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Bone Grafts and Dental Implants  
in the Reconstruction of the Severely  
Atrophied, Edentulous Maxilla

BY

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### **Abstract**

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In two prospective, clinical studies the stability of implants and prosthetic constructions were evaluated after three years of loading. In the first study, the implant and the bridge stability of 39 patients with 1-stage bone grafts, were compared to a reference-group of 37 patients who did not need bone grafts. In the second study, 40 patients were randomised to have either 1-stage sinus inlay bloc grafts or 2-stage sinus inlay particulated grafts.

Implant success in Paper 1, was 75.3 % in the study group and 93.1 % in the reference group. In Paper 2 implant survival in the 1-stage group was 77.7 % and 86.5 % in the 2-stage group. Bruxism and post-operative complications, such as unexpected pain, dehiscence and infection were found to be associated with the later loss of implants.

The volumes of onlay block and inlay particulated bone grafts, after 6 months as evaluated by computed tomography showed the decrease of 49.5 % and 47 % respectively, although there was a wide range in both groups.

Using of cutting torque measurements during the placement of implants in grafted and non-grafted jaw bone, showed a significant inverse correlation to the commonly used clinical estimation of jaw bone quality, acc. to Lekholm & Zarb. Significantly lower torque values were recorded in grafted regions when compared to non-grafted.

It was shown that autogenous bone grafts and implants to the edentulous maxilla, after early high failure rates, showed stable and predictable results after three years. Bruxism was found to be significantly associated with implant failures and initially reduced biomechanical properties was seen in the grafted bone.

*Key words:* Dental implants, maxilla, grafted bone, implant failure, clinical study, computed tomography, volumetry, cutting torque.

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## **Preface**

For many people the loss of teeth can mean the loss of jaw function, and can lead to poor oral aesthetics and severe emotional and psychological handicaps. The rehabilitation of edentulous patients is therefore an important mission.

Osseointegrated dental implants have made it possible to rehabilitate practically all totally edentulous persons. The idea and impetus for the investigations in this thesis was the observation that autogenous bone grafts to the edentulous maxilla made rehabilitation with osseointegrated implants possible in cases where implant-treatment otherwise would have been unpredictable. During these periods, the need for prospective and randomised studies with predetermined protocols became obvious and necessary.

In the first study, maxillary edentulous patients were treated with implants and bone grafts in 1-stage procedures and compared with a reference-group of patients treated according to the standard procedure. This was followed by a randomised, prospective study where 1-stage and 2-stage bone-grafting procedures were compared. These two clinical studies were preceded by firstly, a methodological study to test the precision of computed tomography in calculating bone graft volumes to the maxilla. Secondly, a clinical study, using computed tomography, was done, to measure the volume-changes of the maxillary bone grafts after 6 -months of healing. Finally, a study investigating the cutting torque values needed for placing implants in grafted and in non-grafted maxilla was undertaken.

## Introduction

### *Epidemiology, etiology*

The loss of teeth starts a physiologic resorption of the alveolar crest of the jaws.<sup>1</sup> The degree of resorption varies significantly. Extremes are seen, esp, in the combination of tooth loss due to periodontal disease with wearing badly fitting dentures, for a long time. In severe cases a distortion of the overlying soft tissues, flabby ridges makes denture-wearing difficult or even impossible.<sup>2</sup> Previously, the only available method for rehabilitation of the edentulous patient was to provide removable dentures, sometimes in combination with surgical treatment, in order to improve the area supporting the denture. For many patients this has been a less than perfect treatment.

Despite the fact that in 1973 Sweden introduced an NHS insurance system that has given extensive financial support for dental care over a period of more than 20 years, today more than 350000 persons are edentulous both in the maxilla and the mandible. In the age-group 16 to 84 years, the proportion of totally edentulous persons in Sweden was reduced from 15 % (1980/1981), to approx. 5 % (1996/1997) of the total population in this age group.<sup>3</sup> When a group of 70 year olds were investigated during the period 1973 to 1993, it was found that the percentage of completely edentulous people had decreased from 37 % to 23 %.<sup>4</sup>

Osseointegration, defined as "a direct structural contact between living bone and the surface of a load-carrying implant" was first described by Brånemark (1969).<sup>5</sup> Later this discovery was clinically developed into the concepts of rehabilitation with osseointegrated dental implants by Brånemark et al (1977)<sup>6</sup> and Schroeder et al (1976).<sup>7</sup> Today the rehabilitation of edentulous patients with titanium implants is a well established method and there is as consensus as to the superiority of osseointegrated implants compared to other methods. During the last 20 years, the rehabilitation of edentulous and partially edentulous patients with implants and prosthetic treatments has been well documented and has also shown predictable results.<sup>8-10</sup>

However, in patients with advanced atrophy of the alveolar process, especially in the maxilla, implant treatment is more hazardous and sometimes impossible to perform. In an effort to overcome the anatomical difficulties, different bone-grafting procedures to the maxilla have been introduced. The ultimate goal for these bone-grafting procedures is to correct and to normalise the vertical and horizontal relations of the jaws and thereby create adequate jaw bone volumes and bone quality.

In a cohort study by Petersen et al (1992),<sup>11</sup> 20 % of the maxillary edentulous patients needed bone-grafting procedures before the placement of implants. Even though the number of edentulous persons has decreased, the severity of their handicap has increased as the number of edentulous maxillae that were suitable

for treatment without bone grafts was decreased from 71 % to 51 %, during the period 1983 to 1993.<sup>12</sup>

The degree of reimbursement within the NHS for dental care in Sweden is today 2 billion SKr and about 10% of this, 275 million SEK annually is spent on dental implant treatment. During 1999, more than 11000 dental implant treatments were performed in Sweden with financial support from the NHS (RFV statistics). Forty per cent of these treatments were performed in edentulous patients so approx. 2500 implant treatments were performed in maxillary edentulous patients (NobelBioCare, personal com.). A reasonable assumption would be that about 300 to 400 maxillary edentulous patients in Sweden each year might be candidates for bone-grafting procedures before the placement of implants.

### ***Bone grafting***

Autogenous bone graft is presently regarded as being the golden standard, however there might be alternatives in the future.

Allografts, xenografts, and bone-substitutes of human, bovine- or synthetic origin are used alone or in combination with autogenous bone or blood.<sup>13-18</sup> The clinical value of these substitutes in combination with dental implants has not yet been fully proven.

### ***Bloc graft***

The bloc graft is structurally stable. It is resistant to resorption and gives immediate stability for dental implants. Block grafts are therefore suitable for space-keeping and for the immediate placement of implants (1-stage procedure). These grafts are usually composed of an outer cortical layer surrounding the inner trabecular bone. For the augmentation of the maxilla, the block graft is harvested from many donor sites but commonly from the iliac crest, the tibia or from the mandible (the lateral cortical part of the angle or from the chin, apically to the incisor teeth).<sup>19-22</sup>

The autogenous block bone becomes necrotic after the grafting procedure and to survive it needs to regain its vascular supply. During the first week, the graft becomes the centre of an inflammatory reaction, which over the following weeks gradually changes to a granulation phase, the inflammatory reaction subsides and an osteoclastic activity starts. The block will also act as a scaffold for the ingrowth of vessels and the accumulation of osteoblasts. A new structure of the bone is formed by creeping substitution and a lamellar bone develops. During the following months, this bone gradually calcifies but it takes about a year for it to reach its normal physical strength. The final, stable level of biological properties will not be reached until about 2 years after the grafting and for life the bloc will contain a mixture of viable and necrotic bone, which will be clearly visible microscopically. An interesting observation is that the mechanical strength of the cortical bone graft will, during the resorptive and revascularisation phases, have a significantly reduced mechanical stability until it regains its normal level after about a year.<sup>23</sup>

### *Particulated graft*

Particulated grafts are suitable for packing into defects such as inlay grafts in the bottom of the maxillary sinus or nasal cavity. The graft can be cortical or cancellous bone. The particulation is performed in a specially designed bone mill or the bone is cut into small pieces with a rongeur. When used in combination with implants either, an immediate placement (1-stage) or a delayed placement, after 3 to 6 months of healing (2-stage) is performed. Often particulated bone has been seen as synonymous with cancellous bone. However, this is misleading since the particulated bone graft for maxillofacial purposes is often harvested from the mandible, a bone that is cortical and dense to a high degree.

Nevertheless, a cancellous graft has its total surface exposed to its surroundings for vascular ingrowth and compared to the cortical graft it regains its normal biological properties faster. After the 1st postoperative week all particulated bone will show remnants of a blood clot. As the clot resorbs it is gradually replaced by granulation tissue and after 3 to 4 weeks the clot is rarely visible and the graft has an avascular appearance. At this time, the marrow is replaced by active homeopoietic tissues which, over the following 6 to 12 months, turn into normal fatty bone marrow. A callus develops fairly early and it gradually forms a more calcified cortical-like layer around the periphery. The cancellous graft gradually increases in mechanical strength but will not reach the properties of normal, surrounding alveolar bone until after 1 to 2 years, similarly to autogenous cortical bone grafts.<sup>24</sup>

In summary, the important factors in the healing of all types of autogenous grafts, can be described in 4 stages<sup>25</sup>; 1. the granulation stage, when hematoma develops, an inflammatory response occurs and the formation of granulation tissue takes place, 2. the callus stage in which mesenchymal cells differentiates mainly into osteoblasts and later the calcification starts, 3. the remodelling stage when the fairly hard callus tissue is replaced by lamellar bone and 4. the modelling stage when the bone adapts to the structural demands due to functional stimuli.<sup>26</sup>

The important factors in the healing of onlay bone grafts have been summarised by Gordh & Alberius (1999).<sup>27</sup> The biological properties, revascularisation and resistance to resorption differ between membranous and enchondral bone in favour of membranous bone graft that is preferably harvested from the mandible, the maxilla or the calvaria. Enchondral bone is mostly harvested from the iliac crest or the tibia. However, the harvesting of bone is often a matter of local clinic tradition and the operator's experience. Cortical bone maintains better volume-stability during healing than cancellous grafts, but should be properly stabilised with its trabecular side facing the recipient bone for the prevention of graft resorption and to promote a quick revascularisation. The handling of the host bed is still controversial, but the exposure of the marrow to facilitate the revascularisation, i.e. cortical perforations seems to be recommendable. In

general, it is suggested to use of a gentle and fast surgical technique and the stable fixation of the block grafts.

