# DIGITIZED & COMPUTERIZED RECORDKEEPING IN DENTISTRY (Orthodontics):

## A Technologically Advanced Alternative to the Analysis and Storage of Study Models

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Thesis presented in partial fulfillment of the requirement for the degree of
**MSc in Dentistry**

University of Stellenbosch
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**December 2002**

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**Digitized and Computerized Record keeping in Dentistry:**

A Technologically Advanced Alternative to the Analysis and Storage of Study Models

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A Research Report submitted to:

The Department of Applied Oral Health Science,
Division Orthodontics, Faculty of Dentistry, University of Stellenbosch,

for the fulfillment of the requirements for the degree of MSc in Dentistry



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# Declaration

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and that it has not previously in its entirety or in part been submitted at any university for a degree.

**Signature :** ............................... **Date** 30.08.2002

**A D Kleinloog**

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# Dedication

This research I have dedicated to my lovingly caring husband, Rob, my delightfully precious children, Andrea, Liza, Roscoe, Stephné and my wonderful friends, for their support, patience, understanding and love.

Appreciation is also expressed in this research to the Dental Profession for providing me with the necessary background, experience, knowledge and insight to pursue and persevere.

Without you, none of this would have been possible.

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# Abstract

The research is aimed at investigating and finding alternatives to the physical necessity of producing and storing plaster casts or stone models of the tissues of the mouth. The quest for time and space is universal and the successful management of both results in stress free, financially stable and uncluttered work circumstances.

Study models do play a very important role in diagnostics and treatment planning as well as communicating final results in Dentistry, especially in Orthodontic practice. Conventional study models are bulky, fragile, and expensive diagnostic tools produced from impressions taken of the patient's mouth and cast in plaster or stone. The storage of these records creates major space problems, and recalling or retrieving models at some later stage also causes logistical problems.

Ideally, the tissues of the mouth could be scanned and from this a 3-D image produced on screen, which could later be milled (machining process of reproducing, explained in Appendix B) if necessary.
Three dimensionally accurate, visually pleasing, reproducible, measurable and retrievable records, would be the solution. Computerizing dental records has already revolutionized the industry in the fields of Radiology and written patient data. This information is available at the click of a mouse, and integrated diagnostic tools can be displayed on screen.

A thorough investigation of all methods of capturing dental data and 3D images from previously researched and publicized studies was conducted before attempting the latest technology. The final project involved:

1. requesting an introductory and explanatory demonstration on the scanning possibilities in South Africa
2. organizing and attending a demonstration of the laser and contact scanner on study models and impressions.
3. undergoing training in the use of a contact scanner. Computerizing of these results and comparing data derived from analyzing both study models and impressions, manually and digitally.
4. researching and collecting of data with engineering professionals, to establish the validity and viability of this method ( aiming to use uncomplicated, widely accepted and thoroughly applicable basic criteria in all experiments.)
5. evaluation of data statistically by a statistician.


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**Discussion:**
Digitizing and computerizing of images derived from scanning the models or impressions offers the most attractive alternative for record keeping.

Laser scanning disappointed in general due to the relative unavailability in South Africa, the expensive nature of the service elsewhere and limiting factors due to the sensitivity of the laser beam. It is the most promising alternative in future research, because of improved accuracy, higher speed of scanning, uniformity and reproducibility.

Contact scanning proved to be available, reliable and adjustable. In most applications, the best results in terms of accuracy and quality of surface finish are obtained using contact scanning. The disadvantage of this method is the time factor and therefore it becomes expensive and economically not viable.

The direct scanning of impressions, albeit with laser or contact scanning, remains a scientific and clinical viable option.

**Conclusion:**
Digital imaging is still a young technology and many aspects are not yet completely explored. It is a promising technology and its significance is increasing because it opens the door to diagnostic information.

Another important development is that the software for digital imaging will become more integrated with other computerized dental applications in the dental office, enabling patient data between different and remote practices to be exchanged more easily.

Further progress is not limited by a lack of available image processing tools but rather by our restricted understanding of the various components of diagnostic imaging in dentistry. A Bioengineering exhibition mounted by the University of Munich during a December 2000 conference, displayed a specially adapted CT Scanner that could scan information directly from the mouth. This leads to more possibilities of deriving images without impressions or study casts.

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# Opsomming

Hierdie navorsing was spesifiek gerig daarop om die bergingsprobleem van studiemodelle op te los. Die klem was gele op die beskikbaarheid van ander metodes en die seleksie van die mees gesogte metode. Met behulp van gebruiksvriendelike toerusting , tegnologie en sagteware was die metode op die proef gestel. Die soeke na onbeperkte tyd en spasie is algemeen, en die suksesvolle hantering en beplanning beide tyd en spasie lei tot 'n relatiewe spanningsvrye, finansieel stabiele en ongekompliseerde praktyk.

In tandheelkunde en veral in Ortodonsie, speel studiemodelle 'n baie belangrike diagnostiese rol en is onmisbaar met die verduideliking van 'n behandelingsplan. Die voorspelling van die finale resultaat van behandeling en die kommunikasie daarvan word drie dimensioneel vergemaklik met fisiese modelle .

Konvensionele modelle word gegiet in gips vanaf die afdrukke van 'n pasient se mond. Die eindresultaat is groot, breekbare, lomp en duur om te vervaardig modelle wat spasie en logistiese probleme veroorsaak met die storing en herroeping daarvan.

Akkurate drie dimensionele, stoorbare, herproduseerbare, opmeetbare en herwinbare rekords is die antwoord op die probleem!

Die beskikbaarheid van ander gerekenariseerde tandheelkundige data is reeds besig om groot veranderings in radiologiese en geskrewe rekord se gebiede te veroorsaak. Inligting is onmiddelik beskikbaar en verskeie diagnostiese opsies kan gelyktydig op die skerm bestudeer word.

Voordat 'n indiepte studie van die nuutste tegnologie op hierdie gebied nagevors kon word, was 'n deeglike ondersoek van alle metodes van drie dimensionele vaslegging van tandheelkundige inligting en rekords gedoen. Die ondersoek het op vorige navorsingswerke en publikasies gefokus.

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Die finale werkstuk sluit die volgende aspekte in:

1. inleidende demonstrasie in die skanderings-moontlikhede in Suid Afrika met behulp van 'n Laser en Kontak Skandeermasjien
2. beplanning en bywoning van 'n demonstrasie sessie op persoonlike studie modelle met behulp van beide kontak- en laser-skandeermasjiene
3. onderrig en opleiding in die gebruik en toepassing van skandeer apparaat. Rekenarisering van die verkrygde resultate en vergelyking met 'konvensionele opmetings' van dieselfde modelle.
4. navorsing en praktiese ondervinding tesame met opgeleide inginieurs, om die wetenskaplike waarde van die metode te bepaal.
5. statistiese evaluering van alle data deur 'n erkende statistikus.

**Bespreking:**

Die beste alternatiewe metode vir die stoor van studiemodelle en afdrukke blyk die digitering en rekenarisering (meganisering) van skermbeelde te wees.

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Alhoewel die laser metode oor die algemeen teleurstellend was as gevolg van die relatiewe onbeskikbaarheid en gevolglike onervarendheid in Suid Afrika, word dit ook beperk elders deur ekonomiese implikasies en die komplikasies veroorsaak deur die relatiewe sensitiwiteit van die laserstraal. Dit bly steeds die belowendste roete vir toekomstige navorsing a.g.v die akkuraatheid, spoed, eenvormigheid en herhaling van gegewens.

Kontak skandering was meer betroubaar, beskikbaar en aanpasbaar. Weereens maak die tydfaktor dit nie 'n gunstige opsie t.o.v. tyd en geld nie. In baie van die gebruike vir skandering, bly kontak skandering die mees akkurate en gee 'n beter oppervlaks kwaliteit van die finale produk.

Die toekomstige direkte skandering van afdrukke, met die uitskakeling van gipsmodelle, is die einddoel van die werkstuk.



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**Gevolgtrekking:**

Digitering is 'n baie nuwe tegnologie en baie aspekte is nog in eksperimentele fases. Dit is belowend en die toepaslikheid en belangrikheid daarvan in die veld van diagnose, neem daagliks toe. Sagteware word ook progressief geiintegreer met tandheelkundige toepassings wat afstands-diagnoses en -besprekings vereenvoudig en bespoedig.

Verdere ontwikkeling word alleenlik beperk deur ons vlak van ingeligtheid tov die verskeie komponente in diagnostiese instrumente in tandheelkundige rekords en nie deur die beskikbaarheid van idees nie. Op tentoonstelling by 'n Bio-Inginieurswese uitstalling (Universiteit van Munich tydens 'n Desember 2000 kongres), was 'n spesiaal aangepaste "CT Scanner" wat inligting direk vanuit die orale kawiteit kon lees. Dit maak die moontlikhede van navorsing met direkte data versameling vir drie dimensionele rekords sonder die tussenstappe van afdrukke of gipsmodelle 'n definitiewe toekomstige opsie.

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# Acknowledgments

I would like to express my sincerest gratitude and thanks to the following individuals and companies, whose contributions and support of this thesis are ultimately responsible for its completion

In alphabetical order:

Aztech CNC Programming & Manufacturing Solutions (Georgio Yannikakis, Johannesburg):
for their sponsoring of the demonstration and training on Cyclone scanner with the use of Tracecut software as well as follow up support and advice during later stages of the research.

Dr J Dancaster, (Musgrave, Durban):
for his professional support, clinical advice and the use of his outdated study models as well as his laboratory services

Mechanical Engineering Department, University of Stellenbosch (Ian Smith, Cyclone scanning):
for their mechanical and practical approach and advice during the final stages of the research.

Medical Library staff, Tygerberg Campus:
for their efficient long distance communication and always helpful attitude

Millners, Durban:
for supplying information pamphlets and impression material for the research.

MRI, Cape Town (Prof JS Maritz):
for the statistical analysis and his patient handling of numerous calls for help

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Orthodontic Department, Tygerberg:

Prof AMP Harris:
my advisor at the start of the program and head of the department, also deserves equal acknowledgement because of her faith in me, her understanding of the problems encountered in completion of the thesis, and her continued support in accommodating the unique circumstances under which the work was done. She was the first to support the possibility of a thesis such as this.

Dr VP Joseph:
my major advisor, served as a constant source of inspiration through the years of writing and rewriting, and was firmly supportive of the project in spite of countless delays, postponements, and extensions. It was also his enthusiasm in the field of computerizing orthodontic records, which prompted me to pursue the topic chosen. He provided me with the incentive to critically analyze and resynthesize existing literature in this field.

Sharon Ritchie:
for her editing skills, efforts put forth in delivering several drafts, advice, diplomacy and friendly support during all communications.

Clinical staff and the staff at reception:
for their friendly attitude when I needed volunteers.

Renishaw (UK ):
for the hosting of valuable demonstrations, explanations and information during the early stages of my investigation into the relevant technologies and latest developments.

Ridge Dental, (Musgrave, Durban):
for sponsoring some of my laboratory services

Wizcom, CAD CAM Suppliers (Tony Berkeley and Mike Barber, Cape Town):
for their helpful initial introduction to scanners and the software programme, Rhino.



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# List of Abbreviations and Acronyms

| | |
|---|---|
| $1^{st}$ | First |
| 2-D | Two-dimensional |
| 3-3 | Permanent canine tip to permanent canine tip |
| 3-D | Three-dimensional |
| 6-6 | First permanent molar to opposite first permanent molar |
| | |
| B | Buccal |
| CAD | Computer assisted/aided design |
| CAM | Computer aided manufacturing |
| CT | Computed Tomography |
| D-B | Disto-buccal |
| D-L | Disto-lingual |
| D-M | Disto-mesial |
| DXF files | Digital and Dimensional Imaging help files |
| et al. | and others |
| etc. | and so on |
| e.g. | for example |
| fig. | Figure |
| G | Gingival |
| i.e. | that is to say |
| L | Lingual |
| M-B | Mesio-buccal |
| M-D | Mesio-distal (width of tooth) |
| M-L | Mesio-lingual |
| MR | Magnetic resonance |
| p | page |
| P | Palatal |
| PC | Personal Computer |
| RAM | Random Access Memory |
| STL files | Stereolithography text files |
| vs | versus |

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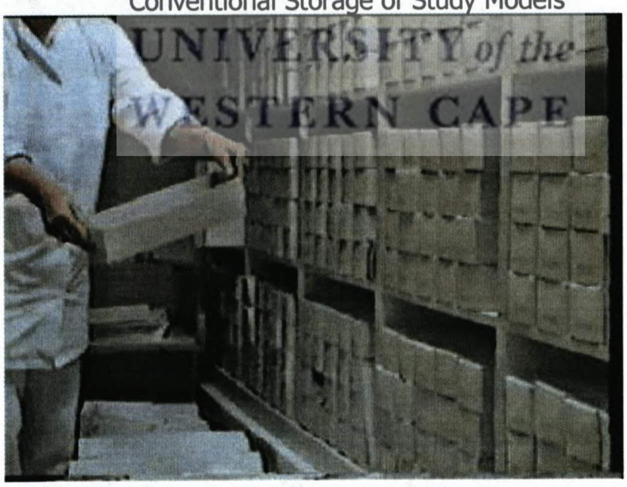
# Chapter One

# Introduction

Study models play a vital role in diagnostics and treatment planning as well as communicating final treatment results in Dentistry, especially in Orthodontic practice. Study models enable the dentist/specialist to determine, visualize, analyze and discuss the treatment plan as well as the final results for each individual patient. They act as powerful training and information tools and form an integral part of the record keeping system of any dental practice.

Storing and archiving of study models have become a problem to most dental schools, as well as to specialist and general dental practices. The manufacturing of good plaster models is a time consuming and expensive procedure, but because their storage is a legal requirement for 27 years, it is a necessity for all practitioners.

Figure 1:- Conventional Storage of Study Models



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Conventional study models are bulky, fragile and clumsy. Not only does keeping these records create major space problems, recalling and retrieving at some later stage also causes logistical problems. (Figure 1) The solution to these problems would be the production and retention of



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three dimensionally accurate, visually pleasing, reproducible, measurable and retrievable study models.

Finding methods and testing results with the most user-friendly equipment, technology and software available, is the aim of this research. Computerizing dental records has already revolutionized the medical and dental offices in radiology and in written patient data. Information is available at the click of a mouse, and integrated diagnostic tools can be displayed on screen.

The direct scanning of impressions will provide all required information on a disc, without the need for study models. This will eliminate the time and cost for the patient and the doctor involving a dental laboratory. The quest for time and space is universal, and the successful management of both results in stress free, financially stable and uncluttered work circumstances. By avoiding the step of casting study models and the consequential physical records, space will be saved and time and money may be put into action more viable and economical.

All conventional and previous experimental methods like Holography, Stereophotogrammetry and Optocom, proved to be cumbersome, inaccurate, expensive and time-consuming. Future implications are considerable and exciting, including promises of research and application in all fields of the medical and dental profession.

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The flow diagram (Figure 2 on page 22) demonstrates the alternative methods (3D imaging, digitizing and computerizing) that can be employed to effect storage of models as opposed to some cumbersome past and current methods (direct and indirect as tabled). The problems encountered are listed and the diagram concludes with an attractive solution which invites further future research in three different directions : Digitizingfrom casts, from impressions or directly from the mouth.



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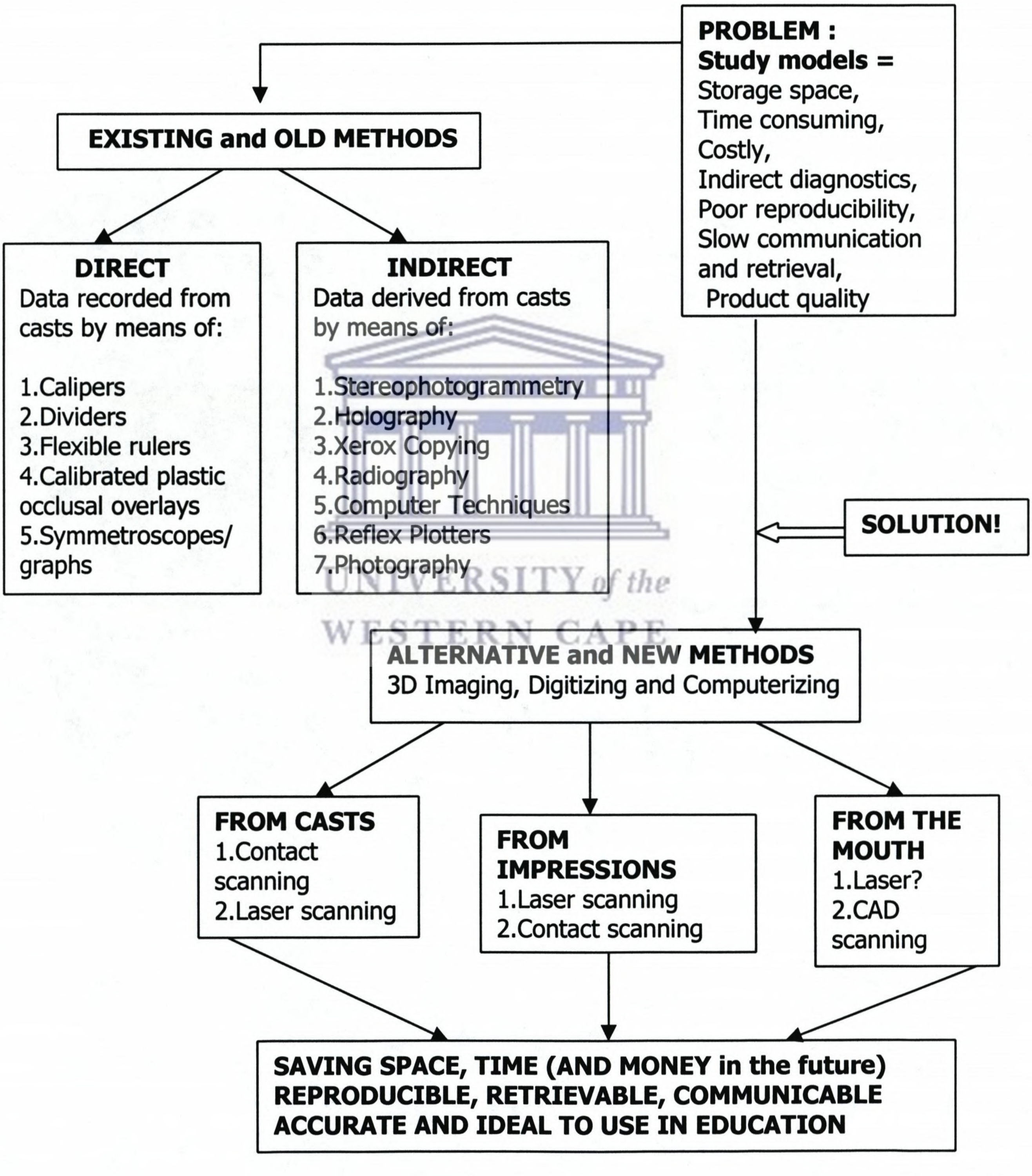
Figure2:- Flow Diagram indicating study model qualities and alternative methods

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# Chapter Two

# Literature Review

## The History of Record Keeping:

The human need for "Record keeping" is one of the major *causes* resulting in the *effect* of Written Language and Art.

The earliest reference to 'dentistry' was found in a Sumerian cuneiform tablet dating 5000BC as Ainsworth[2] (1999) noted in his summary of the history of Dentistry. He found that the next two millennia lacked further information on the development of dentistry, but by 3000BC references began to appear in the ancient Egyptian records again. Proof of lucrative dental practices, separate from the medical field, was found in excavations on the banks of the Nile. Ainsworth assumes that many experiments in dental technology were made over the centuries, but that most have vanished from the historical records. His references include writings and quotes by philosophers like Hippocrates, Aristotle, encyclopaedists like Celsus and physicians like Galen.

