Osaka University Dental Hospital, with 1, 5, and 6 years of implant placement experience, participated in this research. Dentists were asked to identify the 295 preprocessed dental X-ray images as BL, BLT, or TL. The time and accuracies were recorded for comparison. The incorrect results were visualized and examined.

2-3. Results and Discussion

The identification accuracy and total test time of LeNet, Midsize, and Google Inception v3 were 89.8 %, 7.35 s, 89.2 %, 28.37 s, and 92.5 %, 5.75 s, respectively. Google Inception v3 had the highest accuracy and the shortest time logged. The accuracy and identification time per image of Google Inception v3 and dentists 1, 2, and 3 were 92.5 %, 0.02 s, 98.3 %, 1.98 s, 99.3 %, 1.42 s, and 98.6 %, 1.56 s, respectively. Google Inception v3 was significantly faster, while the accuracies of dentists were higher than Google Inception v3. The ablation study showed that the number of training images in this research (n= 61,819) is sufficient.

The identification systems and dentists had difficulty identifying images with distortions and superstructures. As actual implant X-ray images were not needed to develop automatic identification systems based on the methods in this research, the identification of rare implant systems could be greatly aided. Furthermore, automatic identification models could be developed to identify a new implant before it was used and actual X-ray images were available.

Conclusions

Artificial implant X-ray images were successfully generated from the STL data of the implant body. This image generation method can contribute to the identification of implant systems that are rarely used because the artificial neural networks were trained without the actual X-ray images of patients. In this research, three dental implant automatic identification systems were developed successfully by only applying artificial images as training datasets for deep learning and tested with reliable results.

様式7

論文審査の結果の要旨及び担当者

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論文審査の結果の要旨

本研究は、インプラント体のSTLデータから作成した二次元画像とパノラマエックス線画像を合成した画像データを用い、深層学習によるインプラント体の自動識別システムの開発を行なったものである。本手法により、深層学習に必要な大量の画像データを人工的に作成することが可能となり、その結果、インプラント治療の経験を有する歯科医師にはわずかに劣るものの、インプラント体を識別可能なシステムを開発することができた。

以上の研究成果は、インプラント体の自動識別システムの臨床応用に向け、新たな手法を提案するものであり、よって、博士（歯学）の学位論文として価値のあるものと認める。