### *BMPs*

The formation of ectopic bone, subcutaneously and intramuscularly, after the implantation of bone inductive substances, was first shown by Levander (1938).<sup>28</sup> In 1965 Urist discovered that ectopic bone was formed after the injection of demineralised bone-tissues into the muscle of rodents. Later these injected substances were named Bone Morphogenic Proteins (BMP). They could be isolated from both animals and humans, and were found to have the ability to promote differentiation of undifferentiated mesenchymal cells into bone and to promote the bone-induction of osteoblasts.<sup>29,30</sup> This field of research has expanded enormously since then, and several new bone-forming proteins have been found and synthesised.

However, the clinical benefits of BMP, at least for the augmentation of jaws, are still unclear. In experimental, as well as in clinical studies, BMPs have been used to improve the maxillary alveolar bone before the placement of implants.<sup>31</sup>

In addition two other proteins, Platelet Derived Growth Factor (PDGF) and Transforming Growth Factor-beta (TGF-beta1) have received interest and has been proposed, especially in patients with impaired healing ability.<sup>32</sup> Remarkable results have been achieved by concentrating autogenous blood plasma, extracting the platelets which are to be concentrated more than 300 % and mixing with autogenous particulated bone. Even though the procedure is fairly new, and its definite value not yet is proven in controlled clinical studies, it has been shown to increase the rate of maturation of the bone-graft by approx. 200 %, and at the same time it has doubled the density of the bone-graft.

### *Guided Bone Regeneration (GBR)*

Bone healing can be seen as a competition between fibroblasts and osteoblasts, either ending up in a stable bone-healing or a fibrous union. To prevent the faster growing fibroblasts coming ahead, resorbable or non-resorbable barriers have been proven useful. This procedure is usually referred to as Guided Bone Regeneration (GBR) and is more often used in periodontal surgery<sup>33</sup>, bone augmentation procedures with bone-grafts alone or in combination with implants.<sup>34-39</sup>

### *Bone-graft techniques*

Many different surgical procedures have been tried, such as; block-bone / particulated bone; 1-stage / 2-stage; autogenous / bone substitutes; mesenchymal origin / enchondral origin and three procedures for maxillary augmentation are considered to be the most useful and the best documented;

1. total maxillary, sandwich onlay procedures<sup>40,41</sup>
2. le Fort 1 inter-positioning bone grafts<sup>42-44</sup>
3. inlay bone grafts to the maxillary sinus<sup>45,46</sup>

To increase the alveolar height of the maxilla, block grafts are adapted as onlay to the total alveolar crest. Breine & Brånemark (1980)<sup>40</sup> presented a study using horseshoe-shaped iliac crest graft as onlay with implants placed immediately (1-stage). This method was further developed by Adell et al (1990) and Nyström et al (1993) and has mainly been used as a 1-stage procedure.<sup>47,41</sup>

Smaller onlay block-grafts placed on parts of the maxillary alveolar process to selectively increase the width or the height, have been proposed instead of the otherwise rather extensive augmentation procedures.<sup>48-50</sup>

In cases of more extreme maxillary atrophy with major vertical and sagittal discrepancies, or if greater volumes of bone grafts are needed, the le Fort 1 osteotomy using interpositional bone grafts has frequently been used. The method was first described by Sailer et al (1989)<sup>44</sup> using 1-stage implant placement, but was later modified to a 2-stage procedure, with the implants placed in a later session as described by Nyström, et al (1997).<sup>43</sup>

Boyne et al (1980)<sup>51</sup> reported on a method used in 14 patients where cancellous, autogenous bone grafts were placed to the bottom of the maxillary sinus, and simultaneously placed implants without giving results. Kent & Block (1989)<sup>45</sup> used the same method (1-stage procedure) and reported the results after follow-up periods ranging from 4 months to 4 years. Wood et al (1988)<sup>46</sup> used mandibular bone grafts and delayed implant placement (2-stage procedure). Hirsch & Eriksson (1991)<sup>20</sup> presented a technique for sinus augmentation using bicortical chin grafts (mesenchymal) and implants in a 1-stage procedure. Block bone harvested from the iliac crest and placed as sinus inlay in a 1-stage procedure has also been suggested.<sup>52</sup> Since these first reports, several other reports dealing with the same or slightly modified procedures have been presented and summaries have been published.<sup>53,54</sup>

### ***Clinical experiences***

A retrospective Scandinavian multicenter study including 150 maxillary edentulous, bone-grafted patients was recently reported.<sup>55</sup> The study included inlay-, onlay- and le Fort 1 procedures and all patients were followed for at least three years. Since the results were collected from 23 clinics, the inclusion variables were wide and the follow-up routines differed. Nevertheless it was concluded that most failures were observed early on, before loading and during the first year of loading. In total the treatments were regarded as successful, since the majority of patients were successfully prosthetically rehabilitated. Only 15 patients had to go back to removable prostheses.

Esposito et al (1998)<sup>54</sup> in a meta-analysis from 16 studies summarised the results of maxillary bone grafts and Brånemark implants. Although the design and the results differed, it was concluded that implants in maxillary bone grafts show a higher number of failures than after standard implant procedures. A most comprehensive review including 352 articles on bone grafts to the maxilla or the mandible, was presented by Tolman (1995).<sup>56</sup> 72 articles were included in the final analysis. Since the material varied significantly regarding grafting principles, implant systems and prosthetic routines, no significant results were obtained.

A Consensus Conference Report on reconstructive surgery has been published to give clinical guidelines and to highlight topics for future research.<sup>57</sup> Since the data was so multivariate and multifactorial it was difficult to draw definitive conclusions, but it was concluded that "the sinus graft should be considered a highly predictable and effective therapeutic modality".

#### *Immediate / delayed placement of implants*

In a clinical histomorphometric study of sinus inlays it was shown that the proportion of bone was 60% in biopsies from the chin taken 6 to 10 months after the grafting procedure<sup>58</sup> and that, in a similar study<sup>59</sup> increasing volumes of bone were found later after a healing period of 6 to 12 months. By using micro-implants, retrieved with adjacent alveolar bone, far better bone-implant contact was seen after a delayed implant placement, if placing implants 6 or 12 months after the grafting procedure.<sup>60</sup> Similar results were shown by Jensen & Sernerby (1998)<sup>61</sup> showing only minor contact with the graft to implant surface in the early healing periods, but with gradually increasing contact during the following 14 months. Another research group, used similar micro-implants for the study of onlay block grafts and inlay particulate grafts in a delayed, 2-stage procedure.<sup>62</sup> Using a histomorphometric technique, they showed that 6 months after the grafting procedure there was an increase of bone adjacent to the microimplants in particulated sinus inlay grafts, compared with onlay bloc grafts, where a decrease of bone to implant contact was seen. No clinical study has specifically compared the stability of implants placed in maxillary bone grafts, in immediate and in delayed procedures. *It is therefore within the scope of this thesis to compare the two separate treatments; sinus-inlay 1-stage bloc graft and sinus-inlay 2-stage particulated graft focusing on implant success and bridge stability and local and general factors which influence prognosis.*

#### *Clinical studies*

Comparative studies or studies with control-groups have been presented by Jensen (1990),<sup>63</sup> Raghoobar (1993),<sup>52</sup> Isaksson (1994).<sup>64</sup>

The prognosis for implant treatment depends on a wide variety of factors. Different studies are not always comparable and factors influencing the prognosis for implant failures are not always easy to identify mainly due to the variation with the criteria for success and with the study designs. Results are therefore more often based on clinical experience than on theory. Both

exogenous as well as endogenous factors associated with increased failure based on a review of the literature have been presented recently.<sup>65</sup>

*It is within the intention of this thesis to compare 1-stage and 2-stage sinus inlay bone grafting procedures in a randomised, prospective study with a focus on the factors influencing a prognosis.*

### ***Volumetry of grafts***

No comparative study on the resorption of onlay and inlay grafts has yet been published. However, experimental studies indicate that block bone is more resistant to resorption.<sup>66</sup>

Preliminary data exists regarding the clinical outcome of 1-stage and 2-stage maxillary sinus-inlay augmentation procedures,<sup>56,67</sup> but are not conclusive. The height of onlay block graft in edentulous patients has been assessed in a longitudinal study using CT-techniques.<sup>68</sup> Using axial CT scans, the volume of bone grafted to alveolar clefts and that of bone gained after distraction osteogenesis have been estimated.<sup>69,70</sup> The volume changes in particulated sinus-inlay grafts during healing, are however, unclear. The precision of computerised tomography in repeated measurements of bone volumes has not yet been demonstrated. *It is the intention of this study to evaluate the volume-changes in onlay- and inlay grafts in a comparable study and to evaluate the precision of this method*

### ***Bone quality***

Various standards for describing bone quality and bone quantity have been proposed. The clinical classification by Lekholm & Zarb (1985)<sup>2</sup> is the most widely accepted, where the jaw bone shape is classified on a five degree scale (A to E) and the jaw bone quality on a four degree scale (1 to 4). The jaw shape is determined prior to surgery at the clinical and radiological examination. The quality is usually assessed during the explorative drilling at the fixture site. The classification of the edentulous jaw by Cawood & Howell (1988)<sup>71</sup> is based on the assumption that a gradual atrophy will follow the loss of teeth. The edentulous maxilla is classified as Class 1 to 6. The key factors in achieving implant stability are bone-quantity and bone-quality. Friberg et al (1991)<sup>72</sup> showed an overall implant-failure rate of 38 % in edentulous maxillary type 4 bone and 7 % failure rate of 7 mm long implants compared to less than 1 % in implants longer than 10 mm. The impact of the bone structure on implant stability was also shown by Jaffin and Berman (1991)<sup>73</sup> with a failure rate of 44 % in type 4 bone compared to 3.6 % in types 1 to 3.

The question has been raised as to whether a more generalised condition of decreased bone quality, osteoporosis, could be detected within the jaws and be used as a factor of prognostic value.