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A detailed summary of the history of Dentistry in the *FDI WORLD*[14] (2000), analyses this need for the keeping of records, standardizing methods and educating dentists, as part of general medical ethics, through the ages as follows:

* In 1728 Pierre Fauchard, who was widely acknowledged as the 'father of modern dentistry', published 'Le Chirurgien Dentiste' which contained detailed information about all aspects of contemporary dentistry. It was his lead that encouraged the distinguished surgeon,

* John Hunter, who, before the end of that century, published his book, entitled "The Natural History of the Human Teeth", in England. The first course of dental lectures was established at Guy's Hospital, London, at this time.

* The year 1800 heralded the era of increasingly rapid and significant developments in dentistry - not only technical advances, but also the refinement of clinical dental skills and of professional responsibility and organization.



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* In 1839 the world's first dental journal, The American Journal of Dental Science, was published and the following year the first dental school was founded, the Baltimore College of Dental Surgery, which continues to the present day.

- The first national dental society, the American Society of Dental Surgeons, was formed in 1840 in New York.
- And for the new millennium, Prinsloo[33] (2000) stresses the importance of record keeping in modern practices by quoting from Dr. M Butterworth's lectures and the Dental Protection Society Ltd :

"Records today, are convincing and final –it can either make or break you in any dispute."

## The Ethical & Legal aspects of Record keeping:

A perceived need during the 1840's (*FDI World Dental Limited)* [14]for dental legislation which would regulate the training of dentists, would identify those who were suitably qualified, and would prohibit others from describing themselves as dentists, can now be seen as foresight, in the light of increasing litigation and disciplinary hearings.

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Prinsloo[33] (2000) highlights the necessity of keeping patient records in a practice, under the following principles/functions:

i) ethico-legal requirements,
ii) confidentiality and disclosure,
iii) risk management and consent,
iv) accounts and practice management and
v) forensic functions.

The abovementioned requirements should provide information that:

1. is accurate, clear, complete and truthful
2. shows the dates or upgrading of related information
3. is not scratched out, overwritten, added to or altered in any way. Otherwise the authenticity of the record could be jeopardized.
4. clearly indicates the writer's identity by means of a legible signature or practice code.
5. shows facts and provisional diagnosis
6. is not defamatory or rude.



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7. is safeguarded against any form of destruction (i.e. fire flooding, theft, etc)
8. is not negotiable or for sale, unless it is part of the 'assets' of a practice
9. should not be unreasonably withheld
10. protects the dentist and the patient in any legal action, against memory-loss, biased perceptions and misunderstandings

(Translated from Afrikaans – reference 33)

The keeping of computerized records, was clarified and specified for the first time by the NHS (General Dental Services) in 1992. The system was required to fall within the terms of the Data Protection Act of 1984.

According to a publication in the *South African Dental Journal, May 1999,* the Health Professions Council has no objection todentists computerizing their patient records, stating : *" It is important that basic ethical and dento-legal principles must always be applied to new developments in dentistry."*

The stipulated period for the retention of records differs from country to country and ranges between 2 and 7 years. South Africa's legal requirement is for 5 years.

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## A Review of Study model Analysis:

Direct and indirect means of study model analysis have been investigated since the early 1900's and the different methods have been well noted in the literature. Space analysis with the help of these models remains an important part of orthodontic diagnostic procedure. Emphasis is placed on the occlusal views of the upper and lower casts, as one can analyze the arch form, arch symmetry, alignment of the teeth, palate shape, tooth size, tooth shape, rotations of teeth and much more from these perspectives, as noted by Moyers[29].

Van der Linden et al.[42] (1972), measured upper and lower arches as one unit, three dimensionally. They described the sliding table and the mechanics of the Optocom and found the accuracy of this system to be high.



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Lowey [23] (1993) investigated all methods used to measure study models, and published his own results on the comparison between three different assessment methods (2 direct, 1 indirect) in 1993. The two indirect methods (Imscan: - measured 2D and the reflex microscope:- 3D) and one direct (Vernier calipers: - measuring models 3D) method, left him with the conclusion that improved soft- and hardware were needed at the time of his research. The Imscan was less precise than the reflex microscope. He had problems with an inherent magnification error, inadequate illumination with resultant poor landmark identification and a static view of the arches. A definite advantage of the Imscan was the direct on-screen image manipulation. Work done by Henderson during 1974 and 1976 on this feature was also quoted by Lowey.

Lowey[23] (1993) gives an in depth assessment of the methods used for study model analysis.

In the attempt to standardize the record keeping and communication between different operators, several kinds of assessment and indices were developed and established over the years. Otuyemi, Nigeria and Noar[31] (1996) used 3 indices, HMAR, OI and DAI to test for reliability and inter-index correlation. All three had a high level of reliability. The shortcomings of all three indices were also discussed. Later the same year, Otuyemi and Noar[32] (1996) lead another research project, which compared two aesthetic indices. Study models were used at random and the need determined. The consistency in both indices was found to be acceptable and limitations were discussed.

In 1998, Casko et al[8]. established a scoring system available to all, because they felt that previous indices were not precise when comparing pretreatment and post treatment records. The criteria for the use of this objective system are stated in detail.

By using 350 pretreatment models to compare the reliability of three different dental occlusion classification systems, Du et al.[13] (1998) concluded that Katz's classification was more reliable than either the Angle or the British Incisor Classification systems.



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## Alternatives to study models:

Study models are essential for clinical records but have disadvantages like their bulkiness and fragility. They are therefore expensive to store and difficult to transport, Harradine et al,[17] (1990). Keeping these records does create major space problems, and later retrieval causes logistical problems. This has become a problem to most dental schools, specialist and dental practices. The literature presents many articles on the search for substitutes/alternatives of record keeping

McGuinness and Stephens[25] (1993) did a pilot study with the help of holograms to investigate the level of accuracy, quality of reproducibility, analyzing capabilities and computerized storage of three dimensional hologram images obtained from scanned study models. McGuiness and Stephens [25] (1993) mentioned a well documented "disadvantage list" and expressed the need for another form of recording study models that would be desirable and which had to fulfill the following criteria:

1) be able to be stored with patient notes
2) light and easily portable
3) economical and easy to prepare
4) accurate 3-D information
5) easily duplicated
6) resistant to damage

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Mok and Cooke [26] (1998) used sonic digitization to measure lateral cephalometric values, mesio-distal tooth sizes and arch perimeter. The Digigraph was initially developed to reduce exposure to radiation and Chaconas's [46,47,48] (1990) three publications on the Digigraph Workstation explained technical detail used by Mok and Cooke in their research. They found that it overestimated the mesio-distal measurements and the overcrowding of the arch. The reproducibility of these records was found to be comparable to those gained from plaster casts but the technique was to be used with caution. The authors advised that casts were more accurate.

Fiorelli and Melsen [15] (1999) used a flatbed scanner and cephalometric radiographs to apply 3-D software. They stressed the importance of a well-defined treatment goal, which is also important for the correct design of an appliance and for quality control. Huntley[18] (1999) provided an overview of the types of boxes available for the storage of study models.



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In the end all methods of reproducing or replacing study models, proved to be cumbersome, inaccurate, expensive and time-consuming.

## Background to Advanced Technology:

With the development of computer graphics, various non contact 3-dimensional analyzing systems that use Movie Topography were investigated since 1960 by Kuroda, Motohashi and Kato as referred to by Kuroda et al.[21](1996) . Takada et al.[40] (1983) worked on the three dimensional analysis with the help of a Reflex Metrograph. Robertson and Kennedy [35] (1984) compared conventional photography with telecentric photography as methods of recording study models and proved the latter to be more accurate. Also in 1984, Keating et al.[19] tried Holographic storage of models and they quoted Thompson "that the roots of holography went as far back as 1660 with the work of Grimaldi". He asked the question: Can indices be applied to holograms with comparable results as with models? More research on alternative methods of measurement and storage was done by Harradine et al.[17] (1990).They found that Keating et al.[19](1984) used a cumbersome method of holography. Their study revolved around clinical as opposed to laboratory conditions. Holograms were made available with patient cards to four clinicians, instead of conventional models. These were to be used over a period of 6 months and a questionnaire had to be completed on the usage. The results showed three of the clinicians to be happy and the fourth that found it unsatisfactory. Bhata and Harrison.[6] (1987) carried out tests with an on-line traveling microscope and proved it to be quite accurate.

Rossouw et al. [37] (1991) came to the conclusion that holograms are sufficiently accurate to replace study models, after comparing three methods for measuring models. The holographic system was well researched and documented in the years to follow :

Mårtensson and Rydén [24](1992) investigated 3-D measuring by

1) superimposing holographic image on the corresponding model and
2) superimposed images on each other of same object.

Although the superimposition left the contours blurred and masked details on the lower object, the possibility of studying two dentitions simultaneously seemed advantageous. The idea that the holographic film could be stored like X-rays was attractive.



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Romeo [36] (1995) found the holographicdeveloping to be tedious, with a red or green final result and concluded it to be impractical.

McGuinness and Stephens [25] (1993) went to great lengths to list criteria needed for any other form of recording and emphasized the fact that casts are essentially time related records.

The manufacturing of good plaster models is a time consuming and expensive procedure as reported by Ayoub et al.[4](1997). Champagne [9] (1992) came to the conclusion that accurate space analysis and arch length measurements cannot be made from photocopies. Photocopies of study models were used by Schirmer and Wiltshire [39] (1997) to obtain measurements digitally. This enquiry reconfirmed Champagne's [9] (1992) conclusion that the two dimensional copy of a cast is not accurate on the mesio-distal measurements and therefore is not a sufficiently accurate reproduction. Manual measurement of casts is still the best way of analysis. Goshtasby et al.[16] (1997) concluded that digital reconstruction of gypsum casts has tremendous applications. They applied a range scanner to scan a plaster cast for display and storage. This produced multiview range images, which can be saved electronically along with patient data and retrieved conveniently as well as being transmitted over the network for remote diagnosis.

A study to show the importance of three-dimensional accuracy was conducted by Thielke, Serrano and Lepe [41] (1998). They made use of a measuring microscope and by using reference landmarks and markers on the casts, and mathematical rotation to standardize data. With this they were able to compare dimensional changes. They established that exact 3-D measurements are more valuable than relative distances. During the same year, Santler [38] (1998) made use of the *Graz hemisphere splint* (an inter-occlusal splint ) to stabilize the TMJ during CT scanning, by fixing the condyles in centric occlusion. He established that occlusion is a key point for good results and is not necessarily accurately represented in 3D models. 3-Dimensional observation is also important in surgery for precise diagnosis, simulation and prognosis. Unfortunately CT scanning has low resolution and is susceptible to metal interference, giving limited precision, i.e. limited representation of teeth, their occlusal configuration and intercuspation.

The future of document storage in orthodontics will be closely related to digital imaging systems. Digital imaging requires a lot of memory and a fast computer processor (min 233MHz, 4Gbyte hard drive, 32 Mbytes of



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RAM, 17" color monitor-1024X768 pixels). A potential problem with digital images is that they may be altered and data changed if not protected. This aspect needs future attention and specification according to Coimbra and Lomheim. [10] (1999)

Digital imaging was used in research for quite some time before it became available in dental practice. It is still a young technology and many aspects are not yet fully explored. Abelsohn [1] (1999) confirms that "digital technology continues to improve at a breath-taking rate" and explains some basic principles of digital cameras and scanners. It is a promising technology and its significance is increasing because it opens the door to new diagnostic information. Another important development is that the software for digital imaging will become more integrated with other computerized dental applications in the dental office, facilitating exchange of patient data between different applications. Van der Stelt [43] (2000) compared film-based imaging and digital imaging, and observed that whilst digital imaging is now a well-accepted modality, film-based imaging is not yet completely abandoned. He describes a digital image as the electric signal, produced by the sensor, in a voltage that varies according to dimension, interpreted as a function of time. This is an analog signal. The sensor is connected to a PC with a "frame grabber" to convert the analog signal into a digital signal. The output of measurements is stored on PC as numbers.

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The diagnostic outcome of dental digital imaging is in some way limited by human visual perception, with its own flaws and biases that can limit the quality and reliability of the information perceived. An article written by Mol [27] (2000) explores, in depth, dental radiography and image processing. The use of digital measurements in orthodontics has facilitated cephalometric X-ray analysis, especially when combined with automated landmark identification.

Mol A. [27] (2002) stated that: "Dental literature is rich with applications of image analysis and will be even more so in years to come. Most applications, however, are concerned with semi-automated procedures, leaving a distinct role for the clinician. This situation underscores the complexity of the detection process and the challenge of developing uniform algorithms for real-world problems. Further progress is not limited by a lack of available image processing tools; rather, improvement of our understanding of the various components of diagnostic imaging will facilitate the meaningful use of new imaging technologies in dentistry."



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In the same article Mol quoted from a publication by Webber RL (1999): "Although novelty is still a powerful force driving some scientific endeavors, advances in dental imaging will be based on the purposeful, goal-orientated development and application of new technology"

## 3-D Digitizing, Computerizing and Scanning:

The latest methods concentrate mainly on relevant technological skills i.e. laser surface scanning, contact scanning, 3-D digitization and computerizing. Digitizing photographs of dental casts with the help of a certain set of data points was done years before its time by BeGole, Cleall and Gorny.[7] (1981).

Lowey [23] (1993) mentions laser-scanning techniques studied by Arridge et al.(1985) and by Moss et al.(1987). These techniques were used to construct and record three-dimensional surface information. Both research teams found that the advantages of this technique for non-contact, three-dimensional measurement with high spatial resolution and sophisticated graphics would be applicable to study cast measurement.

According to the available literature, Japan is the leader in this field today, and as early as 1989 Kimurah, Sohmura and Watanabe[20](1989) published an article (only available in Japanese) addressing the accuracy of three-dimensional measurement using a high precision laser displacement meter and a computer controlled scanning machine (CAMM 3).

Kuroda et al. [21] (1996) showed an error of less than 0.05mm on measurement of a cast projected and scanned with slit-ray laser beam. Alcaniz et al.[3] (1999), described a low cost, user friendly laser system to capture 3-D images of dental casts and in the same yearMotohashi and Kuroda[28] (1999) used a CAD system, publishing a well researched scientific paper. They pointed out that an advantage of this CAD system would be the avoidance of the need for storage of plaster models. "Clinical trials" suggested that the use of this system was feasible not only for treatment planning and diagnosis, but also for saving time and labour required to make the diagnostic cast. They emphasized that further studies regarding three essential functions i.e. Security, Reproducibility and Accessibility would be needed to construct an electronic storage



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system for the plaster model.

PC capability now has the potential for providing multiple information on the windows of computer displays during imaging editing. This helps in improving the accuracy of the editing processes, allowing for more precision in the registration of anatomical landmarks. Okumuraet al. [30] (1999) suggested further research the amount of data without compromising the accuracy should be directed to reducing.

Digital imaging has created possibilities of using the Internet for acquiring information, communicating with peers or even receiving technical support via avenues of scanned impressions and applicable software.

## Dual Impression Techniques:

Davis and Schwartz [11] (1991) usedmarked Typodont dual arch impressions to compare accuracy with custom tray impressions, and found it to be accurate in all dimensions measured. Davis, Schwartz and Hilton [12] (1992) studied the marginal accuracy to decide to use one technique over another. They found good marginal adaptation with both techniques. In the same year Bass and Kafalias[5] (1992) tried dual-arch impressions to reproduce the bite and both arches for short span bridges. Leknius and Henderson [22] (2000) used self-modified fluoride trays for dual impressions.

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This diversion of literature search was prompted by the need of dual impressions whilst experimenting with a 'carrier' developed during the final research. The relevant publications indicated acceptance of this technique implicating future investigation and possible research.



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# Chapter Three

# Purpose and Objectives

This study was motivated by the recognition of the problems in storing fragile study models and the space demands caused by keeping them for the legally required time. While researching the advanced use of modern, improved and improving, technology and equipment to provide a solution to the storage problem, it was found that this study could address only a limited number of questions related to the ever-advancing technological developments.

The computerization of dental records has already revolutionized this industry in the storing of X-rays and written patient data. Information is instantly available and integrated diagnostic tools can be displayed on screen. Study models play a very important role in diagnostics and treatment planning as well as in anticipating and communicating final results in Dentistry, and especially in the Orthodontic practice. Considerable logistic retrieval problems are associated with their use.

The practical concern arising from personal experience and the information gained from discussions with peers are being addressed in this study. Study models continue to play an important role in diagnostics, but their bulky and yet fragile nature and the high cost of production stimulated the search for alternative methods of acquiring and storing data. The aim of the research is how to produce and to keep three dimensionally accurate, visually correct, reproducible, measurable and easy retrievable computerized records using technology and software which is both user friendly and advanced.

Specific objectives included:

i) The investigation of methods of capturing dental data and 3D images from previously researched and published studies and the introduction to the options of scanning and milling technology available in South Africa.



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ii) The investigation of the level of accuracy, the quality of reproducibility, the analytical capabilities and the computerized storage of three dimensional images obtained from scanned study models and impressions

iii) To draw comparisons between computerized measurements derived from the digitized data and manual measurements obtained from the same cast models, to prove whether digitization is a viable alternative to conventional study models. Internationally accepted and applicable, uncomplicated criteria will be used to derive results.

iv) The statistical evaluation of the data by a statistician.

The central investigation is whether the direct scanning of the patient's impressions will provide all the necessary information on a disc, without the need for study models, with the consequent saving of space, money and time.

The Department of Mechanical Engineering's Biomedical Division was asked for expert advice on the Cyclone Scanner. The aim of this part of the project was to secure as many scanned images and data from different patients as possible. The measurements obtained from the scanned images were compared to those manually derived by different operators, from the same models.

By making use of extremely accurate computerized techniques like calibration, built–in memory of landmarks, automatic recall of values and the consequent exact repetition of measurements, this research also attempts to prove that the accuracy level and quality of data obtained with computers exceeds that secured by conventional methods, fraught as they are by human error in measuring and visualizing and by intra-operator mistakes.

