Radiographic and clinical procedures in single-tooth implant treatment

Ph.D. thesis

by

Lars Schropp
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PREFACE</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>LIST OF ORIGINAL PAPERS</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>1. INTRODUCTION</strong></td>
<td>3</td>
</tr>
<tr>
<td>1.1. History of dental implant treatment</td>
<td>3</td>
</tr>
<tr>
<td>1.2. New concepts in dental implant treatment</td>
<td>4</td>
</tr>
<tr>
<td>1.3. Implant treatment planning</td>
<td>5</td>
</tr>
<tr>
<td><strong>2. AIMS</strong></td>
<td>7</td>
</tr>
<tr>
<td><strong>3. RADIOGRAPHIC IMPLANT TREATMENT PLANNING</strong></td>
<td>8</td>
</tr>
<tr>
<td>3.1. Purpose of radiography</td>
<td>8</td>
</tr>
<tr>
<td>3.2. Radiographic methods</td>
<td>9</td>
</tr>
<tr>
<td>3.3. Comparative studies on radiographic methods</td>
<td>12</td>
</tr>
<tr>
<td>3.4. Indications and recommendations for radiography</td>
<td>17</td>
</tr>
<tr>
<td>3.5. Impact of the radiographic method on implant treatment</td>
<td>18</td>
</tr>
<tr>
<td>3.6. Study I</td>
<td>20</td>
</tr>
<tr>
<td><strong>4. THE RECIPIENT IMPLANT SITE</strong></td>
<td>24</td>
</tr>
<tr>
<td>4.1. The residual ridge in relation to implant treatment</td>
<td>24</td>
</tr>
<tr>
<td>4.2. Bone and soft tissue changes after tooth extraction</td>
<td>25</td>
</tr>
<tr>
<td>4.3. Preservation of the alveolar ridge after tooth extraction</td>
<td>30</td>
</tr>
<tr>
<td>4.4. Study II</td>
<td>31</td>
</tr>
<tr>
<td><strong>5. IMMEDIATE VS. DELAYED IMPLANT PLACEMENT</strong></td>
<td>40</td>
</tr>
<tr>
<td>5.1. Classification – immediate, delayed, and late implant placement</td>
<td>40</td>
</tr>
<tr>
<td>5.2. Studies on immediate implant placement</td>
<td>42</td>
</tr>
<tr>
<td>5.3. Study III</td>
<td>47</td>
</tr>
<tr>
<td><strong>6. CONCLUSIONS</strong></td>
<td>57</td>
</tr>
<tr>
<td><strong>7. FUTURE ASPECTS</strong></td>
<td>60</td>
</tr>
<tr>
<td><strong>8. ENGLISH SUMMARY</strong></td>
<td>62</td>
</tr>
<tr>
<td><strong>9. DANSK SAMMENFATNING</strong></td>
<td>67</td>
</tr>
<tr>
<td><strong>10. REFERENCES</strong></td>
<td>72</td>
</tr>
<tr>
<td><strong>APPENDIX</strong></td>
<td></td>
</tr>
<tr>
<td><strong>ORIGINAL PAPERS</strong></td>
<td></td>
</tr>
<tr>
<td>I.</td>
<td></td>
</tr>
<tr>
<td>II.</td>
<td></td>
</tr>
<tr>
<td>III.</td>
<td></td>
</tr>
</tbody>
</table>
PREFACE

This thesis is based upon studies conducted during September 1999 to February 2002 at the Department of Oral Radiology and the Department of Oral and Maxillofacial Surgery, Royal Dental College, University of Aarhus, Denmark.

I would like to express my sincere gratitude to my supervisors Ann Wenzel, Lambros Kostopoulos and Thorkild Karring for scientific advice, great co-operation, and support.

I wish to thank the staff at the Department of Oral Radiology, the Department of Oral and Maxillofacial Surgery, and the Department of Periodontology & Oral Gerodontology at the Royal Dental College for their assistance and positive attitude.

Furthermore, I want to thank Torben Jørgensen for pleasant conversations and help with the program for digital subtraction radiography.

The editors of “Plus 5” kindly inserted the advertisement on my project, which I acknowledge, and I am grateful to the dentists in private practice in Aarhus Amt, who referred implant patients to the project.

Finally, I wish to give my best thanks to my family, friends and colleagues, who have supported me, and especially my wife and two kids, Laura and Jeppe, for their patience.

The studies were kindly financially supported by 3i Implant Innovations, Palm Beach, FL, USA, and The University of Aarhus Research Foundation.

Lars Schropp, February 2002.
LIST OF ORIGINAL PAPERS

This thesis is based on the following papers, which will be referred to in the text by their Roman numerals.

I. Impact of conventional tomography on prediction of the appropriate implant size.
   Schropp L, Wenzel A, Kostopoulos L.

II. Bone healing and soft tissue contour changes following single-tooth extraction. A clinical and radiographic 12-month prospective study.
    Schropp L, Wenzel A, Kostopoulos L, Karring T.
    The International Journal of Periodontics & Restorative Dentistry, submitted

III. Bone healing following immediate versus delayed placement of titanium implants into extraction sockets - a prospective clinical study.
    Schropp L, Kostopoulos L, Wenzel A.
1. INTRODUCTION

1.1. History of dental implant treatment

Dental implant treatment has revolutionized oral rehabilitation in partially and fully edentulous patients. When the concept of osseointegration was introduced in 1977 by Per-Ingvar Brånemark (Brånemark et al. 1977) in relation to titanium endosseous implants, it became possible to achieve high success rates in association with this treatment modality, and multiple investigations have demonstrated an excellent long-term prognosis (Albrektsson et al. 1986, Jemt et al. 1989, Adell et al. 1990, Shearer 1995). Initially, dental implants were mainly used for anchorage of a removable full prosthesis in totally edentulous jaws (Adell et al. 1981), but later on, also partially edentulous patients were treated successfully with either removable dentures or fixed bridges (Zarb & Schmitt 1993a, 1993b). The indication for implant treatment has been gradually extended, and today an implant-retained single-crown is a well-established option for replacement of a missing tooth (Schmitt & Zarb 1993).

According to the original implant treatment protocol (Brånemark 1985) (termed “gold standard” protocol in this thesis), it was recommended to wait at least 12 months following tooth extraction before insertion of implants. Furthermore, a two-stage approach was advocated which meant that the implant was placed in bone after flap elevation at one operation, the recipient site was covered with mucosa, and after approximately 3 months in the mandible and 6 months in the maxilla, a second-stage surgery was carried out. At this operation, the implant was uncovered and an abutment connected to the fixture component. Hereafter, the impression for the final prosthetic restoration was taken. The sequence of the “gold standard” treatment concept is illustrated in Figure 1.

Figure 1. Time schedule for the “gold standard” implant treatment protocol

<table>
<thead>
<tr>
<th>Tooth extraction</th>
<th>Fixture placement</th>
<th>Abutment installation</th>
<th>Prosthetic restoration (functional loading)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 months</td>
<td>3-6 months</td>
<td>3-4 weeks</td>
<td></td>
</tr>
</tbody>
</table>
The rationale of this treatment sequence was that the extraction socket should be allowed to heal completely before insertion of the implant. Hereafter, the implant should be inserted in the jawbone and covered with mucosa, thereby preventing functional loading and ensuring osseointegration of the implant.

It is obvious that the above described treatment concept is associated with disadvantages such as being a time demanding procedure with several surgical stages that increase unpleasantness and costs to the patient. A prolonged treatment period and the high financial costs may also be considered as disadvantages from a socio-economic point of view. From a biological standpoint, a drawback in deferring the time of implant insertion following tooth extraction is that the alveolar bone begins to resorb soon after removal of the tooth, as a consequence of normal physiologic activity (Atwood & Coy 1971, Atwood 1971). This results in a reduction of the height and width of the alveolar ridge, which may interfere with the subsequent placement of an implant with a proper size and alignment.

It is noteworthy that the “gold standard” implant treatment protocol (Brånemark 1985) was not founded on scientific evidence. E.g. a healing period of 3 to 6 months from fixture insertion to abutment operation and the following prosthetic treatment was empirically estimated on the basis of available knowledge on alveolar bone healing. This treatment concept, however, was tested and survived for more than 25 years (Adell et al. 1981).

1.2. New concepts in dental implant treatment
Within the last decades, the “gold standard” implant treatment protocol has been challenged by experiments, which aimed at shortening the treatment period and by reducing the number of surgical procedures. Various new surgical techniques have been investigated, such as a one-stage technique ( Schroeder et al. 1981, Buser et al. 1990, 1991, 1997, Ericsson et al. 2000). This technique implies that the implant penetrates the mucosa during healing (transmucosal implant). Hereafter two options exist, namely to wait a certain time before loading of the implant, or to load the implant immediately after placement.

Another approach is to reduce the time between tooth extraction and implant insertion. One possibility is to insert the implant before complete healing of the extraction
socket has occurred, optionally to insert the implant immediately after the tooth extraction procedure. The ultimate goal would be to insert the implant immediately after extraction of the tooth and to place the prosthetic restoration on the day of implant surgery. This concept has recently been suggested to be a realistic alternative to the conventional approach both in conjunction with single-tooth implants (Chaushu et al. 2001) and multiple implant restorations (Brånemark et al. 1999), however, there is still little clinical evidence that prognoses of the conventional protocol and this new “immediate” approach are comparable.

In order to estimate the appropriate time for implant insertion, understanding of the healing process at the recipient site after tooth extraction is really essential. Furthermore, since bone remodeling is part of healing, it is also important to acquire knowledge of the contour changes occurring at the extraction site. These changes may adversely affect the quantity and architecture of the alveolar ridge and, thereby have an impact on the possibility to insert an implant, as well as influence the functional and aesthetic outcome in prosthodontic treatment including implant-retained prosthetics (Schneider 1999).

Placement of an implant into a fresh alveolus will in most cases result in a gap between the occlusal part of the implant and the bone walls. To ensure osseointegration, various guidelines for the immediate implantation technique have been suggested including bone reconstructive treatment strategies, such as application of membranes, grafting materials, and bone inductive substances (Lazzara 1989, Block & Kent 1991, Shearer 1995, Lang et al. 1997, Becker et al. 1998a), but so far, no consensus has been reached (Schwartz-Arad & Chaushu 1997, Mayfield 1999). The use of membranes or grafts increases the costs to the patient and complicates surgery. Therefore, it is essential to evaluate in which types of peri-implant defects these additional procedures may be required for achieving osseointegration of immediately inserted implants, and to determine the size and morphology of defects that may have the ability to heal spontaneously.

1.3. Implant treatment planning
The success of any implant treatment depends on careful preoperative planning. In addition to a thorough anamnesis and clinical examination, radiographic assessment is es-
sential to estimate the morphologic characteristics of the proposed implant site and the location of anatomical structures.

Various imaging options are available for the evaluation of the recipient site (Grön-dahl 1997, Jacobs & van Steenberghe 1998b, Kircos & Misch 1999). Panoramic radiographs will provide information on the gross anatomy of the jaws and related anatomical structures. Due to inherent distortions, these images are less well suited for estimating the amount of alveolar bone, particularly in the horizontal planes (Tronje et al. 1982). Furthermore, another drawback associated with panoramic radiography is its in-born unsharpness, which impedes detailed diagnosis in the jawbone. The intraoral peri-apical image is valuable for an estimate of the mesio-distal dimension of the potential implant site, as well as a preliminary estimate of the vertical dimensions. A combination of panoramic and intraoral views is often recommended for a preliminary evaluation of the intended implant site. However, an obvious limitation of these radiographic methods is that they do not provide information on the bucco-oral width or angulation and concavities in the alveolar process, and therefore, it may be preferable to supplement these examinations with some form of cross-sectional tomographic imaging.

So far, there is no consensus regarding the guidelines for pre-implant radiographic planning. In a position paper by the American Academy of Oral and Maxillofacial Radiology, Tyndall & Brooks (2000) recommended that conventional cross-sectional tomography should be the method of choice for most implant patients. Nevertheless, the authors emphasize that currently there is no scientific evidence for that recommendation.
2. AIMS

The purpose of this research project was to evaluate radiographic and clinical procedures related to single-tooth implant treatment. The studies presented by papers I-III were carried out with the following detailed aims:

I. To determine the efficacy of conventional cross-sectional tomography as an adjunct to panoramic and periapical radiography in the prediction of the appropriate implant size.

II. To assess bone formation in the alveolus and contour changes of the alveolar process following single-tooth extraction.

III. To compare bone healing and crestal bone changes following immediate versus delayed insertion of submerged implants in extraction sockets.
3. RADIOGRAPHIC IMPLANT TREATMENT PLANNING

3.1. Purpose of radiography
The purpose of the pre-implant examination is first of all to decide whether implant treatment is appropriate for the patient, and whether it is possible to accomplish. Furthermore, this examination should estimate the prognosis as well as aid in preparing the treatment. Assessment of bone quantity, such as the height of the alveolar process, the bucco-lingual width, the angulation, and the detection of possible undercuts and concavities, is a prerequisite for the planning of implant placement in the jaws.

A clinical examination including analysis of study casts may be helpful in estimating the morphology of the alveolar process. However, it cannot be taken for granted that the morphology of the alveolar process covered with mucosa agrees with that of the underlying bony layer. Therefore, it has been suggested to assess the size and shape of the alveolar bone by “bone sounding” (also termed “ridge mapping”) (Lekholm 1997, Palmer et al. 2002). Following local anesthesia, the thickness of the mucosa is measured by penetrating the soft tissue with e.g. a periodontal probe at various sites in the region. To facilitate interpretation, the measurements of the mucosa thickness may be transferred to a sawed-through cast model.

Radiography is an alternative, non-invasive technique for determining presurgically the alveolar bone quantity as well as the quality. In order to avoid morbidity caused by the surgical procedure, it is essential to know the location of vital anatomical structures such as the inferior alveolar nerve and the extension of e.g. the maxillary sinus. Another yield of the radiographic examination is to identify possible pathological conditions. As will appear from the above, radiographic examination may be regarded as an indispensable part of the implant treatment planning.

The information acquired from radiography should be used to estimate the length and width of the implant to be inserted, the appropriate number of implants, the location and orientation, and the possible need for additional treatment before implant placement, for instance bone augmentation procedures. The dimensions of the implant are of concern since previous studies have indicated that the implant failure rate is associated with the length, i.e. the shorter implant, the higher the risk of failure (Bahat 1993, Bain & Moy 1993, Buser et al. 1997, Goodacre et al. 1999). It is a common observation that
a marginal bone loss of approximately 1 mm may occur around dental implants during the first year after placement and about 0.1 mm annually thereafter (Jacobs & van Steenberghe 1998a). Taking this into account, it is obvious that the length of the implant has an impact on the long-term prognosis. A study by Scurria et al. (1998) has shown that an implant width of less than 4.0 mm likewise deteriorates the prognosis. Besides, an increased length and width of an implant may facilitate the achievement of primary stability which most often is a prerequisite for osseointegration (Brånemark 1985). This is of particular concern in conjunction with immediately placed implants into extraction alveoli because, in many of these cases, bone anchorage can be achieved solely in the apical part of the implant immediately after insertion.

The implant direction is a factor that should also be considered even at the time of treatment planning. Isidor (1996, 1997b) has demonstrated that non-axial loading of an implant was associated with loss of osseointegration, and in another investigation, it was demonstrated that increased osteoclastic activity in the peri-implant bone tissues was the result of this type of loading (Barbier & Schepers 1997). Finally, an adverse inclination of implants may lead to poor esthetic results or necessitate the use of angled abutments.