Osteoporosis is defined as "a situation where there is a general reduction of bone mass without any specific known bone-affecting disease".<sup>74</sup> In Sweden, another definition of osteoporosis is used, "the bone mineral density, radiographically estimated, is 2 standard deviations below the mean for age- and sex-matched individuals".<sup>75</sup> Osteoporotic patients heal fractures just as the non-osteoporotic do and there is no evidence that the healing of dental implants should be impaired.<sup>76</sup> The normal skeletal remodelling influenced by gender, age and physical activity is not specifically reflected in the jaws. A reduction in mandible bone mass has been weakly correlated to cortical bone reduction in other parts of the skeleton, but no relationship to maxillary bone-mass has been shown.<sup>77,78</sup> Changes in bone mass at one site on the skeleton are not reflected in an altered bone mass within the maxilla<sup>79</sup> and there is at the moment no evidence that the generalised disease, of osteoporosis is reflected in the alveolar bone of the jaws, and might specifically become a factor of prognostic influence.

In order to further standardize and to find an objective standard of bone, the cutting torque values was measured at the insertion of an implant and was proposed as an index for bone-structure.<sup>80</sup> This method has been further clinically developed and comparative measurements when placing implants in anterior and posterior parts of the maxilla and mandible, have been performed.<sup>81-83</sup> A significant positive correlation was found between cutting torque-energy values and the clinical assessment of bone quality.<sup>83</sup>

In a number of publications the resonance frequency analysis (RFA) has been used as an instrument to value the stiffness of the implant-anchoring in bone and thereby achieving an objective value of the stability of the implant.<sup>84-86</sup> The gradual increase of bone stiffness, in the clinic understood as improved implant stability, has been shown over time. From the measurements of implant stability using resonance frequency, it has been shown that implant stability increases with time after le Fort 1 grafting procedures,<sup>87</sup> but the initial stability in other situations of maxillary augmentation procedures has not been evaluated. It would be valuable to find an objective tool to evaluate implant stability objectively after different bone-grafting procedures.

*It is in the aim of this thesis to study the jaw bone density both in grafted and non-grafted maxillary bone measuring the cutting resistance at the placement of implants .*

### ***Standards of follow-up***

The standardised factors needed for follow-up have been discussed, such as; length of follow-up period, objective and subjective clinical measurements, definitions of success, survival and failure and also radiological standards and statistical designs. Albrektsson et al (1986)<sup>88</sup> presented the following prerequisites for success of dental implant treatments:

a/ the stability of each implant is to be tested individually, in order to document osseointegration,

b/ there should be no radiological evidence of peri-implant radiolucency,

c/ the vertical, marginal bone loss should not be more than 1 mm after the first year in function and thereafter less than 0.2 mm annually,

d/ no implant should have persistent or irreversible signs or symptoms such as pain, infections, neuropathies or paresthesia and

e/ the success-rate for the 5-year observation period for a definite treatment should be more than 85 % and at the 10-year observation not less than 80 %.

If any one of these criteria was not fulfilled, the definition of *success* was not met and it had to be changed to the level of *survival*. If no control was done or if the patient was somehow lost to follow-up, the implant was defined as *not accounted for*, and if the implant was mobile or caused severe therapy-resistant pain and was subsequently removed, it was regarded as a *failure*.

In order to discuss failures, additional comments are important. Since failures do occur over different periods of time, a separation into early- and late- is recommended.<sup>54</sup> The early failures, before loading, are regarded as due to biological reasons, mainly such as infections, load during healing, surgical trauma etc. The late failures, after the period when implants have been loaded, are looked upon as due to biomechanical factors, such as excessive load related to bone-anchorage, peri-implantitis or technical problems. The majority of late failures are seen during the initial period of loading.<sup>54</sup>

In a paper by Roos et al (1997)<sup>89</sup> a design for a follow-up protocol and a differentiated individual testing of implant stability and periodically intra-oral x-rays was stressed, especially in studies with altered implant-design or when introducing modified treatment procedures. It was also suggested that the number of implants at the start of the study should correspond to the number at the end of the study and that drop-outs should be clearly identified.

A general lack of standardisation and poor study design permeate most reports.<sup>90</sup> It has even been concluded, "a reader cannot help thinking that many of these reports are efforts to promote a given system, rather than to present reliable scientific information based upon sound study design".<sup>91</sup>

From a statistical point of view, the question of dependency has been discussed.<sup>92</sup> If a patient loses one implant, is there an increased risk of additional losses? Does a cluster phenomena exist? When analysing factors for failure it was suggested that the dependency / independency within the material should be considered and that the single implant should not be used as the statistical unit. Instead the

patient should be regarded as the computational unit. Results can be presented in a life-table as well as in a four-field-table, however the former was recommended as being a well accepted statistical method for the presentation of follow-up materials.<sup>92,93</sup>

## **Aims of the investigation**

The work and design of this thesis have been organised round the main hypothesis:

that autogenous bone-grafts, performed in order to augment the atrophied maxilla, will after an initial healing period, permanently allow the osseointegration of implants and give biomechanical properties comparable to rehabilitation with implants in non-grafted maxillas.

This would be achieved by

1. studying the prognosis for 1-stage sinus inlay maxillary bone-grafts and relating these findings to a reference group of non-grafted patients
2. studying and comparing the prognosis and treatment outcomes in a randomised study of 1-stage to 2-stage sinus inlay bone-grafted patients
3. identifying the specific factors influencing the prognosis of implants placed in maxillary bone-grafted patients
4. studying and comparing the changes in volume of bloc- and particulate bone-grafts to the maxilla
5. evaluating the cutting torque values needed for the installation of implants in grafted and non-grafted maxillary bone

## **Material and methods**

### **Patients**

The clinical material for this thesis (papers 1,2,4,5) has been gathered from the rehabilitation of 166 maxillary edentulous patients. 116 of the patients were bone-grafted, either from the iliac crest (n=105) or from the chin (n=11). 50 of the patients served as a control- or reference-group. The indication for bone-grafting was always that the maxillary posterior alveolar bone-height was less than 5 mm. 1042 implants were placed ( papers 1,2,4,5), of which 432 were placed in bone-grafted regions and 610 were placed in non-grafted regions. Practically all the implants were of a selftapping design, Mk 2 (Nobel Biocare AB, Gothenburg, Sweden) and the lengths varied between 10 and 18 mm.

All patients in papers 1,4,5 were surgically treated at the Dept. of Oral and Maxillofacial Surgery, Danderyds Hospital, Danderyd, Sweden. The patients in paper 2 were surgically treated at the Dept. of Oral and Maxillofacial Surgery, Danderyds Hospital, Danderyd, Sweden or at the Dept. of Oral and Maxillofacial Surgery, Gävle County Hospital, Gävle, Sweden.

The prosthetic constructions (papers 1,2,4,5) were provided by the Dept. of Prosthetic Dentistry, S:t Erik's Hospital, Stockholm, (paper 1); the Dept. of Prosthetic Dentistry, Södertälje, Stockholm County Council, Stockholm and (paper 2) the Dept. of Prosthetic Dentistry, Gävle County Council, Gävle, Sweden.

The radiological follow-ups (papers 1,2) were performed at the Dept. of Dental Radiology, Eastman Institute, Stockholm County Council, Stockholm or (paper 2) at the Dept. of Dental Radiology, Gävle County Hospital, Gävle, Sweden.

The radiological investigations (papers 3,4) using computed tomography were performed at the Dept. of Radiology, Danderyds Hospital, Danderyd, Sweden.

Analysis of the torque measurements (paper 5) was provided by the Nobel Biocare AB, Gothenburg, Sweden.

### **Paper 1 (patients, implants)**

During the period 1 Jan. 1990 to 31 Dec 1992, 39 patients needing for posterior maxillary bone grafting and scheduled for implant surgery by one of two surgeons (BJ,KW), were consecutively entered into the study. Altogether 254 implants were placed; 131 implants were placed in grafted regions and 123 were placed in non-grafted regions. During the same period, all the other maxillary edentulous, who were not bone-grafted but surgically treated by one of the two

same surgeons were entered into a reference group. Altogether 206 implants were placed. The overall drop-out in follow-up at the 3-year control was 9 %, equally distributed between the two groups.

### **Paper 2** (patients and implants)

The study consisted of 40 maxillary edentulous patients, consecutively entered. All patients needed posterior maxillary bone grafts and were due to the sinus inlay techniques. The patients were randomly allotted to either the 1-stage surgical group (n=20) or the 2-stage surgical group (n=20). Altogether 288 implants were placed, distributed as (graft/non-graft) in the 1-stage group as 148 (76/72) and 2-stage group as 140 (74/66) implants. The patients were entered into the study during the period of 1 Jan 1993 to 1 Mar 1996 and were surgically treated by one of four surgeons (BJ,KW,MH,TS).

### **Appendix to paper 2** (patients and implants)

All 40 patients in paper 2 participated in a 3-year clinical follow-up. Three patients did however refuse to participate in either the intra-oral radiographic follow-up or in the removal of the prosthetic constructions for the individual implant stability control. Subsequently the stability of the implants was defined acc. to the above definition as survival.

### **Paper 4** (patients and implants)

During the periods 3 Febr 1993 to 7 Oct 1997, 10 maxillary edentulous patients received bone grafts simultaneously placed as onlay bloc graft and as particulated sinus inlay graft and were radiographically evaluated post-operatively and after 6 months using CT scans. The median age (range) was 58 years (49 - 71) and the gender-distribution was 3 males and 7 females. Altogether 68 implants were placed, equally distributed between grafted and non-grafted regions.

### **Paper 5** (patients and implants)

Torque-energy measurements during the insertion of implants were assessed from 40 maxillary edentulous patients of which 27 were bone-grafted and 13 patients were not-grafted. All were consecutively entered into the study. The age-distribution was 56 years (33-82) and the gender-distribution was 15 males and 25 females. A total of 226 implants, 117 in grafted regions and 109 in non-grafted regions, were placed by the same surgeon (BJ) during the period Jun 1994 to Jun 1996.

## Methods

### *Study design (papers 1,2)*

Paper 1 describes a case-control, clinical, prospective study with preoperatively defined treatment protocols. The result from bone-grafted patients are compared with a simultaneously treated group of maxillary edentulous patients receiving implants without bone grafts. Paper 2 incl. appendix describes a randomised, clinical study prospectively designed. Two allotted groups of patients are treated according to a previously defined protocol.

