*Transdisciplinary Engineering: A Paradigm Shift*
*C. Chen et al. (Eds.)*
*© 2017 The authors and IOS Press.*
*This article is published online with Open Access by IOS Press and distributed under the terms of the Creative Commons Attribution Non-Commercial License 4.0 (CC BY-NC 4.0).*
*doi:10.3233/978-1-61499-779-5-576*

# Advanced Manufacturing for Dental Prosthesis Prototypes Development: A Conceptual Model

Athon F.C.Staben de Moura LEITE[a], Matheus Beltrame CANCIGLIERI[a], Anderson Luis SZEJKA[b1] and Osiris CANCIGLIERI JR.[b1]
[a]*Industrial Engineering, Pontifical Catholic University of Parana (EP/PUC-PR), Curitiba, Brazil.*
[b]*Industrial and Systems Engineering Postgraduate Program , Pontifical Catholic University of Parana (PPGEPS/PUC-PR), Curitiba, Brazil.*

**Abstract.** The quantity of research being done in the oral health has grown significantly in the last decades, acquiring a more interdisciplinary characteristic. As consequence, there has been a large amount of engineering applications developed to this knowledge area. Oral health is directed linked to the well-being and can aid in the prevention of several severe diseases. The more recurrent cases of deteriorated oral health are related to the loss of teeth during the patient's life. Oral dental implants are the solution to this problem; however, they present high complexity development processes and in consequence almost all the work is done handcrafted which entails problems with the precision and comfort of the prosthesis. Therefore, the objective of this research is the development of a conceptual model for the use of additive manufacture and rapid prototyping integrated to CAD/CAM systems to aid the development of an oral prosthesis in an integrated product development process environment. To reach this objective, at first was made a literature review of the relevant subjects. Afterwards the advanced manufacture conceptual model is developed to ensure standardization and formalization of the manufacture and development processes of the oral implant. The conceptual model is then applied in the development of an oral prosthesis in a computational environment. This conceptual model aids the surgeon-dentist to develop and manufacture the oral dental implants more rapidly ensuring the products quality, through the standardization of the manufacture and development processes the conceptual model also reduces the cost and waste of resources of the development and manufacture of an oral implant.

**Keywords.** Dental Implants, Advanced Manufacturing, Transdisciplinary Engineering, Integrated Product Development.

## Introduction

In past decades, dental implants have had their cost reduced and an increase on demand with the crescent use of computational tools and the development of new materials. In spite of this increasing use of technology, most of the implant manufacture continues almost handcrafted and made to attend patients in a case-by-case basis, which

[1] Corresponding Author, Mail: anderson.szejka@pucpr.br; osiris.canciglieri@pucpr.br

culminates in low standardisation along the process. The consequence of that problem is an increase in time and costs to the development and to the patient [1].

Computational environments, such as the CAD/CAM environments, associateded with advanced manufacture sistems, e.g. additive manufacture systems and rapid prototyping systems, are able to increase volume and speed in production, reducing the time and costs by adding an standard procedure to the dental implants development and manufacture.

The objective of this research is to develop a conceptual model that uses computational tools integrated to advanced manufacturing systems in an integrated product development environment, defining, by that, an standard methodology that will aid the development and manufacture of a dental implant.

## 1. Research Methodology

This research has an applied nature, using as technical procedure an experimental case. It has a qualitative approach, since a subjective comprehension of a topic is desired by studying its context [2]. The emergent nature of the concepts analysed classifies the scientific objective as exploratory.

The purpose of this research is to develop an advanced manufacturing conceptual model for dental implants, which aims to improve standardisation during the prosthesis development stages. The methodology for this research is mainly divided in four stages, as shown in Figure 1.

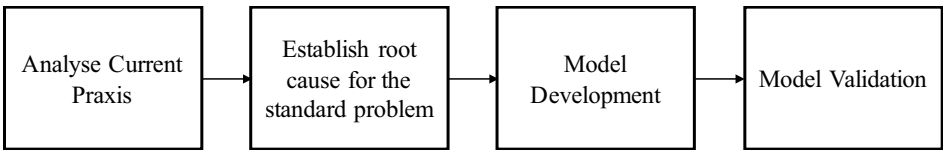


**Figure 1.** Methodological Procedures.

## 2. Research Background

This section approaches the research's background through a literature review, which allows a deeper understanding of the concepts approached. This background reviews the concepts of: Dental Implants and Osseointegration, Integrated Product Development Process (IPDP); Computer Aided Design and Manufacture(CAD/CAM); Design for Manufacture and Assembly (DFMA); Advanced Manufacture.