3.2. Radiographic methods

When implant treatment is considered, a large variety of radiographic imaging techniques exist for the preoperative planning. The choice of technique, projections, and number of exposures depend on the region of the suggested implant treatment in particular, but also other factors should be considered. If severe bone resorption of the jawbone or anomalous anatomical conditions can be expected from the clinical examination, or bone augmentation procedures have been performed before implant surgery, this will influence the choice of examination. Furthermore, the accessibility of radiographic equipment, the financial costs, and radiation risk estimates play an important role. Ideally, the goal of the radiographic examination is to achieve as much information on the jawbone as possible and at the same time minimize the radiation burden to the patient as well as the costs. All types of imaging techniques possess both advantages and disadvantages, and a combination of different methods may be used in order to optimize the diagnostic outcome. In the following, different radiographic methods will be discussed
with regard to their strengths and weaknesses that may be of importance in relation to implant planning.

**Intraoral radiography:** By the use of reference images from mandibular sections presenting three defined classifications for bone trabecular patterns, it is possible to assess the trabecular pattern in intraoral radiographs with high diagnostic accuracy (Lindh et al. 1996). Periapical radiographs can be useful in identifying the approximate location of anatomical structures as well as the relative parallelism of roots adjacent to an edentulous site. Occlusal radiographs are capable of demonstrating the bucco-lingual width of the alveolar ridge in the mandible. A limitation of this method is that the images only display the maximum width of the alveolar process. The dimensional accuracy is poor in intraoral radiography due to inherent magnification and distortion (Klinge et al. 1989, Sonick et al. 1994). The technique is, however, readily available and rather inexpensive.

**Panoramic radiography:** A panoramic image yields an overview of the jaws and the general status of possible remaining teeth. It is most useful in the preliminary evaluation of the implant site. An obvious drawback is that the panoramic radiograph does not provide information on the bucco-lingual width of the alveolar process. Similar to intraoral radiography, some degree of magnification and distortion is inevitable in panoramic views. The magnification varies more in the horizontal plane than in the vertical plane, and it depends on the equipment, the position of the patient, and the location in the arch (Gomez-Roman et al. 1999). Studies have thus shown that distance measurements in panoramic images are unreliable (Klinge et al. 1989, Sonick et al. 1994). Babbush (1991) has described a method to overcome the magnification problem. A reference, e.g. a metal ball, with known dimensions may be placed in the region of interest making it possible to determine the actual magnification in both planes. Some advantages of panoramic radiography are low costs and a rather high availability.

**Lateral cephalography:** Profile radiographs have been proposed as part of presurgical implant planning (Strid 1985, Babbush 1991). These images provide information on the relationship between the upper and lower jaw in the sagittal plane, the inclination, the bucco-lingual width, and the vertical height of the jawbone in the anterior region. Furthermore, knowledge of the anatomical structures in this region can be obtained. Since information from cephalograms is limited to the midline of the maxilla
and mandible, this radiographic method has become less suitable concurrently with the
development of cross-sectional imaging techniques.

*Conventional cross-sectional tomography:* Because information on the jawbone in
all three dimensions is needed for implant treatment planning, it may be preferable to
supplement the aforementioned radiographic techniques with cross-sectional imaging.
Tomography may produce cross-sectional views in any jaw location making it possible
to accurately assess the alveolar bone height, bucco-lingual width and inclination, and
furthermore, the spatial relationship of the anatomical structures at the recipient site.
The principle of this method is blurring of the structures lying outside the image layer of
interest, which can be achieved by a coordinated movement of the x-ray source and the
film. The effectiveness of this blurring depends on the tomographic motion that can be
linear or multidirectional (hypocycloidal, spiral). The more complex motions, the more
effective and uniform blurring can be produced. The tomographic equipment is able to
produce image layers of different thickness. The interpretation of the resulting tomo-
grams is often rather difficult and calls for some experience. To aid the orientation of
the images, it is preferred to place metallic markers at strategic sites in the mouth before
the radiographic examination, which afterwards can serve as references for the exact lo-
cation of the slices. The advantages of conventional tomography include uniform magnification and moderate expenses (compared with computed tomography). The availa-
ility of this method has increased recently, since dental schools, hospitals, and private
practices are more prone to purchase tomographic equipments concurrently with their
reduction in price.

Digital radiography has advantages over film radiography, one of which is the abil-
ity of image manipulation that may result in enhanced diagnostic information (Wenzel
1991, 1999). In addition, software programs have been developed that may aid in simu-
lating placement of an implant in the patient before surgery by using a template on the
radiograph (SIM-Plant, Columbia Scientific Inc., Columbia, Md.; Implant Planner, Got-
fredsen, Aarhus).

*Computed tomography:* An advanced digital radiographic technique proposed for
implant treatment planning is computed tomography, also called CT scanning or just
CT. Like conventional tomography, this method is able to produce cross-sectional cuts
of the jawbone. The technique was introduced by *Hounsfield* (1973) in the 1970s, and
was based on cross-sectional imaging in the axial plane. Attempts were made to produce direct coronal and sagittal images similar to film tomograms, but this direct procedure has limitations when applied to the clinic (Quirynen et al. 1990). Instead, computer software was developed, capable of transforming the data of these axial slices into panoramic images and multiplanar cross-sectional images. This transformation is also known as reformatting or reconstruction. In the late 1980s, commercial programs were developed for application of CT to presurgical implant planning (Rothman et al. 1988, Schwarz et al. 1989).

The advantages of CT include: multiplanar views, high contrast, image layer free of blurring, uniform magnification ("real-size" imaging is possible), availability of image analysis by computer, and 3-dimensional reconstruction. In addition, many implant recipient sites can be evaluated in one exposure. However, computed tomography is also associated with limited accessibility, high expenses, and high radiation doses. Another problem is that presence of metallic restorative materials can cause streak artefacts. For that reason, CT may be more appropriate in the treatment planning of fully edentulous patients.

### 3.3. Comparative studies on radiographic methods

*Dimensional accuracy, and quality of the radiographic image: Measurement accuracy is one of the requirements for a radiographic method to be used in implant diagnostics. The reliability of the radiograph is therefore an important determinant for which methods may be suitable for treatment planning. The possibility to obtain correct measurements on the images is, among other things, dependent on how well the borders of the anatomical structures are depicted. Several studies have been conducted in order to evaluate both the quality of the produced radiographs in terms of the visibility of anatomical structures and the dimensional accuracy of different radiographic methods (Table 1).*
<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Sample</th>
<th>Design</th>
<th>Technique</th>
<th>Evaluation parameter</th>
<th>Evaluation parameter</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrikowski et al.</td>
<td>1989</td>
<td>1 mandible</td>
<td>In vitro</td>
<td>hcT</td>
<td>Height and width measurements</td>
<td>Measurement errors within 1 mm</td>
<td></td>
</tr>
<tr>
<td>Klinge et al.</td>
<td>1989</td>
<td>4 mandibles</td>
<td>In vitro</td>
<td>PA, Pano, hcT, diCT</td>
<td>Localiz. of mand. canal</td>
<td>1. diCT, 2. PA, Pano, hcT</td>
<td></td>
</tr>
<tr>
<td>Kassebaum et al.</td>
<td>1990</td>
<td>20 pt. max. and mand.</td>
<td>In vivo</td>
<td>liT</td>
<td>Visualiz. of anatomical structures</td>
<td>Valuable information</td>
<td></td>
</tr>
<tr>
<td>Lindh et al.</td>
<td>1992</td>
<td>6 mandibles</td>
<td>In vitro</td>
<td>PA, Pano, hcT, spT, diCT</td>
<td>Visualiz. of mand. canal</td>
<td>1. diCT, 2. hcT, spT 3. PA, Pano, 4. reCT</td>
<td></td>
</tr>
<tr>
<td>Todd et al.</td>
<td>1993</td>
<td>5 mandibles</td>
<td>In vitro</td>
<td>liT, reCT</td>
<td>Height and width measurements</td>
<td>1. reCT, 2. liT</td>
<td></td>
</tr>
<tr>
<td>Sonick et al.</td>
<td>1994</td>
<td>1 mandible</td>
<td>In vitro</td>
<td>PA, Pano, reCT</td>
<td>Localiz. of mand. canal</td>
<td>1. reCT, 2. PA, 3. Pano</td>
<td></td>
</tr>
<tr>
<td>Lindh et al.</td>
<td>1995</td>
<td>6 mandibles</td>
<td>In vitro</td>
<td>Pano, hcT, spT, diCT</td>
<td>Localiz. of mand. canal</td>
<td>1. diCT, hcT, spT, 2. Pano</td>
<td></td>
</tr>
<tr>
<td>Ekestubbe et al.</td>
<td>1996</td>
<td>5 mandibles</td>
<td>In vitro</td>
<td>spT, reCT, diCT</td>
<td>Visualiz. of mand. canal</td>
<td>1. spT, 2. diCT, 3. reCT</td>
<td></td>
</tr>
<tr>
<td>Bolin et al.</td>
<td>1996</td>
<td>100 pt., 401 sites mandible</td>
<td>In vivo</td>
<td>Pano, hcT</td>
<td>Bone height measurements</td>
<td>Overestimation with Pano</td>
<td></td>
</tr>
<tr>
<td>Butterfield et al.</td>
<td>1997</td>
<td>5 mandibles</td>
<td>In vitro</td>
<td>liT</td>
<td>Tracings of mand. canal and outer cortical bone</td>
<td>Poor accuracy of liT</td>
<td></td>
</tr>
<tr>
<td>Ekestubbe et al.</td>
<td>1999</td>
<td>17 pt.</td>
<td>In vivo</td>
<td>spT, Low-dose reCT, High-dose reCT</td>
<td>Tracing of anatom. contours</td>
<td>Image quality</td>
<td>1. spT, 2. low-dose and high-dose reCT</td>
</tr>
<tr>
<td>Bou Serhal et al.</td>
<td>2000</td>
<td>6 maxillae</td>
<td>In vitro</td>
<td>spT</td>
<td>Height and width measurements</td>
<td>No sign. diff. between tomographic and true measurements</td>
<td></td>
</tr>
<tr>
<td>Bou Serhal et al.</td>
<td>2001</td>
<td>6 mandibles</td>
<td>In vitro</td>
<td>spT</td>
<td>Localiz. of mand. canal</td>
<td>No sign. diff. between tomographic and true measurements</td>
<td></td>
</tr>
<tr>
<td>Bou Serhal et al.</td>
<td>2002</td>
<td>18 pt., 22 sites</td>
<td>In vivo</td>
<td>Pano, spT, reCT</td>
<td>Localiz. of mental foramen</td>
<td>1. spT, reCT, 2. Pano</td>
<td></td>
</tr>
<tr>
<td>Ekestubbe &amp; Gröndahl</td>
<td>1993</td>
<td>40 pt., mandible</td>
<td>In vivo</td>
<td>spT</td>
<td>Prediction of implant length</td>
<td>Predicted length and length of inserted implant agreed in 70% of the cases</td>
<td></td>
</tr>
<tr>
<td>Reddy et al.</td>
<td>1994</td>
<td>10 pt. max./mand. ??</td>
<td>In vivo</td>
<td>Pano, reCT</td>
<td>Prediction of implant length</td>
<td>1. reCT+Pano, 2. Pano alone</td>
<td></td>
</tr>
<tr>
<td>Jacobs et al.</td>
<td>1999</td>
<td>100 pt., 416 sites max. and mand.</td>
<td>In vivo</td>
<td>reCT</td>
<td>Prediction of number, site and size (length) of implants</td>
<td>Good prediction of site and number, poor prediction of length</td>
<td></td>
</tr>
<tr>
<td>Schropp et al.</td>
<td>2001</td>
<td>46 pt. max. and mand.</td>
<td>In vivo</td>
<td>PA, Pano, spT</td>
<td>Prediction of appropriate implant length and width</td>
<td>1. spT+PA+Pano, 2. PA+Pano alone</td>
<td></td>
</tr>
</tbody>
</table>

PA=Periapical radiograph, Pano=Panoramic radiograph, hcT=Hypocycloidal tomogram, liT=Linear tomogram, spT=Spiral tomogram, reCT=Reformatted CT, diCT=Direct CT

* The radiographic techniques are ranked in some studies according to their superiority (1.=best etc.)
When evaluating these investigations, it is important to consider which method and equipment was used for the examination. As stated in the previous section, several variants are available, e.g. for conventional cross-sectional tomography and CT scanning. One should also notice whether the study was conducted in vitro or in vivo. Some of the techniques are easily performed on maxillary or mandibular specimens while difficulties arise when trying to implement these to patients. Therefore, precautions should be taken when applying results from in vitro studies to the clinic. It is obvious that for ethical reasons, comparison between radiographic measurements and true measurements in human jaws is not possible in vivo.

Several studies have revealed that intraoral and panoramic radiographs are inferior to cross-sectional tomographic images with regard to visualizing the mandibular canal and measuring dimensional accuracy. In vitro, it was found that the visibility of the canal was higher on direct CT scans as well as on conventional cross-sectional tomograms (hypocycloidal and spiral) compared with panoramic views (Lindh et al. 1992). However, the latter was superior to reformatted CT scans. In an in vivo study, the mandibular canal was better visualized on hypocycloidal tomographs than on panoramic images (Lindh & Petersson 1989). Also when evaluating the accuracy of various methods for assessment of bone quantity and location of anatomical structures, panoramic views appeared to be of less value compared with cross-sectional tomographs (Tal & Moses 1991, Sonick et al. 1994, Lindh et al. 1995, Lam et al. 1995, Bolin et al. 1996, Bou Serhal et al. 2002). However, Klinge et al. (1989) found that direct CT was superior to both periapical, panoramic, and hypocycloidal tomography in locating the mandibular canal, while no significant difference existed between conventional cross-sectional tomographs and periapical or panoramic radiographs.

In previous studies, the dimensional accuracy and the image quality of conventional cross-sectional tomography have likewise been evaluated. In vivo, conventional linear tomography (Kassebaum et al. 1990) and hypocycloidal tomography (Aryatawong & Aryatawong 2000) demonstrated good visibility of anatomical structures. Petrikowski et al. (1989) concluded that hypocycloidal tomography was an accurate method for bone measurements (12 slices in one mandibular specimen). In contrast, Butterfield et al. (1997) found poor accuracy of linear tomograms when the outline of the inferior alveolar canal and the outer cortical bone were traced by seven observers with experience in
interpreting this type of radiographs. Furthermore, high intra-observer variability was seen when localizing the mandibular canal by hypocycloidal tomography (Gröndahl et al. 1991). Conventional spiral tomography demonstrated a high diagnostic accuracy in the maxilla (Bou Serhal et al. 2000) and in the mandible (Bou Serhal et al. 2001). In these two studies, none of the differences between tomographic and true measurements of the specimens were statistically significant. Ekestubbe & Gröndahl (1993) found that the measurement reproducibility was better in spiral tomographic images made by the Scanora® technique (Soredex, Orion Corporation Ltd, Helsinki, Finland) than in radiographs obtained with hypocycloidal tomography. It is noteworthy that no direct comparison between linear and multidirectional tomography has been reported.