### *Inclusion criteria, treatment protocol (papers 1,2,4,5)*

All patients were selected according to specific inclusion criteria: edentulous maxillas, posterior bone-height less than 5 mm and no diagnosed bone disease or medication known to affect bone metabolism. Indeed, patients with more jaw bone volume than this, might be suitable candidates for bone-grafting and in some clinics also patients with less than 5 mm alveolar bone-height seem to be successfully rehabilitated without bone grafts.<sup>94,95</sup> All patients were clinically free of any pathology in the maxillary sinuses. All patients were preoperatively examined radiographically either by computed tomography or tomography, which besides giving information on the maxillary alveolar process also gives some information on the status of the maxillary sinus. Smoking habits were recorded either, as the question about smoking or not (paper 1) or if the daily consumption exceeded 5 cigarettes per day (paper 2). Cigarettes was the only smoking-habit that was reported and the recording was done at the start of the treatment. No major medical obstacle that could prevent treatment under general anaesthesia or prevent bone grafting was known. The distribution of the preoperative factors is given in Table 1.

The specific distribution of patients, age, gender and preoperative registrations from paper 1,2 is given below in Table 1.

	Paper 1		Paper 2	
	Study-group (n= 39)	Reference-group (n=37)	1-stage (n=20)	2-stage (n=20)
Age, median (range)	56 (40-77)	68 (38-86)	54(31-72)	57(39-78)
Gender, male	8	10	6	6
ASA-index				
	1	34	24	15
	2	5	13	5
Smoking	15	14	8	8
Reason for edentulism				
	Caries	24	25	7
	Periodontitis	14	12	10
	Trauma	1	0	3 (other)
Duration of edentulism	> 10 years	28	19	5
Opposing jaw				
	Own teeth	32	26	18
	Implant	7	9	2
	Denture	0	2	4
Bruxism habit			7	3
Origin of graft				
	Iliac crest	28		
	Mandible	11		

Table 1. Distribution of preoperative factors in patients in paper 1 and paper 2.

*Randomisation (paper 2)*

In paper 2, 40 patients were randomised to one of two grafting procedures: 1-stage sinus inlay bloc graft or 2-stage sinus inlay particulate graft. Before the allocation, each patient who fulfilled the inclusion criteria was informed about the ongoing study and was asked to participate. If the patient agreed to participate, he was allotted to one of the two treatments according to a previously designed schema by a third person. All patients gave their informed consent and the design of the study was approved by the Ethical Committee, Karolinska Hospital, Stockholm, Sweden.

*Surgery (paper 1,2,4,5, appendix)*

During the grafting procedures, all patients were treated under general anaesthesia and bone grafts were harvested from the iliac crest (papers 1,2,4,5 n=105) or from the chin (paper 1, n=11). The iliac graft, consisting of both cortical and trabecular bone, was approximately 2x1.5x1.5 cm in size and was harvested from the superior and lateral part of the iliac crest.<sup>19</sup> The mandibular graft was smaller in size, approximately 1,5x1x1 cm and consisted mainly of cortical bone harvested from the subapical symphysis.<sup>20</sup> Both grafts were of monocortical structure.

*1-stage sinus-inlay bloc bone grafts (papers 1,2,5)*

Monocortical bone blocs were harvested and shaped to fit the maxillary sinuses which were explored by the sinus lift technique.<sup>96</sup> The bone blocs were orientated with the cortical layer uppermost and were stabilised to the alveolar ridge, in general, with 2 implants. In order to simplify the prosthetic handling, efforts were made to place the implants as vertically as possible. Three to 4 implants were placed in the frontal, non-grafted bone (papers 1,2). Cover screws were placed and the implants were left to heal in a submerged position for approx. 6 months. The placement of implants was performed according to the standard principles given by Adell et al (1990).<sup>8</sup>

*2-stage sinus-inlay particulate bone grafts (papers 2,4,5)*

The graft was always harvested from the iliac crest.<sup>19</sup> Before insertion into the maxillary sinuses, which were explored with the same sinus lift technique, the harvested cortico-cancellous bone was particulated in a bone mill (Tessier Osseous Microtome, Leibinger, Germany) and was mixed with blood that was sampled from the crest or drawn from a vein. The milled bone was condensed onto the floors of the maxillary sinus beneath the elevated sinus membrane. The technique used was slightly modified from the technique described by Jenssen et al (1990).<sup>63</sup> After wound closure the region was left to heal for 6 months. Then, where possible, 2 implants were placed in each of the grafted regions. The implants were placed as vertically as possible. Three to 4 implants were placed in the frontal non-grafted bone following the standard procedure.<sup>8</sup> The healing time allowed after implant placement was approx. 6 months.

*1-stage alveolar onlay bloc grafts, 2-stage alveolar onlay bloc-grafts (papers 4,5)*

The bone-graft, always harvested from the iliac crest, was first trimmed to a good fit to the alveolar process, then it was stabilised with 2.0 mm osteosynthesis titanium screws (Leibinger, Germany) and left to heal for 6 months before the implant placement (2-stage procedure)<sup>63</sup> or was immediately stabilised by the dental implants (1-stage procedure).<sup>96</sup> The flaps were carefully shaped and sutured to ensure complete soft-tissue coverage. Implants were placed according to the standard principles.<sup>8</sup>

*Post-surgical care (papers 1,2,4,5)*

Benzyl-penicillin was routinely administered pre-operatively, intravenously and phenoxymethyl-penicillin was prescribed for ten days post-operatively. Analgesics containing paracetamol or NSAIDs was normally prescribed for the immediate post-operative periods. In most cases, the pain from the site where the graft was taken was more intense. However, in all patients the pain from the operated regions was well managed and subsided within two to three weeks post-operatively.

Patients with grafts taken from the iliac crest were normally partially disabled for 1 to 2 months. All patients were totally recovered after three months. No dentures were allowed during the first 10 days after surgery and the dentures were adjusted and relined before insertion. The patients were reviewed during the healing periods for surgical and prosthodontic controls. Any surgical or prosthetic complication during the healing period such as severe pain, dehiscence, fistulae or local infections (e.g. maxillary sinusitis), was registered in the individual protocols. After six months of healing, abutments were connected according to the standard protocol. In general, standard abutments were used. However, the need for angulated abutments to obtain a satisfactory functional and aesthetic result was noted to assess the degree of technical difficulty (paper 2).

*Prosthodontics (papers 1,2,4,5)*

Most of the patients were provided with a gold/acrylic, fixed prosthesis.<sup>8</sup> In the study group (paper 1) 3 patients (8 %) were provided with overdentures, since the number of implants was regarded as insufficient or the load factors were regarded as unfavourable. In the reference group (paper 1), 4 patients (11 %) received overdentures for the same reasons. The overdentures were of a fixed/removable design and the implants were splinted with a gold bar onto which the denture was attached.<sup>97</sup> In papers 2,4,5 all the patients were initially provided with a fixed prosthesis.

***Follow-up***

When the prosthetic treatment was completed and at the 1 year and 3 year control, the patients' protocols, including clinical and radiographic data, were filled in. The protocol included:

- Lengths and position of implants (paper 2)
- Technical data on prosthetic restorations
- Surgical and prosthetic complications
- Immediate and late implant instability
- Marginal bone level on the mesial and distal surface of each implant (paper 1,2)
- Level of grafted bone in relation to the tips of the implants (only paper 2)
- Radioluscent slits between implants and bone, visible on radiographs
- The presence of clinically noticeable peri-implant disease

The radiographic examinations were done using parallel intra-oral techniques.<sup>98</sup> The mean marginal bone loss in grafted and in non-grafted regions was calculated (papers 1,2) as well as the frequency of implants with a marginal bone-resorption > 2 mm (paper 2). At the 1-year and 3-year controls all prosthetic constructions were removed and the individual implant stability was manually tested (papers 1,2).

Those that were clinically mobile were considered to be failures and were removed. The patients who did not agree to the individual implant stability test or the intra-oral radiographic examination were specified (appendix).

***Volumetry (papers 3,4)******radiological (papers 3,4)***

The maxilla was examined radiologically using a CT-scanner (CT Pace Plus, General Electric, Milwaukee, USA) and a software program (9.0, Denta Scan, General Electric, USA). The maxillary alveolar process, including simulated or real bone grafts, was examined with 15 to 20 contiguous axial sections of 2 mm thickness.<sup>99</sup> The borders of plaster or grafted bone, as onlay and inlay, of each radiological section were plotted and the areas were automatically calculated.

The volumes of the simulated grafts were calculated by adding the sums of the plotted areas and multiplying these with the thickness of the sections, using the formula,  $V^{\text{tot}} = \sum \text{of plotted areas} \times \text{thickness of the section}$ . All plotting was done by the same investigator.

To differentiate grafted bone, described as not yet fully calcified woven bone, from the closely related soft tissues, the graft was defined as having a level of attenuation of at least 150 Hounsfield Units (HU).<sup>100</sup> All plotting was done by the same investigator. The radiographic examinations were performed within two weeks postoperatively and again six to seven months later, before implant placement (paper 4).

*Experimental (paper 3)*

Plaster of Paris (Coecal, GC Europe, Leuven, Belgium) was placed bilaterally as buccal alveolar onlays and as maxillary sinus inlays to simulate bone grafts on a dry skull. The pieces of plaster were made water-resistant with a layer of varnish (approx. 0.1 mm thick), (Correctur Roller, Tombo Pen & Pencil, GMBH, Hannover, Germany) and were lowered into a cup of water placed on measuring scales (Fig 1). The volume of the plaster pieces were calculated according to the displaced water technique and the volume of each piece was estimated. The real volume calculation was compared to the radiographic measurements.

Fig 1. Set up for the displaced water technique, acc. Archimedes' principle.

In order to verify the precision of the method and to what extent a non-standardised radiological technique would affect the measurements, three different volumes of plaster were examined using 3 different projections, a) approx. parallel to the palatine process, b) with approx. 5 degrees flexion to the palatine process and c) with approx. 5 degrees extension to the palatine process.

*Clinical (paper 4)*

Augmentation of the maxillary process was performed either as 2-stage sinus-inlay particulate bone grafts or as 2-stage alveolar onlay bloc-grafts. CT scan examination was performed 1-2 weeks postoperatively and approx. 6 months later, before the placement of implants.