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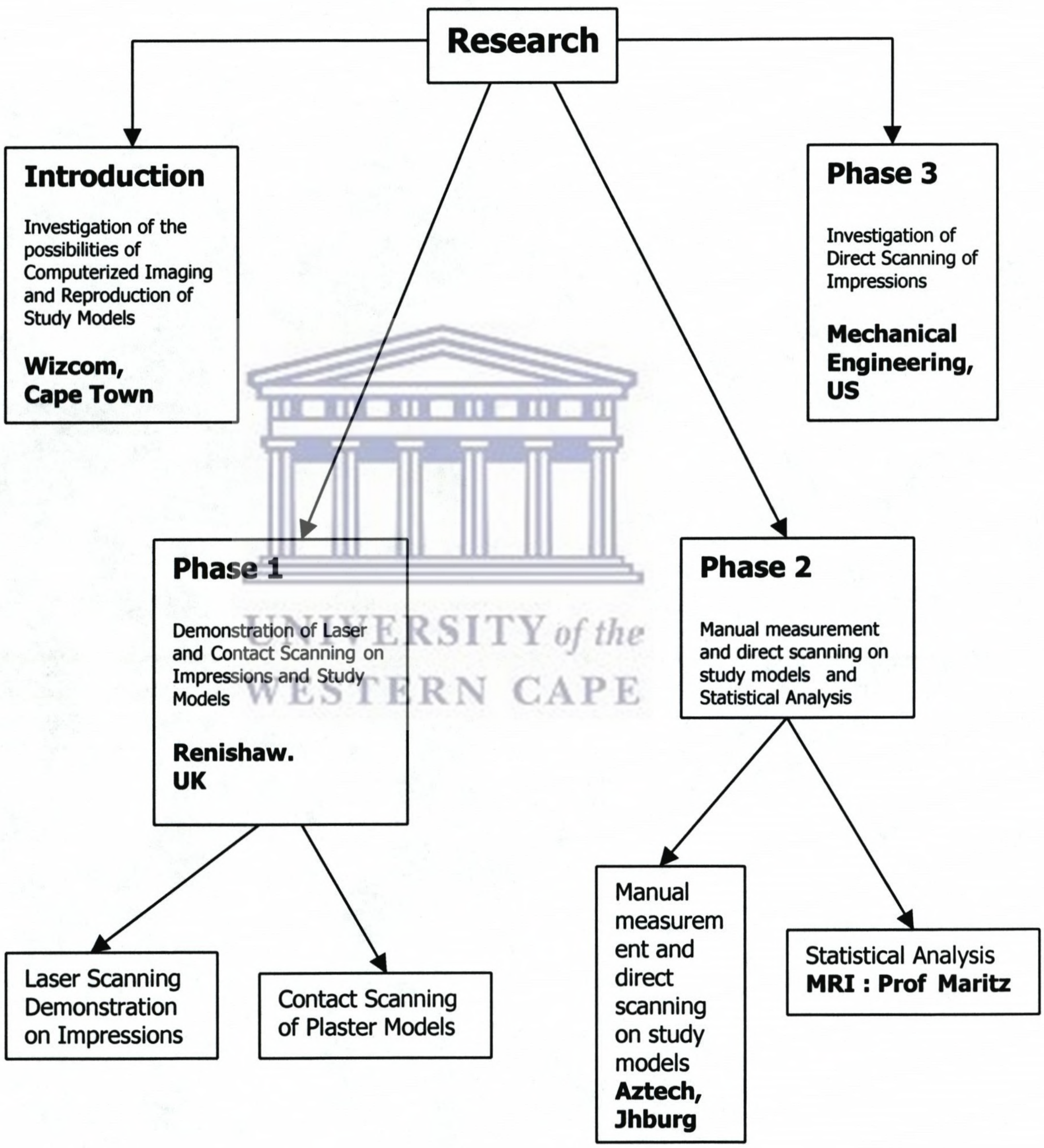
Figure 3:- Flow diagram explaining the sequence of research and recording:

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# Chapter Four

# Materials and Methods

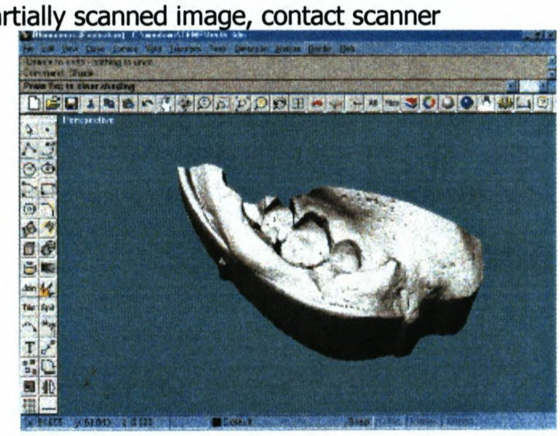
## Introduction:

### The Investigation of the possibilities of Computerized Imaging and Reproduction of Study Models:

Attendance at demonstrations of computer programmes designed for record keeping and analysis in dentistry (JOE 32 and Dentsply's Denoptix) and at exhibitions of the latest technology, confirmed the need for the investigator to be exposed to more advanced engineering processes, particularly in the direction of 'Graphic Design, Manufacturing and Precision Engineering'. The application to dentistry of the latest technology, and availability of the software, had to be established.

A single arch alginate impression was used for a demonstration on the abilities of the Isel-CNC Machines and of the relevant software ((Isy-CAD/CAM) by Wizcom, CAD CAM Suppliers. Manipulative software, "Rhino" was also evaluated. The demonstration took place on a contact scanner, although free-form scanning without contact could be performed faster and more accurately on a laser scanner. The single impression was partially scanned, the surface feedback carried out and data processed further with the software package used by this company to produce a clear "negative" image (Figure 4:- actual picture of the impression) on the screen.

Figure 4 :- Partially scanned image, contact scanner





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The three dimensional CAD system reads the data from the grid system (using STL or DXF files ) and may be used in procedures such as:

- volume operations,
- edge and surface roundings,
- projective images to any surface,
- interactive shaping,
- smoothing and partitioning.

Figure 5 :- Grid within which contact scanning takes place

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A grid is formed (as seen on screen fig. 5) by the prescan motion of the stylus to ascertain the basic shape of the object to be fully scanned. Within this grid the scanner then 'reads' the finer details of the object by means of the amount, and depths of the different pressure points, sending information to the computer in a point or dot-pattern. This point-pattern consists of all the contact points made by the stylus within the framework of the grid, and enables a record of the finer detail of the surface scanned.

Depending on the requirements, these dots can bedenser to have more detail and the scanner setting will be changed to more contact points per unit surface/area (Fig. 6). This will in turn influence the time it needs to complete the scan.



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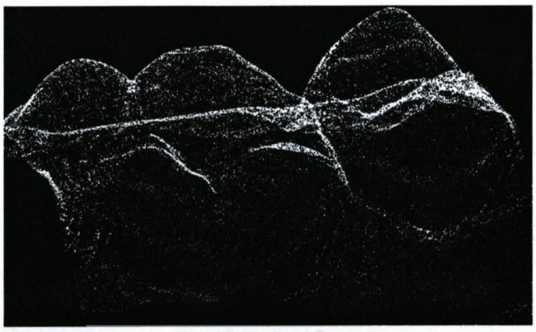
Figure 6 :- 'Point'pattern due to the multi-point contact scanning method



This information can once again be evaluated visually, after rendering the grid image into a positive, realistic image with the software package. Any desired colour can be chosen to give a 'smooth', three dimensionally exact, positive result. (Fig. 7, an image similar to the original plaster model, different in colour):

Figure 7 :- Scanned grid, rendered in gold!

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Specific areas can be located on a scanned image and enlarged to demonstrate detail. With the field in perfect view, specific landmarks or points can be established, marked and distances can be measured as seen in Fig.8 and Fig 33.



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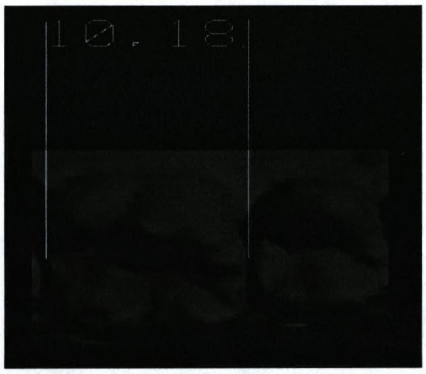
Figure 8:- Mesio-distal measurement of a molar




The rendered image can be manipulated, turned upside down, and looked at, at any desired angle. Inspection of any chosen area can be done on screen. The final image can be saved with the patient records. These records can be retrieved at any given time, the information can be sent to the computer and through appropriate links with a milling machine, an exact reproduction of the original model can be milled out of any material of choice.

All the processed data can ultimately be used to create a duplicate prototype of the scanned object, at the CNC machines, with the mere entering of a few basic milling parameters (i.e. the type of cutting tool, required accuracy etc).

One program used in this trial demonstration, “Rhino”, may be downloaded on the internet from website www.rhino3d.com. The site proved to be informative on all the uses of this type of software. “Rhino” can create, edit, analyze and translate NURBS (non-uniform rational B-splines) curves, surfaces and solids in Windows. There are no limits to complexity, degree or size of the object.

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This demonstration and investigation identified further reqiirements to be investigated i.e.:

to verify the accuracy,
to compare this to other systems,
to legalize the information on the disc,
to maintain original data tamper-free
to include the palate shape and depth
to be able to record all parameters necessary for calculation
* Little's Mandibular Index / Little Irregularity Index
** Moyers Analysis
***Bolton's Analysis
to include therefore: D-M of all teeth,
B-L alignment of rotated teeth,
Intercanine distance,
Arch length,
Arch depth (3-3 ⊥ midline),
Inter-molar width (MB cusps)

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* Little's Index: measures the amount of crowding by using the sum of labiolingual displacements of the six anterior mandibular teeth

** Moyers: predicts the sizes of the unerupted permanent canines and premolars by measuring the sum of the mesio-distal widths of the mandibular four permanent incisors and the physical archlength form from mesial of the first permanent molar to the equivalent on the opposite side. The data are used to evaluate the probability for satisfactory inclusion of the permanent dentition within the arch(Mixed Dentition)

*** Bolton: is used to relate ratios for maxillary versus mandibular tooth sizes in the permanent dentition. Discrepancy may predict crowding in either the upper or lower arch and consequent overbite and/or overjet.



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Figure 9 :- Images available on the Internet ( 3Dent Product Information)

A literature search revealed theworldwide interest in solving these and similar questions. Images were collected from the Internet, courtesy of 3Dent Product Information, Germany, as an example of software products and programs already available (Fig. 9).

Researching this vast topic leaves more questions than answers. Gaining insight through experience and personal practical application of the principles of basic record keeping and scanning methods will be the motivation for the next phase of this research.

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## Phase 1 :

### The Demonstration of Laser- and Contact Scanning on Impressions and Study Models:

**Laser Scanning Demonstration on Impressions:**

Aztech CNC Programming & Manufacturing Solutions provided information (See Appendix B), which was most useful, but which reconfirmed the void in dental applications. *

In preparation for this demonstration, four volunteers had two sets of impressions taken:

> The first set, (comprising an upper and lower) was taken with an alginate impression material for the immediate pouring of study models. These 4 sets of study models were collected after a few days, allowing for drying and polishing. (Fig. 10)

Figure 10:- One set of the plaster casts (from the first set of impressions)

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* The parent company of AZTech, the Renishaw Group (registered in England no. 1106260. Registered office: New Mills, Wotton-under-Edge, Gloucestershire, GL12 8JR, United Kingdom) demonstrated laser scanning and the validity of application of this method in Dentistry. One set of study models and part of an impression were generously scanned at Renishaw's head offices at New Mills, UK



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The second set was taken with President System 75 Mono Body ** impression material (donated by Millners, Durban). (Fig. 11)
The study models and the second set of impressions were carefully packed and despatched to the firm in the UK. The parcel was delivered to Renishaw prior to the appointed demonstration date and time, to allow for pre-scanning to be completed.

Figure 11:- One set of President impressions (the second set)

Scanning is defined as the process of gathering data about an undefined 3-Dimensional surface. It is used in all fields where there is a need to reproduce a complex free-form shape. During the scanning process, an analogue scanning probe is commanded to contact and move back and forth across the unknown surface. During this process, the system records information about the surface in the form of numerical data. This data may then be used to create a CNC program, which can machine a replica or geometric variant of the shape. Alternatively, the data can be exported in various formats to a CAD/CAM system for further processing. New sensor developments are constantly evaluated and the optimum methods of gathering surface data updated. For most applications, the best results in terms of accuracy and quality of surface finish are obtained using contact

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** This is a Polivinylsiloxane, addition-type, surface activated silicone elastomer, with medium viscosity consisting of a base and catalyst. It was the material of choice because of its low distortion factor and relative high stability over a period of time. (Dimensional change: < -0.20 %, Recovery after deformation: > 99.5%).



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sensors. However, where very soft and fragile materials are to be scanned, non-contact laser systems can be used.

Demonstration on impressions:
The Cyclone high-speed digitizing machine with the SP600 scanning probe was used for the demonstration scanning on the impressions and plaster models. The Cyclone is designed to do high speed and fine detail scanning. The very low probing forces also allow for the scanning of delicate materials (soft impression material, or brittle plaster). The ability to use extremely small styli (0.3mm) allows the scanning of very fine detail, interproximal areas, detail of dental anatomy etc. The Cyclone combines output from its scanning probe and reference axes positions using the purpose built scan control card.

The "TRACECUT" software calculates the surface coordinate data point and a new target position to which the machine should move. This data capture software system also enables the operator to manipulate data and then to create an NC program or CAD output. The CAM package has powerful machining strategy choices. Once the data has been captured, model variants can be produced by mirroring, scaling, rotation, translation and male/female inversion.

The models and impressions were scanned by means of both contact and laser scanning. The outcome and any problems encountered will be discussed in Chapter 5, Results.

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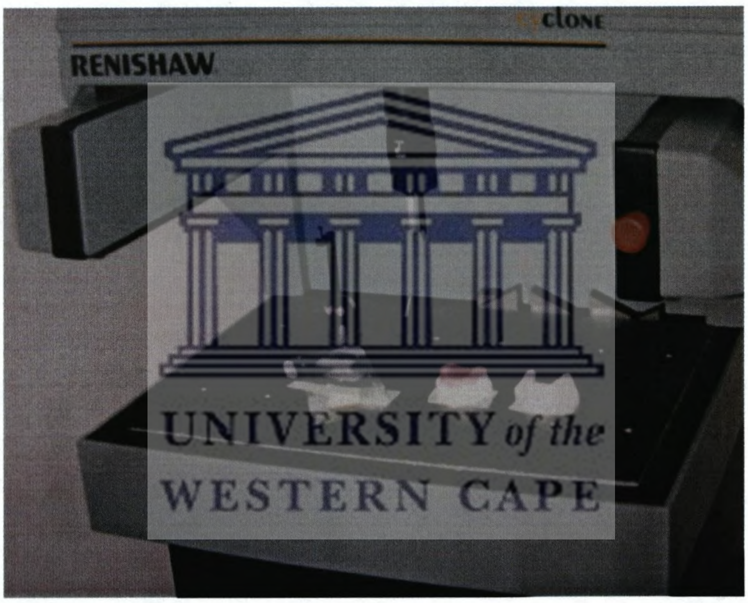
## The Contact Scanning of Plaster Models:

Contact scanning could be completed on only one set of models. The maneuverability on the screen of the 3-D images (exact replicas of the models) was demonstrated in all directions and at differing angles of view. The ability to define landmarks, the plotting and calculation of specific areas, measurement of distances and retrieval of other data for computerized analyses, were all convincingly achieved.

Figure 12:- Contact scanning of the models in process on the Cyclone Scanner

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Different levels or grades of quality of definition depend on the stepover size (the distance between the successive points of contact of the tip of the scanner) and the speed at which the scanner tip moves in the action of scanning. To show this relationship between scanning time and quality of surface definition, the same upper model was used and the scanning process was repeated with different step-over values between the scan lines.(Fig. 32 and Table 2)

This proved that the choice of step over size and scanning speed are determined by the amount of detail needed for a specific project.



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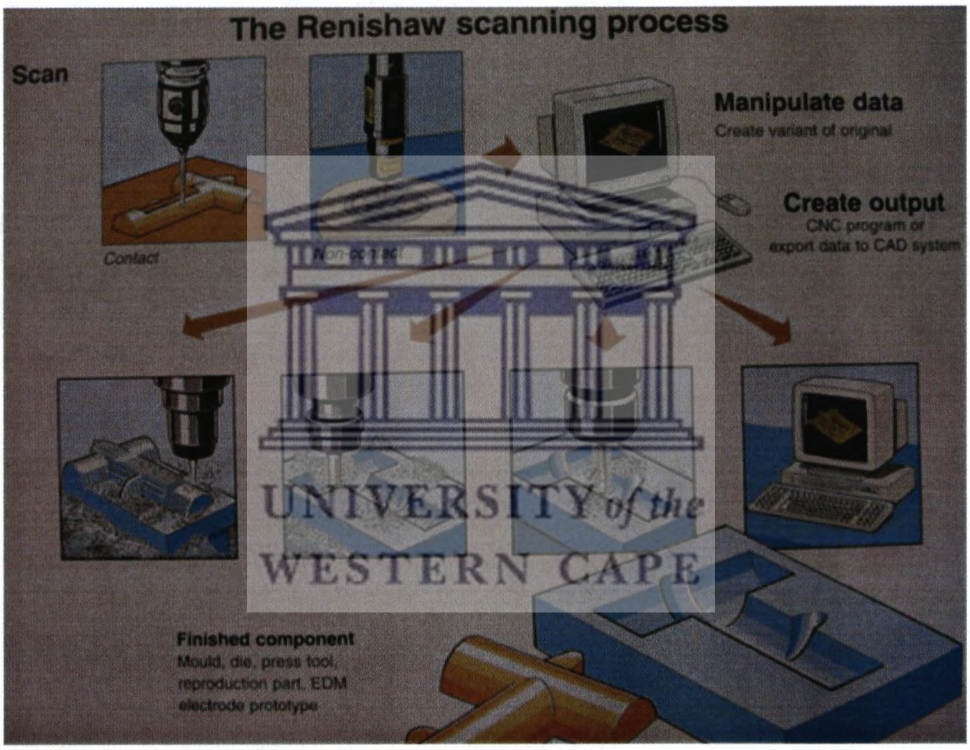
## Phase 2 :

### Manual measurement and direct scanning on study models :

(See Appendix C for the full explanation on the use of the Cyclone Scanner and the introduction to Tracecut Software.)

Figure 13:- The Scanning Process

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During the session of introduction to, and training on the Cyclone Scanner and the Tracecut software, measurements were recorded to enable statistical assessment of the scientific validity of this study.

A selection of study models was done as follows:

- 10 sets of study models were collected from the archives (older than 5 years) of a private orthodontic practice in Durban.



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- Care was taken to select only models in good condition. No broken, or chipped models, no absent or heavily restored teeth.
- Only models of permanent dentition were chosen.
- All permanent first molars and canines present.

The sets were manually measured with a precision Bowley Gauge and the data tabled in an orderly fashion, using basic criteria to simplify the methods of collecting data. (Fig. 14)

Figure 14:- Part of the selection of 10 Models for the Training session

Fifteen measurements were recorded in each arch as follows:

- The greatest M-D (mesiodistal) width of each individual tooth ($1^{st}$ permanent molar to $1^{st}$ permanent central) was measured, and recorded.
- The dental arch length, calculated as the sum of the M-D widths of the teeth from $1^{st}$ permanent molar to $1^{st}$ permanent molar on the other side.
- The cross-arch distances between the molars and canines.

These basic measurements gave a total of 30 readings per set of models.



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All manual measurements on the ten sets of plaster study models were done with a precision Bowley Gauge. The results were recorded and arranged tables. (All Measurement Tables are explained in Appendix D)

During the session at AZTech, all methods of scanning were tried and applied to the suitable situations. For example, the 'Pencil-scanning' option provided a free-hand tracing of all relevant and chosen landmarks. This proved to be a time-saving method and computerized measurements could be read from the relevant positions of the X,Y and Z axes. Captured computerized tracing and measurements are discussed and explained in detail in the Chapter on Results.

Over a three-day period, one set of models was fully scanned by means of multi pointed contact scanning. This was the trial session and had to be aborted and restarted a few times. The normal stumbling blocks of unexplored and new developments had to be negotiated, like problems with undercuts and difficult angles.

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## Phase 3:

### The Investigation of the Direct Scanning of Impressions: (Stellenbosch):

The Biomedical Research group of the Department of Mechanical Engineering at the University of Stellenbosch possesses a Cyclone Scanner, and agreed to cooperate in the project. The focus of this part of the research was on the visual effects and gathering a quantity of data for statistically acceptable data.

Comparing the measurements obtained from the scanned images of the impressions to the manual measurements obtained later from the corresponding models:

- for statistical purposes we would need quantity (comparisons in tables)
- for scientific purposes, quality (linear distances and angles, perfectly measured) and
- for practical/visual purposes, perfect 3D images presented on screen.

One set of impressions was taken per day of the staff of the Orthodontic Department, Dental School at Tygerberg Hospital. These alginate impressions were wrapped in moistened paper towel, packed in airtight Tupperware holders and transported by motor vehicle to the Department of Mechanical Engineering in Stellenbosch for scanning. While the one impression was being scanned, the other was kept sealed and moist in the temperature regulated scanning room.

After the scanning process was completed, these impressions were returned in the same manner to the department at Tygerberg. Plaster was mixed and models were cast on the same day, to control distortion of the impression material and any consequent interference with the final results. The models were left overnight to set and dry properly, before trimming and polishing in final preparation for themanual measurements.
The process was repeated over the ensuing four days.