Relatively few studies have been conducted to compare CT with conventional cross-sectional tomography. In one study, direct CT was found to visualize the mandibular canal better than both hypocycloidal and spiral tomography (Lindh et al. 1992) whereas Ekestubbe et al. (1996) demonstrated that direct as well as reformatted CT were inferior to conventional spiral tomographic images. However, for visualization of the alveolar bone crest, direct CT was superior to spiral tomography. In vivo, it was seen that the contours of the marginal crest and mandibular canal were untraceable in more cases using reformatted CT compared with spiral tomography (Ekestubbe et al. 1999). With regard to accuracy of bone measurements including localization of the mandibular canal, investigations have shown that direct CT performed better than hypocycloidal tomography (Klinge et al. 1989), and similarly reformatted CT better than linear tomography (Todd et al. 1993). In contrast, a more recent study revealed that direct CT, hypocycloidal tomography, and spiral tomography performed equally well (Lindh et al. 1995). Likewise, Bou Serhal et al. (2002) found that neither spiral tomography nor reformatted CT differed significantly from direct perioperative measurements when determining the location of the mental foramen.

In conclusion, the results of several studies show that measurements on tomographic radiographs are more reliable than on intraoral and panoramic radiographs. Furthermore, only small and contradictory differences have been found between the accuracy of conventional tomography and that of CT. These differences may have no clinical importance, and therefore other factors such as radiation risks and costs associated with the radiographic technique should also be considered in conjunction with the choice of
method. *Ekestubbe et al.* (1997) stressed that the choice of tomographic method seems to be dictated more by the availability of the equipment than its clinical necessity. This opinion is shared by the authors of a guide on selection criteria for dental radiography (Faculty of General Dental Practitioners (UK) & the Royal College of Surgeons of England 1998).

*Radiation risks associated with the radiographic method:* As mentioned above, the radiation hazards of a radiographic method also play a role when deciding which examination to choose for implant treatment planning. Previous studies have reported on radiation doses from various radiographic techniques. Intraoral and panoramic radiography are associated with low radiation doses (Ekestubbe 1999). The radiation dose from conventional tomography is comparable with that from intraoral radiography (Ekestubbe 1999) while CT examinations are associated with a high radiation burden to the patient (Clark et al. 1990, Kassebaum et al. 1992, Frederiksen et al. 1994, 1995, Dula et al. 1996, 1997). In two studies by Ekestubbe et al. (1992, 1993), absorbed doses from conventional (hypocycloidal and spiral) tomography and computed tomography (axial and coronal/sagittal) were compared. It was shown that the doses were higher with spiral tomography than with hypocycloidal tomography. The investigators also found that the doses absorbed by most internal organs were 3 to 10 times higher - and, by single organs, up to 200 times higher - for CT scanning than for conventional tomography.

Attempts have been made to reduce the radiation doses from CT scanning. In two studies, the influence of radiation exposures and scanning techniques in mandibular pre-implant CT examinations was evaluated *in vitro* (Ekestubbe et al. 1996) and *in vivo* (Ekestubbe et al. 1999). Different scanning protocols with varying tube current (mAs), slice thickness, slice distance, and tomographic plane were compared. *In vitro,* it was found that the image quality with respect to the visibility of the mandibular canal and the alveolar bone crest, obtained by low-dose and high-dose CT, was comparable. *In vivo,* it was demonstrated that low-dose CT scanning performed even better than high-dose tomography. Despite these modifications of the standard scanning protocol, the radiation doses were still higher for CT than for conventional tomography. Furthermore, conventional spiral tomography was shown to be superior to axial CT scanning concerning image quality in both studies.
In the clinical situation, CT scanning in the axial plane is preferred to direct coronal or sagittal images. To reformat these axial scans to cross-sectional radiographs, even when planning a single-implant treatment, it is needed to scan the entire jaw. When multiple sites in one arch are examined, however, the radiation risk does not increase further, which is in contrast to conventional tomography.

It may be concluded that from a radiation hygiene viewpoint, conventional tomography is preferred in most cases for implant treatment planning. However, for multiple-site imaging in the maxilla, CT scanning may be more appropriate, since the radiation doses can actually be reduced compared with conventional tomography (Kassebaum et al. 1992).

3.4. Indications and recommendations for radiography

Various recommendations and indications for the choice of radiographic method related to pre-implant imaging have been proposed (Schwarz et al. 1989, Quirynen et al. 1990, Williams et al. 1992, Faculty of General Dental Practitioners (UK) & the Royal College of Surgeons of England 1998, Jacobs & van Steenberghe 1998c). Despite the above considerations, CT has been recommended as the most suitable method for implant treatment planning. Schwarz et al. (1989) summarized that CT makes it possible to plan fixture positioning more effectively while Jacobs & van Steenberghe (1998c) concluded in their textbook on radiographic planning of oral implants that CT is the most reliable and accurate radiographic technique for implant site assessment and is therefore preferred to conventional tomography. They suggested the use of CT in all maxillary cases and in the posterior parts of the mandible, except where only one or two implants per patient were planned. In these cases, intraoral/panoramic radiography or conventional tomography should be the technique of choice according to their recipe. Quirynen et al. (1990) recommended CT over conventional tomography on the basis of the advantage of inherent software evaluation functions (reformatting, measuring, magnification), facilitating the estimation of bone quantity, quality, and dimensions. Furthermore, they pointed out that conventional tomography is very time consuming. In a book on selection criteria for dental radiography (Faculty of General Dental Practitioners (UK) & the Royal College of Surgeons of England 1998), it is proposed that for the planning of single-implants, intraoral radiographs, panoramic radiography, lateral cephalography or a
combination of these is suitable in the anterior and premolar areas in both jaws, alternatively conventional cross-sectional tomography, while conventional tomograms are particularly useful in the molar regions. For the assessment of multiple implant sites, the authors find that the use of conventional or computed tomography becomes more obvious as an alternative to non-cross-sectional radiography.

The above recommendations, however, are mainly based on an overall assessment of the advantages and disadvantages of the methods with regard to measurement accuracy, image quality, radiation risks, costs, availability, and convenience. Only few studies have evaluated whether the radiographic method chosen might have an impact on implant treatment planning, and few have compared the preoperative planning with the surgical outcome. In more recent publications (Ekestubbe 1999, Tyndall & Brooks 2000), conventional tomography has been advocated for pre-implant radiography. Ekestubbe (1999) stated that tomography is needed for the evaluation of bone height and that conventional spiral tomography is preferred to CT in general. Tyndall & Brooks (2000) recommended: “…some form of cross-sectional imaging be used for implant cases and that conventional cross-sectional tomography be the method of choice for gaining this information (anatomical features) for most patients receiving implants”, and: “…CT is most appropriate for patients who are being considered for many implants (8-10 or more) or when grafts or reconstructive surgery have been done or are being considered.” At the same time, however, they emphasized: “…currently there is no published evidence to support the position that some form of cross-sectional imaging should be part of implant site assessment because the overall success rate for dental implants is high, even without the use of imaging in multiple planes.”

3.5. Impact of the radiographic method on implant treatment

In the last part of Table 1, below the touched-up line, studies evaluating the impact of different radiographic methods on the implant treatment planning and treatment outcome (the latter only in one study, Study I) are displayed. One previous study aimed at comparing the diagnostic outcome of treatment plans made on the basis of panoramic radiography alone or panoramic plus CT images (Reddy et al. 1994). Four dentists made treatment plans for ten patients. The authors did not report on whether the implants were to be placed in the maxilla, mandible or both. The implant length was predicted, first by
means of a panoramic image alone and subsequently by means of both the panoramic image and CT scans. The “ideal” implant length was determined at the time of surgery by placing a calibration depth gauge into the osteotomy and then taking a direct digital radiograph. Surgical templates were made to the proper scale of each radiographic type to account for magnification. The “ideal” implant length and the length predicted in conjunction with the first and the second treatment plan were compared. It was found that when evaluating the panoramic view alone, there was a tendency to underestimate the length of the implant, while there was no significant difference between the “ideal” length and the length predicted using both panoramic and CT images. Moreover, the dentists felt more confident with the planning when having access to CT scans.

The purpose of a second study was to determine the reliability of reformatted 2D-CT for preoperative implant planning (Jacobs et al. 1999). The number, site and size of implants, the bone height and anatomical complications were predicted in 100 patients (416 implants in the maxilla or mandible), and these parameters were then compared with what was found and decided at surgery (395 placed implants). A relatively poor agreement between the pre-operative data and the findings and decisions at surgery was found for implant size (44%) and anatomical complications (46%) while the prediction of the appropriate implant site (70%) and the number of implants (60%) was good.

In a third study (Ekestubbe & Gröndahl 1993), the ability of predicting the appropriate implant length pre-operatively by conventional spiral tomography was evaluated. In 40 patients referred for implant treatment in the posterior part of the mandible, the implant lengths planned on tomograms obtained from a Scanora® x-ray unit were compared with those actually inserted. It was found that the suggested implant length agreed with the one inserted in 70% of the cases.

None of the above studies included implant width in their prediction, and they all terminated their evaluation at the time for implant surgery. Thus, no studies have evaluated whether the type of pre-operative imaging has an effect on the success of the implant treatment on a short or long-term basis. Figure 2 illustrates the sequence of implant treatment planning and the subsequent evaluation of implant treatment.
3.6. Study I

The present study (I) was performed in order to evaluate whether the use of conventional spiral tomography as an adjunct to periapical and panoramic radiography for planning of single-tooth implants may affect the prediction of the length as well as the width of the actually inserted implant. Besides, in order to go one step further than previous studies, the patients were examined clinically and radiographically just after implant placement and again after the final prosthetic treatment (5 months after implant placement) to assess whether the size of the inserted implant was in fact the appropriate one, and thereby to evaluate the short-term success of treatment (acceptable functional and esthetical results).

Forty-six patients referred for single-tooth implant treatment at the incisor, canine or premolar regions of the maxilla or the mandible were enrolled in this study. The patient sample is described in detail in Chapter 5.3.

All patients were exposed to periapical, panoramic and cross-sectional tomographic radiography approximately one week before implant surgery.

In order to achieve reproducible periapical radiographs, a method for standardizing the images with regard to projection angles and film-tube distance (Sewerin 1990) was applied. The paralleling technique was used along with an occlusal bite-index, individually fabricated for each patient, and fixed to the film-holder. After placement in the mouth, the film-holder was attached to the cone of the x-ray unit. The bite-index was saved for use at all visits. Despite the fact that the examination was carried out careful-
ly, some degree of magnification and distortion of the images was inevitable, in some cases due to the anatomical conditions in the patients.

The panoramic and conventional cross-sectional tomographic examinations were performed in a Scanora® x-ray unit. This multimodal imaging system was introduced in the late 1980s and enables both spiral tomography as well as rotational and linear narrow beam radiography (Tammisalo et al. 1992). To locate the region of interest for implant placement, a metal rod and a ball were fixed with wax to the facial surface of the tooth mesially and distally to the implant site. A 15x30 cm film-cassette was used with a Lanex medium or fine intensifying screen and Kodak Tmat G film (Eastman Kodak Company, Rochester, NY, USA).

No surgical stent was used for implant placement in the present studies (I and III), since this would further extend the clinical procedures. Therefore, also no radiographic reference was used. It was assumed that discrepancies from the average 30% magnification in the panoramic image would be negligible from a clinical point of view when meticulous positioning of the patient was provided.

By wide-angle spiral tomography, four images, 4 mm in thickness were achieved. Cuts were produced with a dento-tangential projection except in the premolar areas of the mandible where a maxillo-tangential projection was chosen according to the operation manual for the Scanora® x-ray unit.

Presurgically, the surgeon performed two treatment plans including determination of implant length and width. Treatment plan 1 was based on the clinical examination, diagnostic casts and the periapical and panoramic views (record 1; Fig. 3). Immediately after, treatment plan 2 was made by means of periapical + panoramic images combined with tomograms (record 2; Fig. 3).
In conjunction with treatment planning, transparent templates were used to compensate for the magnification in the panoramic view (approx. x1.3) and the tomographic image (approx. x1.7) (Tammisalo et al. 1992). A transparent template with the different sizes of Osseotite® implants (3i Implant Innovations, Palm Beach, FL, USA) and the proper magnification factor was superimposed on the radiograph and the appropriate implant size was determined. At surgery, the dimensions of the implants actually inserted were recorded (record 3). Finally, another observer than the surgeon evaluated clinically and radiographically (periapical image) the treatment success just after implant placement and again after insertion of the final tooth restoration in order to determine whether the
dimensions of the inserted implants were "appropriate" (record 4). The percentage agreement between the implant size predicted when making the two treatment plans (records 1 and 2) and the size of the inserted implant (record 3) and the “appropriate” implant size (record 4), respectively, were calculated, and the differences were statistically tested.

In the present study, it was found that the additional use of tomograms gave rise to a change in the implant dimensions in 70% of the cases. Most changes were made in the mandible, and the length was more often changed than the width. The number of patients in the present study was too small in order to analyze whether there were common denominators among the cases where no change in the treatment plan was recorded. The agreement between the size, both length and width, of the inserted implant (record 3) and the implant size predicted with tomograms (record 2; 87%), and without tomograms (record 1; 33%) differed significantly. In 15% of the cases, the implants actually inserted were subsequently assessed not to be appropriate in length, width, or both, but despite this discrepancy, the agreement between the appropriate implant size (record 4) and the treatment plan with tomograms (record 2) was significantly higher than the agreement between the plan without tomograms (record 1) and the appropriate implant size (record 4; 72% versus 33%). From the results of this study, it may be concluded that conventional cross-sectional tomography increased the efficacy of periapical and panoramic images in the prediction of the appropriate implant size by a factor of 2.5. These results were thus in accordance with the findings of the previous study described above (Ekestubbe & Gröndahl 1993).

One can speculate that the surgeon might have changed the planned implant size at surgery, even without access to the tomograms resulting in a similar short-term success of treatment. However, it will be beneficial to the surgeon to be as well prepared as possible before the operation. For instance, he can ensure that the proper implants are in stock and be prepared for possible additional treatment procedures.

Other options for the study design have been considered. A randomized allocation of the patients into two groups, one where the implant site is planned with periapical and panoramic views alone and another where the treatment planning included tomo-
grams, followed by a comparison of the success of treatment in the two groups, would have been an option. The patients were, however, already split into two groups in connection with the study on the appropriate time for implant insertion (Study III), and therefore the material would be two small for this design. It is believed, however, that the design chosen for the present study was suitable in demonstrating the efficacy of conventional tomography on the prediction of the appropriate implant size, and thus its impact on the treatment success on a short-term basis.

Based on the results of Study I, it can be concluded that conventional cross-sectional tomography is effective in the prediction of the size of the implants to be inserted in 87% of the cases and the appropriate implant size in 72% of the cases, and thereby tomography increases the efficacy of periapical and panoramic images to predict the appropriate implant size by a factor of 2.5.

4. THE RECIPIENT IMPLANT SITE

4.1. The residual ridge in relation to implant treatment
Morphologic changes of the alveolar process following tooth extraction are a common clinical observation. This phenomenon has been described as residual ridge reduction (RRR) (Atwood 1971). One of the reasons for being concerned about RRR from a clinician’s point of view is that poor quantity and an unfavorable architecture of the alveolar bone may complicate prosthodontic rehabilitation (Schneider 1999). Both the functional outcome of conventional prosthetics, e.g. retention and stability of removable dentures, as well as the esthetics in fixed and removable prosthodontics are influenced by the characteristics of the alveolar process.