## *Torque measurements (paper 5)*

### *Surgery*

Bone grafts to augment the maxilla and to improve the placement of dental implants were done either by 1-stage sinus inlay bloc grafts; by 2-stage sinus-inlay particulate bone grafts or by 1-stage or 2-stage alveolar onlay bloc grafts. The placement of implants in the grafted regions and in the non-grafted regions in patients was performed according to the principles described earlier.<sup>8</sup>

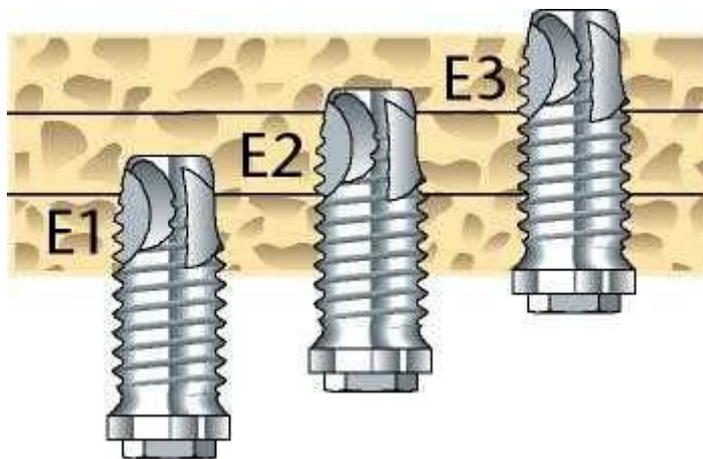
### *Measurements*

The torque measurements were taken by a Torque Controller, DEA 020, Nobel Biocare AB, Gothenburg, Sweden). The actual current needed for the placement of each implant was assessed. The measurements were calibrated prior to each session by subtracting the basic current needed for make the angle-piece move without any load. The voltage over a known resistance and a known current was measured. A data logger was built to store the voltage data, on a memory card with an 8-bit resolution. After each measurement this data was transferred to a PC having a special software application to convert the voltage needed to torque measurements into the torque power given as Ncm.

The cutting torque value for each implant was related to the length of the actual implant and was further separated into thirds of the threaded part of each implant. The torque values were presented as the mean value of;  $E_1$  (first third) the crestal bone,  $E_2$  (second third) the trabecular bone in the middle and  $E_3$  (last third) the apical bone, from the tip to the flange, Fig. 2.

Fig 2.

The energy levels of  $E_1$ ,  $E_2$  and  $E_3$  represent the mean torque when inserting the MKII implant into the first, second and third sections of the site. The apical tip of the implant is excluded from the measurements due to its conical design. The recorded values of each implant comprised the true cutting torque and the friction torque.



### *Statistical methods*

*(papers 1,2,appendix)*

The Albrektsson et al criteria (1986)<sup>88</sup> of success and survival was modified so that implant success was only considered to have been met after an individual manual implant stability control and a clinical investigation. In papers 1 and 2 the stability was individually tested. However, since three patients at the 3-year control in paper 2, refused to agree to the removal of their prosthetic constructions, all implants in this group were defined as survived. Periodically, identical intra-oral x-rays were performed at the 1 and 3 year controls, but the results are only presented in paper 1 and 2, and the definition regarding radiological evaluations for the definition of success are not included in the results.

The 1-year and 3-year cumulative success rate (CSR) of the implant and prosthesis stability is presented in a life table<sup>101</sup> (paper 1,2,appendix). The impact on implant failures of various factors taken individually or in combination, were analyzed using logistic-regression.<sup>90</sup> The probability of future implant failure was analyzed at an individual level with the attention to the number of patients with implant losses (papers 1,2) and was also analyzed considering the loss of 1 or several implants in each patient using the rank sum test (paper 2). The dependence between implants failures in each patient was estimated by the intra-class correlation coefficient (paper 2).<sup>92,102</sup> The interaction-effect between smoking in relation to study group and reference group was calculated from paper 1 and included in these thesis. A students t-test was used to analyze the differences between groups regarding marginal bone loss (paper 2). The level of statistical significance was set at  $p < 0.05$ .

*(papers 3,4)*

The volume of the different grafts was expressed as  $\text{cm}^3$ , median and range. The precision of measurements was given as reliability coefficients.<sup>103</sup> All estimates of the variations between cases and tests were calculated by using ANOVA (paper 3).

The changes from 0 to 6 months and the different reductions in volume between the grafts were analysed by the two-factor ANOVA.<sup>103</sup> The coefficient of variation was calculated to show the difference in volume change within the two groups, inlay (left, right) and onlay (left, right). Linear regression was used to analyse the differences in volume changes compared with different initial levels (paper 4).<sup>103</sup>

In all calculations the statistical significance was set at  $p < 0.05$  (papers 3,4).

*(paper5)*

The analysis were performed with the data regarded as being non-dependent. The impact of graft compared to non-graft on the outcome of variables  $E_1$ ,  $E_2$  and  $E_3$  was estimated by ANOVA-analysis. To analyse the impact of the various

specific types of graft, inlay/onlay and 1-stage/2-stage procedures on  $E_1$ -,  $E_2$ - and  $E_3$ -levels, a two-way ANOVA analysis was performed which also was used to test the three quality-categories, 2-3-4, with the respect to the outcome variables  $E_1$ ,  $E_2$  and  $E_3$ .

The level of significance was set to  $p < 0.05$ .

## Results

### *Clinical*

#### *Papers 1,2*

Implant stability after 3 years in 39 patients in the study and in 37 patients in the reference group (paper 1), is shown in a life-table, Table 2.

*Table 2.* Life table of implant stability, success rate (SR) and cumulative success rate (CSR)

<b>Study group</b>		<b>Total (n:o implants)</b>	<b>Failed (n:o implants)</b>	<b>Withdrawn (n:o)</b>	<b>SR (%)</b>	<b>CSR (%)</b>
Placement -	non-	123	11	-	91	91
- loading	grafted	131	21	-	83.9	83.9
Loading - 1 year	non-	112	4	-	96.4	87.2
	grafted	110	5	-	95.5	80.1
1 year-3 years	non-	108	-	3	100	87.2
	grafted	105	-	2	100	80.1
3 years	non-	105	6	-	94.3	82.2
	grafted	103	6	-	94.1	75.3
<b>Reference group</b>						
Placement – loading		206	6	-	97.1	97.1
Loading - 1 year		200	7	2	96.5	93.7
1 year - 3 years		191	-	10	100	93.7
3 years		181	1	-	99.4	93.1

Implant stability after 3 years in 20 patients in the 1-stage grafting group and 20 patients in the 2-stage grafting groups respectively (paper 2+appendix), is shown in a life-table, Table 3.

One patient, in the 1-stage group, at the 3-year control showed a midline fracture of the fixed bridge. At the control, severe occlusal facets were seen, indicating hyperfunction of the jaw muscles. Two implants, in the non-grafted region were found to be unstable and were removed. This patient is due for replacement of implants and a redesigned bridge. Special attention will then be given to the bruxism habit; a reduction of the cantilevers, reduced occlusal surfaces and a balanced occlusion.

Table 3.

Life table of implant stability, success rate (SR) and cumulative success rate (CSR).

(3 patients rejected the removal of the fixed bridge at the 3-year control).

		Total (n:o implants)	Failed (n:o implants)	Withdrawn (n:o implants)	SR (%)	CSR (%)
<b>1-stage</b>						
Placem. to loading	Non-graft	72	3	-	95.2	95.2
	Graft	76	11	-	85.5	85.5
Loading to 1 year	Non-graft	69	1	-	98.6	94.4
	Graft	65	5	-	92.3	79.0
1 year to 3 years	Non-graft	68	2	10	97.1	91.7
	Graft	60	1	11	98.4	77.7
<b>2-stage</b>						
Placem. to loading	Non-graft	66	1	-	98.4	98.4
	Graft	74	7	-	90.5	90.5
Loading to 1 year	Non-graft	65	1	-	98.5	97.0
	Graft	67	1	-	98.5	89.2
1 year to 3 year	Non graft	64	1	-	98.5	95.5
	Graft	66	2	-	97.0	86.5

The stability after 3 years of the prosthetic constructions (paper 1) was 94.8 % and 97.3 % in the study group and the reference group, respectively.

The stability after 3 years of the prosthetic constructions (paper 2) was 85% in both the 1-stage group and in the 2-stage group.

The marginal alveolar bone resorption in paper 1 and 2 is shown in Table 4.

Table 4. Marginal Bone resorption in paper 1 and 2

<b>Paper 1</b>	<b>0 to 1 year (mm)</b>	<b>1 to 3 year (mm)</b>
Study group	-1.1 ± 0.1 (-4 to 9)	-0.3 ± 0.1 (-4.5 to 0)
Implants in grafted bone		
Implants in non-grafted bone	-1.3 ± 0.1 ( 3.8 to 0)	-0.3 ± 0.1 (-2.4 to 1.2)
Reference group	-0.8 ± 0.1 (-7.2 to 0)	-0.3 ± 0.1 (-2.4 to 1.8)
<b>Paper 2</b>		
1-stage	0.2 (S D 1.0) 5 % >2 mm	-
2-stage	0.2 (S D 0.61) 1.6 % > 2 mm	-
Non-grafted	0.3 (S D 0.54) 5.1 % > 2 mm	-

The correlation of implants placed in 1-stage vs 2-stage bone grafts (paper 2), related to implant failures, angulated abutments and perforation of the sinus membrane during surgery is shown in Table 5.

Table 5

risk of implant failure		angulated abutm	sinus mucosa perforation
1-stage to non-graft	8.9, CI 2.9; 28	40%	27.5%
2-stage to non-graft	4.1, CI 1.2; 14	15%	27.5%
1-stage to 2-stage	2.3, CI 0.6; 8.5		

Implant failures, in relation to local and general factors in papers 1 and 2, studied in a multivariate model, (method 1) and (method 2) is shown in Table 6.

Table 6.

Factors of prognostic influence.	Paper 1 odds ratio	Paper 1 p-value	Paper 2 p-value (method 1)	Paper 2 p-value (method 2)	Paper 2 odds ratio (method 2)
Smoking	0.99	n.s.	n.s.	n.s.	3.1
Health index, ASA = 2	1.69	n.s.	n.s.	n.s.	1.7
Opposing occlusion, own teeth	2.14	n.s.			
Duration of edentulism	0.99	n.s.			
Complications during healing period	11.4	< 0.05	0.07	< 0.05	13.8
Origin of graft, iliac crest	1.5	n.s.			
Reduced initial stability			n.s.	n.s.	1.0
Bruxism			< .05	n.s.	3.0

p-values and odds ratios are given without respect to grafting technique. n.s. = not significant

The interaction effect between smoking and implant failures in the reference- and study groups, respectively is presented in Table 7. Calculations are made from the results in Table 5 from paper 1. The odds ratio for implant failure among smokers in the study group is 2.3 and in the reference group is 0.3. There is a non-significant correlation,  $p=0.08$ , regarding the factor smoking between the two groups.