### *2.1. Dental Implants and Osseointegration*

Dental implants arose significantly as a research topic and praxis in past decades, achieving more than one million procedures every year [3]. The implants work as a solution for esthetical issues, problems in the chewing process and phonetic functions of patients.

The process of osseointegration (also called the Bränemark system) is largely adopted by surgeon dentists in latest decades as means to perform the implant. The osseointegration works as a connection, in structure and function levels, of the living

tissue and the implant structure, subject to functional tensions [4]. Osseointegration mainly adopt implants consisting in two parts. The base (placed inside the organism) is commonly known as “pin”, which consists in a conical structure made of titanium (for its biocompatibility and mechanical properties) ; and the external part is commonly known as “crown”, which consists in a polymer exterior, and a metallic inner structure [5]. The crown still presents issues in its manufacturing, as its development is still done mostly by hand and with no standardisation.

As of procedure, the Bränemark system gathers two stages: the first is the Surgical phase, in which the titanium pin is inserted; and the second is the Prosthetic phase, in which the prosthesis (crown) is connected to the pin [6].

### *2.2. Integrated Product Development Process*

The competitive industrial environment is characterized by atending the needs of the consumers for inovative products. The product development oriented to the client aids in the achievement of a competitive advantage and indicates important factors to the success of the product [7].

The product development process has become one of the main factors in the competitiveness in the industrial world. In consequence, a demand to integrate the phases of this process has become vital, as it reduces the development costs and enables the conception of products with higher quality. Therefore, methods were created to aid in this integration, composing the methodology of Integrated Product Development Process [8][9][10][11].

This methodology might bring significant improvements to de the dental implant area, as IPDP is an approach for integrated and parallel development in which are considered the life cycle processes, manufacturing processes alongside the products thecnical requirements [12]. In dental prosthesis development, these three planning factors are key to an optimized result.

### *2.3. Computer Aided Design and Manufacture (CAD/CAM)*

The use of computer software to assist in the product design and manufacture is a practice in expansion and aids remarkably in the stages of product development. Through the use of CAD and CAM software during the development of the project, it is possible to carry out simulations in virtual prototypes which gives greater reliability to the product and reduces the cost of the development process [13].

The use of computational systems in the product development process is not restricted to the manufacturing industries. In recent years, the use of CAD/CAM systems for the development and manufacture of dental implants, especially zirconia and ceramic crowns, has emerged as a popular treatment alternative [14] [15].

Improvements in CAD/CAM technology have changed the way dental implants are placed and fabricated. The use of computational environments and a process planning model, based on prosthesis treatment, enables more precision to the procedure, implying less discomfort for the patient and issues to the surgeon [16].

### *2.4. Design for Manufacture and Assembly*

The Design for Manufacture and Assembly (DFMA) is a method for supporting the product development, aiding the sincronicity of design and planning stages. DFMA considers the product's manufacturing and assembly process during its conceptual development [17]. One of the methodology's big differentials is its capacity to analyse each component and system of the product, regarding necessity and function, as well as manufacturing capacity and methods to simplify the assembly of the final product [18].

In an integrated product development environment, DFMA aims to product design and manufacture planning take place simultaneously. The methodology helps to adapt the product to the productive characteristics of the company, reducing costs and production time while increasing product quality [19].

In dental implants, the most important to consider during manufacturing and assembly is the surface. To achieve that, original requirements of a product development project should be rethought during the application of DFMA to establish new quality requirements, considering: simplicity, materials, standard components, releasing tolerances and reducing secondary operations [20]. In this context, the DFMA methodology considered might bring new thoughts regarding the mentioned requirements associated with the surface of the prosthesis [21].

### *2.5. Advanced Manufacture*

Advanced manufacturing systems are systems that use mechanical, electronic and computational subsystems to operate and control production, encompassing a large set of machines that execute, monitor and connect production processes [22].

The adoption of advanced manufacturing technologies is a key condition for maintaining the company's competitiveness in the long run [23]. However, many advanced manufacturing implementation projects fail to be more significant in small and medium-sized enterprises, as the managers of these companies trust their instinct and base the information from similar companies instead of creating an specific model [24].

Currently, dentists are tending to use advanced manufacturing techniques more often. The applications vary from prosthesis manufacturing, patient's analysis and diagnosis to the creation of study materials and manufacturing of aiding tools [25].

## 3. Conceptual Proposal of an Advanced Manufacturing for Dental Prosthesis Prototypes Development

This research proposes a conceptual model, in order to adress the lack of standardisation and to approach the new tecniques used in dental implants procedures. The development of the model considered the root cause for the issue with standards, which consists in little or no defined methodology. Commonly, a patient has its information collected and the dentist starts the creation of the model right afterward. This method implies in a trial and error situation based on the skill of the professional, in which to create the prostheis, he must design and manufacture a number of prosthesis until one presents the correct characteristics.