Also when one deals with implant treatment, RRR plays a major role, considering both the surgical and prosthetic aspects. It is obvious that the length and width of the implant that can be selected, but also the position of the implant in an apico-coronal aspect, to some extent are dictated by the amount of alveolar bone. This, in turn, may affect the crown-fixture ratio and the loading conditions of the implant-retained restoration. Resorption of the buccal wall of the extraction alveolus may result in that the implant must be placed more orally than the adjacent teeth and thereby compromises the
esthetics. Also the possibility of inserting the implant with a proper angulation is of significance for the cosmetic outcome as well as for the loading of the implant (Isidor 1996, 1997b). Extensive ridge resorption often leads to a “knife-edge” ridge (Denissen et al. 1993). This shape of the alveolar bone is inappropriate and may force the use of narrow implants or result in an increased risk of exposure of the implant surface. Also the risk of compromising vital anatomical structures is increased when little alveolar bone is available.

4.2. Bone and soft tissue changes after tooth extraction
Several histological and histochemical studies in animals (Huebsch & Hansen 1969, Carvalho et al. 1997, Devlin et al. 1997) and in humans (Amler et al. 1960, Boyne 1966, Amler 1993) have described the healing process in an extraction socket. A few investigations have evaluated this phenomenon by means of radiographic densitometry (Bodner et al. 1993), but no studies have described radiographically bone healing after tooth extraction in man.

In the following, the process of extraction socket healing will be summarized on the basis of results from previous studies in animals and humans (Adriaens 1999). Immediately after tooth extraction, the alveolus is temporarily closed by a blood clot. Within the first week, this blood clot is transformed into a well-organized granulation tissue with blood vessels, fibroblasts, and collagen fibers, simultaneously with a proliferation of epithelial cells from the wound edges. Bone remodeling and resorption occur at the socket walls. The granulation tissue is progressively transformed into connective tissue and the epithelial coverage of the wound is completed during week three. Active formation of new bone is seen as early as two weeks after tooth extraction and at the same time, osteoclastic activity at the buccal, lingual and interdental margins of the alveolus takes place. When multirooted or multiple teeth are extracted, the intraradicular or interdental bone is resorbed as well. The healing of the extraction socket is completed after approximately two months, but bone may still grow in the coronal direction during the first four to five months, while further maturation of the newly formed bone occurs until six to twelve months after extraction of the tooth.

Under normal conditions, the healing of an extraction site will be attended by anatomical changes of the alveolar ridge as a consequence of tissue remodeling and resorp-
tion (Atwood 1971). These changes occur in both the vertical and horizontal directions and result in a decrease of the height as well as the width of the alveolar process. The size of the alveolar ridge is most rapidly reduced during the wound healing period of around six months. However, even after the extraction socket has healed, the initial bone remodeling is succeeded by a bone resorption activity that, though at a slower rate, continues throughout life (Jahangiri et al. 1998). It is obvious that apart from the post-extraction changes, bone resorption prior to extraction of teeth caused by e.g. periodontal disease, trauma to teeth or bone, periapical pathology, or damage of the bone tissues as a result of the extraction procedure also contribute to the overall loss of alveolar bone volume. Various etiologic factors that cause RRR have been suggested. Atwood (1979) categorized the factors in four major groups as follows: anatomic, prosthetic, metabolic, and functional. In another paper, the evidence for the etiology of RRR and the role of local and systemic factors have been reviewed (Devlin & Ferguson 1991). Local mechanical stress generated by removable dentures has often been proposed as an aggravating factor for RRR (Devlin & Ferguson 1991, Jahangiri et al. 1998). Numerous investigations have been conducted to describe the morphologic changes following tooth extraction. In previous studies from the 1960s and 70s, the gross changes of the anatomical structures have been evaluated by means of lateral cephalograms (Carlsson et al. 1967, Carlsson & Persson 1967, Atwood & Coy 1971) or by measurements on study casts (Lam 1960, Johnson 1963, Pietrokovski & Massler 1967, Johnson 1969). In the following, data dealing with alveolar ridge changes within the first twelve months after tooth extraction are brought into focus, mainly from studies where the patients wore no prosthesis during the healing period. In Table 2, previous studies on alveolar tissue changes evaluated by measurements on study casts are displayed. Retrospective studies on completely edentulous patients are not included.
Table 2. Previous studies on alveolar tissue changes evaluated by measurements on study casts

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Sample</th>
<th>Design</th>
<th>Follow-up period</th>
<th>Denture wearing</th>
<th>Number of teeth</th>
<th>Evaluation parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lam</td>
<td>1960</td>
<td>3 pt.</td>
<td>Prospective</td>
<td>0-12 months</td>
<td>Immediate, partial denture</td>
<td>All anterior teeth</td>
<td>Loss in height and labial thickness</td>
</tr>
<tr>
<td>Johnson</td>
<td>1963</td>
<td>9 pt.</td>
<td>Prospective</td>
<td>0-12 months</td>
<td>From 10-20 weeks after tooth extraction</td>
<td>All maxillary teeth</td>
<td>Loss in height and width</td>
</tr>
<tr>
<td>Pietrokovski &amp; Massler</td>
<td>1967</td>
<td>149 casts</td>
<td>Retrospective</td>
<td>-</td>
<td></td>
<td>Single tooth</td>
<td>Loss in width</td>
</tr>
<tr>
<td>Johnson</td>
<td>1969</td>
<td>11 patients (5 at 12 m.)</td>
<td>Prospective</td>
<td>0-12 months</td>
<td>From 10-20 weeks after tooth extraction</td>
<td>All maxillary teeth</td>
<td>Loss in height and width</td>
</tr>
<tr>
<td>Watt &amp; Likeman</td>
<td>1974</td>
<td>25 pt.</td>
<td>Prospective</td>
<td>0-30 months</td>
<td>Immediate in 12 cases, from 3-12 m. in 13 cases</td>
<td>All or fewer maxillary teeth</td>
<td>Loss in height and width</td>
</tr>
<tr>
<td>Lekovic et al.</td>
<td>1997</td>
<td>10 pt.</td>
<td>Prospective</td>
<td>0-6 months</td>
<td>Not reported</td>
<td>2 or more anterior or premolar teeth</td>
<td>Loss of bone height and width</td>
</tr>
<tr>
<td>Schropp et al. (Study II)</td>
<td>2001</td>
<td>46 pt.</td>
<td>Prospective</td>
<td>0-12 months</td>
<td>No (except 2 patients – removable partial denture)</td>
<td>Single premolar/molar</td>
<td>Loss in height and width</td>
</tr>
</tbody>
</table>
In an investigation from 1963 (Johnson 1963), the period of normal healing of the alveolar bone following tooth removal in the maxilla was studied. Extraction of all remaining teeth was performed in nine patients, and when healing of the alveolar process was considered complete, a full maxillary denture was constructed. The period from tooth extraction to complete clinical healing varied from 10 to 20 weeks. In all cases, a rapid reduction in height and width of the alveolar bone was found after extraction of the teeth. The results revealed that the reduction in width was greater than the reduction in height in both the anterior and posterior segments. The vertical reduction in the anterior and posterior regions varied between 2.5 and 5.0 mm and between 3.0 and 7.0 mm, respectively. A width reduction in the range of 3.0 to 7.0 mm was seen in both the anterior and posterior segments. Almost all changes of the alveolar bone took place during the first 2-3 months following removal of the teeth while further ridge resorption after insertion of the denture had occurred in only two patients. Later, these results were confirmed when the previous study was repeated with an additional group of patients (Johnson 1969). Another early study (Lam 1960) provided information on the rate and distribution of alveolar contour changes following extraction of all maxillary anterior teeth in three patients. It revealed that maximum loss of tissue took place during the first month (approximately 70-90%) while a further minuscule loss continued until the end of the fifth month. After one year, the loss in height ranged from 3.0 to 4.5 mm and the loss in labial thickness was in the range 3.0 to 5.6 mm. No measurements on the lingual aspect were presented. In this study, the patients wore a partial denture immediately after removal of the teeth. Watt & Likeman (1974) assessed the average rate of alveolar tissue changes within a period of 2½ years in a sample of 25 patients. Half of the patients wore a denture immediately after tooth extraction while the rest received a denture from three to twelve months after extraction. After one month of healing, 40% of the total tissue loss at 2½ years had occurred. At three, six and twelve months after tooth extraction, 65%, 80% and 90% of the loss, respectively, had occurred. Pietrokovski & Massler (1967) studied retrospectively the amount of tissue loss after single-tooth extraction in 149 patients. The changes were recorded by superimposing a tracing of the edentulous region of a study cast over its contra-lateral ridge with teeth present. They found an average width reduction of the alveolar ridge amounting to approximately 3 to 5½ mm in the front and premolar areas, and 7 to 8½ mm in the molar areas. No signifi-
cant difference existed between the changes in the maxilla and the mandible. The results also revealed that more resorption occurred on the buccal than on the lingual surfaces of the ridge in both the upper and lower jaw. In this study, there was no information on the time between tooth extraction and measurements of the study casts and whether the patients had worn prosthesis. In a more recent study of Lekovic et al. (1997), bone changes of the alveolar ridge height and width after extraction of two or more anterior teeth or premolars in 10 patients were determined by clinical measurements during the extraction procedure and by measurements on models poured from silicone impressions of the exposed sockets. In each patient, one socket was covered with a barrier membrane while the other socket was a control allowed conventional healing. In the control sites, the loss of socket width was greater than the loss of height, and the reduction in height and width was of a similar magnitude as reported in the aforementioned studies. In most of the referred studies, a wide variation was found in the reduction rate and the total amount of reduction, indicating that this phenomenon varies a great deal among individuals.

In the previous studies evaluating the morphologic changes of the alveolar bone following tooth extraction, most of them involve extraction of multiple teeth. The study involving single-tooth extraction has evaluated the changes of the alveolar ridge retrospectively, and only the reduction in width. Furthermore, only few studies have assessed the alveolar changes in patients who did not wear a prosthesis soon after tooth extraction. Because multiple extractions may result in a greater trauma to the alveolar bone than extraction of a single tooth, one should be cautious about applying the results previously reported to cases involving single-tooth extraction. Likewise, it must be pointed out that observations from investigations where the patients wore a denture soon after tooth extraction are inter-dependent, since denture-wearing may advance the loss of alveolar tissue (Devlin & Ferguson 1991, Jahangiri et al. 1998). The gross morphologic changes have been studied in cephalograms whereas none have evaluated the reduction in alveolar bone height following extraction of single teeth by means of linear measurements on intraoral radiographs or by more advanced radiographic methods.
4.3. Preservation of the alveolar ridge after tooth extraction

As described above, the quantity of the alveolar bone may have an influence on the success of implant treatment and if at all it is possible to place implants in the jaws. When RRR already has occurred, several approaches for reconstruction of the alveolar process have been suggested. According to the “gold standard” implant treatment protocol, Brånemark proposed that severely resorbed jaws might be augmented with autogenous bone blocks (Brånemark 1985). Horizontal and vertical bone augmentation of implant sites by means of guided bone regeneration using membranes alone or combined with bone grafts or bone substitutes (Simion 1999), or reconstruction with a bone block or particulated bone without membrane protection (Weingart & Petrin 1999), have resulted in high success rates. However, these augmentation procedures are associated with a prolonged treatment period and increased costs to the patient. Therefore, it would be beneficial to prevent resorption of the alveolar bone after tooth extraction.

Various techniques have been applied to promote or guide bone healing in extraction sites in an attempt to preserve the osseous tissues. To preserve the bone volume, grafting materials in extraction sockets have been used, but with diverging results (Gülalı et al. 1998, Becker et al. 1998b). The principle of guided tissue regeneration has been employed at fresh extraction sites with positive results, either with the use of barrier membranes alone (O'Brien et al. 1994, Lekovic et al. 1997) or in combination with grafting materials (Nevins & Mellonig 1992).

Implant treatment and RRR are interrelated in the sense that the success of implant treatment may be dependent on the degree of alveolar reduction, while insertion of implants following loss of teeth in itself has a bone preserving capacity (von Wowern et al. 1990, Denissen & Kalk 1991, Wheeler et al. 2000). A long-term study showed that submerged hydroxyapatite implants placed immediately after tooth extraction contributed to the maintenance of alveolar ridge volume (Denissen & Kalk 1991). von Wowern et al. (1990) concluded that the presence of loaded implants in the mandible resulted in a reduced loss of bone mass. A clinical report presented a technique combining immediate insertion of stepped-tapered root-analogue implants in extraction sockets with the use of custom healing abutments (Wheeler et al. 2000). It was demonstrated that it was possible to preserve both hard and soft tissue while enhancing the esthetic results by this protocol. These previous studies indicate that early or immediate placement of implants
into extraction sockets is a way of preserving the alveoli and surrounding bony structures, and thereby later reconstruction of the alveolar bone can be avoided.

4.4. Study II

The present study (II) was carried out in order to assess bone formation in the extraction socket and contour changes of the alveolar process following single-tooth extraction. The study differed from previous studies by evaluating healing of the extraction site with the use of a combination of measurements on study casts, linear radiographic measurements, and an advanced radiographic technique (digital subtraction radiography). Furthermore, solely single-tooth extraction sites, which were not exposed to compressing forces from a denture in the healing period (except in two cases), were included.

Forty-six patients referred for single-tooth extraction of a premolar (21) or molar (25) in the maxilla or mandible were enrolled in the study (Table 3).

Table 3. Distribution of extraction sites according to jaw and region

<table>
<thead>
<tr>
<th>REGION</th>
<th>JAW</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maxilla</td>
<td>Mandible</td>
</tr>
<tr>
<td>Premolar</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>Molar</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>26</td>
</tr>
</tbody>
</table>

The selection of the study group is described in detail in Chapter 5.3. Clinical and radiographic evaluation of the extraction site was carried out within a healing period of twelve months.

Casts were prepared from alginate impressions taken immediately after tooth extraction, and at follow-up visits three, six and twelve months after removal of the tooth. The changes in alveolar height over time were determined by measuring the distance from the midpoint of the extraction site - at the most occlusally situated point both buccally (B) and orally (O) - perpendicular to the line connecting the occlusal surfaces of
the adjacent teeth. In addition, the width of the alveolar ridge was measured perpendicular to the tangent of the dental arch at the midpoint of the extraction site as the distance between the most prominent points buccally and orally (Fig. 4).