Table 7.

	odds ratio
Smoker, reference-group	1.0
Non-smoker, reference-group	3.4
Smoker, study-group	7.3
Non-smoker, study-group	16.5

***volumetry (papers 3,4)***

The volumes of simulated using of plaster in the three experimental tests, approx.,  $0^0$ ,  $+5^0$  and  $-5^0$  in relation to the palatine process and the real-volume of each test body is given after the determination using the displaced water test as reliability coeff.; inlay right 0.97, inlay left 0.60, onlay 0.96.

The decrease in bone volume (median, range) after six months, was 49.5% (31-78 %) for sinus inlay and 47% (4-79%) for onlay. The variation in volume changes expressed as the coefficient of variation was; 0.37 (inlay right); 0.39 (inlay left); 0.74 (onlay right) and 0.85 (onlay left). There was no significant difference in the resorption of onlay grafts compared with inlay grafts in individual patients, although the range within the onlay group was significantly wider,  $p < 0.05$ .

Significantly lower graft volume was noted in all groups at the 6-month control,  $p < 0.001$ . Significantly greater volumes of bone were grafted to the right maxillary sinus compared with the left, this did not influence the actual reduction,  $p < 0.05$ . The greater the initial volume, the greater was the decrease,  $r = 0.70$ ,  $p < 0.001$ .

Altogether 68 implants were installed, this distribution and 1-year follow-up are shown in Table 8. Since the prosthetic constructions were not removed, survival rates within each group were calculated as a 1-year CSR of 97.1 %.

Table 8. Implant stability after 1 year, survival rates are given.

<b>Grafted</b>	<b>Total no of implants</b>	<b>No of failed implants</b>	<b>SR (%)</b>	<b>CSR (%)</b>
Placement to loading	38	1	97.1	-
Loading to 1 year	37	-	100	97.1
<b>Non-grafted</b>				
Placement to loading	38	1	97.1	-
Loading to 1 year	37	-	100	97.1

***torque measurements (paper 5)***

The implants were followed up to the 1-year control which was performed without an individual implant stability test, to subsequently give the rate of survival. The results are shown in Table 9.

The dropout figure in the grafted group was 5 implants and 3 implants in the non-grafted group. Since the 1-stage onlay block group only contained measurements from 4 implants it was excluded from further analyses.

Table 9.

<b>Grafted</b>	<b>No of implants</b>	<b>No of failed</b>	<b>SR</b>	<b>CSR</b>
Placement to loading	117	6	94,9	-
Loading to 1 year	111	10	91.0	86.4
<b>Non - grafted</b>				
Placement to loading	109	9	91.8	-
Loading to 1 year	100	5	95.8	87.2

Twenty of the failing implants were seen in 4 patients.

The torque measurements from each individual grafting procedure and from non-grafted regions are shown in Table 10.

Table 10. Cutting torque values (Ncm) in the three grafted situations and in control/non-grafted sites, 1-stage inlay bloc graft, 2-stage particulate graft and 2-stage block particulated graft.

	<b>Control/non-grafted</b>	<b>1-stage inlay block</b>	<b>2-stage inlay part.</b>	<b>2-stage onlay block</b>
	Mean (SD) n=109	Mean (SD) n=30	Mean (SD) n=46	Mean (SD) n=37
E <sub>1</sub>	21.3 (8.6)	18.7 (6.2)	14.7 (8.0)	11.2 (5.5)
E <sub>2</sub>	43.1 (23.3)	27.9 (15.6)	21.9 (13.3)	17.8 (9.8)
E <sub>3</sub>	73.0 (40.3)	43.9 (30.3)	41.1 (26.0)	34.7 (15.1)

The comparison between inlay- (particulate) and onlay- (bloc) grafts after 6 months of healing (two-stage) revealed that significantly higher energies were needed for placing implants in particulated grafts (inlay) compared to bloc grafts (onlay), ( $p < 0.001$ ). The analyse of the two variants of bloc grafts, one-stage inlay to two-stage onlay demonstrated that significantly higher torque energies were required at the 1-stage inlay procedures.

In relation to control, significantly lower torque values were seen for the delayed bloc graft, two-stage onlay procedures. When comparing torque measurements to the clinical estimation of bone quality acc. to Lekholm & Zarb (1985)<sup>2</sup>, a strong correlation was seen on all levels E<sub>1</sub> - E<sub>3</sub>,  $p < 0.001$ . At all levels, the placement of implants in type 4 bone required the least torque, and placing implants in type 2 bone needed the most.

In the analyse of implant failures, total and early before loading, lower torque values were registered compared to clinically stable implants. However, these differences were not statistically significant.

## Discussion

### *Comments on patients and methods*

The patients included in this thesis were all maxillary edentulous and the aim of the treatment was rehabilitation with fixed dental bridges. In order to specify the inclusion criteria, it was decided that only patients with a maxillary posterior alveolar height of less than 5 mm should be included (papers 1,2,4,5). Patients with an alveolar height of < 5-7 mm and width of < 5 mm in the anterior maxilla received in general onlay block bone grafts (papers 4,5).

### *Medical factors*

In defining the medical status of the patients, the ASA-score was introduced (papers 1,2,4). This anaesthesiological risk index makes possible the identification of medically compromised patients for further analysis. There is currently no consensus as to any definite medical contra-indication for implant treatment.<sup>65</sup> The patients included in this thesis were mostly classified as ASA 1. Since implant treatment is elective by its nature, a few patients (diabetics, hypertonics) who were initially classified as ASA 3, were "transferred" to ASA 2 after receiving appropriate medical treatment. It is interesting to note, that the reference group (non-grafted) (paper 1) had the highest number of patients in ASA 2, 35%. In no way could this factor be shown to be of prognostic importance to implant failures.

### *Smoking*

Smoking habits were recorded in two ways. In papers 1 and 4, each patient was asked with regard to the smoking habits at the start of the treatment. In paper 2 the patient was classified as a smoker if this habit exceeded 5 cigarettes a day. No objective tests, such as recording nicotine levels in urine or blood, were done and no further questions regarding the extent or duration of the habit were put. No patient was denied the actual treatment because of high tobacco consumption, although efforts were made to encourage them to reduce their use. It is noticeable from paper 2, that as many as 40 % of the patients smoked 5 cigarettes or more at the start of the surgical treatment. In none of the studies (papers 1,2,4,5) were further questions asked during or after the treatment. Few clinical studies have given significant information about the influence of smoking apart from Bain et al (1993).<sup>104</sup> However several experimental studies have clearly shown the negative influence of nicotine on bone grafts.<sup>105-107</sup>

### *Bone quantity and bone quality*

Bone quantity in the grafted patients was classified according to Cawood and Howell (1988)<sup>71</sup> as Class V and VI, indicating a severe jaw atrophy which in this thesis could be explained by the fact that more than 50% of the patients (papers 1,2) had been maxillary edentulous for more than 10 years.

The Cawood & Howell classification describes the increasing atrophy over the years of edentulousness. The Lekholm & Zarb index (1985)<sup>2</sup> was used for the bone quality classification of the implant site (paper 5).

There has been speculations on the effect of osteoporosis on jaw bone, although no studies have demonstrated this influence on maxillary bone structures.<sup>77-79,108,109</sup> No patient in these studies had been diagnosed with osteoporosis so no patient was on any medication, i.e. bifosphonates or steroids. Bifosphonates, being osteoclast-inhibiting, ought in future, to be further studied in relation to the mechanisms of bone graft healing. Interesting data has also recently been published on the positive effects on early bone healing, in normal and also in compromised implant sites, after the local application of bifosphonates.<sup>110,111</sup>

*Comments on cutting torque measurements*

The cutting torque values recorded at the insertion of implants after 3 different grafting procedures were evaluated in paper 5. The differences in bone density of the mandible and the maxilla had previously been verified by this method.<sup>83</sup> Since recordings were made with implants of different cutting abilities and different drill-diameters, the results reflect the stability of the actual implant. The recordings made in paper 5 were standardised: one operator, using a twist drill of the same diameter of 3 mm, and self-cutting Mk 2 implants. The value of each recording does therefore reflect the bone structure of the actual site.

Each registration reflects the sum of values from the true cutting torque, the idling torque and the friction energy. The idling energy was prior to each recording estimated. The friction torque was difficult to assess while placing implants in various bone qualities. Due to the mixture of residual and grafted bone in each site, the friction energy was likely to differ depending on the recorded level E<sub>1</sub> to E<sub>3</sub>. Comparisons of recordings taken from different levels i.e. onlay grafts on E<sub>1</sub>-level and inlay grafts from E<sub>3</sub>-level are therefore difficult to make, because of marked differences in the bone structure.

Others have shown that implants placed in bone quality 4 show increased implant failure rates.<sup>72,73</sup> In paper 5, a strong correlation between low torque values and bone quality 4 was seen, verifying the observation by Friberg (1999).<sup>83</sup> Based on these studies, initial stability seems to be of importance to achieve a permanent osseointegration. Reduced initial stability was noted in 6 implants in paper 2 (2-stage surgery). It is however a draw-back in these papers not to preoperatively have made a clinical definition of reduced initial stability.

We were not able to show any significant correlation between early implant failures, or implant failures as a whole, and cutting torque values. Preliminary data using RFA on implants in compromised sites, has identified implants at risk of later failure<sup>112</sup> and the benefits of extending the healing period were speculated on. On the other hand, the healing and the permanent stability of an

implant in the bone grafted maxilla is influenced by a great number of factors and is not likely to be detected by a single measurement or estimation. Using RFA, it has recently been suggested that implants placed in maxillary bone grafts will achieve increased stability during the early healing period.<sup>87,113</sup> *If placing implants in sites with reduced stability, i.e. after a bone grafting procedure, it seems recommendable to extend the healing periods, before loading.*

#### *Maxillary sinus mucosa*

The importance of keeping the sinus mucosa lining intact, has been discussed and different processes have been recommended. Kent et al (1989)<sup>45</sup>, suggested postponement of the sinus inlay bone-graft in the event of a major perioperative tear of the sinus membrane, and Keller (1999)<sup>114</sup> recommended the use of bloc grafts instead of particulated grafts in the same situation.