The conceptual model proposes a method to reduce the uncertainty and depend less on the skill of the dentist and seeks to standardise the stages of development and manufacturing of dental implants.

Firstly, it was defined that information should be digitalized so it becomes easier to communicate each step of the model. To scan and generate a 3D model, the DICOM (Digital Imaging and Communications in Medicine) was used, as it is the standard method used in medical applications [26].

The conceptual model consists of 7 steps that range from the collection of patient information to the manufacture of the dental implant to the processes of additive manufacturing and rapid prototyping (Figure 2).

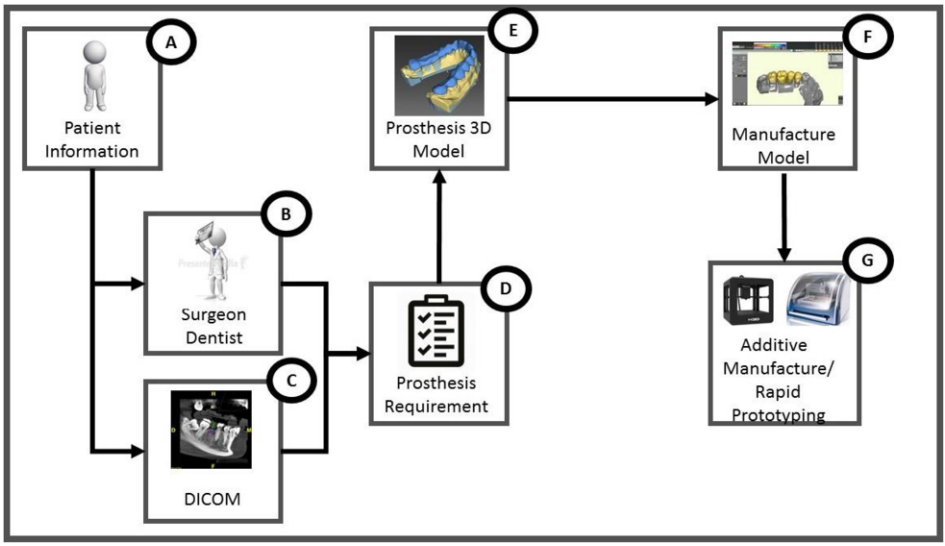


**Figure 2.** Dental Prosthesis Development Model.

Detail A of Figure 2 refers to the set of patient information necessary for the development of the implant, information such as bone density, teeth to be placed, etc. This information is translated to implant technology information through the observations of the dentist and DICOM (Details B and C of Figure 2). The dentist is responsible for translating patient information into pin specifications, procedure to be performed, etc. While the DICOM method translates the location information, size and shape of the implant.

Detail D of Figure 2 is the compilation and conversion of patient information that has been translated into details B and C of Figure 2 into design requirements, e.g. patient information creates constraints that the dental surgeon will have to follow during the development and manufacture of the dental prosthesis. This step is the main difference from the traditional method, as before modelling, all constraints are considered in order to provide an optimization in the modelling process.

The detail E of Figure 2 is the development of a three-dimensional model in a virutal environment (CAD) of the dental implant, based on the scan using DICOM and respecting the requirements created in the previous step. This model is then converted to the creation of the model of manufacture, also in virutal environment (CAM) (Detail F of Figure 2). The manufacturing model is then used for the manufacture of the

prosthesis through additive manufacturing processes or rapid prototyping (Detail G of Figure 2).

## 4. Experimental Case

The experimental case proposed compares the average time of the prosthesis developmet using the conventional method and the proposed by the conceptual model. The conventional method, which is the most used currently, consists in the dentist creating 3D models to rough manufacture and finishing by hand a number of times depending on his skill, with little or no standardisation in the process. The proposed model consists in capture and standardise information, creating a 3D model, a virtual manufacturing model and further 3D printing, reducing it to one or two iterations, regardless the skill of the professional.

For this case, the fictional patient is considered to be completely edentulous (no teeth), so the prosthesis development must rely on patient's information and developed from scratch. This particular case was selected so that no teeth can be used as a basis to start, as in partially edentulous patients the development is based on simetry.

The experiment used the work of Joda and Brägger [27] as the reference time to the traditional model. The time was measured using a chronometer during the development of the prosthesis. The results are shown in Table 1.

