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Clinical Report

CLINICAL VALIDITY OF THE INTERACTIVE AND LOW-DOSE THREE-DIMENSIONAL DENTO-ALVEOLAR IMAGING SYSTEM, TUNED-APERTURE COMPUTED TOMOGRAPHY

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Abstract

Based on technical studies and clinical examinations, the clinical value of a new three-dimensional dento-alveolar imaging system, Tuned-Aperture Computed Tomography (TACT®), were examined for dental applications. TACT is a conventional and low-cost tomosynthesis method in which the benefit of digitization is fully utilized. The clinical information yield of TACT has been examined for the detection of dental caries, periodontal defects and radicular fractures, and also for the pre-surgical assessment of implant placement and impacted teeth. In this article, we introduce basic TACT technology, review the literature pertaining to *in vitro* and *in vivo* studies, and describe the outline of our study of TACT to determine its clinical value in the assessment of impacted maxillary teeth.

Key words: Tuned-aperture computed tomography—Intraoral radiography—Tomosynthesis—Impactions—Flat panel detector

INTRODUCTION

Because newly developed, small, flat-panel detectors with high sensitivity to X-ray and comparatively low-noise characteristics have been utilized for intraoral radiography, tomosynthesis has become practical for dento-alveolar imaging. TACT®, Tuned-Aperture Computed Tomography, is an interactive, low-dose, low-cost, three-dimensional (3-D)

tomosynthesis system in which the benefit of digitization is fully utilized[29,30]. A 3-D image-forming algorithm, TACT, which can be implemented with virtually any projection-based imaging system capable of digitized output, produces true 3D data from any number of arbitrarily oriented two-dimensional projections.

In the middle of the 1990's, the principal theory of TACT was described by Webber (Wake Forest University, School of Medicine, Winston-Salem, North Carolina, USA)[29,30]. The outline of TACT theory will be described in this article. We also introduce basic TACT technology, review the literature pertaining to TACT, and outline our study of TACT to determine its clinical value in assessment of impacted teeth in the maxillary incisor region.

THEORY

TACT is a technique for 3-D diagnostic imaging which can be carried out with low dosage. Application of the algorithm is not only applied to dento-alveolar imaging but also to digital mammography[24,32] and scinti-mammography[8]. TACT technology is now licensed to Instrumentarium Imaging (Tuusula, Finland).

As shown in Fig. 1, intraoral radiographs are made in different directions while a small flat-panel detector is held in the oral cavity. The images are obtained by "component projections" and are called TACT basis images. The projections are made at with different angles and repeated four to six times. The TACT workbench (Verify Software, Winston-Salem, North Carolina, USA) stacks the images, inputs locations of fiduciary markers for each basis image, and reconstructs a series of arbitrary multi-planar cross-sectional images. Such reconstruction of a series of arbitrary section images can produce pseudo-holograms. Iterative restoration to remove blurring is also available after three-dimensional models are built. TACT is based on tomosynthesis and aperture theory[29,30].

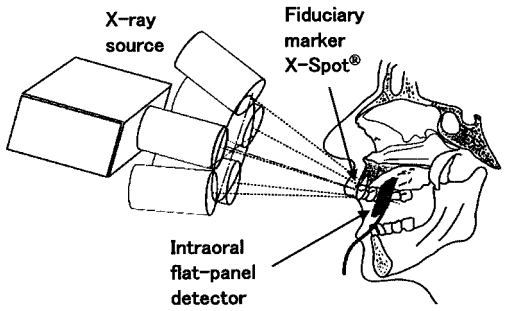

Fig. 1 Schematic presentation of component projections for obtaining TACT base images. A fiduciary marker is attached at the buccal surface of the oral mucosa. Four to six exposures are made from different directions while the small flat-panel detector is held in the oral cavity.

LITERATURE REVIEW

Dental Caries: Abreu *et al.* studied TACT in dental caries detection[1–4,25]. Effects in caries detectability were examined under various acquisition parameters of basis images, presence or absence of iterative restorations, and the choice of reconstruction algorithms. Their 1999 report[4] indicated that TACT images did not improve caries detection over that using film or digital radiography, but they nevertheless used their research data to calculate the optimum parameter settings of TACT for caries detection. In 1997, Tyndall *et al.* had previously explained that the relatively poorer performance yielded by the digital control images suggested that increased information capacity associated with more modern CCD detectors might improve the diagnostic performance of TACT displays[25]. In contrast, in 1998, Nair *et al.* showed that TACT images held the promise of a more effective imaging modality than film or individual digital images for the detection of recurrent caries[22].