![Figure 4. Measurements on study casts](image)

Various methods for measuring dimensional changes of the alveolar processes on study casts have been suggested (Carlsson 1966). Many of these are more or less advanced techniques requiring special-purpose apparatuses or instruments. Carlsson (1966) stated some sources of measurement error, such as errors in marking the reference points, errors in orienting the casts, and errors incurred in taking the impressions or making the casts. However, for most of the methods used, the precision and accuracy have not been evaluated or, at best, incompletely reported. Since measuring casts in a large longitudinal study is very time-consuming, a more simple method was employed in Study II. Nevertheless, a high repeatability was found comparing the first and second measurements by means of Wilcoxon matched-pairs Signed Ranks Test (Table 4), except when measuring the alveolar height orally at baseline and the width at baseline and after twelve months. These measurements revealed a systematic error resulting in greater values in the second recording compared with the first one. This indicates that it was difficult to follow the criteria defined for measuring the alveolar width on the casts.
Table 4. Reproducibility test for measurements on study casts

<table>
<thead>
<tr>
<th></th>
<th>1st recording</th>
<th>2nd recording</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buccally</td>
<td>7.3 (6.3/9.6)</td>
<td>7.3 (6.2/9.1)</td>
<td>0.35</td>
</tr>
<tr>
<td>Orally</td>
<td>6.1 (5.2/7.4)</td>
<td>6.3 (5.3/7.4)</td>
<td>0.05</td>
</tr>
<tr>
<td>Width</td>
<td>11.7 (10.6/13.2)</td>
<td>11.9 (10.6/13.5)</td>
<td>0.01</td>
</tr>
<tr>
<td>3 months</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buccally</td>
<td>7.6 (6.7/9.2)</td>
<td>7.4 (6.6/9.4)</td>
<td>0.50</td>
</tr>
<tr>
<td>Orally</td>
<td>7.1 (6.2/8.3)</td>
<td>7.2 (6.2/8.3)</td>
<td>0.19</td>
</tr>
<tr>
<td>Width</td>
<td>7.9 (6.6/9.5)</td>
<td>8.1 (6.8/9.3)</td>
<td>0.26</td>
</tr>
<tr>
<td>6 months</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buccally</td>
<td>7.5 (6.6/8.7)</td>
<td>7.5 (6.5/8.8)</td>
<td>0.69</td>
</tr>
<tr>
<td>Orally</td>
<td>7.0 (6.0/8.2)</td>
<td>7.3 (6.2/8.2)</td>
<td>0.19</td>
</tr>
<tr>
<td>Width</td>
<td>6.8 (5.6/8.1)</td>
<td>6.7 (5.7/7.9)</td>
<td>0.95</td>
</tr>
<tr>
<td>12 months</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buccally</td>
<td>7.2 (6.3/8.2)</td>
<td>7.4 (6.3/8.3)</td>
<td>0.88</td>
</tr>
<tr>
<td>Orally</td>
<td>6.8 (6.1/8.3)</td>
<td>7.1 (6.2/8.2)</td>
<td>0.23</td>
</tr>
<tr>
<td>Width</td>
<td>5.7 (4.9/6.5)</td>
<td>6.0 (5.0/6.5)</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Changes in alveolar bone height from the time of tooth extraction to 12 months after were evaluated by linear radiographic measurements. Reproducible periapical radiographs were obtained just after tooth extraction and at follow-up visits three, six and twelve months after removal of the tooth (see detailed description of the method in Chapter 3.6). All radiographs were digitized by a flatbed scanner for analyses in Studies II and III. Linear measurements of the alveolar bone crest level corresponding to the extraction socket as well as at surfaces of the adjacent teeth mesially and distally to the extraction site (Fig. 5b, c) were performed by means of PorDiosW (PorDiosW, Institute of Orthodontic Computer Sciences, Middelfart, Denmark), a program designed for linear and angular analyses in radiographs (Gotfredsen et al. 1999).
Prior to measuring, a reference line was drawn on the radiograph taken before tooth extraction (Fig. 5a), and then transferred to the images taken just after extraction (Fig. 5b) and twelve months after (Fig. 5c), respectively. Likewise, the contour of the extracted tooth was drawn and transferred between the same images. It is obvious that this procedure may cause some degree of measurement inaccuracy, which among other things is influenced by the number of reference points used and thus the ability to align the images properly. To measure the bone levels in PordiosW, the user marks the bone margins
and the reference line by placing digitally points on the computer screen with the mouse. Since it was expected that also this procedure might be associated with some inaccuracy, a test for reproducibility was performed (Wilcoxon matched-pairs Signed Ranks Test). It was found that the intra-examiner reproducibility of this method was high (Table 5).

Table 5. Reproducibility test for linear radiographic measurements of alveolar bone levels

<table>
<thead>
<tr>
<th></th>
<th>Median (25/75-percentiles)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1&lt;sup&gt;st&lt;/sup&gt; recording</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; recording</td>
</tr>
<tr>
<td><strong>Baseline</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesial tooth</td>
<td>2.4 (1.9/3.4)</td>
<td>2.3 (1.6/3.4)</td>
</tr>
<tr>
<td>Extraction site - mesially</td>
<td>2.9 (2.0/3.9)</td>
<td>3.1 (1.9/3.9)</td>
</tr>
<tr>
<td>Extraction site - distally</td>
<td>3.3 (2.4/5.0)</td>
<td>3.4 (2.4/5.2)</td>
</tr>
<tr>
<td>Distal tooth</td>
<td>3.7 (2.1/4.6)</td>
<td>3.6 (2.2/4.9)</td>
</tr>
<tr>
<td><strong>12 months</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesial tooth</td>
<td>2.7 (1.7/3.9)</td>
<td>2.8 (1.7/3.7)</td>
</tr>
<tr>
<td>Extraction site - mesially</td>
<td>3.4 (2.4/4.5)</td>
<td>3.5 (2.2/4.6)</td>
</tr>
<tr>
<td>Extraction site - centrally</td>
<td>5.0 (3.8/6.1)</td>
<td>5.0 (3.8/6.3)</td>
</tr>
<tr>
<td>Extraction site - distally</td>
<td>3.9 (2.7/5.0)</td>
<td>3.9 (2.7/5.2)</td>
</tr>
<tr>
<td>Distal tooth</td>
<td>3.3 (2.7/4.4)</td>
<td>3.3 (2.4/4.5)</td>
</tr>
</tbody>
</table>

As stated earlier, it must be emphasized that some degree of magnification is inevitable despite the fact that the intraoral radiographs were standardized. In some cases, difficulties in placing the bite-index correctly in the mouth at all visits arose. Therefore, the measurements are approximated and not “real-size”. However, it is believed that this measurement error is of no clinical significance.

In the present study, subtraction radiography was introduced as a new method for assessing morphologic changes and bone formation and remodeling of extraction sites during the healing period. Subtraction radiography is a well-established method for detection of subtle bone changes in serial radiographs. The technique was introduced in the 1930s and has been applied to several diagnostic tasks within dental research, for instance detection of lesions in teeth (dental caries, root resorption) (Hintze et al. 1992, Wenzel & Halse 1992), healing effect after periodontal treatment (Wenzel et al. 1992, Jeffcoat 1992b, Christgau et al. 1996), follow-up assessment after implant treatment (Reddy et al. 1990, Brägger et al. 1991, Reddy et al. 1992, Jeffcoat et al. 1992, Jeffcoat
During the years, different subtraction systems have been developed, from photographic subtraction to digital subtraction, either manually operated or by the use of more advanced automated systems (Lehmann et al. 2000). In several reports, subtraction radiography has been evaluated in terms of technical facilities and diagnostic effectiveness for estimation and interpretation of bone mass changes (Jensen et al. 1998, Loftin et al. 1998, Christgau et al. 1998a, 1998b). However, healing of the extraction socket and changes of the alveolar process following extraction of teeth have not been evaluated by means of subtraction radiography in previous studies.

In the present study, a semi-automated subtraction program, X-PoseIt (Ver. 3.01, Torben Jørgensen, Lystrup, Denmark) was used. Basically, in digital subtraction radiography, a computer program analyses the gray shade values in two radiographs to be compared. Following alignment of these images, the gray shade value of each pixel in one image (Fig. 6a) is subtracted from the corresponding pixel-value in the other image (Fig. 6b), resulting in the subtraction image (Fig. 6c, d) that represents the differences in gray shades between the two radiographs. The differences in gray shades may be interpreted as differences in bone mineral content. By definition, all pixels in a perfect subtraction image of a site without bone changes would have a mean gray level of 128 when the program operates with a dynamic range of 256 gray shades. However, in order to determine whether gray shade values smaller or larger than 128 in a region of interest (ROI) (Fig. 6) are due to differences in the recording and processing of the radiographs (noise) or actually are due to biological changes, these gray shade values should be related to the mean gray value in a region of control (ROC) (Fig. 6), which is expected not to be involved in bone changes. For that purpose, thresholds for the pixel values must be defined in order to take the physical noise of the method into account (Wenzel & Sewerin 1991). The “noise” in the subtraction image is expressed by the standard deviation of the histogram distribution of the pixels in the ROC. In this study, gray shade values in the ROI larger or smaller than the mean gray value of the ROC plus/minus the standard deviation multiplied by a factor of 2 was regarded as a change in bone mineral content. After performing the subtraction procedure with different SD values in 10% of the material, it was found that this factor of 2 yielded the best resulting subtraction image.
Despite the fact that subtraction radiography has been recommended for detection of minor bone changes in radiographs, one must be aware of the weaknesses associated with this technique. In Study II, 11 patients were excluded from the image analysis; in 3 of these, it was not possible to define a sufficient number of reference points, while in 8,
poor agreement between pre-subtraction evaluation of the radiographs and the resulting subtraction images of these patients was found. Among the latter cases, the unexpected results of the subtraction procedure may be explained by problems with alignment of the radiographs due to difference in projection geometry. In a study (Aagaard et al. 1991), it was found that 10-15 reference points defined in the two radiographs intended for subtraction were optimal for correction of geometric differences between the images. In this study, however, it was possible to mark only 4 to 9 reference points in each image (Fig. 6a, b).

Another limitation of subtraction radiography when analyzing changes of a defect is that the visualization depends on the bucco-oral width of this defect. For example, total bone fill with uniform density in a cone-shaped defect like an extraction socket may be visualized only in the coronal part because the alveolus makes up a larger fraction of the total width of the alveolar bone in the coronal part as compared with the apical part. Likewise, one must bear in mind that the subtraction image is a product of remodeling of the bone walls buccally and orally to the socket on one hand and bone formation/resorption within the socket on the other, and obviously, it is not possible to distinguish these biological phenomena. However, these limitations are not related to subtraction radiography in itself, but rather related to the two-dimensional nature of radiography in general.

Despite the above disadvantages, subtraction radiography may be beneficial for assessment of bone changes in serial radiographs, since the technique, in contrast to histological investigations, is applicable to humans.

The results of Study II showed that the width of the alveolar ridge was reduced to 50% during the observation period of 12 months. Approximately 2/3 of this reduction occurred within the first 3 months after tooth extraction. Only slight changes in soft tissue height took place in both jaws during the 12 months of healing. The data concerning width reduction was in agreement with the early studies (Lam 1960, Johnson 1963, 1969), which on the other hand reported a greater amount of height reduction compared with the present study. This discrepancy may be explained by the fact that these studies involved multiple tooth extractions that may be expected to cause a greater trauma to the alveolar bone. In an early study (Lisowski 1945), it was concluded that the alveolar
resorption was aggravated proportionately to the extent of surgery. This was confirmed by Gazabatt et al. (1965) who demonstrated that more resorption took place when the tooth extraction procedure was followed by labial alveolectomy compared with intraseptal alveolotomy. Moreover, in one of the older studies (Lam 1960), the patients (n=3) examined received a removable partial denture immediately after removal of the teeth whereas in Study II, no patients except two wore a prosthesis in the 12-month healing period.

The results further showed that the extraction alveoli healed almost completely with bone after 12 months. By means of linear radiographic measurements, it was found that the bone level mesially and distally to the extraction site after healing was situated less than \( \frac{1}{2} \) mm more apically than at baseline. Between the mesial and distal point of the extraction site, the alveolar crest became curved with the “lowest” point situated approximately 1 mm more apically to these two points.

By subtraction radiography, it was demonstrated that a great amount of bone formation, bone loss as well as remodeling occurred within the first year after tooth extraction. The greatest amount of bone generation and loss of crestal bone height took place during the first 3 months. The latter observation was in agreement with the measurements on the study casts. Furthermore, the findings of the subtraction analysis agreed very well with the linear radiographic data when studying the bone changes of the alveolar crest. In conclusion, the present study confirms the results of other studies that subtraction radiography, as a non-invasive method could be an alternative to histologic techniques for assessment of changes in the mineral content of bone if periodic identical radiographs are obtained.

Based on the results of Study II, it can be concluded that a major reduction of the width of the alveolar ridge occurs during the first 3 months after tooth extraction, while only little change occurs in height. Furthermore, a great amount of bone formation, bone loss and remodeling occurs within the first year after tooth extraction. The bone level of the extracted tooth rather than the bone level of the adjacent teeth dictates the level to which the bone crest heals after extraction.
5. IMMEDIATE VS. DELAYED IMPLANT PLACEMENT

5.1. Classification – immediate, delayed, and late implant placement
The timing of implant placement following tooth extraction has been a matter of discussion in dental implant treatment. A waiting period of 12 months or longer to allow socket healing has been the “gold standard” protocol (Brånemark 1985). Various alternatives to this approach may be considered in order to reduce the treatment/waiting time. In the literature, there is some confusion about definitions and terminology on the time of implant placement after tooth extraction. Different terms have been used, such as: immediate, delayed-immediate, delayed, short-term delayed, long-term delayed, and late placement. A classification has been suggested by Mayfield (1999): a) implantation into the fresh extraction socket at the time of tooth extraction is termed immediate implant placement, b) implantation from six to ten weeks after tooth extraction is termed delayed implant placement, and c) late implant placement is defined as implantation six months or longer after tooth extraction and thereby the procedure, which best corresponds to the “gold standard” protocol. However, as it appears, this classification is not exhaustive, which means that not all time points for implant insertion are covered. Nevertheless, the above terms are used in the following description of implant studies and when divergences from these occur, it will be stated.

None of the treatment concepts regarding time of implant insertion is superior in every respect, and the advantages and disadvantages related to each of them have been discussed (Lazzara 1989, Barzilay 1993, Schwartz-Arad & Chaushu 1997, Klokkevold et al. 1999).

Late implant placement allows adequate time for osseous and soft tissue healing. A healing period of at least six months most often results in the implant surface being totally embedded in bone immediately after insertion. However, the alveolar bone may become resorbed to such an extent that preceding bone augmentation procedures are required to be able to place implants of a proper size and in a favorable position. Additionally, this concept is adverse to the patient because of a prolonged waiting period following tooth extraction and further surgical interventions.

Delayed implant placement allows time for resolution of preexisting infections at the extraction site. This technique also allows for soft tissue healing and closure of the
extraction site, and hence the use of mucosal grafts or muco-gingival flap advancement can be avoided. This may be desirable from an esthetical point of view as well as improve the periodontal conditions around the final restoration.

Even though delayed implantation reduces the treatment time compared with late implant placement, it would be advantageous to further shorten the edentulous time period. This can be achieved by immediate implant placement, which in addition requires fewer surgical interventions. Unfortunately, various disadvantages are associated with this treatment concept. It has been stated that infection associated with an extracted tooth contraindicates immediate implant insertion (Mayfield 1999). Some studies have on the other hand demonstrated successful treatment outcomes related to immediate implantation at chronically infected extraction sites (Novaes Junior & Novaes 1995, Pecora et al. 1996, Novaes Junior et al. 1998). Furthermore, placement of an implant in a fresh extraction socket often implies that the entire implant surface does not engage the bone walls of the coronal part of the alveolus, unless root-analogues are used. Therefore, in order to achieve primary stability, it is often necessary to place the implant 3-5 mm beyond the apex of the extraction alveolus. If alveolar bone height is inadequate, this procedure may complicate implant placement, e.g. necessitate sinus floor elevation or transposition of the alveolar inferior nerve to minimize the risk of compromising these vital anatomical structures. Another drawback of the immediate technique is that the muco-gingival conditions just after tooth extraction may be unfavorable for primary flap closure. However, the immediate technique no doubt is convenient to the patient and also possesses biological as well as prosthetic advantages. One advantage is that normal bone healing within the extraction alveolus takes effect around the implant. Studies have demonstrated that this may lead to preservation of alveolar bone height and width (Denissen & Kalk 1991, Wheeler et al. 2000) and furthermore, it may enhance the bone-to-implant contact. The benefits of preserving alveolar bone volume in relation to implant placement have been discussed in the previous chapter. Provided that the extracted tooth has a proper alignment, immediate implantation may facilitate placement of the fixture in an ideal axial position, thus enhancing fabrication, esthetics, and biomechanics of the subsequent restoration (Werbitt & Goldberg 1992).