**Table 1.** Method Comparision.

| Procedures | Proposed Model |
|---|---|
| Patient Information | 21 min |
| Surgeon Dentist | 6 min |
| DICOM | 9 min |
| Prosthesis Requirement | 20 min |
| Prosthesis 3D Model | 26 min |
| Manufacture Model | 33 min |
| Manufacturing | 43 min |
| **Total Time of the Proposed Model** | **Approx. 158 ± 6 min** |
| **Total Time of the Traditional Model** | **Approx. 185.4 ± 17.9 min** |

As demonstrated, the model offers a time reduction in the process. The standardisation provided by the model and the requirement step made easier to define the parameters to move between each stage. This validates the hypothesis that the conceptual model proposed could reduce time in comparision with the traditional model.

## 5. Results of the Experimental Cases

The experimental case has shown a remarkable reduction in time using the conceptual model, in comparision with the traditional method, almost 15% less time. The manufacture of the dental prosthesis in the case considered a set of standardised information and of easy manipulation, which saved time during the design and

manufacturing planning of the product. Each stage was submitted to scrutiny after its completion, so there was no misinterpretation or redundance passed onwards.

It is possible to imply that the created model was cheaper than the traditional one, as very few adjustments were necessary to achieve a final product. The prosthesis presented a satisfatory finishing visually, which shows that its complex geometry can be achieved through advanced manufacturing process.

The printed crown fits in with the pin, but its assembly in a human subject still must be tested. Also, for this research, the crown wasn't tested regarding its tension limits and different possible materials, which might be analysed in further research.

The conceptual model proposed has shown a simplified way to standardise the manufacture of a dental prosthesis, this way improving communication, sincronicity and reducing time in development. Also, the information in the process is now traceable, so when there is a problem it becomes easier to find.

## 6. Conclusion

The proposed conceptual model was able to standardise the phases of the dental prosthesis design and manufacturing process, reducing the time and cost of the project without reducing the final quality of the product in many aspects. This standardisation, coupled with the use of advanced manufacturing processes such as manufacturing and fast prototyping, integrated into CAD/CAM computing environments, guarantees the geometric and dimensional characteristics of the implants, as well as providing the flexibility for the development and manufacture of several implants according to the need of the surgeon.

This research provided a formalisation for the process of prosthesis development, improving this way the communication and information sharing. The model integrates new technology and validated procedures to improve the current status of dental implant, this way optimizing the method and possibly the surgical procedure as well.

For further works, it is suggested that research shine light to different materials to explore, tensions in the printed product and testing in human subjects. Other possible works relate to the exploration of this model as basis to develop a formal informational base, to develop knowledge and explore an automated system alternative.

## References

[1] A. L Szejka, *Proposta conceitual de um sistema especialista de projeto orientado ao processo de implante dentário*, PhD thesis, Pontifical Catholic University of Parana, Curitiba, 2012.
[2] D. E. Gray, *Doing Research in the Real World*, *SAGE Pulishing, Ltd.* London, 2013.
[3] L. Le Guehenec, *et al.*, Surface treatments of titanium dental implants for rapid osseointegration. *Dental Materials*, Vol. 33, 2007, No. 7, pp. 844-854.
[4] P. I. Bränemark, *et al.*, Osseointegrated Implants in the Treatment of Edentulous Jaw: Experience from a 10-year Old Period. *Scand. J. Plast. Reconstr. Surg.*, Vol. 16, 1977, No.1, pp. 132.
[5] P. Magne, *et al.*, Fatigue resistance and failure mode of CAD/CAM composite resin implant abutments restored with type III composite resin and porcelain veneers. *Clinical Oral Impacts Research*, Vol. 22, 2011, No. 11, pp. 1275- 1281.
[6] P. I. Bränemark, *et al.*, Introduction in Osseointegration: Tissue-integrated prosthesis. In: *Osseointegration in Clinical Dentistry*, Quintessence Books, Chicago, 1985.
[7] J. A. Pereira and O. Canciglieri Junior, Product Development Model Oriented for the R&D Projects of the Brazilian Electricity Sector, *Applied Mechanics and Materials*, Vol. 518, 2014, pp. 366-373.