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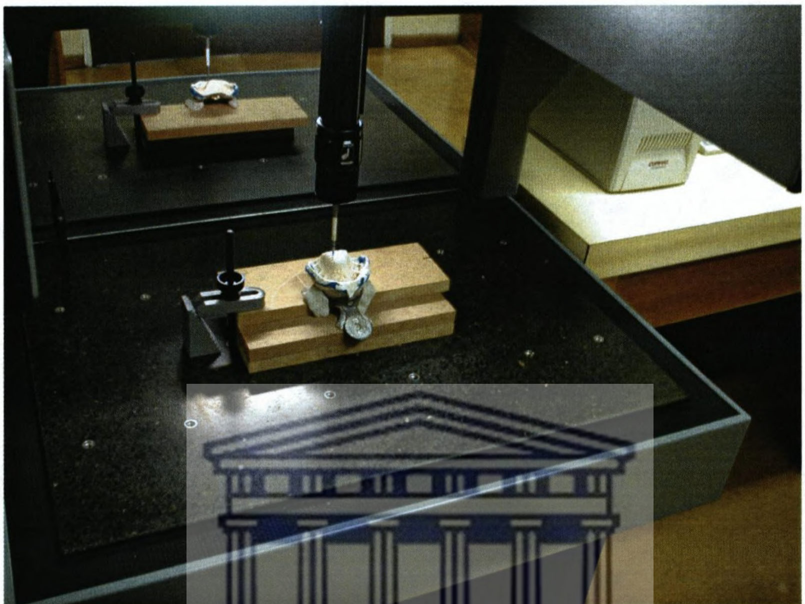
Figure 15:- Alginate Impression on Scanner Table, scanning in process.



On the first day, one set of upper and lower impressions was taken to Stellenbosch to be used for the initial introduction and explanation of the needs and procedures of the research to the engineers. (Fig.15). The subsequent "trial and error" process that naturally stems from involving a new department and different mind-set people, took up the better part of the day.

Scanning of these first impressions proved to be a valuable exercise in observing and solving technical and logistical problems like:

Scanning at difficult angles,
Scanning of deep and unreachable undercuts,
Stabilizing the deflection of flimsy areas under the 'normal' pressure of contact scanning,
Controlling the speed of scanning for quantity,
Choosing the right step-over size for higher quality,
Time management etc.



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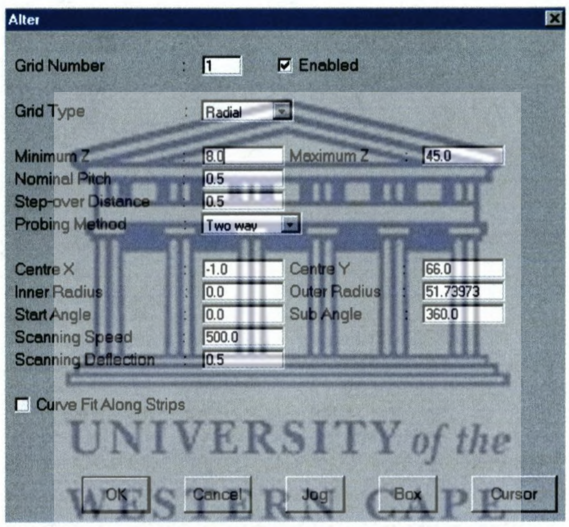
An initial 'quick' scanning was done to get the 'feel' and to visualize the effects and errors. That gave a foundation to work from.

The scanner was initialized and set up in the following manner: (see notes on Scanner Training): Ball stylus 1mm, was used, 0.5mm Step-over, which gave a rough and uneven finish. (Fig. 16)

Figure 16:- Scanner Settings for the first impression scan, speed 500, step .5 etc.

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A two dimensional grid was established along the outlines of the impression, to reduce peripheral scanning areas, but to include the palatal surface. Radial 'rough' scanning was done on this grid as guideline. (Fig.17).

The final scanning of the upper impression took 3hrs 20 min to complete, at a scanning speed of 500. The rendered positive' image from the 'negative impression (as seen in Results), showed impressive detail on all flat surfaces. The only problems encountered were with undercuts and 'thin' areas of impression material.



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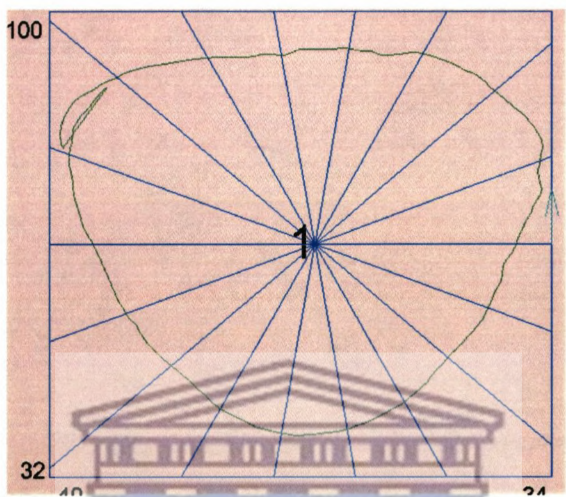
Figure 17:- Radial scanning pattern on upper impression




The problem of occluding models/images was addressed. With available software and ever improving technology, bringing two separate images together and displaying them on the screen as a single entity, isalready possible and techniques are improving by the day to make the process user-friendlier.

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During this exploration phase, a concept of implementing dual-impressions took shape. This entailed a whole new topic of research. As the latest impression materials allow for flexibility as well as stability, it was decided to try a combined impression (i.e upper and lower simultaneously) by using a 'sausage' of impression material (President putty). This material proved to be very stable and sturdy on its own. A 'sausage' of mixed and ready impression material was placed on the patient's lower arch and he was asked to bite in the centric position into the bulk of material. (Fig. 18 a+b).

While the Dentist /Researcher manipulated the material buccally with the fingers, the patient had to manipulate it lingually with powerful 'pushes' of the tongue against the palatal surfaces of the teeth.



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Figure 18 (a):- Dual 'sausage' impressions taken without a tray. (b)Thin areas visible anteriorly

Despite the relative success of this basic technique, it was soon realized that some sort of "carrier" would be necessary to hold or carry the material in a more stable manner. It was also necessary to be able to standardize readings and measurements. A reference table was needed to provide coordination of the three axes used by the scanner. The computer could then bring upper and lower images together standardization of the coordinate reference system, irrespective of the angle at which the "carrier" was set during the taking of the impression.

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The "carrier" consisted of a framework of steel, with a reference point (circular is best for contact scanning) and a flat, stable reference table built into the handle. The first rough design sent to the engineering workshop resulted in a small and easy "carrier". (Fig. 19 a). Peripheral flexibility and resultant instability of the impression material ('sausage') around the most distal parts was a concern of this design. That could interfere with the data capturing and final results.



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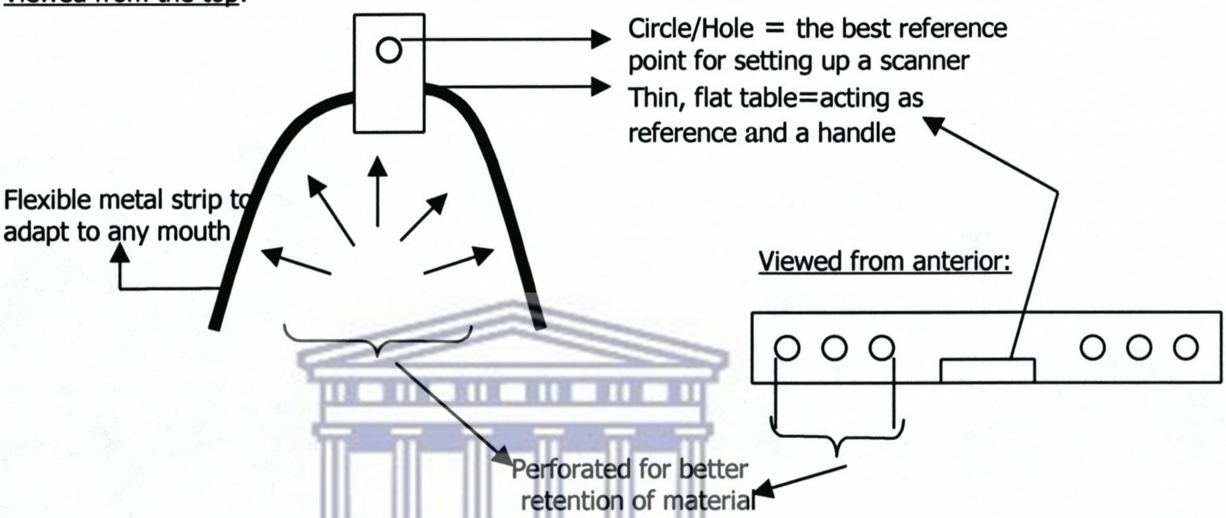
Figure 19 (a):- First rough design of the Dual-Impression Carrier

Viewed from the top:




Changes made to initial design:

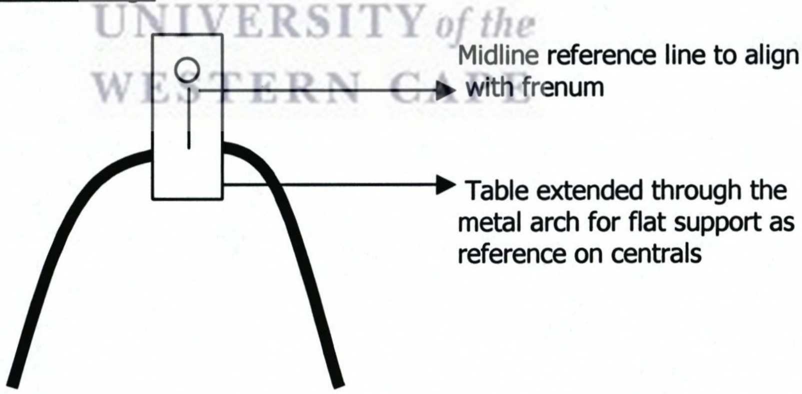



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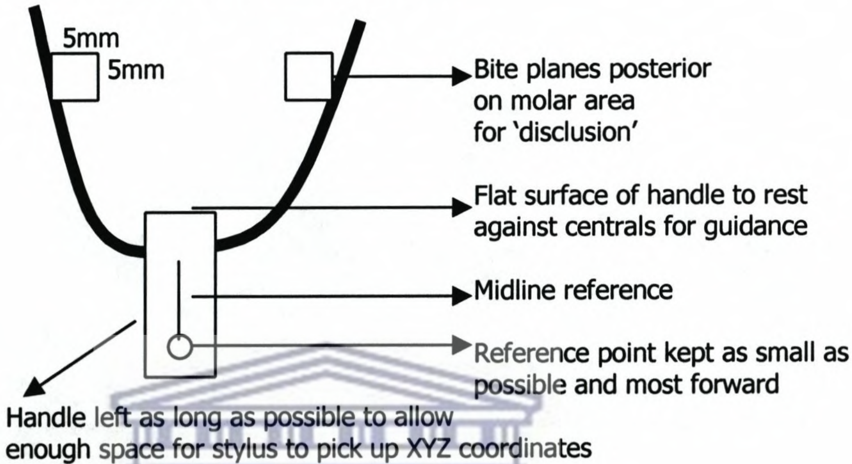
Figure 19 (b):- Changes made to the initial design to allow for more support and better reference




The design was modified and now sported posterior flexible 'wings' made of wire attached/welded onto the stainless steel body, which was again perforated to give mechanical retention to the impression material for better stability. (Fig.19 b). The midline could be visually and manually aligned with the help of a straight line on the handle/ reference table,

Queries regarding the limitations and expectations of this 'special carrier' included: i) the necessity to capture the palatal vault, and/or the bulbous buccal 'vaults
ii) the definition of the frenae

A prototype was manufactured by using 1mm thick, bendable, 8mm wide stainless steel strip. Previous experience with impressions taken without a support had identified the concern about thinness of material in the fully occluded areas. In certain areas the 'bite' would go right through, leaving holes where the stylus of the scanner could penetrate, recording data and surfaces wrongly. By opening the bite posteriorly by 1mm, more and thicker material was allowed to 'flow' into the interocclusal areas. This compensation could be accommodated in the analytical system and be cancelled out by relevant software. For all reference points, tables and surfaces to be functional, the placement of the "carrier" in the correct position in the mouth was important (i.e. the anterior flat plane against the



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centrals, the line on the handle visually aligned with the midline and the patient closing down gently on the posterior bite planes placed on the 1st molars). The final design had to be manufactured into a user-friendly "carrier" by the workshop.

Impressions with the "new carrier" were taken so as to start the scanning as early as possible. Before the actual impression was taken, a few trials had to be done to get the bite right. An informed patient made the procedure run smoothly. The 'sausage' of President (a more stable and harder material than Alginate) was contoured around the steel arch, the flat anterior plane was pressed against the two centrals and the midline was adjusted while manipulating the 'carrier' onto the top arch, with the bite planes resting on the upper first two molars. The patient was then asked to bite down slowly, in central occlusion as practiced just before, until the upper and lower molars hit the little plane ether side. On this point of contact, the patient was asked to use his tongue to press the material against the inner surfaces of the teeth and into the palate, while the researcher was working the excess of material into the buccal fossae. Because of the patient's relatively deep bite, the impression and bite had to be repeated twice to get a satisfactory result due to the presence of occlusal perforations. A few small perforations discovered later, had to be covered with wax and the possibility of interference with detail in those areas was expected.

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Initial pencil scanning was used to utilize the scanning space and time more efficient and effectively.

After the frame was drawn, different areas were 'boxed'. (Fig 21 a for the upper arch, Fig.21 b for the lower arch).

The final combination of all the different boxes/scanning grids is part of the computer program and enables the image to be shown with more detail. This procedure was followed with each impression or model scanned with slight differences according to shape and size.( Compare Fig 21 a to Fig 25.) Each numbered grid/box is initialized individually and specifications tabled as seen in Fig.20 . Three sets of set ups were required per one arch scan.



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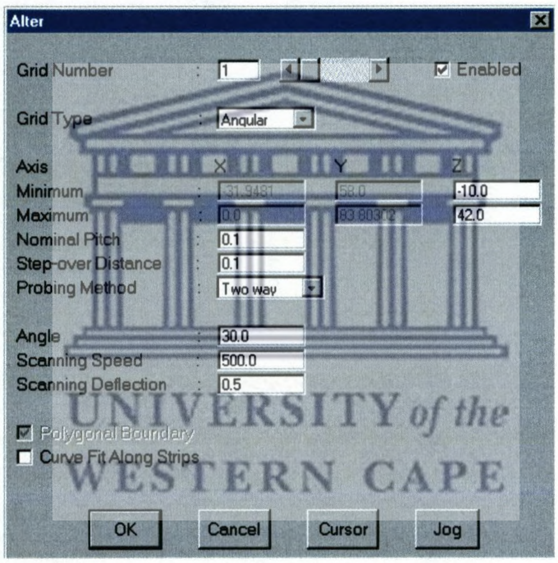
The final scanning of the first dual impression took place with the following settings and specifications for the upper arch: (Fig. 20)

Scanner setup : 1mm ball stylus,
0.1 mm stopover and pitch ,
speed 500 and
deflection 0.5

The scanning procedure was extended between 11h00 – 16h30

Figure 20:- Typical display of specifications on computer screen ( i.e. for grid no 1)



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There was a problem with scanner stylus deflection on some of the deep fossae due to the thinness of the material as anticipated. This is discussed in Results.

The next problem encountered was with the setup and initializing of the scanner. The XY axes normally represent the 'table of reference' and the Z-axis is automatically adjusted to record in a perpendicular direction/fashion. (This is described in detail in appendix on Scanner Training). This led to a tilt that allowed the scanner to miss out on the far ends (most buccal edges and incisal tips) of the anterior teeth, thus 'cutting' the teeth in half, in other words not scanning the full length. This automatic adjustment of the computer had to be considered when placing



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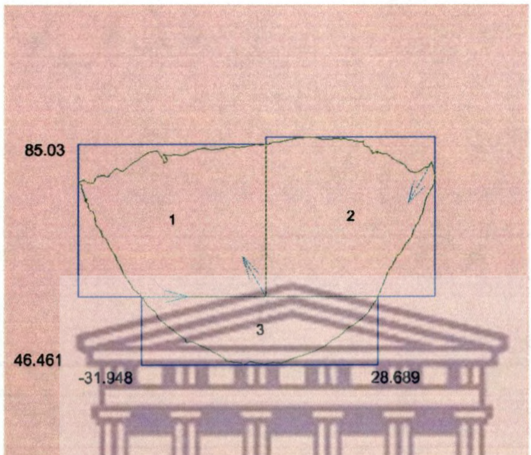
the impression, compensating for the tilt so as to include wider areas of scanning for the inclusion of all the 'deeper' parts.

Figure 21 a):- Trial dual arch impression:
Upper_scan_grids 1(boxed areas after pencil scan)




The scanner was set up and initiated and left to scan the opposite side of the dual impression (the lower arch) overnight

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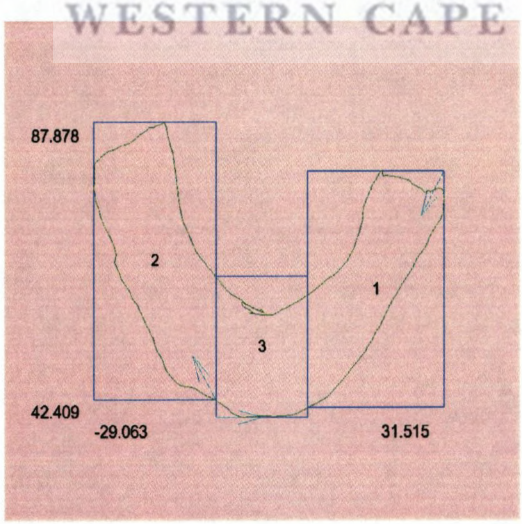
Figure 21 b) :- Trial dual impression scanning lower_scan_grids1



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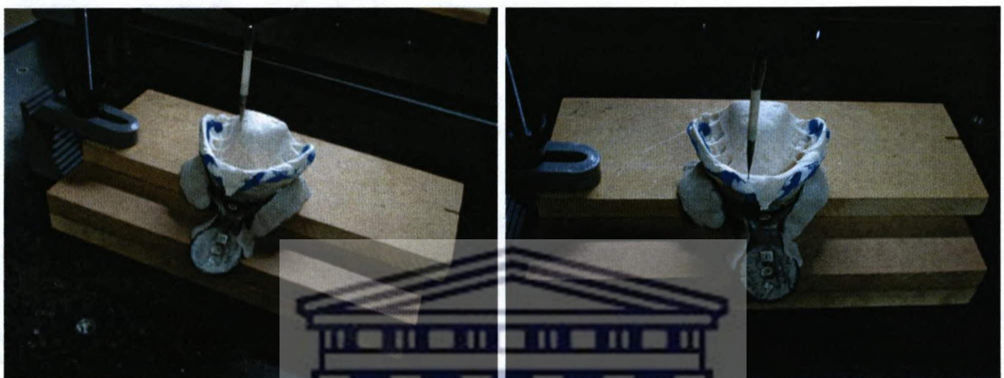
Conventional alginate impressions (upper and lower) were taken from a second volunteer to enhance the volume of data of this research for statistical purposes. (Fig 22)

Figure 22:- Upper Alginate impression on scanner table, Stabilised with Prestik, in the process of undergoing scanning



Inquiries at the other departments in the Faculty of Dentistry regarding the dual impression methods and accumulated data stirred interest in the "carrier" prototype. Satisfaction was expressed with the amount of soft tissue detail obtained with the impression. The Prosthodontists used a device resembling the carrier, called a bite-taker, which was not popular with the staff at that department, mainly due to the fact that these 'trays' worked unilaterally and the record was therefore not stable, nor precise enough. Bite registration in general was a problem, every attempt yielding a different result.

The plaster casts of the first dual impressions were carefully removed from the prototype and the models were trimmed. More time was spent on redesigning the "carrier". Modification included a fine mesh attached to the steel frame, which formed the outside border, and to an inside border of wire acting as an interior frame to hold the mesh in position. The mesh was added to prevent biting through the material and to provide a 'stop' for the ball stylus when scanning took place in the thin areas. This was flexible enough to allow 'giving' under the pressure of biting down. (Fig 23) Keeping the jaws in the closed position until the material was set further allowed the mesh to maintain the 'impression' imprinted by the teeth contact points.



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The original built-in 'separator' on the molars might not be needed anymore. The mesh was left "floating" in the anterior region as to allow for the overbite and overlap. During the redesign period the scanning was completed on alginate impressions.