Immediate, delayed and late implant placement can be applied both in association with submerged and non-submerged (=transmucosal) implants. By the submerged
mode, the implant is covered with mucosa during the healing phase, whereas the non-submerged protocol implies that the implant penetrates the mucosa immediately after placement. In the present thesis, the focus is put on submerged immediate implants.

5.2. Studies on immediate implant placement

Implants primarily designed for immediate replacement of a tooth are available. These can be pre-fabricated root-analogues, usually made of a ceramic material (Quayle et al. 1989). However, implants of the cylindrical type are more commonly used, and these have been evaluated in several previous animal studies (Becker et al. 1991, Gotfredsen et al. 1993, Parr et al. 1993, Cellett et al. 1994, Becker et al. 1995, Mao et al. 1997, Schliephake & Kracht 1997, Karabuda et al. 1999), case reports (Marcus & Dzyak 1990, Evian & Cutler 1994, Wilson, Jr. et al. 1998), and clinical studies (Pecora et al. 1996, Becker et al. 1998a, Grunder et al. 1999, Polizzi et al. 2000). Histological findings in animal studies have shown that osseointegration of immediately placed implants into extraction sockets can be achieved (Barzilay et al. 1991, Warrer et al. 1991).

Barzilay et al. (1996a) demonstrated similar conditions for immediate and late implants in monkeys evaluated histologically in terms of osseointegration and bone stability. Furthermore, case reports and clinical studies have revealed a high rate of survival associated with immediate implant placement ranging from 94% to 100% (Schwartz-Arad & Chaushu 1997).

As stated above, there is frequently incongruence between the walls of the extraction socket and the coronal part of the fixture resulting in localized peri-implant bone defects when inserting screw- or cylinder-type implants immediately after tooth extraction. To fill this empty space, bone reconstructive techniques such as the use of various graft materials and guided tissue regeneration (GTR) have been suggested and used in most previous studies with high success rates (Schwartz-Arad & Chaushu 1997, Mayfield 1999). The rationale for placing a barrier membrane is to create a space adjacent to the implant allowing osteogenic cells to migrate in the coronal direction, and at the same time to prevent apical proliferation of epithelium which is a prerequisite for bone formation in peri-implant defects (Karring et al. 1997). In combination with GTR, one purpose of bone grafts or bone substitute materials is to act as support for the membrane and thereby prevent a collapse that otherwise may compromise maintenance of
the space between implant and membrane. Moreover, graft materials serve as a scaffold for ingrowth of capillaries and bone forming cells. Other types of defects, which may occur as a consequence of immediate implant insertion into fresh extraction sockets, are dehiscences and fenestrations. These defects are characterized by exposure of part of the implant surface, and similarly at infrabony peri-implant defects, bone reconstructive techniques may be considered in order to promote bone formation at dehiscences and fenestrations. Fugazzotto et al. (1997) reported a success rate of 97% when treating dehiscences and fenestrations at immediately inserted implants by barrier membranes and graft materials. Likewise, another study demonstrated good short-term clinical results of delayed-immediate implants (placed 5 to 7 weeks post-extraction) with buccal dehiscence-type defects treated with guided bone regeneration procedures using bovine bone mineral and resorbable collagen membranes (Nemcovsky et al. 2000).

Since the introduction of mineralized and demineralized bone particles for obtaining bone augmentation around immediately inserted implants (Todescan, Jr. et al. 1987) and the use of ePTFE membranes in conjunction with immediate implant placement (Lazzara 1989), a wide range of membrane and grafting materials has been developed. Several experimental animal studies and clinical studies have been carried out in order to evaluate the effectiveness of various procedures involving these materials on bone formation (Schwartz-Arad & Chaushu 1997). In Table 6, above the touched-up line, previous studies comparing immediate placement of submerged implants with and without the use of bone reconstructive techniques are displayed. Studies involving biologically active bone-inductive substances, root-analogue implants, and simulated (artificially created) extraction sockets are excluded.

Although previous studies have demonstrated high success rates of immediate implantation into extraction sockets in combination with bone reconstructive techniques, it was concluded in a review of the literature: “There is no consensus regarding the need for gap filling and the best grafting material”, and: “The use of membranes does not imply better results; on the contrary, membrane exposure may lead to adverse complications” (Schwartz-Arad & Chaushu 1997). In a second review, Mayfield (1999) concluded: “There is no consensus regarding the ideal graft material for use in conjunction with immediate implant placement.”
Table 6. Previous studies on immediate placement of dental implants

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Sample (impl.)</th>
<th>Design</th>
<th>Controls†</th>
<th>Follow-up period</th>
<th>Evaluation parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Becker et al.</td>
<td>1991</td>
<td>12</td>
<td>Animal</td>
<td>No</td>
<td>18 weeks</td>
<td>Clinical and histology</td>
</tr>
<tr>
<td>Warrer et al.</td>
<td>1991</td>
<td>14</td>
<td>Animal</td>
<td>No</td>
<td>3 months</td>
<td>Histology</td>
</tr>
<tr>
<td>Gottfredsen et al.</td>
<td>1993</td>
<td>32</td>
<td>Animal</td>
<td>No</td>
<td>2-12 weeks</td>
<td>Histology</td>
</tr>
<tr>
<td>Celletti et al.</td>
<td>1994</td>
<td>16</td>
<td>Animal</td>
<td>No</td>
<td>14 weeks</td>
<td>Clinical and histology</td>
</tr>
<tr>
<td>Becker et al.</td>
<td>1995</td>
<td>12</td>
<td>Animal</td>
<td>No</td>
<td>12 weeks</td>
<td>Clinical and histology</td>
</tr>
<tr>
<td>Pecora et al.</td>
<td>1996</td>
<td>32</td>
<td>Human / prospective</td>
<td>No</td>
<td>22 months</td>
<td>Clinical and radiography</td>
</tr>
<tr>
<td>Mao et al.</td>
<td>1997</td>
<td>18</td>
<td>Animal</td>
<td>No</td>
<td>14 weeks</td>
<td>Clinical and histology</td>
</tr>
<tr>
<td>Schliephake &amp; Kracht</td>
<td>1997</td>
<td>60</td>
<td>Animal</td>
<td>No</td>
<td>3-5 months</td>
<td>Histology</td>
</tr>
<tr>
<td>Wilson et al.</td>
<td>1998</td>
<td>5</td>
<td>Human / case report</td>
<td>Yes (1)</td>
<td>6 months</td>
<td>Histology</td>
</tr>
<tr>
<td>Grunder et al. /</td>
<td>1999 /</td>
<td>264</td>
<td>Human / prospective</td>
<td>No**</td>
<td>3 years / 5 years</td>
<td>Clinical and radiography</td>
</tr>
<tr>
<td>Polizzi et al.</td>
<td>2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marcus &amp; Dzyak</td>
<td>1990</td>
<td>2</td>
<td>Human / case report</td>
<td>No</td>
<td>Up to time for restoration</td>
<td>Function and esthetics of restoration</td>
</tr>
<tr>
<td>Barzilay et al.</td>
<td>1991</td>
<td>1</td>
<td>Animal / pilot study</td>
<td>No</td>
<td>12 months</td>
<td>Histology, clinical and radiography</td>
</tr>
<tr>
<td>Parr et al.</td>
<td>1993</td>
<td>13</td>
<td>Animal</td>
<td>No</td>
<td>5 months</td>
<td>Histology</td>
</tr>
<tr>
<td>Evian &amp; Cutler</td>
<td>1994</td>
<td>4</td>
<td>Human / case report</td>
<td>No</td>
<td>24 months</td>
<td>Survival rates</td>
</tr>
<tr>
<td>Barzilay et al.</td>
<td>1996</td>
<td>48</td>
<td>Animal / split-mouth</td>
<td>Yes (12)</td>
<td>13 months</td>
<td>Histology, clinical and radiography</td>
</tr>
<tr>
<td>Rosenquist &amp; Grenthe*</td>
<td>1996</td>
<td>109</td>
<td>Human / case series</td>
<td>No</td>
<td>Mean of 30.5 months</td>
<td>Survival rates, clinical</td>
</tr>
<tr>
<td>Novaes et al.</td>
<td>1998</td>
<td>28</td>
<td>Animal / prospective</td>
<td>No</td>
<td>12 weeks</td>
<td>Histology, clinical and radiography</td>
</tr>
<tr>
<td>Becker et al.</td>
<td>1998</td>
<td>134</td>
<td>Human / prospective</td>
<td>No</td>
<td>Up to 8 years (1 impl.)</td>
<td>Survival rates, radiography</td>
</tr>
<tr>
<td>Karabuda et al.</td>
<td>1999</td>
<td>4</td>
<td>Animal / pilot study</td>
<td>No</td>
<td>8 weeks</td>
<td>Histology</td>
</tr>
<tr>
<td>Schultes &amp; Gaggl</td>
<td>2001</td>
<td>16</td>
<td>Animal / prospective</td>
<td>Yes (8)</td>
<td>8 months</td>
<td>Histology</td>
</tr>
<tr>
<td>Schropp et al. (Study III)</td>
<td>2001</td>
<td>46</td>
<td>Human / randomized</td>
<td>Yes (23)</td>
<td>3 months</td>
<td>Clinical and radiography</td>
</tr>
</tbody>
</table>

# Controls ~ delayed/late implants
* ePTFE membranes used in five cases
** Comparison between immediate and delayed-immediate (placed 3-5 weeks after tooth extraction) implants
In Table 6, below the touched-up line, previous studies on immediate placement of submerged implants with the use of neither membranes nor graft materials are displayed. In animal studies (Barzilay et al. 1996a, 1996b) comparing immediate implants and implants placed in healed extraction sites (six months of healing following tooth extraction), histological observations revealed no significant differences with regard to osseointegration and bone stability around the implants. Furthermore, no statistically significant differences were found when evaluating the implants clinically. However, more marginal bone loss was detected radiographically associated with late implant insertion than with immediately inserted implants. The results of these studies were confirmed in a recent histological study comparing immediate and delayed placement of implants after tooth extraction in eight beagle dogs (Schultes & Gaggl 2001). It must be noted that delayed implant placement in that study means that the extraction sites had healed six months before implant insertion. It was concluded that the differences between immediate and delayed implants were minimal. However, formation of a long soft tissue attachment in the cervical region of immediate implants as a result of early bone resorption in the crestal part of the alveolar bone was reported.

Although experimental animal studies have demonstrated that osseointegration can be obtained of immediately inserted implants in fresh extraction sockets even without the use of grafts or membranes, this treatment concept may not be directly applicable to the human situation. Case reports have indicated that immediate implant placement could be a successful treatment also in man (Marcus & Dzyak 1990, Evian & Cutler 1994). Survival rates of 93% or higher have been reported involving from 41 to 303 immediate titanium implants in three studies in humans (Parel & Triplett 1990, Tolman & Keller 1991, Krump & Barnett 1991). Bone reconstructive techniques were not used in any of these investigations, but implantation was performed following either alveolectomy or alveoloplasty implying that the implants were placed in a recipient site resembling the bone of a healed extraction site (alveolar bone was either removed to a level corresponding to the bottom of the extraction sockets or to a level ensuring bone contact of the entire superior circumference of the implant after insertion and thereby avoiding presence of gaps between the implant surface and the walls of the socket). Therefore, findings from these investigations are not completely comparable with findings in investigations on insertion of implants in fresh extraction sites. In a study aiming
at determining implant survival of immediately placed implants following tooth extrac-
tion, a 93.6% success rate of 109 Nobelpharma implants (Nobelpharma AB, Göteborg,
Sweden) in 51 patients was reported (Rosenquist & Grenthe 1996). The follow-up peri-
od ranged between one and 67 months with a mean of 30.5 months. No grafting proce-
dures were carried out in this study, and in only five cases were membranes used for
bone augmentation. At abutment operation, total remodeling of the extraction socket
had occurred in all implant sites and in most of the patients, the marginal bone was at
the level of the cover screw. The implant screws were partially covered by bone in 18
patients and totally covered in five patients. The authors concluded: “…immediate
placement of implants into extraction sockets without grafts or membranes seems to be
a safe and predictable method.” It was, however, stated that one disadvantage of the
immediate technique may be that the keratinized gingiva often is displaced in the at-
tempt to cover the extraction site by the muco-gingival flap, which may result in unfa-
vorable functional and esthetic conditions. In a prospective clinical study (Becker et al.
1998a), excellent long-term success rates of immediately placed implants were obtained
without the use of membranes or grafts for bone augmentation. One hundred thirty-four
implants were inserted in 81 patients. Forty-seven implants were followed for four to
five years with a cumulative success rate of 93.3%. The marginal bone level of 108 im-
plants was evaluated in non-standardized periapical radiographs. The average mesial-
distal bone level changes over a mean of 31.4 months of loading amounted to 0.3 mm in
the maxilla and 0.5 mm in the mandible. The authors stated that this bone loss was less
than they had previously reported for immediately placed implants augmented with bar-
rier membranes (Becker et al. 1994).

Similar to submerged implants, transmucosal one-stage implants may be placed in
fresh extraction sockets. Several studies have revealed that good results can be obtained
when combining immediate transmucosal implants and the use of guided bone regenera-
tion (Mayfield 1999). Furthermore, it has been demonstrated that there were no differ-
ences in clinical parameters when comparing transmucosal implants placed in healed
extraction sockets with immediate transmucosal implants with or without the use of
membranes/graft materials (Brägger et al. 1996).

As it appears from the above, knowledge about immediate implant treatment with-
out the use of bone reconstructive techniques is mainly based on animal studies and
case reports. No previous randomized, controlled investigations in humans have been conducted in order to directly compare the outcome of immediately placed implants into extraction sockets with that of delayed or late placement of implants, disregarding studies where bone augmentation procedures have been used.

5.3. Study III

The present study (III) was performed in order to compare bone healing and crestal bone changes following immediate versus delayed insertion of submerged implants in extraction sockets.

Below, a detailed description of the patients enrolled in Studies I, II and III is given. The sample size in Study III was based on a power calculation, which indicated that 26 patients in each group should be included in order to be able to find a statistically significant difference in bone defect reduction of one mm or more between the two groups:

\[
N = \frac{2 \cdot \sigma^2}{(\mu_1 - \mu_2)^2} \cdot f(a, b) = \frac{2 \cdot 1^2}{(4 - 3)^2} \cdot f(0.05, 0.05) = 2 \cdot 13 = 26
\]

\((N = \text{number of patients in each group; } \sigma = \text{standard deviation for the response; } \mu_1 = \text{expected value of the defect reduction in the immediate group; } \mu_2 = \text{expected value of the defect reduction in the delayed group; } a, b = \text{sum of type 1 and type 2 errors}).\)

Patients referred for tooth extraction and subsequent single-tooth implant treatment at the incisor, canine, and premolar regions of the maxilla or the mandible were allocated to either the immediate group (IM), the delayed group (DE) (Study III), or the group of patients waiting 12 months of healing after tooth extraction (HE; Study II). Patients referred for replacement of a molar were likewise included in Study II, and a total of 52 patients (26 premolars and 26 molars) was planned to be included in this study. The reason for not including patients in Study III, who were to have a molar extracted, was that immediate insertion of an implant into a fresh socket following extraction of a molar was expected to lead to large peri-implant defects. It was thought to be desirable at first to evaluate spontaneous healing of peri-implant defects after placement of implants in smaller extraction sockets before challenging molar sites.