[8] A.C. Ward, J.K. Liker, J.J. Cristiano and D.K. Sobek, The Second Toyota Paradox: How Delaying Decisions Can Make Better Cars Faster. *Sloan management Review*, Vol. 36, n.3, p 43-61, 1995.
[9] D. K. Sobek, A. C. Ward and J. K. Likker, Toyota's Principles of Set-Based Concurrent Engineering. *Sloan Management Review*, vol. 40, n.2, p 67-83, 1999.
[10] M. Kennedy, K. Harmon and E. Minnock, Ready, Set, *Dominate. Implement Toyota's Set-Based Learning to Develop Products and Nobody Can Catch You*. 1a Edição, Oaklea Press, 295 p. 2008.
[11] M. Khan, A. Al-Ashaab and E. Shehab, Towards Lean Product and Process Development. *International Journal of Computer-Integrated Manufacture,* Vol. 26, 2011, No.12, p 1105-1116.
[12] G. Loureiro, P. G. Leaney, A Systems and Concurrent Engineering Framework for the Integrated Development of Space Products. *Acta Astronautica,* Vol. 53, 2003, No. 1, p. 945-961.
[13] R.D.C. Amaral and A.C.P. Filho, A evolução do CAD e suas Aplicações em Projetos de Engenharia. *9º Simpósio de Mecanica Computacional:* Universidade Federal de São João Del-Rei, Minas Gerais, 2010.
[14] M. Takaba, T. Shinpei, I. Yuichi and B. Kazuyoshi, Implant-Supported Fixed Dental Protheses with CAD/CAM-Fabricated Porcelain Crown and Zirconia-Based Framework. *Journal of Prosthodontics*, vol. 22, 2013, No. 5, p. 402-407.
[15] T. V. Carnaggio, R. Conrad, R. L. Engelmeier, P. Gernoss, R. Paravina, L. Perezous and J.M. Powers, Retention of CAD/CAM All-Ceramic Crowns on Prefabricated Implant Abutments: An In Vitro Comparative Study of Luting Agents and Abutment Surface Area. *Journal of Prosthodontics*, Vol. 21, No. 7, 2012, p. 523-528.
[16] B.M. Stapleton, W. Lin, A. Ntounis, B. Harris and D. Morton, Application of Digital Diagnostic Impression, Virtual Planning and Computer -Guided Implant Surgery for a CAD/CAM-Fabricated, Implant-Supported Fixed Dental Prothesis: A Clinical Report. *Journal of Prosthetic Dentistry*, Vol. 112, 2014, No. 3, pp. 402-408.
[17] G. Boothroyd, P. Dewhurst, W. Knight, Product Design for Manufacture and Assembly. *Marcel Dekker inc*, New York, 1994.
[18] C. Estorilio and M. C. Simião, Cost Reduction of a Diesel Engine Using the DFMA Method, *Product Management & Development*, Vol. 4, 2006, No. 2, p. 95-103.
[19] C. A. Dufour, Estudo do processo e das ferramentas de reprojeto de produtos industriais, como vantagem competitiva e estratégia de melhoria constante. Dissertation. *Federal University of Santa Catarina*, Florianópolis, 1996.
[20] G. Boothroyd, P. Dewhurst, W. Knight, Product development for manufacture and assembly. 2nd ed. rev. exp. *Marcel Dekker:* New York, 2002.
[21] A. Boschetto, L. Bottini, Design for Manufacturing of Surfaces to Improve Accuracy in Fused Deposition Modeling, *Robotics and Computer-Integrated Manufacturing*, Vol. 37, 2016, No. 1, p. 103-114.
[22] P. Kotha and P. Swamidass, Strategy, advanced manufacturing technology and performance: empirical evidence from US manufacturing firms, *Journal of Operations Management,* Vol. 18, 2000, No. 3, p. 257-277.
[23] K.K. Boyer, P.T. Ward and G.K. Leong, Approaches to the Factory of the Future: An Empirical Taxonomy, *Journal of Operations Management*, Vol. 14, 1996, No. 4, pp. 297-313.
[24] S. Mellor, L. Hao and D. Zhang, Additive manufacturing: A framework for implementation. *International. Journal of Production Economics,* Vol. 149, 2014, pp. 194-201.
[25] F. Rengier, A. Mehndiratta, H. von Tengg-Kobligk, C. M. Zechmann, R. Unterhinninghofen, H. U. Kauczor and F.L. Giesel, 3D printing based on imaging data: review of medical applications. *Int J Comput Assist Radiol Surg*, Vol. 5, 2010, No. 4, p. 335-341.
[26] A. Tahmaseb, R. de Clerck and D. Wismeijer, Computer-guided implant placement: 3D planning software, fixed intraoral reference points, and CAD/CAM technology. A case report, *The International Journal of Oral & Maxillofacial Implants*, Vol. 24, 2009, No. 1, pp. 541–546.
[27] T. Joda and U. Brägger, Time-Efficiency Analysis Comparing Digital and Conventional Workflows for Implant Crowns: A Prospective Clinical Crossover Trial, *Int. Journal of Oral Maxilofacial Implants*, Vol. 5, 2015, pp. 1047-1053.