Figure 23a):-
Carrier with floating mesh anterior

Figure 23b):-
Carrier with thin metal strip to hold material

The new model of 'carrier' was used to take another set of dual-impressions. The scanner was set up and initialized to proceed with the scanning overnight.

Impressions of both arches were taken simultaneously in the same manner as the first dual impressions. (Fig 24)

Figure 24 a):- Anterior labial view of the dual impression on modified carrier



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Figure 24 b):-
Upper arch view of dual impression

Figure 24 c):-
Lower arch view of dual impression

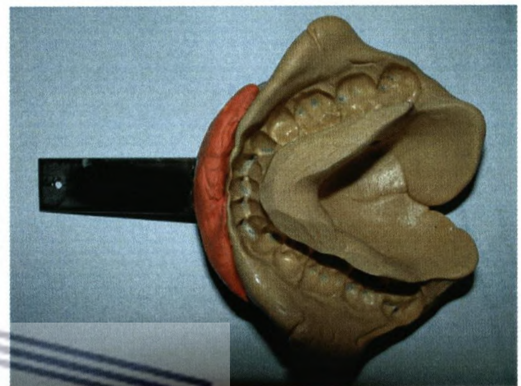
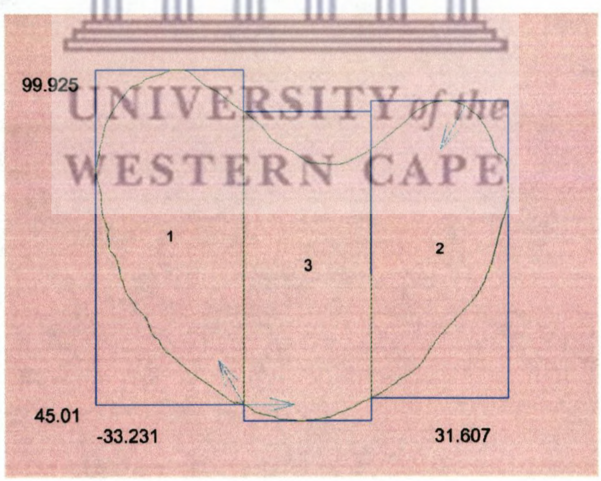


Figure 25 :- Upper_scan_grids :2nd dual imp trials ('boxes slightly different to Fig.21 a due to palate size)

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# Chapter Five

# Results

## Introduction:

### Results of the Investigation of the possibilities of Computerized Imaging and Reproducing of Study Models:

The partially scanned single impression resulting from the use of Wizcom (CAD CAM Suppliers), showed a clear "negative" image, representing the actual impression, on the screen.(Fig. 4). The rendered 'positive' image could, with the help of specific software, be covered in any colour of preference, to give a 'smooth', three dimensionally exact, positive image. White was used in most cases because of the resemblance to the original model.

It was possible to locate and enlarge specific areas. Landmarks could easily be defined and intervening measurements calculated. (Fig.8 and Fig.33). The rendered image could be manipulated, turned and looked at, at any desired angle on the screen. Closer inspection of any chosen area could be done on screen. The final image could then be saved on the patient records. Detail on the partially scanned area of the impression can be seen in the pictures (Figs 26 a + b).

Figure 26 a) :-
Occlusal view of scanned and rendered molar and premolar

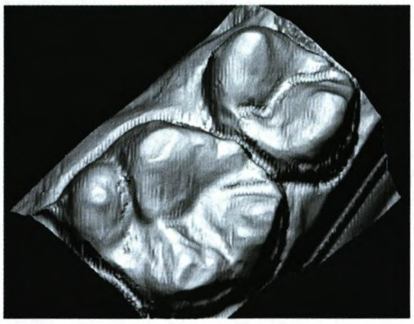

Figure 26 b):-
'Dragging' on the impression as seen distally and on the buccal aspect of the molar



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These records can be retrieved at any given time. Information can be sent to the computer connected to a milling machine, and the exact reproduction of the original model can be miled out of any material of choice.

## Phase 1 :

**Results of the Demonstration of Laser and Contact Scanning on Impressions and Study Models:**

**a) Contact and Laser Scanning on the Impressions:**

At Renishaw in the UK, the impressions were scanned by means of both contact and laser scanning, and the following problems were encountered:

1.*Contact scanning* directly on the *impression* material showed slight deviations in the very thin interproximal areas because of the local flexibility of the impression material. Therefore, laser scanning would be the method of choice when scanning impressions.

2.The smooth, shiny surface of the *impression* material posed a practical problem in the reflection of the scanner rays of the *laser scanner*, causing scattering with consequent inaccurate data. Using a non- 'shiny' impression material, sandblasting or spraying impressions before scanning, could possibly overcome this problem.

3.The operator also experienced problems in scanning the deep undercuts accurately, especially in the deep anterior labial sulci. To overcome this, the i*mpressions* can be fully scanned at different angles, the results then superimposed over each other and integrated, with the help of existing software, to give a single 3-D image of the scanned surfaces.

Different levels or grades of definition quality depend on the stepover size (the distance between successive contact points made by the tip of the scanner) and the speed at which the scanner tip moves in the action of scanning. The choice of step-over size and scanning speed will be determined by the amount of detail needed for a specific project.

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**b) Results of the Contact Scanning ofStudy Models:**
(Renishaw,UK)

Figure 27 a) :- Picture of the "Dental Master"

( i.e. Study model of the Mandible, prepared by a Dental Technician for conventional record keeping purposes)

Fig. 27 b):-
Original models presented to Renishaw

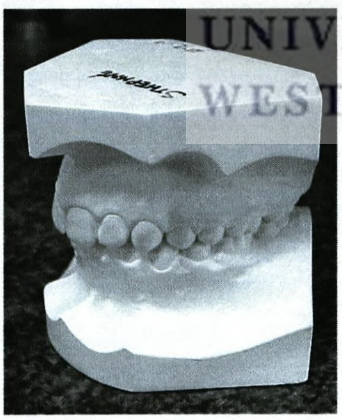

Fig. 27 c):-
Models with wax bite in position

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The technician/engineer needed to set the scanner up for specific purposes. To be able to secure the image needed from the study models, it was used as follows: (Table 1)



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Table 1 :- Scanning parameters used for the scanning of study models at Renishaw

**Scanning parameters**

| | |
|---|---|
| Probe dia. 1.0mm | Scanning speed 1000mm/min |
| Chordal tolerance 0.01mm | Scanning deflection 0.2mm |
| Nominal pitch 2.0mm | Multi grid scan |
| Step-over 0.05mm | Build tolerance 0.01mm |

Once the set-up was completed, the scanner automatically started tracing the outline and surface of the undefined object:

Figure 28 :- Contact scanning of the "dental master" in process

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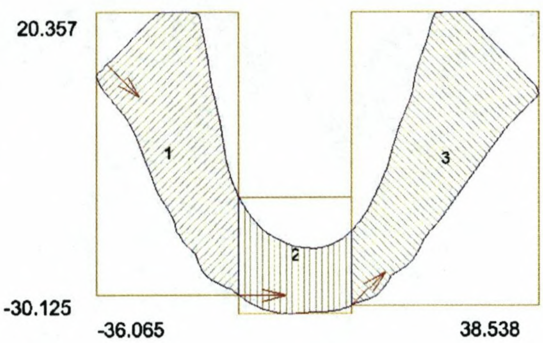
Figure 29 :- Multi-grid set-up using a 2D profile to limit the scan area (Also fig.20,21)




Numbers 20.357,
-30.125,
-36.065 ,
38.538
representing the relative positions of the X- and Y-axis while scanning the multigrid areas 1, 2 and 3

After the scanning process was completed, the captured data could be verified visually as a rendered image. (Fig 30)



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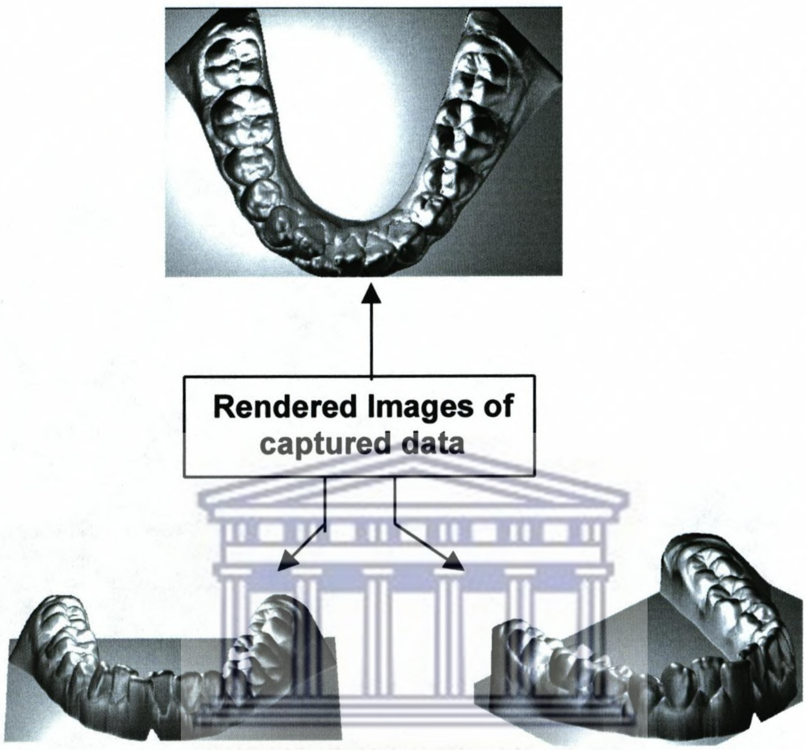
Figure 30:- Rendered Images

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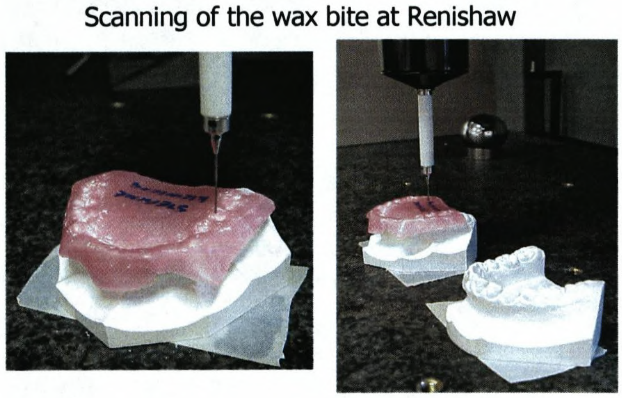
Renishaw's technicians also proved that scanning of the "bite" could be done successfully.(Fig.31) (The relationships between the tooth impressions and the bite impressions were not stored – and no final image available). Had this been done, it would have been possible to take cross sections through each tooth so that relationships between lower and upper teeth could be visualised.

Figure 31:- Scanning of the wax bite at Renishaw





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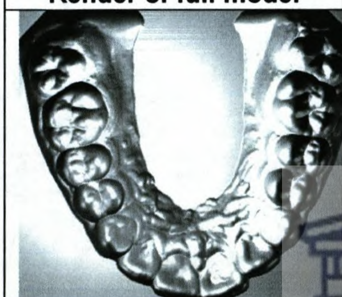
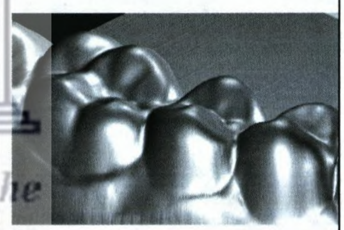
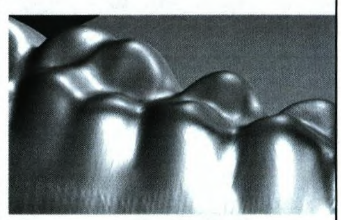
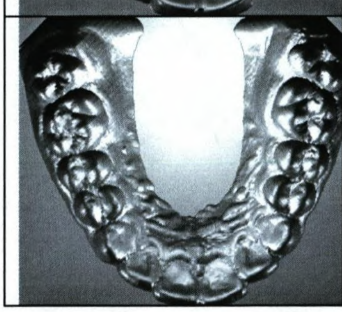
The scanning process was repeated with different step-over values between the scan lines. The results below show the relationship between scanning time and quality of surface. The same upper model was used to make comparison of detail easier. (Table 2)

Table 2:- Scanned and rendered images:
Comparing step-over sizes to the time and quality of finish

| Render of full model | | Render of magnified area |
|---|---|---|
|  | **Captured at 0.05mm steps**<br>**Time: 5hr 56min**<br>**No. of points: 439,007**<br><br>***High level of detail*** |  |
|  | **Captured at 0.1mm steps**<br>**Time: 3hr 4min**<br>**No. of points: 215,353**<br><br>***Good detail but not as crisp on the margin line*** |  |
|  | **Captured at 0.2mm steps**<br>**Time: 1hr 36min**<br>**No. of points: 109,081**<br><br>***Margin line detail lost*** |  |
|  | **Captured at 0.5mm steps**<br>**Time: 0hr 43min**<br>**No. of points: 44,575**<br><br>***Data too coarse to apply the data filter*** |  |

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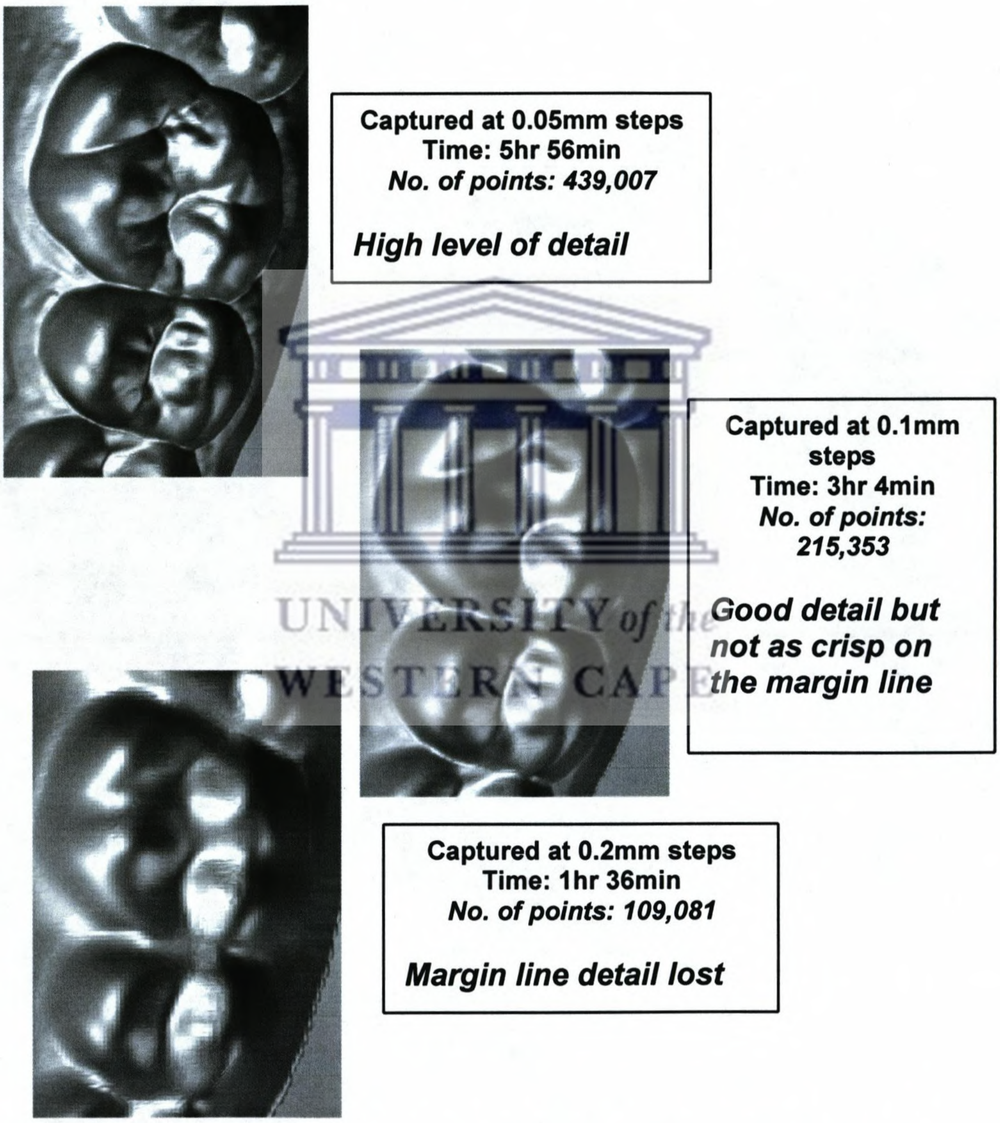
The dimensional accuracy achievable from scanned data will be dependent on the step-over between each scan line. The examples show the surface quality resulting from different step over values.

Figure 32 :- Detail results with different size step-overs




*Dimensional data from the 0.05mm model will give accurate results, the 0.1mm data accuracy will start to fall away and at 0.2mm step-over, poor results will be recorded.*

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Captured and rendered images can be analysed and diagnostic data can be obtained by establishing specific XYZ positions and readings.

Figure 33 :- Specific landmarks can be marked and precisely measured i.e. interproximal contacts, central fossae, canine tips.


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These results and deductions drawn from the scanned images, answered most of the immediate questions regarding the capability of this technology. Full insight can only be gained by personal use of the scanner and the application of the basic principlesof dental record keeping within the field.



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## Phase 2 :

### Results of the research in Implementation of Scanning and Measuring on Study Models:

Pencil scanning and landmark measurements on the ten sets of models during the session at AZTech, resulted in a series of arch outlines and numbers. As an explanatory example only the first set of study models' scan and measurements can be seen in Fig. 34a (lower) and 34b (upper).

First Set of Study Models
Figure 34 a :- Lower

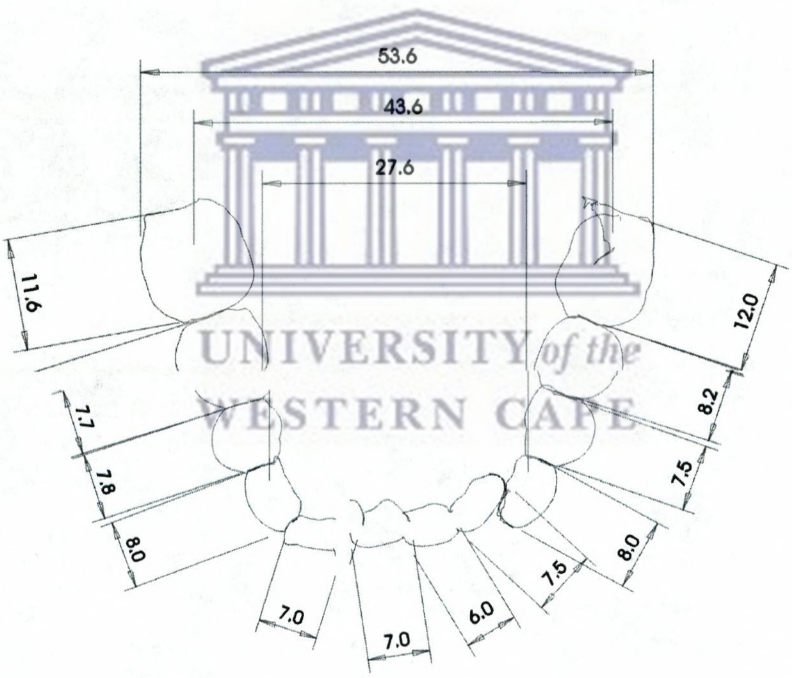


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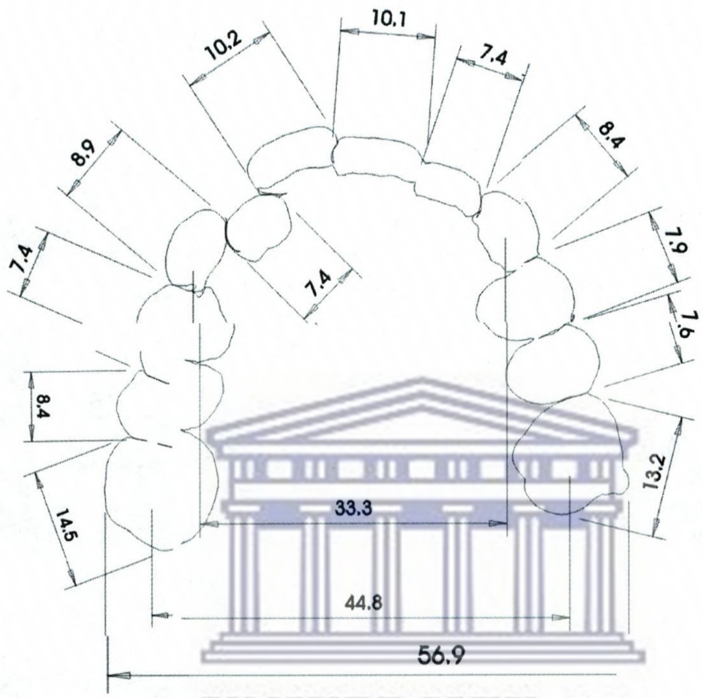
Figure 34 b):- Upper

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The action of the scanner, 'reading' the surface of the object (model) sent information to the computer in the image of a grid. (Fig.35).