An even distribution of patients referred for replacement of an incisor, a canine or premolar in the three groups was ensured by performing a closed randomization: Pa-
tients intended for extraction of a incisor or canine drew a card from an envelope containing 26 cards marked IM and 26 cards marked DE. A second envelope containing 26 IM cards, 26 DE cards and 26 HE cards was used for the patients referred for extraction of a premolar. When an IM or a DE card was drawn from one of the envelopes, the corresponding card was removed from the other envelope.

Originally, it was the intention to solely include patients who were screened for single-tooth implant treatment at the Royal Dental College, University of Aarhus, Denmark. However, it soon appeared that it was rather difficult to recruit enough patients suitable for the studies, and other initiatives were needed to supply the study material with more patients. Therefore, by advertising in “Plus 5”, a paper for members of the local division of the Danish Dental Association, we requested dentists in private practice to refer implant patients to the project (Appendix 2). 32 patients were referred to the studies by general dental practitioners.

Nevertheless, at the end of the time period scheduled for patient selection, only 47 patients (26 females, 21 males) had been included in the study (III). Twenty-three patients were randomly allocated to the immediate group and twenty-four to the delayed group. The patients in Study III also participated in Study I. They were given oral and written information regarding the study, and their written informed consent was obtained (Appendix 1). The investigation was approved by the Danish Committee for Clinical Research Ethics as being in accordance with the Helsinki Declaration II.

A total of 46 Osseotite® implants (3i Implant Innovations, Palm Beach, FL, USA) were inserted - one implant per patient – since in one patient in the delayed group, it appeared at surgery that implant placement was not possible due to a large bone defect at the recipient site. The distribution of the implant sites in the Im and De group is displayed in Table 7.
Table 7. Distribution of implant recipient sites according to jaw and region

<table>
<thead>
<tr>
<th>Immediate placement</th>
<th>REGION</th>
<th>JAW</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Front</td>
<td>Maxilla</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mandible</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Premolar</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mandible</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>23</td>
</tr>
</tbody>
</table>

| Delayed placement   | Front  | Maxilla | 10    |
|                     |        | Mandible| 1     |
|                     | Premolar|         | 7     |
|                     |        | Mandible| 5     |
|                     | Total  |         | 17    |
|                     |        |         | 6     |
|                     |        | Total   | 23    |

Due to the fact that the study was underpowered according to the power calculation, there was an obvious risk for not detecting a significant difference between the two groups if the differences in defect reduction were small. However, it appeared not to be a major problem since a difference in defect reduction between the immediate and delayed group of approximately one mm actually was found.

In the present study (III), immediate implant placement implied that the implants were inserted from three days and up to two weeks after tooth extraction, while placement of implants approximately three months after tooth extraction was defined as delayed implant placement (Fig. 7).

Figure 7. Distribution of the time for implant placement after tooth extraction

---

49
There were two reasons for modifying the immediate technique by deferring the time of implant insertion. Since a radiographic examination including tomography should be performed in all patients after extraction of the tooth and before the implant placement surgery (Study I), for practical reasons, it was not possible to carry out the tooth extraction and the implant insertion on the same day. Another reason was to reduce the possible risk of complications caused by pre-existing infections at the recipient site, and thereby allowing inclusion also of patients with non-healed root fractures and periapical lesions (10 patients).

Before surgery, patients were anesthetized with an appropriate local anesthetic. To preserve the alveolar bone, the tooth was extracted as atraumatically as possible with an extraction forceps after luxation with an elevator, and the socket was debrided with curettes. In some situations, it was necessary to elevate a muco-periosteal flap for removal of the tooth to further reduce the trauma.

The implant placement was performed at a second operation. The patients were given Amoxicillin tablets 750 mg and Naproxen tablets 500 mg one hour before surgery and the medication was continued for 5 days. Furthermore, the patients rinsed the mouth with chlorhexidine digluconate 0.1% solution for 1 minute twice a day for 14 days following implant surgery. Following local anesthesia, a crestal incision connected with two vertical releasing incisions mesially and distally to the extraction site was performed, and the muco-periosteal flap was elevated. Meticulous degranulation of the socket/remaining alveolar defect was done prior to the preparation of the implant site. The sequence of drilling was initiated by a round bur and followed by twist drills with a diameter corresponding to the suggested implant width. The appropriate implant dimensions were determined on the basis of pre-surgical radiographs (Study I) and a clinical evaluation of the recipient site at surgery. In the immediate cases, the preparation was usually done along the palatal or lingual aspects of the extraction socket to ensure a proper alignment of the implant restoration. The implant was placed in such a way that the cover screw corresponded to the level of the adjacent bone, and primary stabilization was provided. Countersinking was performed where it was assessed to be necessary. For ethical reasons, autogenous bone chips harvested from the adjacent bone were grafted to any exposed implant threads in cases of dehiscences present in the delayed group. In both groups, it was, in some of the cases, necessary to perform an intra-
alveolar sinus floor elevation to be able to insert an implant with a sufficient length. Primary closure of the wound was achieved with 5-0 silk sutures, and following a periosteal incision of the buccal flap.

Approximately three months after implant placement, an abutment installation surgery was conducted. Following local anesthesia, a crestal incision at the implant recipient site connected with two vertical releasing incisions was performed, and the mucoperiosteal flap was raised. A one-piece EP® Healing Abutment (3i Implant Innovations, Palm Beach, FL, USA) was connected to the fixture, except in a few cases where a two-piece component was used because of loosening of the former type. The mucoperiosteal flap was sutured with 5-0 silk sutures. In cases of dehiscences or fenestrations, autogenous bone chips were grafted to the defects.

According to the “gold standard” protocol, insertion of an implant necessitates a muco-gingival flap elevation procedure. A novel surgical protocol (Landsberg & Bichacho 1998, 1999) has been suggested that makes use of a mucosal tissue punch technique, which means that flap elevation can be avoided. This method was intended for the one-stage as well as the two-stage approach. Also for immediate implant placement, a procedure without incisions may be favorable (Schwartz-Arad & Chaushu 1998). In this study, however, the flap elevation procedure was used in conjunction with both operations in order to be able to measure the dimensions of the peri-implant defects immediately after implant placement and at abutment installation surgery.

The dimensions of the marginal peri-implant bone defects at the mesial, distal, buccal and oral site of each implant were measured at the fixture operation and at the abutment installation surgery by means of a periodontal probe: 1) the horizontal width of the defect parallel to the implant (PaW), 2) the horizontal width of the defect from the bone crest to the implant surface in a direction perpendicular to the long axis of the implant (PpW), and 3) the vertical defect depth measured from the implant-abutment joint and apically to the bone-to-implant contact (VD) (Fig. 8).
The validity of the measurements was considered to be high, since the same examiner made the recordings in all patients, and moreover direct access for inspection of the defects was provided at both operations.

One of the success criteria used to evaluate implants is to measure marginal bone levels radiographically at follow-up visits. In Study III, a computer program, PorDiosW (Gotfredsen et al. 1999), was used for evaluation of the crestal bone levels mesially and distally to the implants in periapical radiographs taken just after implant insertion and three months after at the abutment operation (see description of the radiographic technique and the program in chapters 3.6 and 4.4). The distance from the shoulder of the implant (implant-abutment joint level) to the first visible bone-to-implant contact was determined by linear measurements (Fig. 9a, b). In addition, the length of the implant was measured in order to determine the magnification factor in the radiograph. The measurements of the bone levels were then adjusted according to the magnification.
Figure 9. Linear radiographic measurements of bone levels mesially and distally to the implant

It was found by means of Wilcoxon matched-pairs Signed Ranks Test that the repeatability of the method (PorDiosW) used in this study was high (Table 8).

<table>
<thead>
<tr>
<th></th>
<th>Median (25/75-percentiles)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st recording</td>
<td>2nd recording</td>
</tr>
<tr>
<td><strong>At implant surgery</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesially to implant</td>
<td>0.1 (0.1/0.2)</td>
<td>0.1 (0.0/0.7)</td>
</tr>
<tr>
<td>Distally to implant</td>
<td>0.1 (0.1/0.3)</td>
<td>0.1 (0.1/0.8)</td>
</tr>
<tr>
<td>Implant length</td>
<td>14.7 (12.6/17.0)</td>
<td>14.9 (12.7/16.9)</td>
</tr>
<tr>
<td><strong>At abutment surgery</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesially to implant</td>
<td>0.1 (0.1/0.6)</td>
<td>0.1 (0.0/0.3)</td>
</tr>
<tr>
<td>Distally to implant</td>
<td>0.1 (0.1/0.7)</td>
<td>0.1 (0.1/0.7)</td>
</tr>
<tr>
<td>Implant length</td>
<td>14.1 (12.1/16.7)</td>
<td>14.2 (12.3/16.6)</td>
</tr>
</tbody>
</table>

However, in spite of the fact that efforts were made to obtain standardized periapical radiographs, it was revealed that the agreement between the clinical and radiographic recordings of the defect depth mesially and distally to the implant immediately after implant placement was poor. In contrast, the defect depth measured clinically and radiographically three months later at the abutment operation agreed very well. Previous animal studies have demonstrated significant correlations between linear radiographic and histologic assessments of peri-implant bone levels at six months (Hermann et al. 2001) and 18 months (Isidor 1997a) after implant insertion. Our findings indicate that radio-
graphic detection of peri-implant bone defects immediately after placement into fresh extraction sockets may be subjected to some uncertainty, which could be due to the morphology of these defects. Most of the interproximal defects were of the infrabony type with a mean perpendicular width of only 1.5 mm. The width was measured clinically at the most coronal part of the defect, and it is quite usual that the defects become narrower towards their apical part. Furthermore, due to the two-dimensional nature of radiographs, it may be expected that defects with a small bucco-lingual width in some cases will be masked when surrounded by a buccal and/or oral bone wall.

The results of Study III showed that significant bone formation occurred in 3-wall infrabony defects around immediately placed implants during a 3-month healing period (Fig. 10). A 72% reduction of the depth for this type of defects was found. Although the immediate implants were associated with a higher frequency of wide and deep defects just after insertion compared with the delayed implants, no significant difference existed between the groups following three months of healing. 3-wall infrabony defects with a parallel width of up to 5 mm, a perpendicular width of up to 2 mm, and a depth of maximum 4 mm healed totally in 70% of the cases.

Analysis of the dehiscence-type defects revealed that reduction of the defect dimensions was much smaller than for the 3-wall infrabony defects. During the healing period, the depth was reduced with only 28%.

In conclusion, the present study demonstrated that substantial amounts of bone were generated in 3-wall infrabony defects within a 3-month healing period after placement of titanium dental implants with this type of acid etched surfaces into fresh extraction sockets. In contrast, dehiscence-type defects had poor capacity of spontaneous healing. It must be emphasized that no bone reconstructive techniques, such as the use of barrier membranes, graft materials or both, were applied in this study.

Even though the results of this study have shown that successful treatment outcomes could be achieved in conjunction with immediate implant placement, it is of course important to point out that the patients were evaluated for only three months. Since long-term survival of the implants is definitely of more significance for the patients, these will be evaluated at future visits.
Based on the results of Study III, it can be concluded that bone healing and crestal bone changes following immediate versus delayed placement of submerged implants into extraction sockets were comparable evaluated three months after insertion. Significant bone formation occurs during a 3-month healing period in 3-wall infrabony defects associated with immediately placed Osseotite® implants into extraction sockets whereas peri-implant dehiscence-type defects had poor capacity of spontaneous healing.
Figure 10. Case of immediate implant placement

Recipient site at implant placement surgery

Immediately after implant insertion

At abutment installation surgery

One week after placement of final restoration
6. CONCLUSIONS

Study I:

- The use of cross-sectional tomograms gives rise to a change of the implant dimensions to be used during surgery in 70% of the cases. The length is more often changed than the width.

- Conventional cross-sectional tomography is effective in the prediction of the size of the implants to be inserted in 87% of the cases and the appropriate implant size in 72% of the cases.

- Conventional tomography increases the efficacy of periapical and panoramic images to predict the appropriate implant size by a factor of 2.5.

- Conventional cross-sectional tomography is recommended in treatment planning for single-tooth implants in areas evaluated in the study.
Study II:

- The width of the alveolar ridge is reduced to 50% during 12 months after single-tooth extraction. Approximately 2/3 of this reduction occurs within the first 3 months.

- Only slight changes in soft tissue height take place in both jaws during the 12 months of healing following single-tooth extraction.

- A great amount of bone formation, bone loss and remodeling occurs within the first year after tooth extraction. Bone formation and loss of crestal bone height mainly occur within the first 3 months, while remodeling takes place during the entire healing period.

- The bone level at the extraction site rather than the bone level of the adjacent teeth dictates the level to which the bone crest heals after extraction.

- Placement of implants should be performed as soon as possible following tooth extraction in order to maintain the dimensions of the alveolar bone.
Study III:

- Bone healing and crestal bone changes following immediate versus delayed placement of submerged implants into extraction sockets were comparable evaluated three months after insertion.

- Significant bone formation occurs during a 3-month healing period in 3-wall infrabony defects associated with immediately placed Osseotite® implants into extraction sockets. 3-wall infrabony defects with a parallel width of up to 5 mm, a perpendicular width of up to 2 mm, and a depth of maximum 4 mm healed totally in 70% of the cases.

- Peri-implant dehiscence-type defects had poor capacity of spontaneous healing.

- Bone reconstructive techniques may not be needed in small 3-wall infrabony defects related to single-tooth immediately placed implants in the front and premolar regions.
7. FUTURE ASPECTS

For assessment of the implant site prior to insertion, it is a prerequisite to have access to radiographic images. However, today no consensus exists on which radiographic techniques are appropriate, and various recommendations and indications for pre-implant imaging have been proposed. It can be concluded from previous studies that cross-sectional tomography, either conventional or CT scanning, has several advantages over non-cross-sectional radiography (such as intraoral/panoramic radiography, lateral cephalography). It has been demonstrated that the image quality in terms of better visibility of anatomical structures, and the dimensional accuracy of the tomograms are superior to non-cross-sectional radiography. Furthermore, the results of the present thesis indicate that conventional tomography improves treatment planning for single-tooth implants. It is, however, important to bear in mind that tomographic radiography is a time-consuming procedure that implies increased costs to the patient, and that CT is associated with appreciably higher radiation risks compared with conventional techniques. Besides, it has never been demonstrated that the use of CT has an impact on the success of implant treatment.

Therefore, more controlled, clinical studies are needed that aim at evaluating whether conventional tomography as well as CT scanning increase the long-term success rates of dental implants. In addition, it may be advantageous to be able to identify sites for which a tomographic examination is indicated. Finally, studies should be conducted evaluating whether cross-sectional tomography has an impact on implant treatment planning and success of treatment in the molar regions.