Periodontal status: Chai-U-Dom *et al.* examined TACT for the *in vitro* detection of pericrestal and periodontal bone gain[6,7]. They indicated that TACT associated with digital subtraction radiography provided greater sensitivity while the technical flexibility remained. Nair *et al.* concluded that TACT was a more effective and accurate imaging modality for

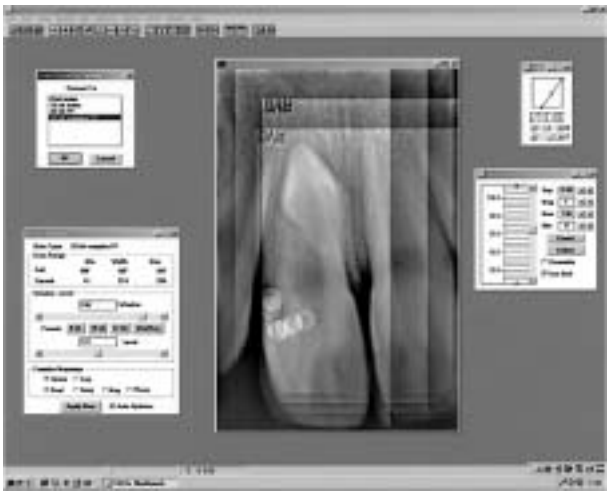

Fig. 2 A selected screen of the TACT Workbench. The tool box, "Clinical TACT slice control", enables the operator to control the position and the interval of the reconstructed sectional images.

non-destructive quantification of osseous changes within healing bony defects[20,21]. Ramesh *et al.* conducted research on the detection of simulated periodontal defects and concluded that TACT images processed by weak iterative restoration provided the best performance[23]. Nair *et al.* also reported that TACT performed significantly better than planar images for the detectability of trauma-induced radicular fractures, vertical root fractures, and mandibular fractures in their *in vitro* studies[18,19].

Implants: The clinical value of TACT for presurgical implant imaging was examined by Liang *et al.*, who found that TACT may provide an alternative to conventional tomography for dental implant imaging[14,15]. Morant *et al.* reported that TACT was significantly more accurate than standard application of the buccal object rule for assessing the relationship between tooth roots and the inferior alveolar canal[17].

Since 1998, we have also reported several basic studies of TACT, including collaborative work with the inventor, Webber[9,34,35,39]. We analyzed the accuracy of depth discrimination affected by projection geometry and the number of projections in our studies.

CLINICAL APPLICATION: IMPACTED TOOTH ASSESSMENT

As a further step in our research, we performed a clinical study on the diagnostic information yield of TACT in the assessment of impacted teeth in comparison with conventional dentoalveolar imaging[11,36–38].

1. Procedures for TACT

A small flat-panel detector system, CompuRay® (Yoshida Dental Trading, Tokyo, Japan) was employed as the intraoral X-ray detector. This is known as the RVG-ui sensor (Trophy Radiology, Marne-la-Vallée, France) in the rest of the world. Basis images are collected and stacked. The input of each projection position using the fiduciary marker on individual images is carried out, and a reconstruction algorithm is applied. Stability for maintaining continuity in geometric projection conditions is required for the generation of 3D images, such as CT, at the time of collection of image data. However, TACT enables an arbitrary setup of projection directions, because the position of the fiducial marker is always available. The operation for cross-sectional reconstruction can be carried out interactively. The

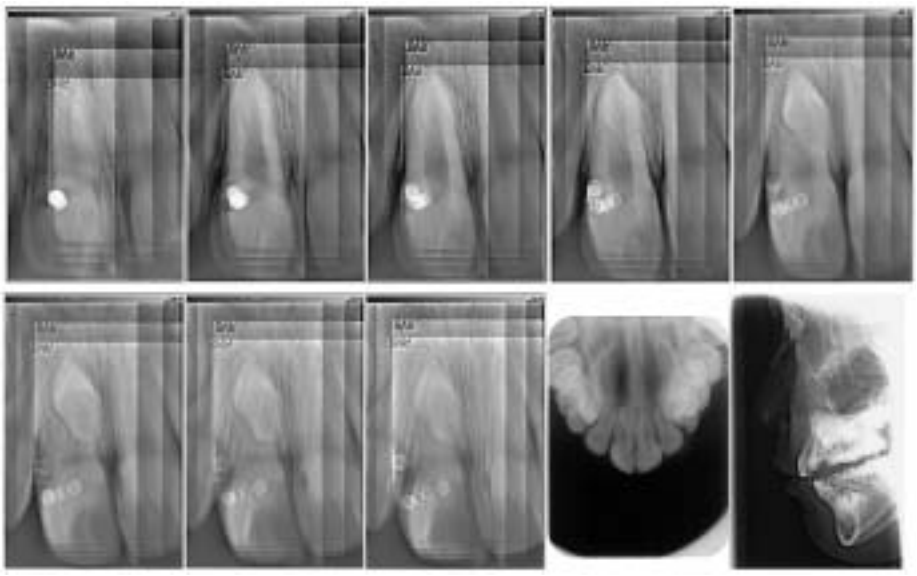

Fig. 3 Patient is a 9-year-old female. An impacted tooth is located in the maxillary incisor region. Based on the six component projections, TACT images were constructed. Eight sectional images are arranged in order from the buccal side (upper left) to the lingual side (lower center). These TACT images were selected at the same intervals. The occlusal and lateral radiographs are presented at the lower right.