In this initial stage of scanning, the occlusal surfaces of the upper and lower models were scanned. The information was then used to create rendered images of these views. (Fig. 36, 37 and 38)

A lot of time was spent on trial and error. These images were rendered to produce manoeuvrable 3-D pictures on screen. (Fig.37, 38)



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Figure 35:- Initial grid pattern of the scanned object

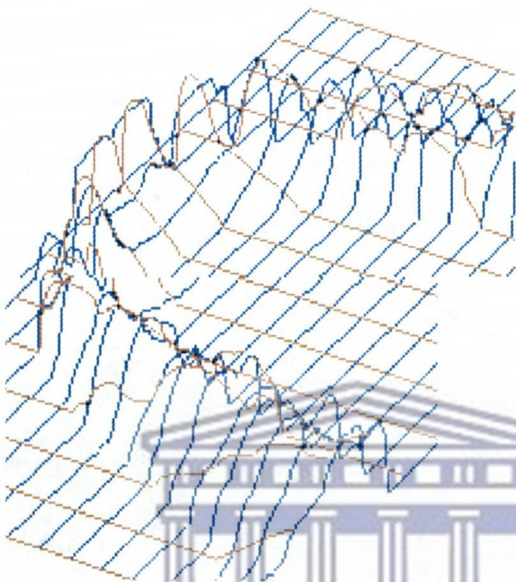

Figure 36:- Rendered image from the grid pattern, lower cast

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Figure 37:- Close up view of the anterior labial aspect of the two models in occlusion.

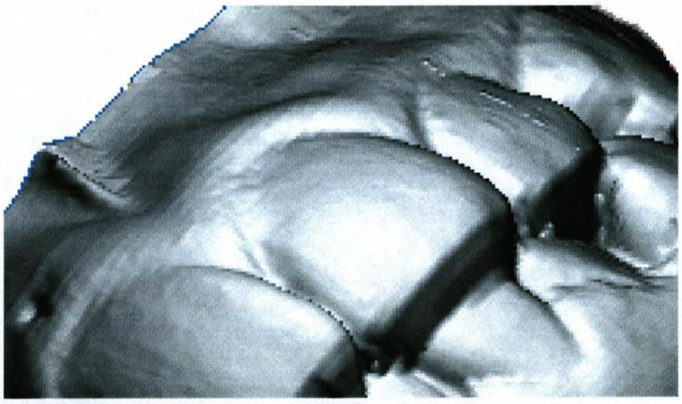

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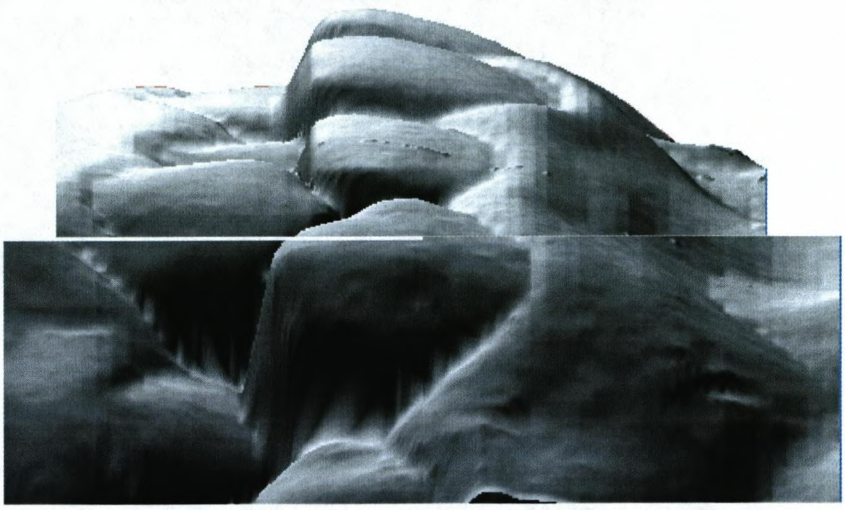
Figure 38:- Close up view of the overbite/overjet (put together in 4 pieces, as the saved image was too big for normal copying)





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Computerized measurements were also done on all 10 sets of models. The first set of measurements on the models had errors and measuring mistakes, but the accuracy improved noticeably with sequential attempts. As the Renishaw scanner is also used as a 'testing' instrument for precision engineering, most errors can be related to human handling.

The accuracy of the measurements was influenced by the following factors:

i) Inexperience with the scanner
 -rotated teeth
 -absent lateral incisors(estimated widths)
 -blocked out units
 -abnormal anatomy e.g. diastemas
 -finding the tip of the canines with the probe tracer

ii) Operator error:
 Due to time restrictions, machine availability and other logistic problems, some measurements were done by operators who were not dentally educated or informed.

iii) Communication errors due to all above.

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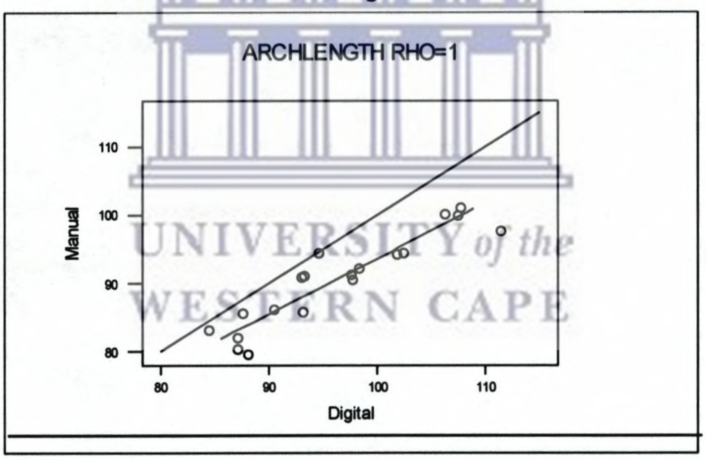
**Statistical Analysis:**

Results of analysis 1:

The digitally derived data were tabled ( Appendix D, table11) along with the data secured manually from the original 10 sets of plaster casts and the composite sent for statistical/scientific evaluation and analysis:

For the comparison of Manual and Digital measurements of the plaster models one has to accept that neither measurement is perfectly accurate, in other words, there is a measurement error variance associated with each of the methods. Figure 39 is a plot of Manual versus Digital measurements, showing two lines, one fitted by the method of maximum likelihood assuming a certain ratio of the error variances, the other a 45 degree line through the origin.

Figure 39:- Plot of Manual vs Digital *




Every dot represents the manual and a digital reading for the same point on the same cast. The ordinate of a particular dot is the manual reading, the abscissa ( shortest distance from a point to the vertical or y-axis, measured parallel to the horizontal or x-axis is the corresponding digital reading.

Two observations emerge from the plot :

First, there is a bias away from the 45-degree line; the digital values tend to be greater than the corresponding manual values.

Second, the relation between manual and digital measurements seems to be linear, the fitted line plotted being

$$Manual = 12.468 + 0.812\ Digital$$



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Results of analysis 2:

Manual re-measurement data of the original 10 sets of gypsum models was sent to the statistician to fulfill the need ( to establish the true ratio of the error variances and their values. Repeat measurements of the same model by at least one of the methods. Another way out would be if the value of one of the error variances were known, possibly from other sources), that developed from the first analysis:

**1.** This analysis gives details of some calculations of `error' variances and some other statistics, based on the manual measurements and the digital measurements of the models supplied. In the first calculations of error variances of Archlength-measurements, '6'+'5'+...+'6' was used for the manual measurements and the third column below for the digital measurements.

| Archl. | '6'+'5'+...+'6' | DIGITAL |
|---|---|---|
| 111.4 | 111.4 | 111.4 |
| 98.3 | 98.3 | 98.3 |
| 107.4 | 107.6 | 107.6 |
| 90.5 | 90.5 | 90.5 |
| 107.7 | 107.7 | 107.7 |
| 97.6 | 97.6 | 97.6 |
| 101.8 | 101.8 | 101.8 |
| 93.1 | 93.1 | 93.1 |
| 93.2 | 101.2 | 101.2 |
| 87.1 | 87.9 | 87.9 |
| 87.6 | 95.4 | 95.4 |
| 88.0 | 88.0 | 88.0 |
| 106.2 | 106.2 | 106.2 |
| 97.7 | 97.7 | 97.7 |
| 102.4 | 103.1 | 103.1 |
| 87.1 | 87.1 | 87.1 |
| * | * | 94.8 |
| 84.4 | 84.4 | 84.4 |
| 94.6 | 101.9 | 101.9 |
| 93.0 | 93.0 | 93.0 |



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2. Considering `error of measurement' in manual Archlength values using the two sets of manual measurements for calculation.

The first manual measurement is $X_1$ the second, i.e. the repeat set supplied later, $X_2$. According to a `constant bias' model, described for example by Jaech(1985), (as quoted by the statistician) taking $X_1$-$X_2$ differences and then calculating the sample variance of these differences gives an estimate of $2\sigma_x^2$, where $\sigma_x^2$ is the manual measurement error variance. The estimate of $\sigma_x^2$obtained in this way is 2.129, i.e. $\hat{\sigma}_x$] = 1.459. (i.e. standard deviation fluctuating either side of the mean).

Y is the digital measurement, and $\sigma_y^2$ its error variance. An estimate of $\sigma_x^2$ was made by again using the constant bias model. Firstly, $\overline{X}$ is the mean of $X_1$ and $X_2$, that is, for each $X_1$, $X_2$ pair the mean $\overline{X}$ was calculated, giving 20 values of $\overline{X}$. The error variance of $\overline{X}$ is $\sigma_x^2/2$ estimated as 1.065. Next calculated, the 20 differences Y-$\overline{X}$. The sample variance of these differences is an estimate of $\sigma_y^2+\sigma_x^2/2$. Its value is 9.180, giving the estimate of $\sigma_y^2$ as 8.115, $\hat{\sigma}_y$] = 2.849.

Summarised: $\hat{\sigma}_x$] = 1.459 and

$\hat{\sigma}_y$] = 2.849.

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**3.** All calculations were done with the constant bias model. (Is there really a bias?) The mean of the 20 $X_1$-$X_2$ values is -1.075, its standard error is 0.461, so it differs significantly from zero; *t*=-2.33, P=0.031. There is an even bigger bias between the manual and the digital measurements. The mean of the 20 $\overline{X}$-*Y* values is -6.253 its standard error is 0.677, so it differs significantly from zero; *t*=-9.23, P<0.00005.

**4.** Figure 40(a) is a plot of *Y* vs $\overline{X}$ values with a superimposed straight line of slope=1 through the origin. There is a slight indication of non-constant bias.



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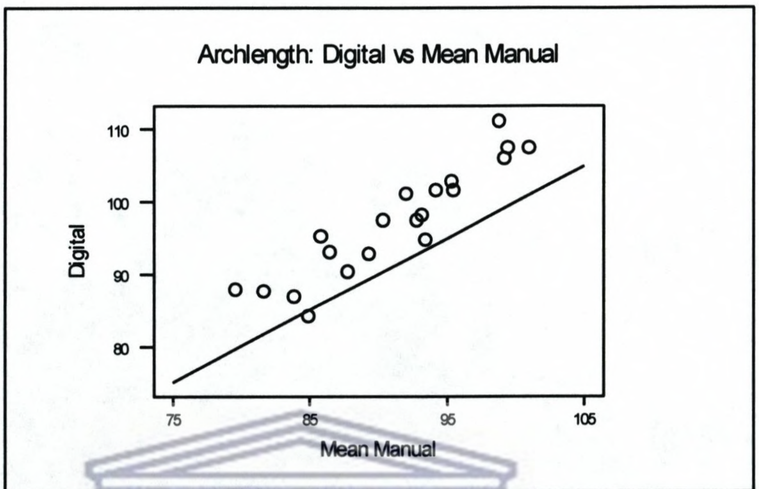
Figure 40 (a):- Plot of Archlength comparisons : Digital vs Manual




Using the value of $\sigma_x^2$ obtained above it is possible to make an adjustment to the estimate of $\sigma_y^2$. The details briefly are as follows: Let

$$E(\bar{X}|\xi) = \xi$$

$$E(Y|\xi) = \alpha + \beta\xi$$

$$var(\bar{X}|\xi) = \sigma_x^2/2$$

$$var(Y|\xi) = \sigma_y^2$$

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following the approach described by Jaech(1985)

$$var(\bar{X}) = \sigma_x^2/2 + \sigma_\xi^2$$

$$var(Y) = \sigma_y^2 + \beta^2\sigma_\xi^2$$

$$var(Y - \bar{X}) = \sigma_y^2 + \sigma_x^2/2 + (\beta - 1)^2\sigma_\xi^2$$

Substituting the already estimated value of $\sigma_x^2$, and the sample versions of var($\bar{X}$), var(Y) and var(Y-$\bar{X}$) three equations are achieved that can be solved for estimates of $\sigma_x^2$, $\sigma_\xi^2$ and $\beta$.



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The results are

$$38.901 \rightarrow \sigma_x^2/2 + \sigma_\xi^2$$

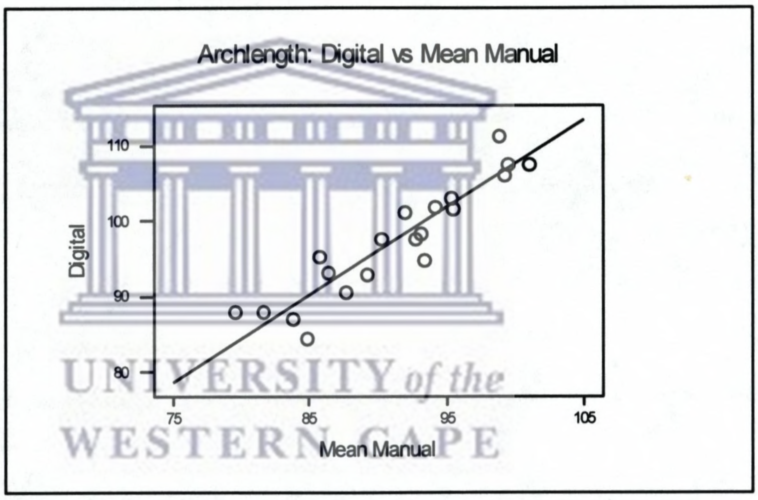
$$58.997 \rightarrow \sigma_y^2 + \beta^2 \sigma_\xi^2$$

$$9.180 \rightarrow \sigma_y^2 + \sigma_x^2/2 + (\beta - 1)^2 \sigma_\xi^2$$

giving estimated $\beta$ = 1.172 and estimated $\hat{\sigma}_y^2$ = 7.026; $\hat{\sigma}_y$ = 2.651.

Figure 40(b) is a plot of Y vs $\overline{X}$ values with a superimposed straight line of slope=1.172 and `best fit' intercept=9.44.

Figure 40 b):- Plot of Archlength values with superimposed straight line

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The digital measurement seemed to be more variable than its manual counterpart due to the relative inexperience of operators and the new and unfamiliar technologies that need adaptation of techniques in the field of Dentistry.



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## Phase 3:

### Results of the Investigation of the Direct Scanning of Impressions: (Stellenbosch)

Investigation of the scanned image of a part of the first impression showed vertical lines. The stylus-shaft was found to interfere with the 'bulbosity' of the buccal surfaces of the teeth, creating this pattern. Scanning was stopped and a different approach sought. The problem was overcome by tilting the impression in a more favorable position before scanning, so that the undercuts were minimized.

Scanning was started again and completed with disappointing results. The rendered image showed deflectionof the interproximal 'flimsy' parts and poor definition and detail in the fossae. No record of this rendered image was taken. The Alginate was not 'strong'/non-porous enough to handle the pressure of the stylus while contact scanning. (Fig.41) This problem can be overcome with future development and advanced technology in the field of LASER scanning. Scanning was repeated with lighter stylus pressure while contact scanning. The rendered, 'positive' image derived from the 'negative' scanned data, showed impressive details on all flat surfaces.

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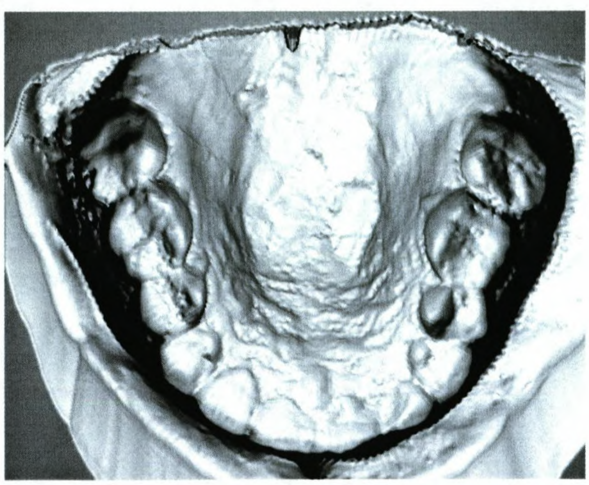
Figure 41:- The furrow around the buccal edge due to 'negative' scanning area. (1st impressions)





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President (a more stable and harder material than Alginate) was used for the trial dual impression to minimize pressure point deflections. Combining the different boxed areas in the end enabled one to see a single image with more detail. Example of the 'boxes' used for the scanning can be seen in the outlay of the grid (Fig. 21a+b, 25). Scanning time (11h00 – 16h30) took five and a half hours to complete the upper impression.

There was a problem with scanner deflection on some of the deep fossae areas due to the thinness of the material. These areas and surfaces were reinforced with wax, but the wax attached itself to the tip of the stylus and caused more deflection and inaccurate data reading! All other surfaces where substantially thicker and therefore more sturdy material was scanned, the surface proved to be smooth and very 'scannable'.

The next problem encountered was with the setup and initializing of the scanner. With the axial adjustments, the XY normally represents the 'table of reference' and the Z-axis is automatically adjusted to scan in a perpendicular direction. (as described in detail under Scanner Training). This led to a tilt that allowed the scanner to miss out on the far ends of the anterior teeth, thus 'cutting' teeth in half…not scanning the full length. The automatic adjustment of the computer had to be considered when tilting the impression, as to include wider areas of scanning for inclusion of 'deeper' parts.