Following extraction of teeth, the alveolar bone undergoes morphologic changes resulting in a reduction of hard and soft tissue volume. Since the success of conventional as well as implant-retained prosthetics may depend, among other things, on the shape and size of the alveolar process, insight into the healing process after tooth extraction including the time aspect is of significance. More controlled studies are needed investigating techniques for preservation of alveolar bone following tooth extraction.
Immediate implant placement has been demonstrated to be a predictable concept associated with high success rates and should be considered an alternative to the “gold standard” protocol. The immediate technique has several advantages including preservation of the alveolar bone and reduction in treatment time and costs. However, more controlled, prospective clinical studies are needed to determine the indications for this treatment strategy. Furthermore, since the use of bone augmentation techniques increases the treatment costs and may complicate the surgical intervention as well as the following treatment course, it is of importance to identify the type and size of peri-implant defects that have the potential of spontaneous healing. More controlled, randomized studies should be performed to evaluate bone healing following immediate placement of dental implants into extraction sockets in the molar regions as well. Eventually, investigations evaluating the long-term prognosis of immediate implant insertion into fresh extraction sockets are still lacking.
The present Ph.D. thesis comprises three studies (I-III) with the main purpose to evaluate radiographic and clinical procedures related to single-tooth implant treatment.

Dental implant treatment has revolutionized oral rehabilitation in partially and fully edentulous patients. Today, implant retained single-crowns is a well-established option for replacement of a missing tooth. According to the original implant treatment protocol, it was recommended to wait at least 12 months following tooth extraction before insertion of implants, and to leave the implants unloaded for 3 to 6 months hereafter. However, this protocol was not founded on scientific evidence. Within the last decades, the original implant treatment protocol has been challenged by experiments, which aimed at shortening the treatment period and by reducing the number of surgical procedures. One approach may be to reduce the time between tooth extraction and implant insertion, e.g. to insert the implant immediately after extraction of the tooth. It is obvious that this immediate technique is advantageous by the fact that treatment time and costs can be reduced, and additionally, previous studies have demonstrated that preservation of the alveolar bone can be achieved as well. However, more controlled, prospective clinical studies are needed to determine the indications for this treatment strategy. To ensure osseointegration, various guidelines for the immediate implantation technique have been suggested including bone reconstructive treatment strategies, such as application of membranes, grafting materials, and bone inductive substances, but so far, no consensus has been reached. Therefore, it is essential to evaluate in which types of defects these additional procedures may be required for achieving osseointegration of immediately inserted implants, and to determine the size of defects that may have the ability to heal spontaneously.

Following extraction of teeth, the alveolar bone undergoes morphologic changes, which may adversely affect the quantity and architecture of the alveolar ridge. Since the characteristics of the alveolar bone may have an impact on the possibility to insert an implant, as well as influence the functional and esthetic outcome of prosthodontic treatment including implant-retained prosthetics, it is important to obtain knowledge of these contour changes at the extraction site. Furthermore, in order to estimate the appro-
appropriate time for implant insertion, insight into the time aspect of the healing process after tooth extraction is essential.

The success of any implant treatment depends on careful preoperative planning. In addition to a thorough anamnesis and clinical examination, radiographic assessment is essential to estimate the morphologic characteristics of the proposed implant site and the location of the anatomical structures. So far, there is no consensus regarding the guidelines for pre-implant radiographic planning. Cross-sectional tomography, either conventional or CT scanning have been proposed as a supplement to intraoral and panoramic radiography. However, there is no evidence showing that these radiographic methods have an impact on implant treatment planning or the success of treatment.

The studies presented by papers I-III were carried out with the following detailed aims:

I. To determine the efficacy of conventional cross-sectional tomography as an adjunct to panoramic and periapical radiography in the prediction of the appropriate implant size.

II. To assess bone formation in the alveolus and contour changes of the alveolar process following single-tooth extraction.

III. To compare bone healing and crestal bone changes following immediate versus delayed insertion of submerged implants in extraction sockets.
Study I. Impact of conventional tomography on prediction of the appropriate implant size.

The implant length and width of 46 patients referred for single tooth implant treatment were determined pre-surgically first by periapical+panoramic images (record 1), and afterwards by periapical+panoramic images+tomograms (record 2). These dimensions were compared with the dimensions of the implants actually inserted (record 3), and the dimensions assessed to be the "appropriate" ones according to defined criteria for success (record 4).

In 70% of the cases, the implant length and/or width were changed after the tomogram was available. The implant dimensions determined with tomography were maintained at surgery in 87% of the cases. In only 33% of the cases did the implant size predicted without tomography correspond to the size of the inserted implants. The agreement between record 2 and 3 was significant higher than between record 1 and 3 (p<0.001). Similarly, the agreement between record 2 and 4 was significant higher than between record 1 and 4 (p<0.001).

This study demonstrated that the use of tomograms increases the ability of periapical+panoramic images to predict the appropriate implant size by a factor 2.5. Therefore, conventional cross-sectional tomography is recommended for treatment planning before placement of single-tooth implants.
Study II. Bone healing and soft tissue contour changes following single-tooth extraction. A clinical and radiographic 12-month prospective study.

Tissue changes after removal of a premolar or molar in forty-six patients were evaluated in a 12-month period by means of measurements on study casts, linear radiographic analyses, and subtraction radiography.

The results demonstrated that a major width reduction of the alveolar ridge occurred during the first 3 months after tooth extraction while only slight changes in height was seen. In the following 9 months, the tissue changes continued, though to a much lesser extent. By means of linear radiographic measurements, it was found that the bone level mesially and distally to the extraction site after 12 months of healing was situated less than ½ mm more apically than at baseline. By means of subtraction radiography, it was demonstrated that a great amount of bone formation, bone loss as well as remodeling occurred within the first year after tooth extraction. The greatest amount of bone generation and loss of crestal bone height took place during the first 3 months.

It can be concluded that placement of implants should be performed as soon as possible following tooth extraction in order to maintain the dimensions of the alveolar bone.
Study III. Bone healing following immediate versus delayed placement of titanium implants into extraction sockets - a prospective clinical study.

46 patients were randomly allocated to an immediate group (Im) or a delayed group (De) (n=23/group) and received an implant at the incisor, canine, or premolar regions of the maxilla or the mandible. Osseotite® implants were inserted on average 10 days following tooth extraction in the Im group and approximately 3 months after in the De group. The widths (parallel and perpendicular to the implant) and the depth of the marginal bone defects around the implants were measured clinically just after insertion and 3 months later at the abutment installation surgery. The crestal bone changes mesially and distally to the implants were evaluated radiographically by linear measurements.

The survival rate was 91% (Im) and 96% (De). In the Im group, the mean reduction in parallel width, in perpendicular width and in depth of the defects amounted to 54% (from 3.9 to 1.8 mm), 74% (from 1.9 to 0.5 mm) and 59% (from 5.6 to 2.3 mm). The corresponding mean reduction in the De group amounted to 42% (from 3.1 to 1.8 mm), 69% (from 1.3 to 0.4 mm) and 35% (from 4.3 to 2.8 mm). The reduction over time was statistically significant only in the Im group (p<0.05). In the Im group, a higher degree of bone healing was achieved in the infrabony defects (approx. 75% for depth) than in the dehiscence type of defects (approx. 25%). Furthermore, 70% of the 3-wall infrabony defects with a parallel width of up to 5 mm, a depth of maximum 4 mm and a perpendicular width of up to 2 mm had a capacity of spontaneous healing within a period of 3 months.

It can be concluded that significant bone formation occurs in infrabony defects associated with immediately inserted implants in extraction sockets. Furthermore, it was demonstrated that bone healing and crestal bone changes following immediate versus delayed insertion of submerged implants in extraction sockets were comparable evaluated three months after insertion.
9. DANSK SAMMENFATNING

Denne Ph.D.-afhandling består af tre undersøgelser (I-III) med det overordnede formål at evaluere røntgenologiske og kliniske procedurer i relation til behandling med enkelttands implantater.

Behandling med tandimplantater har været epokegørende for genopbygning af tyggefunktionen hos tandløse og delvist tandløse patienter. I dag er implantatretinerede enkelttandskroner en veletableret mulighed ved erstatning af en manglende tand. Ifølge den oprindelige protokol for implantatbehandling blev det anbefalet at vente mindst 12 måneder efter tandudtrækning før indsættelse af implantatet og at lade dette være ubelastet i 3 til 6 måneder herefter. Retningslinjerne i denne protokol baserede sig imidlertid ikke på et videnskabeligt grundlag. Inden for de sidste årtier har man derfor udforsket den oprindelige protokol for implantatbehandling ved at udføre eksperimenter, som har haft til formål at forkorte den samlede behandlingstid samt reducere antallet af kirurgiske procedurer. En mulighed kunne være at forkorte tiden mellem tandudtrækning og implantatindsættelse, f.eks. at indsætte implantatet umiddelbart efter fjernelse af tanden (immediat-indsættelse). Ud over at denne teknik naturligvis har den fordel, at behandlingstiden og udgifterne kan reduceres, har tidligere undersøgelser vist, at det herved også er muligt at bevare mere alveoleknogle. Der er dog behov for flere kontrollerede, prospektive studier for at kunne bestemme indikationerne for denne behandlingsstrategi. For at sikre osseointegration af implantatet har forskellige retningslinjer for immediat-indsættelse været foreslået, bl.a. knoglerekonstruktionsteknikker såsom anvendelse af membraner, ”grafting”-materialer og knogleinduktive substanser, men indtil nu er der ingen consensus. Det vil derfor være hensigtsmæssigt at identificere, i hvilke typer defekter disse supplerende teknikker er påkrævede for at opnå osseointegration af immediat-indsatte implantater samt at bestemme størrelsen af de defekter, der har evnen til at hele spontant.

Efter tandudtrækning sker der morfologiske forandringer af alveoleknoglen, som kan have uheldig indflydelse på mængden og morfologien af alveolekammen. Da den alveolære knogles beskaffenhed netop kan have betydning for muligheden for at indsætte et implantat og desuden influere på det funktionelle og æstetiske resultat af den protektive behandling, er det vigtigt at opnå et kendskab til disse konturendringer af ekstrak-
tionsstedet. Desuden er det vigtigt at få indsigt i tidsaspektet vedrørende helingsproces-
sen for at kunne bestemme det rigtige tidspunkt for implantatindsættelse.


Undersøgelserne, som er præsenteret ved artiklerne I-III, blev udført med følgende delformål:

I. At bestemme effekten af konventionel tværsnitstomografi som et supplement til panoramaoptagelse og periapikal radiografi på prædiktionen af den rigtige implantatstørrelse.

II. At vurdere knogledannelse i alveolen samt konturændringer af alveolekammen efter ekstraktion af enkelttænder.

III. At sammenligne knogleheling og marginale knogleændringer efter immediat versus forsinket indsættelse af to-fasede implantater i ekstraktionsalveolen.
Undersøgelse 1. Betydningen af konventionel tomografi for prædiktionen af den rigtige implantatstørrelse.


I 70% af tilfældene blev implantatlængde og/eller -bredde ændret efter at tomogrammerne var tilgængelige. Det implantat der blev forudsagt med tomografi stemte overens med det der blev indsat ved operationen i 87% af tilfældene. Kun i 33% af tilfældene svarede implantatstørrelsen bestemt uden brug af tomografi til størrelsen af det indsatte. Overensstemmelsen mellem 2. og 3. registrering var signifikant højere end mellem 1. og 3. registrering (p<0.001). Ligeledes var overensstemmelsen mellem 2. og 4. registrering signifikant højere end mellem 1. og 4. registrering (p<0.001).

Denne undersøgelse viste, at brugen af tomogrammer, som et supplement til peri-apikale og panoramaoptagelser, forøger muligheden for at forudsige den rigtige implantatstørrelse med en faktor 2.5. Det kan derfor anbefales at anvende konventionel tværsnitstomografi ved planlægningen af behandling med enkelttandsimplantater.
Undersøgelse II. Knogleheling og ændringer af bløddelskonturerne efter enkelttands-ekstraktion. En klinisk og røntgenologisk 12-måneders prospektiv undersøgelse.

Vævsforandringer efter fjernelse af en præmolar eller en molar blev vurderet i en 12-måneders periode hos 46 patienter ved hjælp af målinger på studiemodeller, lineære målinger på røntgenbilleder samt subtraktionsradiografi.

Resultaterne viste, at en stor breddereduktion af alveolekammen fandt sted i løbet af de første 3 måneder efter tandekstraktion, mens kun en lille ændring af højden sås. I de efterfølgende 9 måneder sås fortsat vævsforandringer, skønt i væsentligt mindre omfang. Lineære målinger på røntgenbilleder viste, at knogleniveauet mesialt og distalt for ekstraktionsstedet efter 12 måneders heling lå mindre end ½ mm mere apikalt end hvad var tilfældet ved baseline. Ved hjælp af subtraktionsradiografi blev det påvist, at en stor mængde knogledannelse og knogletab, såvel som remodellering forekom inden for det første år efter tandekstraktion. Den største del af knogledannelsen og tabet af den marginale knoglehøjde skete i løbet af de første 3 måneder.

Det kan konkluderes, at implantatindsættelse bør ske så hurtigt som muligt efter tandekstraktion for på den måde at bevare alveoleknog lens dimensioner.
Undersøgelse III. Knogleheling efter immediat versus forsinket indsættelse af titanium-implantater i ekstraktionsalveoler - et prospektivt klinisk studie.

46 patienter blev tilfeldigt fordelt til en ”immediate”-gruppe (Im) og en ”delayed”-gruppe=forsinket indsættelse (De) og fik injsat et implantat i en fortands-, hjørne- eller præmolarrregion i maksillen eller mandiblen. Osseotite®-implantater blev indsat i gennemsnit 10 dage efter tandekstraktion i Im-gruppen og ca. 3 måneder efter i De-gruppen. Bredden (parallelt og vinkelret på implantatet) samt dybden af de marginale knogledefekter rundt om implantatet blev målt klinisk umiddelbart efter indsættelsen og igen 3 måneder senere ved abutment-operationen. De marginale knogleforandringer mesialt og distalt for implantatet blev vurderet ved hjælp af lineære målinger på røntgenbilleder.

Overlevelsesraten var 91% (Im) og 96% (De). I Im-gruppen sås en gennemsnitsreduktion i bredden parallelt på implantatet, bredden vinkelret på, og dybden af defekterne på henholdsvis 54% (fra 3.9 til 1.8 mm), 74% (fra 1.9 til 0.5 mm), og 59% (fra 5.6 til 2.3 mm). De tilsvarende værdier for gennemsnitsreduktionen i De-gruppen var 42% (3.1-1.8 mm), 69% (1.3-0.4 mm), og 35% (4.3-2.8 mm). Reduktionen over tid var kun statistisk signifikant i Im-gruppen (p<0.05). I Im-gruppen blev der opnået en større grad af knogleheling i de intraossøse defekter (ca. 75% for dybden) end i defekter af dehiscence-typen (ca. 25%). Desuden sås, at 70% af defekter med en parallel-bredde på op til 5 mm, en dybde på maksimalt 4 mm og en vinkelret-bredde på op til 2 mm havde evnen til at hele spontant inden for en periode på 3 måneder.

Det kan konkluderes, at der sker betydelig knogledannelse i intraossøse defekter i forbindelse med immediat-indsættelse af implantater i ekstraktionsalveoler. Desuden blev det påvist, at knogleheling og marginale knogleforandringer efter immediat-indsættelse versus forsinket indsættelse af to-fasede implantater var sammenlignelig vurderet 3 måneder efter indsættelse.
10. REFERENCES


Todescan R, Jr., Pilliar RM, Melcher AH. A small animal model for investigating endosseous dental implants: effect of graft materials on healing of endosseous, porous-