reconstruction of a series of dento-alveolar depths is easily realized in compliance with diagnostic tasks. A selected screen of the TACT Workbench is shown in Fig. 2.

In accordance with the results of previous *in vitro* studies[34,35,39], in which influences of the number of and the angle of component projections to the accuracy of depth discrimination were reported, five or six component projections with conical beam-projection array per reconstruction, and approximately 20 degrees of angular disparity were chosen. The fiduciary marker we used was a 1.5 mm diameter X-Spot® lead pellet (Beekley, Bristol, Connecticut, USA). The X-Spot was packed under an adhesive tab used to help keep track of sensor positioning. The coordinates on each image were inputted into a reconstruction algorithm as reference points.

2. Case presentation

The case presented in Fig. 3 is an examination of an impacted tooth in the anterior region of the maxilla. Impacted teeth do often occur in the anterior maxilla, and their occurrence is significant in early mixed dentition in view of both esthetics and occlusion. TACT was applied for the radiological diagnosis of the status of the impacted tooth and its positional relationship with surrounding tissue and adjacent teeth. Various radiographic techniques have been reported for recognizing the position of an impacted (clinically "missing") tooth. Radiological diagnosis is necessary for clarifying the morphologic status of impacted teeth and their relationship with the surrounding tissues. Traditionally, the intraoral radiograph with an orthogonal projection has been used with an additional mesial, distal, inferior, or superior projection. With such parallax methods, the position of the impacted tooth in relation to its surrounding tissues can be estimated, but with limited accuracy. Given these limitations, it is possible that TACT might be used to study the morphology of impacted teeth in the incisor and canine regions of the maxilla.

As indicated in Fig. 3, TACT revealed the morphological relationship between the impacted tooth and surrounding tissues,

Table 1 Items used in the clinical evaluation

Anatomical structure depiction (unclear—clear)
1. An outer contour of the impacted tooth: dental crown
2. An outer contour of the impacted tooth: dental root
3. Developmental status of the dental root of the impacted tooth
4. Buccal/palatal position of the impacted tooth
5. Upper/lower position of the impacted tooth
6. Mesial/distal position of the impacted tooth
7. Relationship between the impacted tooth (permanent tooth germ in particular) and adjacent teeth
Subjective assessments (not sufficient—sufficient)
8. Estimate how useful you consider the existing radiographic information to be when considered only with regard to its potential for altering clinical treatment options.
9. Estimate the extent to which you feel that you have all the information you need to be confident in your clinical assessment of the patient's surgical prognosis.

including the regular teeth. Both the impacted tooth and the roots of adjacent teeth are sharply depicted in different sectional images with different depths in the buccolingual direction. All the TACT images were processed by the installed iterative restoration to remove blurring.

3. Statistical analysis

Previously, TACT has been compared variously with conventional intraoral, occlusal, rotational panoramic, and lateral cephalographic examinations of impacted maxillary incisors. Since the results are already published[37,38], only a brief outline is given in this report. TACT was used to examine 20 dental impactions in 20 patients. Sixteen dentists trained to read TACT image reconstructions independently carried out the following tasks: (1) clarity of depiction of the impacted tooth and its surrounding tissues, (2) estimation of confidence in clinical assessments of the patient by using the provided images, and (3) estimation of the diagnostic potential of TACT for altering the selection of treatment options. Table 1 lists the seven objective criteria for the evaluation of image clarity and an additional two subjective assessments. The continuous confidence-rating method was employed for each evaluation (Fig. 4). Mean

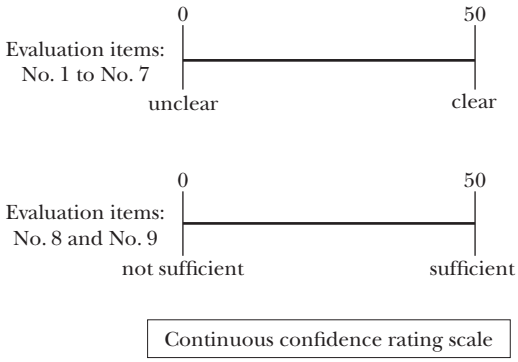

Fig. 4 A continuous confidence rating method. A bar of 50 mm length for each evaluation item is given on each observer's sheet. Each observer independently selected an optimal position on the bar dependent on his/her opinion. Each observer was instructed in advance that the range gradually changed from poor (at 0), to substandard, acceptable, good, and finally excellent (at 50) in sequence.