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Figure 42:- Scan_up_true_inv : dual trial imp

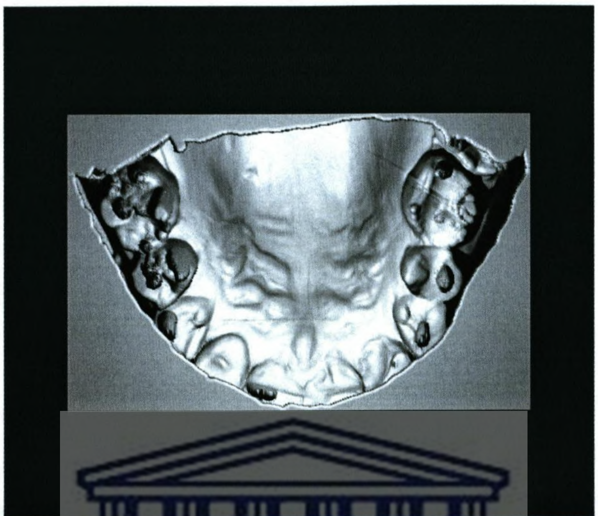
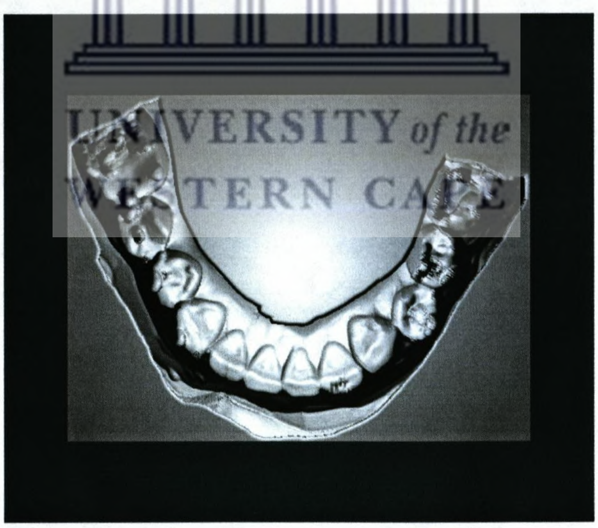


Figure 43:- scan_lo_true_inv : dual trial imp



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The visual results were pleasing, as was the scientific precision of the measuring capabilities on the captured images. All the visual images acquired at Stellenbosch were applied and sent to the researcher via the Internet. (figs.42 ,43,44, 45). The final measurements and resulting data from this research were lost because of a Departmental error and could not be repeated or retrieved.



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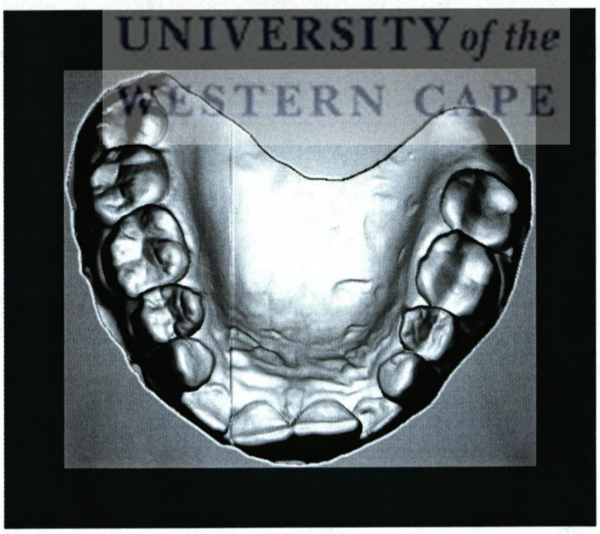
Fig.44:- scan_lo_true_inv : dual imp trials

Fig.45:- scan_up_true_inv : dual trials



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# Chapter Six

# Discussion

Plaster casts have traditionally served two main purposes in orthodontics: as a permanent three-dimensional record of the malocclusion, and a source of information for diagnosis and treatment planning. Goshtasby AA et al.[16] (1997) concluded that digital reconstruction of gypsum casts has tremendous applications, by applying the use of a range scanner to scan a plaster cast for display and storage. This produced multiview range images, and it can be saved along with patient data and retrieved conveniently as well as being transmitted via Internet for remote diagnosis. Because of their physical nature, however, plaster casts have inherent shortcomings in terms of storage, retrieval, transferability, and diagnosis.

Various alternatives have been investigated over the years. Although Lowey [23] (1993) encountered problems with an inherent magnification error on the IMSCAN, he found the greatest advantage was the direct on-screen image manipulation. The digitizing and computerizing of images derived from scanning the models, remains the most attractive alternative at this point. The presently available and constantly improving, software provides actions and options of unlimited caliber.

Another important development is that the software for digital imaging will become more integrated with other computerized dental applications in the dental office, enabling the exchange of patient data between different and remote practices more easily. For instance, according to Redmond[34] (2001) the digital models can be incorporated into computerized patient records, eliminating the need for model storage. In addition, they can be transmitted by e-mail with accompanying text to referring dentists or specialists.



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Laser scanning disappointed in general during this research, due to:

a) the relative unavailability in South Africa, as the demand is not yet sufficiently established to justify Departmental acquirement
b) the expensive nature of the service in terms of operator fees, machine cost etc.
c) and limiting factors like
   i) reflecting beams on shiny surfaces
   ii) angle of scanning to accommodate undercuts
   iii) standardization of scanning parameters.

It is, however, the most promising alternative for future research, because of the high level of accuracy, speed of scanning, uniformity and reproducibility.

Contact scanning proved to be more reliable, available and adjustable. The disadvantage of this method is the time factor and therefore it becomes expensive and economically not viable at this point in time. In most applications, the best results in terms of accuracy and quality of surface finish are obtained using contact scanning.

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During this research, investigation of the scanned images obtained from the Alginate impressions showed discrepancies:

a) with bulbous surfaces, unless tilting of the object becomes part of the setup routine. The different angles for different surfaces and combining of all the images at the end made it cumbersome. The reference table needed to be standard and stable to make scanning easier and quicker.

b) with the physical properties of Alginate. The stylus needs to be as small as possible to allow for higher quality surface finish, but this penetrates the soft material and leads to false readings. This was not encountered with the plaster casts



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Emphasis was placed mostly on the occlusal views of the upper and lower casts or images, because these perspectives allow one to analyze the arch form, arch symmetry, alignment of the teeth, palate shape, tooth size, tooth shape, rotations of teeth. According to the textbook Moyers [29] the results from analysis from these perspectives, can be applied to accommodate most requirements. But scanning possibilities are endless and not restricted. In Orthodontics, however, the precision of contact in occlusion, plays a vital role in diagnostics and treatment planning.

As W Redmond [34] (2001) demonstrated, digital models can be sectioned at any point in the sagittal or transverse plane- unlike their plaster predecessors. This capability may shed a new light on skeletal and dental asymmetries, and can help pinpoint skeletal and dental midlines. He pointed out that the virtual caliper allows any section of the model to be measured to within 100 microns ( 0.1mm) and that widely used analyses such as Bolton can be calculated electronically

The direct scanning of impressions, with either laser or contact scanning, remains a viable option for further and future research.

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# Chapter Seven

# Conclusion

Digital imaging is still a young technology in Dentistry and many aspects are not yet completely explored. It is promising and its significance is increasing because it opens the door to diagnostic information. Computerized study models overcome many of the shortcomings of plaster casts.

Further progress is not limited by a lack of image processing tools; rather by our understanding of the various components of diagnostic imaging in dentistry.

Although this research (in capturing 3-D images on screen) has only touched the surface of the vast field on future possibilities, the conclusions at this point in time are:

i) Conventional record keeping is becoming outdated, is creating storage problems and involves doctor, patient and technician time and money. The manufacturing of good plaster models is a time consuming and expensive procedure as Ayoub AF et al.[4] reported in 1997

ii) Contact scanning at the time of this research is far too slow to make it economically viable.

iii) Laser scanning is still relatively unobtainable due to the high import cost involved, but would be faster and more accurate.

iv) Digital measurements were found to be more variable statistically than the manual measurements because of the inexperience of operators and the breaking in of the 'new' field of scanning. Precision engineering and testing on scanning equipment have proved otherwise in fields other than Dentistry.

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v) Research was always hampered by the funding/cost factor.

vi) The results proved viability and a definite need for further funded research.

vii) Recent literature from over the globe proves international interest in digitized and computerized record keeping.

viii) A recently introduced OrthoCAD digital model service in USA, overcomes most of the problems encountered with the conventional plaster casts. In addition to being the last component of a fully electronic patient chart, this computerized system opens a new realm of orthodontic diagnosis as advertised and discussed by W Redmond[34] (2001)

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# Appendix: A

Methods of measuring study models – extracted from the Lowey [23] (1993) as mentioned in the literature review.

**Direct methods**:

i) *Calipers* were documented by several authors :
Vernier calipers: –
Walter, 1953 ; Cooper, 1960; Hunter and Priest, 1960; Huckaba, 1964; Sarin and Savara 1964 and 1971; Claridge, 1973; White, 1977; Doris et al 1981.

ii) *Dividers* were in use since 1947 by Nance and followed by researchers like Neff 1949 &1957, Steadman 1952, Walter 1953, Bolton 1958, Huckaba 1964

iii) *Flexible rulers* were tried in 1953 by Walters

iv) *Other linear* measurement methods were explored by Lysell 1958, and Lavelle 1968 &1972

v) *Calibrated plastic occlusal overlays* were tried by White and Hobbs in 1977

vi) *Symmetroscopes/graphs:* The history goes back as far as 1921, tried by Gruenberg and fdlowed up by Korkhaus 1930, Lysell 1958 and Lebret 1962.

**Indirect methods**:

vii) *Stereophotogrammetry* was first reported in 1852 by Captain Laussedat of the French Corps of Engineers. In 1901 Professor Pulfrich applied the techniques of stereoscopic observation and became the founder of the specialty.
Viewing of these photographs and three-dimensional image measurement was conducted by Van Orel (1901). Mannsbach, (1922) measured study casts using this method. It was then

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largely forgotten until Thalmann-Degen, (1944) and, much later, Zeller, (1956) studied tooth filling contours with this technique again, and Tham, (1957) utilized it to measure tooth surface morphology. Savara and Sanin (1969) used the technique for a quantitative appraisal of study casts and highlighted a number of problems affecting accuracy.
Berkowitz and Pruzansky (1968) extended Savara's work, using original models rather than duplicated casts and took more care to orientate them in a constant manner to the camera.
Subsequently Beard and Burke (1967). Burke and Beard (1971) investigated and modified the technique, while Biggerstaff (1969) used the system to examine variations of interpremolar and intermolar widths.

viii) *Holography.* Mikhail (1974), as a photogrammetrist, was one of the first people to research holographic measurement. Gibson (1982) used the reflex metrograph to measure a holographic image of study casts. Keating et al. (1984) measured one unmarked upper plaster cast and its holographic image obtained from a single beam reflection homographic set up. (Vernier caliper was used for this). Harradine et al (1987) ran a 6month prospective clinical trial to assess the clinical usefulness of holographic images of study casts.

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ix) *Laser scanning.* Laser scanning techniques are used to construct and record three-dimensional surface information. At the time of the current research, reports only involved measurements taken from facial profiles. (Arridge et al., 1985;Moss et al., 1987) The advantage of this technique for non contact, three-dimensional measurement with high spatial resolution and sophisticated graphics would be equally applicable to study cast measurement.

x) *Xerox copying and radiography.* Mensuration has also been applied to Xerox copying machine reproductions of dental casts according to Singh and Savara (1964) and Huddart et al., (1971) and Mazaheri et al., (1971). Steadman (1952) obtained orthodontic measurements from X-ray films of dental casts in occlusion.



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xi) *Computer techniques*. The introduction of computers heralded a new generation of study cast measuring devices allowing greater numbers of landmarks and planes to be recorded.

xii) *OPTOCOM* The OPTOCOM, developed by Van der Linden et al., (1972) allowed three-dimensional measurements to be recorded using a fixed magnification (x10) microscope. It was found to be time consuming and the depth of field was limited to 5 mm.

xiii) *Reflex-plotters.* Mikhail (1974) described the principle later used by Scott and Abdel Aziz. (1980), and Scott, (1981) to design the reflex microscope and reflex metrograph. Takada et al., (1983) and Tkatch et al., (1983) examined inter-operator variability on marked study casts.

xiv) *Photography*. BeGole et al. (1981) used a Fortran computer program to digitize 1:1 photographs of study models. Robertson and Kennedy (1984) compared telecentric photography with conventional photography of dental casts. Photographic methods of study cast measurement allow only two-dimensional assessment of a three-dimensional object.

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# Appendix : B

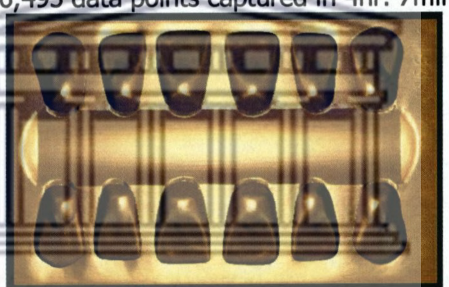
Website data and information available on scanning

Table 3:- Scanning parameters

| | |
|---|---|
| Probe dia. 0.5mm | Step-over 0.05mm |
| Chordal tolerance 0.01mm | Scanning speed 1000mm/m |
| Scan X axis two way | Scanning deflection 0.2mm |
| Nominal pitch 1.0mm | Build tolerance 0.01mm |

Figure 46:- These screen dumps have been taken directly from the screen display of the rendered model within TRACECUT software.

a) 206,495 data points captured in 4hr. 7min.



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b) X & Y screen display

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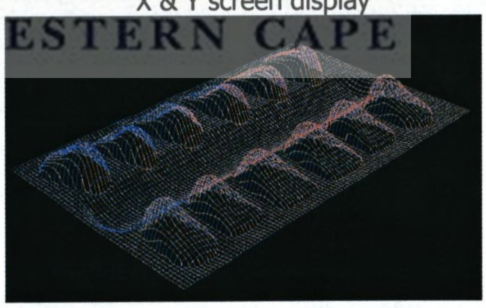



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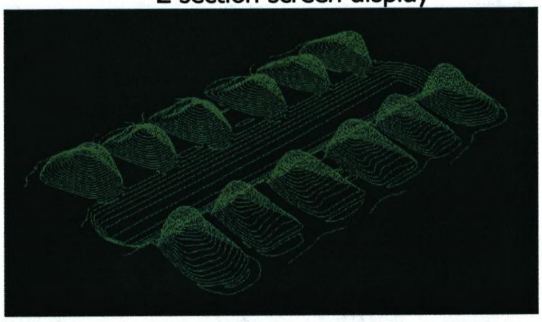
c) Z section screen display



**Scanning of the sample tooth used the following parameters:**
Scanning Pitch 1.0mm  Speed 1000 mm/min  Deflection 0.5mm

Table 4:- Scanning results of sample tooth

| 1 | 2 | 3 | 4 |
|---|---|---|---|
| **Stopover 0.05mm** | **Stopover 0.1mm** | **Stopover 0.2mm** | **Stopover 0.5mm** |
| **Number of points 65537** | **Number of points 34091** | **Number of points 17565** | **Number of points 8574** |
| **Scanning time 35 minutes** | **Scanning time 19 minutes** | **Scanning time 10 minutes** | **Scanning time 6 minutes** |

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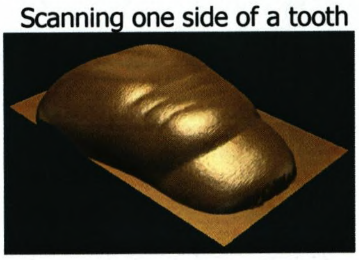
Figure 47:- Scanning one side of a tooth



Scanning time
19 mins. 26,089sec
Data points:
Stylus diameter 1.0 mm
Scanning pitch 0.5 mm
Scanning stopover 0.05 mm
Scanning speed 300 mm/min
Scanning deflection 0.2 mm



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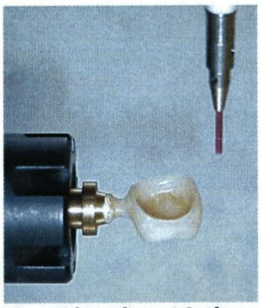
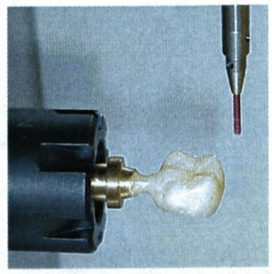
Table 5:- Example scanning of a dental inlay



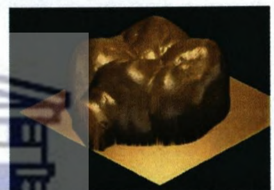
Scanning of a master dental cap for reproduction in a ceramic material.



**Scanning time 16mins**
**18507 data points**

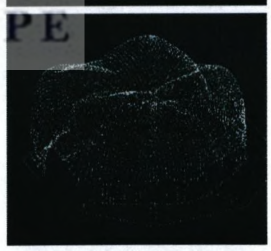
**Scanning time 14mins**
**14720 data points**

**Rendered screen image from TRACECUT software.**



**Screen display showing section lines**

**Screen display showing point distribution.**



**Screen display showing scan lines.**

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*Scanning strategies*
Scanning strategies have been established, by first generating a 2D-profile from the master that is then used to limit the scan areas. From the 2D-profile template a series of scanning grids are generated which approach normal to vertical surfaces where possible to ensure the best possible data quality. This process ensures that the scanning is only in the areas required and time is not wasted scanning off the part.

Figure 48:- Capturing parts of stylus.

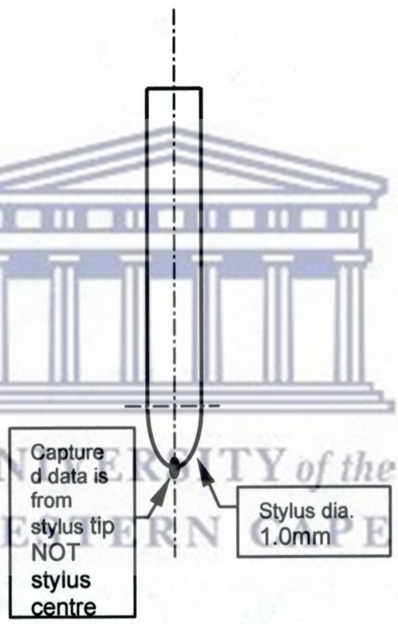
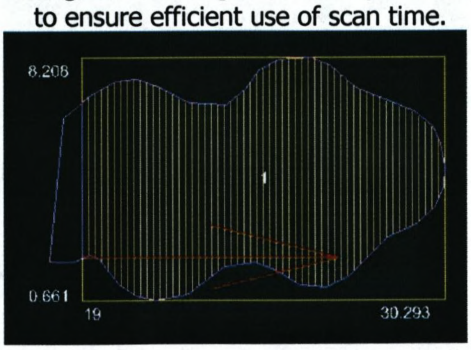



Figure 49:- The rectangular scanning is limited by the 2D profile to ensure efficient use of scan time.



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*The Machining operation*

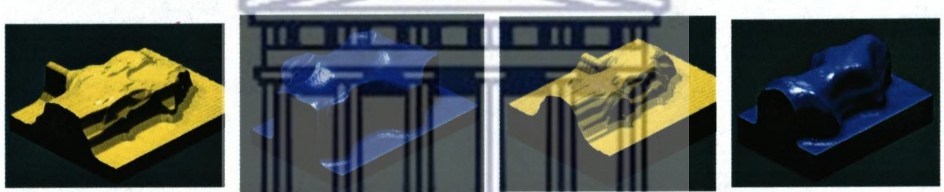
The machining operation uses two tools per side, each side using the following parameters:

Table 6:- Parameters for Machining

| | |
|---|---|
| Tool 1 – 3.0mm Ball end | Tool 2 – 1.0mm Ball end |
| Feedrate 2000mm/min | Feedrate 1000mm/min |
| Spindle speed 8000 RPM | Spindle speed 6000 RPM |
| Depth of cut 1.0mm | |
| Surface offset 1.0mm | Surface offset 0mm |

*Tool Path Verification using the Virtual Machining Module of TRACECUT*

Table 7:- Tool path verification of 3.0mm & 1.0mm tool for the first side.



1st. Side Tool 1 Rough m/c | 1st. Side Tool 2 Finish m/c | 2nd. Side Tool 1 Rough m/c | 2nd. Side Tool 2 Finish m/c

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**A sample dental impression in a rubber material scanned directly to eliminate an intermediate stage of casting a gypsum model.**

Table 8:- Scanning parameters for the sample impression

| | |
|---|---|
| Probe dia. 0.5mm | Scanning speed 300mm/min |
| Chordal tolerance 0.01mm | Scanning deflection 0.2mm |
| Nominal pitch 2.0mm | X axis scan |
| Step-over 0.05mm | Build tolerance 0.01mm |

Due to the flexibility of the impression material a low scanning force was used, 0.1mm target deflection resulting in 10 grams of force



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Figure 50:- Scanning of a sample impression


Number of data points captured 59,060

Capture time 1hr 29 mins

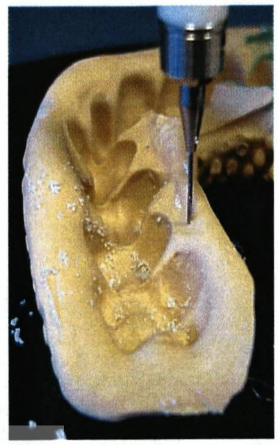

Figure 51:- A perspective view from both sides of the captured data.