In our first paper we decided not to evaluate the eventual sinus membrane tears. To place intra-sinus bloc grafts as is discussed in paper 1, a fairly large opening to the maxillary sinus is needed, which would probably implicate a greater risk of tears to the mucosa and these are difficult to detect. In paper 1, the influence of complications during the healing period on implant failures was demonstrated so we decided to register tears of the sinus membrane in the following studies. In this paper (2), we found that 27% of the sinus cavities revealed perforations in the mucosa. Two patients developed acute sinusitis postoperatively; in one patient this was following an upper airway infection and in the other the bone graft was found to be unstable. In paper 4, no mucosa tear was detected. The marked volume decrease in several of the sinus grafts, could not be correlated to this or to any other patient- or operator-specific factor.

Our patients were clinically and radiographically free from pathology in the maxillary sinus at the start of the grafting procedures and at the 3-year control. It should however be emphasised that plain radiology techniques correlate poorly with sinus pathology compared to antro-scopy,<sup>115,116</sup> and thickening of the sinus mucosa is seen on x-rays in approx. 20% of the population but does not equate to a diagnosis of sinusitis. Timmenga et al (1997)<sup>117</sup> reported on a follow-up study of 45 patients treated with sinus lift. This involved questionnaires and radiographic and naso-endoscopic examinations. Only patients with a previous history of chronic maxillary sinusitis showed postoperative symptoms of sinusitis, which was also shown to predispose them to implant loss in sinus inlay grafting. The conclusion of the Sinus Consensus Conference<sup>57</sup>, "that as long as the sinus graft does not interfere with ostiae function, grafting in the area of the maxilla is not contraindicated physiologically and is a generally benign procedure" seems therefore justified.

#### *Antibiotics*

The justification of prophylactic antibiotics in dental implants without bone grafts has been discussed.<sup>65,118</sup> All our 166 patients (paper 1,2,4,5) received antibiotics according to the same protocol. The immediate postoperative

infections were few (approx. 10 %). The definition "post-operative complication" included both infectious and non-infectious sequelae, and these were found significantly associated with implant-failures. However, *there is presently no data to support the omission of prophylactic antibiotics during bone-grafting procedures as described in these papers.*

### *Analgesics*

In experimentally induced fractures in rodents it has been shown that indomethacin significantly inhibits bone formation and reduces the mechanical strength of the bone and the amount of mineralized callus.<sup>119-121</sup> The more modern non-steroidal-anti-inflammatory drugs, NSAIDs, are likely to have a similar influence on bone healing, causing inhibitory effects on the prostaglandin synthesis. Its deleterious effect of postponing fracture healing and inhibiting ectopic bone-formation, has been evaluated in a randomized clinical study on diclofenac (Voltaren<sup>R</sup>).<sup>122</sup> Similar effects of indomethacin and diclofenac have also been shown in experimental studies.<sup>123</sup>

The influence of NSAIDs in the clinical situation on bone healing is still unclear, and the possible negative influence of postoperative medication by diclofenac cannot be evaluated in these studies since this was one of our standard analgesic drugs. *Based on the studies mentioned, it is recommended not to use NSAIDs in situations with impaired healing, i.e. in bone-grafting procedures.*

### *Comments on statistical methods*

The clinical results from these thesis (papers 1, 2 including appendix, 4, 5) were presented in a life-table design.<sup>101</sup> With this design, the results including drop outs, within each defined time-period was presented. All the patients were followed for the whole of the time-period. The difference between success and survival was modified by using the individual implant stability-test or not. All the patients from Paper 1 and 2 (including 3-year follow-ups), except for three patients, fulfilled this definition of success.

Intra-oral radiographs of each implant were used for the study of peri-implant radiolucencies and for alveolar bone level calculations. This measure might be unnecessary, since bone grafts studied in papers 1 and 2 were placed as inlays and the marginal, residual bone was studied. As shown in Paper 1, several clinically unstable implants were detected after the removal of the prosthetic constructions and were not found as a result of the radiographic assessments. Conversely, in Paper 2, peri-implant radiolucency was seen close to 3 implants that were found to be stable at the mobility test which was performed later. However, radiography has shown a high positive prediction, 83%, in finding failed implants.<sup>124</sup> *Based on experience from this study, the individual stability test seems to be a more useful tool for finding unstable implants than radiography.*

It is well known that the majority of implant failures are mostly seen in a small number of patients.<sup>90</sup> This cluster phenomenon was also seen in these studies; in Paper 1: 14 patients out of 24 lost more than 1 implant; in Paper 2; 13 patients out of 17, lost more than 1 implant; in paper 4; all, 2, implants were seen in the same patient; paper 5: 2/3 of the failed implants, 30, were seen in 4 patients. It has therefore been suggested that implant failures should be considered as patient-dependent both before and after loading, and that the analysis should be made at the individual level.<sup>89</sup>

In Paper 1 and 2 (method 2), calculations were made at the individual-level - patient with implant failures or not. The intra-class correlation coefficient calculated in Paper 2 was 0.58, indicating that 58 % of the variation was seen among the patients, since a fairly high number of patients were seen with more than one failed implant.<sup>102</sup> Since the intra-class correlation coeff., calculated in Paper 2, revealed the cluster phenomenon, the patients with failures were also ranked according their number of failed implants (method 1).

This observation, probably present in many other clinical cohorts, is favouring that the statistical analysis should be performed using the Rank Sum Test.

### *Comments on results*

The 3-year results of implant stability in the two clinical studies from grafted regions were: 75.3 % (Paper 1), 77.7% (1-stage, Paper 2) and 86.5 % (2-stage, Paper 2) respectively. Implant stability in non-grafted regions in the same studies were: 82.3 % (1); 91.7 % and 95.5 % (2) respectively. These results reflect the success rates, although a few results from Paper 2 reflect survival-rates, since individual implant stability was not obtainable from 3 patients out of a total of 40. However, all the implants in this "surviving" group of patients were functioning well and therefore the survival rates seem therefore accurate.

It is difficult to compare with other studies since follow-up routines (success-survival), inclusion criteria and follow-up periods differ. Nevertheless, these results are fairly comparable for sinus-inlay grafting procedures. Others showed 86 % survival after 33 to 41 months of follow-up<sup>64</sup>; 80 % survival after average follow-up of 22 months<sup>50</sup>; 83% survival after 1 year,<sup>125</sup> and 81 % after more than 3 years of follow-up in a multicenter-study.<sup>55</sup>

Bridge stability in study (1) and (2), also corresponded well with others. After 3 years 37 out of 39 patients in Paper 1 (94) and 37 patients of totally 40 had functioning prosthetic constructions after 3 years, 93 % (paper 2). Corresponding figures have been reported in other studies.<sup>55,64</sup> Most studies report of clusters of implant failures in a few patients.<sup>41,47,125,126</sup> In this thesis this was verified from Study 1 -14 patients of totally 24 patients with implants failures and from study 2 - 13 patients of 17 patients lost more than 1 implant each. In Papers 4 and 5, the corresponding 1-year results from grafted regions were 97 % (survival rate) and

90 % (survival rate) and a similar cluster phenomenon was also seen in Paper 5, since 2/3 of the failures were seen in 4 patients. *This cluster phenomenon is an important observation and highlights the importance of identifying patients who are at risk, before the start of treatment and focussing on the failed patients when evaluating the results.*

The success/survival rates from the reference group (Paper 1) and these from non-grafted areas (Paper 2) are in accordance with other reports on Brånemark implants.<sup>54</sup> In both Papers (1,2) the success/survival rates after three years in use were significantly lower than in non-grafted anterior maxillary bone or compared to the reference group. This observation is also seen in other controlled studies<sup>125</sup> but the benefits of bone grafts in the reconstruction of maxillae have been reported in a study of 150 patients with edentulous maxillae and it was therefore concluded that "it seems possible to improve an initially poor bone situation by means of augmentation".<sup>127</sup>

The volume-changes in maxillary bone grafts were evaluated (Paper 4). In this study it was shown that the median decrease after 6 months of healing was 49.5 % in onlay block grafts, and 47 % in inlay particulate grafts. The precision of the method was determined and was used in a follow-up designed study. In planning bone grafting procedures, this possible decrease of graft volumes must be taken into consideration. Despite the wide range, these figures correlate well with the clinical impressions from others,<sup>50,64,125</sup> that occasionally extensive volume reductions of onlay grafts are seen after 6 months in healing before the placement of implants. Nyström et al (1995)<sup>98</sup> showed a significant reduction in the height and width of alveolar onlay bloc grafts and speculated about the difference in reduction, seen between the sexes. We did not test this factor, since the majority of our patients in this study were women. The changes in volume of sinus inlays have not previously been evaluated. Our results (Paper 4) showed a similar level of decrease compared with onlays, but also a similarly wide range.

The better soft-tissue covering due to the onlay flap seems therefore to have no influence on the maintenance of graft volume. On the other hand, the observation of the faster ingrowth of vessels seen in trabecular bone grafts compared to block grafts<sup>24</sup> might similarly be seen in the healing of particulated bone grafts.

It might be suggested that additional CT-scans of the volumes of maxillary bone grafts at a later stage of the healing process is performed. However, Nyström et al (1986)<sup>98</sup> showed that the large reduction in width of the onlay graft, was seen during the initial postoperative 3 months and that the reduction in block graft height was stopped after the first year of healing. The physiological stimuli to the onlay block graft by occlusal loads seem to be the most probable reason for this relative volume stability and it would be tempting to apply these observations also to the sinus-inlay situation. From the histological point of view, however, 6 or even 12 months of healing seems to be too short a period for complete recovery.<sup>23,24</sup>

Presenting the results in a life-table, makes the distribution of failures clear. Esposito (1998)<sup>54</sup> in a literature survey of implants in grafted and in-non-grafted bone, suggested a categorisation into early (before loading) and late (after loading) failures and showed that approx. 50 % of implant failures happens before loading. In this material (Papers 1 and 2), after three years of loading, approx. 50 % of the failures seen, had been recorded before loading. *These early failures can be regarded as due to biological, host reactions and the late ones due to an imbalance between bone remodelling capacity and load factors, each situation needing to be evaluated separately. It seems that after being initially high, the implant failure rates decline and level out. However, this stability could be disturbed by changing biological and biomechanical factors.*

Measurements of the marginal bone level in relation to implants were performed up to 1 year (Papers 1,2) and up to 3 years (Paper 1) using intra-oral radiographic techniques.<sup>98</sup> The changes after the first year of loading in paper 1 were significantly greater than in Paper 2. This reduction, comparable to other studies,<sup>8</sup> is likely to be due the fact that base-line calculations were taken from an estimated implant level (Paper 1), but the figures from Paper 2 were taken from the radiographically calculated base-line level. The figures in Paper 1 are well within the definition of success according to Albrektsson (1986).<sup>88</sup>

Gröndahl et al (1997)<sup>124</sup> evaluated the predictive value in radiography of implant stability and found that 5 % of implants were found to be unstable without however being previously detected on x-rays. In this clinical material the same observation was made with a few implants in Paper 1, and 6 implants in Paper 2, all diagnosed as being false positive.