scores compare the observers' evaluations for structural clarity, observers' perceptions of the potential for TACT altering patient's treatment options, and observers' confidence in the reading of the position of the impacted tooth. Collected data were analyzed by means of *t*-tests performed with StatView (Abacus Concepts, Berkeley, Calif. USA). The *a priori* was set at 0.05.

Mean scores and 95% confidence intervals

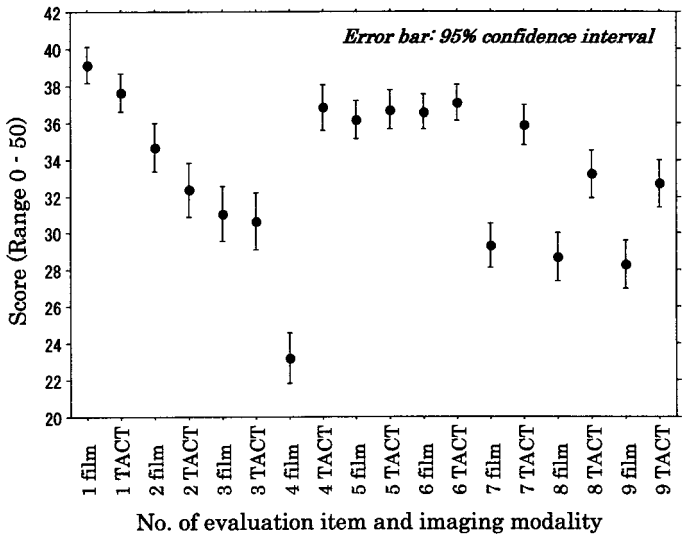

Fig. 5 Chart comparing observers' evaluation of depiction of anatomic structures (items 1 to 7) and observers' subjective assessments (items 8 and 9). Each error bar expresses the 95% confidence interval.

are indicated in Fig. 5. The clarity of the outer contour (items 1 and 2) was rated relatively low with TACT ($p<0.05$). In some cases, the impacted teeth and surrounding tissues were not completely depicted by TACT because of the small imaging area of the CCD sensor. Scores for accuracy in determination of the "buccal/palatal position of the impacted tooth," and the "relationship between the impacted tooth (permanent tooth germ in particular) and adjacent teeth" and subjective assessments (task 2 and 3) were high for TACT compared with those of conventional radiographs. TACT was perceived to improve depiction of the buccal/palatal position of the impacted tooth and its relationship with adjacent teeth ($p<0.0001$). TACT outperformed conventional images in terms of both subjective assessments for clinical decision making. The added diagnostic value with TACT varied from case to case.

DISCUSSION

Our research on TACT imaging, which was recently published, is the second *in vivo* study[38]. The first such study was reported by the inventor, Webber and Messura[31]. His group concluded that TACT displays were more diagnostically informative and had more impact on potential treatment options than did conventional radiographs. Some *in vitro* studies, which were mentioned in the short review section, indicated that TACT is sensitive or compatible in comparison with conventional dento-alveolar radiography examinations to detect dental caries, periodontal bone dynamics and other diagnostic tasks.

Since the image detector of intraoral radiography is changed from film to flat-panel detector (CCD or C-MOS sensor), TACT becomes convenient as such digital procedures are utilized. The digital revolution of the recent decade has put interactive and low-dose three-dimensional imaging systems, such as TACT tomosynthesis, into practice[26]. In a recent study, TACT projection data was utilized for rendering 3-D models for quantitative analysis of image subtraction methods[13]. In addition to research for the optimization of TACT procedures and algorithms[16,27,28], Webber recently used a hand-held X-ray system[33], in an attempt to increase the user-

friendliness of TACT for the use in dental offices.

For the last decade, researchers have carried out 3-D dento-alveolar imaging by using single- or multi-row spiral CT[5] and cone-beam CT images[10,12,40]. In comparison with such CT systems, TACT is characterized by a low-cost and low-dose 3-D image-forming system, which has been demanded by the medical and dental community in recent years. In this article, we introduced the basic TACT technology, reviewed the literature, and described the outline of our study. Our *in vivo* study shows the validity of using interactive 3-D TACT to improve the benefits of a digital flat-panel detector employed for intraoral radiography in the assessment of dental impactions.

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