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The captured data has been filtered and represented as rendered image to allow visual inspection prior to the generation tool paths for manufacture.



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Figure 52:- Rendered images generated from Tracecut using the captured scanned data.

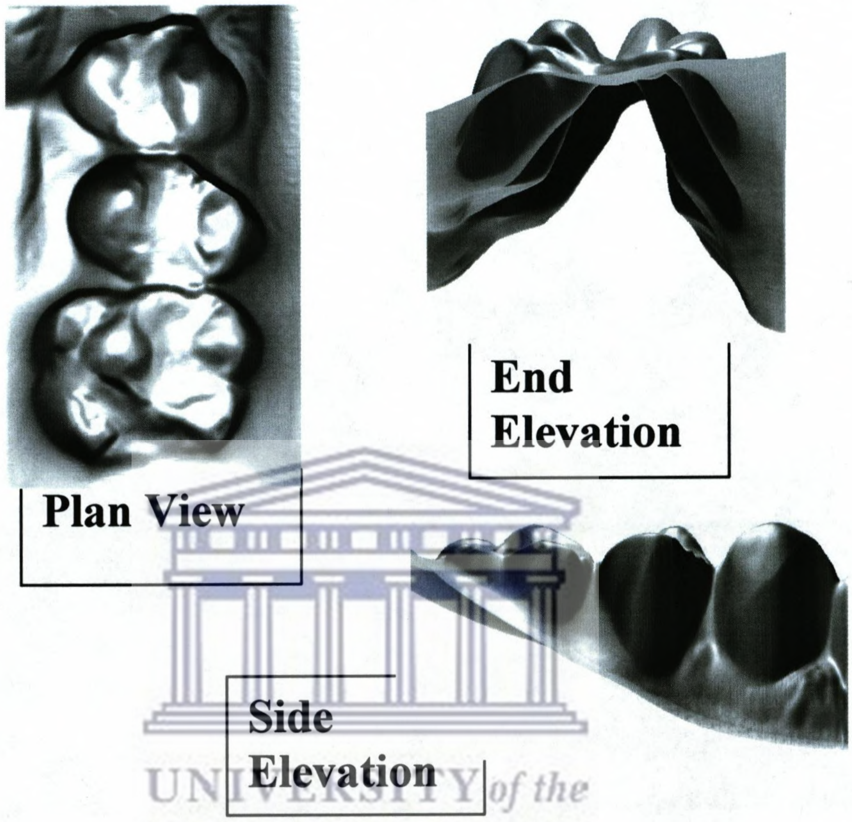
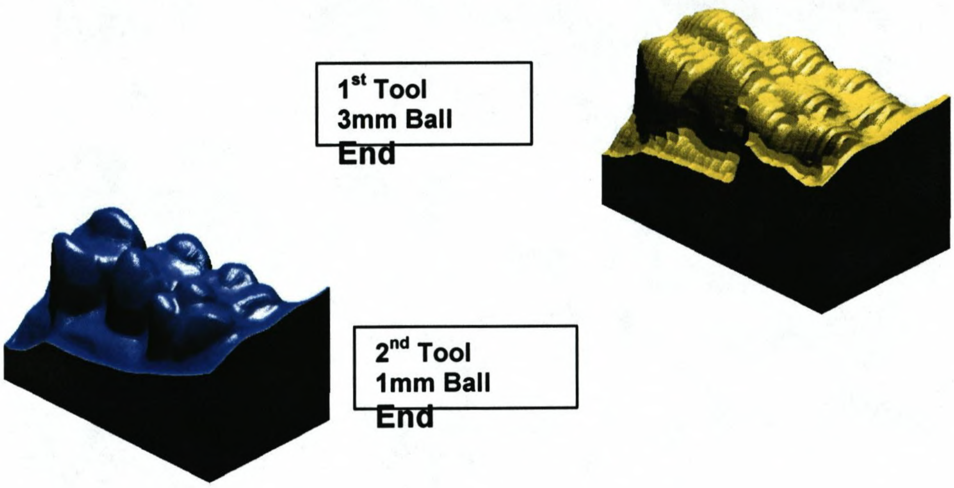



Figure 53:- The tool path generation can be verified using the Virtual Machining Module

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# Appendix C:

## i) Cyclone & Tracecut Introduction :

The Cyclone Scanner is an interchangeable machine that allows it to perform different tasks. From contact – to laser scanner by replacing the tips, connected to a milling machine – it reproduces any object. The components and functions of the scanner and the introduction to the software (Tracecut) used, can thus be summarized:

Figure 54:-

**Cyclone:-** *Machine parts*


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<u>Styli</u> : *Shaft* - shape = taper or straight
- size = length, radius

*Tip* – disc
square : 2-D scanning
ball

<u>Table and Clamping</u> :- for the setting up of objects on a flat and stable, controllable surface.

<u>MOTORS AND CALIPERS</u>:



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*Scanning* of objects to obtain three-dimensional information for the purpose of computerizing all data is done along three axes, the X, Y and Z.

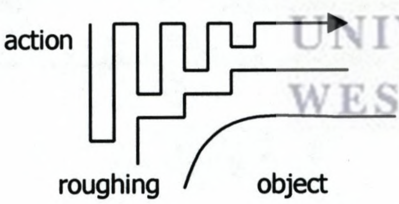
X = left to right movement
Y = forward and backward movement
Z = up and down

Reading the project correctly and setting up the scanner saves time with the struggle with depth of undercuts', severity, etc. Factors to take into consideration when 'setting up' the scanner, basically include:

The Stylus : size, length
The Position : Cut / mould direction, exact $180^\circ$ turn
The Strategy : Need to index the machine in a way that is perfect for the planned project : 2-D Scanning ≅ quick scan
Radial Scanning ≅ good for round objects

*Machining* :- Different methods of reproducing an object(milling) can be programmed for the perfect result :

Roughing : used in hard materials (like Ti) and it gives a semi-finish

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Semi-finishing takes away the extra rough parts.

Straight cutting : needs less time

*Rendering* :- this is an option on the computer software to check if the appearance of the scanned object is acceptable. Any unwanted areas can be corrected by a process termed "over grid".



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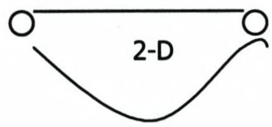
*Measuring :-* is done by sliding on chosen planes. Therefore, locating and measuring distances can be done instantly and on screen.
CAD gives physical readings

Volumes 


The training was completed with 'hands-on' scanning and measuring of the ten sets of models. Scanning of the alginate impressions proved cumbersome. All data that was captured was tabled and compared to manual measurements derived from the correspondng models.

## ii) Software application for future use, as follows:

(Transform the scanned data in the *Tracecut* model file (ex. scan_up_ true.mod) to the inverse by using the following procedures in *Tracecut*: Open up *3D Surface Operations*; *Recall* the model file by browsing to the right directory; *Transform* the model from male to female by selecting the appropriate tick box; Select *OK* to complete the transformation process, *Save* the model to a new name (ex. scan_up_true_inv.mod).
Create images from the scanned data by using the following procedures in *Tracecut*: From the *View* toolbar open up the *Display Settings* dialog box; Select the *View* tab and select *Top* view; Select the *Solid* tab; Select the *Show* tick box, set the *Material* to Matt White and set the *Resolution* to 500; Activate these new display settings by clicking on the *Generate* button; Wait until the generation of the image is completed then from the *Edit* toolbar select *Save Graphics*; Enter a name and *Save* the display in a bitmap file format.)



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# Appendix D:

Each table represents **one set** of study models

The **type of measurement** is indicated in the first column: (of all 10 tables)

6x6 = measurement between the central fossae of the first permanent molars, both sides

3x3 = measurement between the canine tips, both sides

6 = 1st molar (mesiodistal width of the number of tooth measured = as described previously)

5 = 1st premolar

4 = 2nd premolar

3 = canine

2 = lateral incisor

1 = central incisor

Arch length = totals of individual tooth measurements per model.

And the **measuring method** in the following two big down columns: (of all 10 tables)

The **manual** and **digital** data taken from the numbered set (2 sub-headings), is then subdivided into the respective

**upper** and **lower** models (maxilla and mandible for the respective methods), which in turn are divided into the relevant

**quadrants** (4 per set of models) for uniform measuring, reading and communicating purposes:

Quadrant 1 = upper right,

quad 2 = upper left,

quad 3 = lower left,

quad 4 = lower left of the specifically numbered set of models.

**Discrepancies** found to be bigger than 1mm were identified and explained:

* = Rotated, tilted, blocked-out teeth

# = Tracing error, overlapping measurements

(PE)= Partially erupted tooth

(-) = Absent tooth



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Table 9:- Tables recording the Example of the Measurements of the 10 sets of study models (explanation p.109)

Measurements taken from the first set of Study models

| Data | MANUAL | | | | DIGITAL | | | |
|---|---|---|---|---|---|---|---|---|
| | Study models no 1 | | | | Measurements 1 | | | |
| | Maxilla | | Mandible | | Maxilla | | Mandible | |
| 6x6 | 47 | | 41 | | # 44.8 | | # 43.6 | |
| 3x3 | 35.5 | | 28 | | # 33.3 | | # 27.6 | |
| | Quad 1 | Quad 2 | Quad 3 | Quad 4 | Quad 1 | Quad 2 | Quad 3 | Quad 4 |
| 6 | 11 | 11 | 11 | 11.3 | #14.5 | #13.2 | #12 | 11.6 |
| 5 | 7 | 7 | 8 | 7.4 | # 8.4 | 7.6 | 8.2 | 7.7 |
| 4 | 7.3 | 7.6 | 7 | 7 | 7.4 | 7.9 | 7.5 | 7.8 |
| 3 | 8 | 8.5 | 7.8 | 7.5 | 8.9 | 8.4 | 8 | 8 |
| 2 | 6 | 6.2 | 7 | 6.9 | # 7.4 | # 7.4 | 7.5 | 7 |
| 1 | 9 | 9.1 | 5.3 | 6 | # 10.2 | # 10.1 | 6 | #7 |
| | 48.3 | 49.4 | 46.1 | 46.1 | 56.8 | 54.6 | 49.2 | 49.1 |
| Arch length | | 97.7 | | 92.2 | | 111.4 | | 98.3 |

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Table 10:- Spreadsheet data for Statistical analysis of measurements as seen above.

**Manual measurements**

| | 6x6 | 3x3 | 6 | 5 | 4 | 3 | 2 | 1 | 1 | 2 | 3 | 4 | 5 | 6 | AL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U:1 | 47 | 35.5 | 11 | 7 | 7.3 | 8 | 6 | 9 | 9.1 | 6.2 | 8.5 | 7.6 | 7 | 11 | 97.7 |
| L: 1 | 41 | 28 | 11 | 8 | 7 | 7.8 | 7 | 5.3 | 6 | 6.9 | 7.5 | 7 | 7.4 | 11.3 | 92.2 |
| U:2 | 44.5 | 33.2 | 11.8 | 7 | 7.5 | 7.5 | 7 | 9 | 9.1 | 7 | 8 | 7 | 7 | 12 | 99.9 |
| L: 2 | 39.3 | 26.5 | 11 | 7 | 6.8 | 7.2 | 6 | 5.3 | 5 | 6 | 7 | 7 | 7 | 11 | 86.3 |
| U:3 | 46 | 38.1 | 11.5 | 7 | 8 | 9 | 7 | 9 | 9 | 6.9 | 8 | 7.8 | 7 | 11 | 101.2 |
| L: 3 | 42 | 28.2 | 12 | 7.1 | 7 | 7.4 | 6.3 | 6 | 6 | 6 | 7 | 7.3 | 7.6 | 12 | 91.3 |
| U:4 | 45 | 34 | 10.5 | 6.3 | 7 | 8 | 6.9 | 8.1 | 8.6 | 7 | 8 | 7 | 6.2 | 11 | 94.3 |
| L: 4 | 42 | 35 | 10.8 | 7 | 7 | 7 | 6 | 5 | 5 | 6.5 | 7 | 7 | 7 | 11 | 85.8 |
| U:5 | 42 | 33 | 10 | 6 | 7 | 7.5 | 6.5 | 8.8 | 8.4 | 6.5 | 7.5 | 7 | 6 | 10 | 91.2 |
| L: 5 | 37 | 23 | 10 | 6.3 | 6.5 | 6.2 | 6 | 5 | 5 | 6 | 6.5 | 6.2 | 6.7 | 10 | 80.4 |
| U:6 | 46 | 34 | 10 | 6 | 6 | 7.5 | 5.8 | 7.5 | 7.5 | 5.9 | 7.5 | 6 | 6.2 | 9.8 | 85.7 |
| L: 6 | 45 | 22.5 | 10 | 7 | 6 | 6.5 | 5 | 4.8 | 4.8 | 5.6 | 7 | 6.5 | 6.5 | 10 | 79.7 |
| U:7 | 49 | 36 | 11.4 | 7 | 7 | 8 | 6.9 | 9.9 | 9 | 6.9 | 7.8 | 7.2 | 7 | 12 | 100.1 |
| L: 7 | 45 | 27 | 12 | 7.2 | 7.5 | 6.5 | 6.1 | 5.2 | 6 | 6.2 | 7.3 | 7.1 | 7.9 | 12 | 90.5 |
| U:8 | 39.2 | 33.2 | 10 | 7 | 7 | 7 | 7.5 | 9 | 8.8 | 6.5 | 7.6 | 7.2 | 7 | 10 | 94.6 |
| L: 8 | 35.5 | 24.5 | 10.2 | 7 | 7 | 6.5 | 5.5 | 5 | 5 | 5.6 | 6.5 | 7 | 6.9 | 10 | 82.2 |
| U:9 | 46 | 26.6 | 10.5 | 6.2 | 7 | 7 | 6 | 8 | 8.2 | 6.2 | 7 | 7 | 7 | 11 | |
| L: 9 | 41 | 26 | 11 | 7 | 6.5 | 7 | 5.5 | 5 | 4.6 | 5 | 6.7 | 7 | 7 | 11 | 83.3 |
| U:10 | 40 | 32 | 11 | 6.5 | 7.1 | 7.8 | 7 | 8 | 8 | 7 | 7.5 | 7.2 | 6.5 | 11 | 94.6 |
| L:10 | 44 | 25 | 11 | 7.8 | 7.8 | 6.5 | 5.6 | 5 | 5.5 | 5.7 | 7 | 7.5 | 10 | 12 | 90.9 |



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## Digital Measurements

| | 6x6 | 3x3 | 6 | 5 | 4 | 3 | 2 | 1 | 1 | 2 | 3 | 4 | 5 | 6 | AL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | |
| U: 1 | 44.8 | 33.3 | 14.5 | 8.4 | 7.4 | 8.9 | 7.4 | 10.2 | 10.1 | 7.4 | 8.4 | 7.9 | 7.6 | 13.2 | 111.4 |
| L: 1 | 43.6 | 27.6 | 12 | 8.2 | 7.5 | 8 | 7.5 | 6 | 7 | 7 | 8 | 7.8 | 7.7 | 11.6 | 98.3 |
| | | | | | | | | | | | | | | | |
| U: 2 | 44.5 | 32.3 | 12.4 | 7.2 | 9.3 | 8.1 | 7.2 | 9.6 | 9.9 | 8.2 | 7.9 | 7.3 | 7.4 | 13.1 | 107.4 |
| L: 2 | 39.2 | 26.1 | 11.5 | 7.4 | 7.3 | 5.3 | 6.6 | 6.1 | 5.9 | 6.8 | 7.1 | 7.2 | 7.4 | 11.9 | 90.5 |
| | | | | | | | | | | | | | | | |
| U: 3 | 46 | 35 | 11.8 | 7.2 | 8.6 | 8.4 | 7.9 | 9.8 | 9.8 | 7.4 | 8.4 | 7.8 | 7.7 | 12.9 | 107.7 |
| L: 3 | 41.3 | 26.7 | 12.6 | 8.3 | 7.6 | 7.8 | 6.5 | 6.5 | 5.5 | 6.5 | 7.7 | 8 | 8.1 | 12.5 | 97.6 |
| | | | | | | | | | | | | | | | |
| U: 4 | 44.8 | 32.5 | 11.4 | 6.8 | 7.8 | 8.1 | 7.8 | 8.9 | 8.9 | 8 | 7.8 | 6.9 | 7 | 12.4 | 101.8 |
| L: 4 | 42.4 | 26.4 | 11.4 | 7.3 | 7.3 | 7.5 | 6.5 | 5.8 | 6 | 6.9 | 7.3 | 7.5 | 7.8 | 11.8 | 93.1 |
| | | | | | | | | | | | | | | | |
| U: 5 | 41.5 | 30.9 | 10.9 | 6.3 | 9.1 | 7.5 | 7.3 | 9.3 | 9.2 | 6.7 | 8.1 | 7.9 | 7.2 | 11.7 | 93.2 |
| L: 5 | 37.4 | 22 | 11.8 | 6.7 | 7.1 | 6.6 | 6.3 | 5.7 | 5.6 | 6.3 | 6.3 | 7.2 | 6.7 | 11.6 | 87.1 |
| | | | | | | | | | | | | | | | |
| U: 6 | 48 | 32.3 | 10.5 | 6.1 | 7.1 | 9 | 6.5 | 7.9 | 7.8 | 7.8 | 7.7 | 6.7 | 6.6 | 11.7 | 87.6 |
| L: 6 | 39.6 | 23.3 | 11.1 | 7.6 | 7 | 6.6 | 6.1 | 4.7 | 5.4 | 5.9 | 6.9 | 7.3 | 7.5 | 11.9 | 88 |
| | | | | | | | | | | | | | | | |
| U: 7 | 49.9 | 33.7 | 11.6 | 6.9 | 7.6 | 8.7 | 7.2 | 10.1 | 9.1 | 7.2 | 7.9 | 8 | 8.2 | 13.7 | 106.2 |
| L: 7 | 44.9 | 27 | 13.1 | 8 | 7.8 | 7.4 | 6.4 | 6 | 6.4 | 7.1 | 7.3 | 8 | 7.9 | 12.3 | 97.7 |
| | | | | | | | | | | | | | | | |
| U: 8 | 40.4 | 33.1 | 11.3 | 7.3 | 8.5 | 7.6 | 8 | 8.7 | 9.7 | 7.2 | 7.2 | 7.7 | 7.6 | 12.3 | 102.4 |
| L: 8 | 35.7 | 24.8 | 10.9 | 7.1 | 7.7 | 6.4 | 5.7 | 5.8 | 5.3 | 5.1 | 5.6 | 8.5 | 6.9 | 12.1 | 87.1 |
| | | | | | | | | | | | | | | | |
| U: 9 | 47.8 | 28.8 | 11.8 | 7.5 | 7.2 | 6.2 | 6.2 | 8.7 | 7.7 | | 5.9 | 8.1 | 7.9 | 11.4 | |
| L: 9 | 41.9 | 26.2 | 11.7 | 7.4 | 6.9 | 5.5 | 5.3 | 5.3 | 5.6 | 5.6 | 6.5 | 7.3 | 6.5 | 10.8 | 84.4 |
| | | | | | | | | | | | | | | | |
| U:10 | 41.3 | 31.9 | 11 | 7.6 | 7.4 | 7.9 | 7.4 | 9.2 | 8.6 | 7.3 | 7.5 | 8 | 7.1 | 12.9 | 94.6 |
| L:10 | 45.1 | 24.5 | 11.6 | 8.1 | 7.9 | 5.6 | 6.2 | 5.8 | 5.8 | 6.2 | 7.2 | 7.3 | 10.2 | 11.1 | 93 |
| | | | | | | | | | | | | | | | |

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