Since, in studies using well documented implant designs and routine procedures, radiography seldom shows diverging mean values,<sup>65,89</sup> in Paper 2 we decided to calculate the frequency of marginal bone resorption of >2mm, which was found to be approx. 5 %. No patient was found to have both marked marginal bone resorption *and* purulent gingivitis, and subsequently no case of peri-implantitis was documented, which is probably due to the surface properties of Brånemark implants and good control of load factors.<sup>128</sup>

The odds ratio for implant failures in 1-stage and 2-stage procedures were found to be significantly different to the non-grafted areas, 8.9 and 4.1 respectively. Comparing 1-stage to 2-stage after the first year of loading, the odds ratio were in favour of 2-stage procedures, but were not statistically significant after the first year of loading. After 3 years of loading, this difference in odds remained constant but this was still not a statistically significant difference. However, *since 1-stage bone grafting procedures have been shown to be technically more demanding, with extended surgical time and a more angulated position of the implants, and since both histological and biomechanical factors seem to favour 2-stage procedures, 2-stage procedures seems to be recommendable.*

### *Factors of prognostic influence*

The factors of prognostic influence on implant stability were studied in univariate and multi-variate analysis in both clinical studies (Papers 1,2) Similar results were found regardless of whether the analysis was performed using logistic regression (paper 1 and paper 2, method 2) or rank sum test (paper 2, method 1). In Paper 1, complications during healing were found to be significantly associated with implant failures and in Paper 2, the habit of bruxism was found to be significantly correlated to implant failures.

The habit of smoking was more frequently seen in the group with failed implants within the grafted group in Paper 1, but it was of no statistical significance, since the opposite findings were seen in the reference group. If specifically analysing the study-group, smoking habits were seen to increase the implant failures with the odds ratio of 2.3, however not statistically significant, but smoking was in the non-grafted group seen to *decrease* the implant failures with the odds ratio of 3.4, not significantly significant.

Others have reported that smoking negatively influenced the stability of implants in a large group of non-grafted patients.<sup>104</sup> The negative impact of smoking plus and a history of previous sinusitis have been reported in a previous study, of 54 patients, although there was no statistical evaluation.<sup>114</sup> Timmenga (1997)<sup>117</sup> reported on the negative influence of a previous history of maxillary sinusitis on sinus-inlay bone grafting healing. The Sinus Consensus Conference<sup>57</sup> agreed to recommend stopping smoking for "weeks or months" before the grafting and to extending this into the healing phase. It must however be concluded, that according to the related findings the impact of smoking on the healing of bone grafts and dental implants is not yet fully explored.

Schliephake et al (1997)<sup>129</sup> performed a multivariate analysis on the various influences on implant failures in 137 maxillary bone grafted patients and having found significantly worse prognosis in females, they speculated on osteoporosis as one influencing factor. Blomqvist et al<sup>108,109</sup> tried to determine any factors of influence for implant stability in bone grafted patients using osteometric and endocrinological analysis but found contradictory results.

Factors of prognostic influence for implant treatment as a whole, have been discussed by Weyant (1994)<sup>76</sup> who pointed out that the patients medical status and any surgical and healing complications were of significant importance. These results are not directly applicable since more than 15 brands of implants were included and no patients were bone grafted. Two patients in each paper (1,2) developed acute sinusitis after the bone-grafting, although all patients were free from maxillary sinus pathology preoperatively, so these complications seemed instead to be due to the surgical procedures.

Complications during the postoperative phase, previously described, showed (in paper 1) significance and a slight but not significant correlation to implant

failures in paper 2. This observation supports the theory, that maxillary bone-grafting is surgically dependent. Keller (1987)<sup>130</sup> repeated the factors (previously described by Breine and Brånemark (1980)<sup>40</sup> of importance to the healing of maxillary bone grafts, these are: flap integrity; operation time; graft handling; graft stability; loading and healing time.

The factors of importance to be statistically verified from this thesis: such as complications during the healing periods and occlusal overload (bruxism) are all factors over which it is possible to keep control, by accurate and careful surgical techniques and by thorough follow-up regimes. *Since prognostic factors, positive or negative are cumulative, the recommendations must include a thorough assessment of the patient before treatment.*

Initial implant stability has been stated as being of great importance to permanent osseointegration<sup>131</sup> and reduced bone quality has proved to increase the risk of future implant failures.<sup>73</sup> In situations with reduced bone volume in the maxilla, autogenous bone grafting techniques have proved its value.<sup>47</sup> Primary stability is monitored by: bone quality; surgical techniques, and implant design while the secondary stability is the result of : primary stability; implant surface, and the bone remodelling capacity.<sup>132</sup>

In order to evaluate the bio-mechanical properties of maxillary bone grafts, the cutting torque values at the placement of implants were registered. The difference between grafted regions and non-grafted regions were shown to be significant although it was not significant in relation to particulated grafts using delayed implant placements. The lowest cutting torque was registered when placing implants in sinus-inlay bloc grafts in a delayed, 2-stage procedure. The significant difference, in relation to both sinus block inlays (1-stage) and sinus particulate inlays (2-stage), must be due to biological factors. The revascularisation and the normalisation of biomechanical properties of block grafts takes long, sometimes up to 2 years,<sup>23</sup> so the onlay block graft gives still after 6 months a reduced biomechanical stability. This observation, histologically verified in a case report,<sup>133</sup> must be taken into account when designing the early occlusal loads on the implants.

The healing pattern of implants in contact with bone grafts favours the delayed implants placement procedure.<sup>60,62</sup> Nevertheless, as been shown in this thesis, implants and 1-stage bloc grafting procedures have given predictable and quite acceptable results.<sup>134,135</sup>

In all the regions, the cutting torque values from implants that later failed were lower than for stable implants, although this difference was not statistically significant. Since implants fail for various different reasons, it is unlikely that we can identify these failures by using cutting torque measurements alone. If using RFA<sup>87</sup> it has been shown possible to identify implants at risk.<sup>86,112</sup>

Cutting torque values from crestal level,  $E_1$  are well correlated to RFA values.<sup>112</sup> This observation highlights the importance of the residual bone height to the initial stability, a factor that not always is reported in clinical follow-up studies. In a cross-sectional study of RFA performed on patients with bone grafts and le Fort 1 osteotomies in 2-stage procedures, Rasmusson et al (1999)<sup>87</sup> found a tendency to increased implant-stability over time. In a similar set-up, but longitudinally designed, Sjöström et al (2000)<sup>113</sup> reported on the decrease of implant stability after the placement of implants and during the following 6 months. This was based on a group of maxillary edentulous patients who had reconstructions with onlay/ sinus inlay and interpositional bone grafts/ le Fort 1 osteotomies, all in 2-stage procedures, After further healing and 6 months of occlusal, prosthetic load, the stability of the implants, as evaluated with RFA, increased to a similar level to implants placed in non-grafted regions.

The results from this study are consistent with the clinical observation in this thesis and with the related histological studies,<sup>23,24</sup> that after initially reduced properties, the grafted maxilla will catch up to the biomechanical and biological level of the non-grafted maxilla.

The **aims** are repeated here together with the **conclusions** on the opposite side.

1. studying the prognosis for 1-stage sinus inlay maxillary bone-grafts and relating these findings to a reference group of non-grafted patients.
  
2. studying and comparing the prognosis and treatment outcomes in a randomised study of 1-stage to 2-stage sinus inlay bone-grafted patients.
  
3. identifying the specific factors influencing the prognosis of implants placed in maxillary bone-grafted patients.
  
4. studying and comparing the changes in volume of bloc- and particulate bone-grafts to the maxilla.
  
5. evaluating the cutting torque values needed for the installation of implants in grafted and non-grafted maxillary bone.

## CONCLUSIONS

1. 1-stage sinus inlay bone-grafting and dental implants in a group of maxillary edentulous patients and showed a predictable outcome and acceptable success rates, for implant and bridge stability, although these were lower than amongst the reference group of non-grafted patients.
2. predictable and similar results, regarding implant and bridge stability, were found in a randomised, clinical study of 1-stage and 2-stage maxillary sinus inlay bone-grafting.
3. bruxism and complications during the healing process were found to negatively influence implant stability in sinus inlay bone grafted patients
4. the changes in bone volumes, estimated by computed tomography, of onlay block grafts and of sinus-inlay particulate grafts showed a similar decrease of about 50 % after 6 months of healing before the placement of implants, although a wide individual variation was seen.
5. significantly lower cutting torque values were seen in maxillary grafted bone when compared to non-grafted bone, the clinical bone-quality description acc. to Lekholm & Zarb was significantly correlated to the cutting torque values and placing implants in onlay bloc grafts in a 2-stage procedure showed lower cutting torque values.

## **Perspectives**

Despite, that autogenous bone grafts and dental implants in the reconstruction of the edentulous maxilla, today are time-consuming and might be regarded as not fully physiologic, still good and predictable results are achieved.

Bone Morphogenic Proteins have not yet proven to be useful in the clinical practice, however preliminary results from the use of Platelet Rich Plasma-techniques seem promising. Callus-distraction techniques, not yet fully evaluated clinically or biologically, might be useful for special indications. In ultimate patients, with impaired healing capacity, micro-vascular bone grafts might come to use.

The changes in surgical techniques, with individualised healing periods and prosthetic loads have already proved its efficiency. Altered implant surface design might be beneficial, however needs to be clinically verified. The benefits of extra long implants in order to find stable bone anchorage in the zygomatic buttress need also to be proven in large controlled clinical studies.

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