A QUALITY FUNCTION DEPLOYMENT-BASED DECISION APPROACH FOR PRODUCT IMPROVEMENT IN THE DENTAL IMPLANT MANUFACTURING INDUSTRY

(DENTAL İMPLANT İMALAT ENDÜSTRİSİNDE ÜRÜN İYİLEŞTİRMESİ İÇİN KALİTE FONKSİYON YAYILIMI TEMELLİ KARAR VERME YAKLAŞIMI)

by

Celal Berk BURUN, B.S.

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LIST OF SYMBOLS

QFD : Quality Function Deployment
HOQ : House of Quality
TQC : Total Quality Control
SME : Small Manufacturing Enterprises
TQM : Total Quality Management
QPD : Quality Policy Development
SPC : Statistical Process Control
TRIZ : Theory of Inventive Problem Solving
JIT : Just-in-time
MCDM : Multiple Criteria Decision Making

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ABSTRACT

Quality function deployment (QFD) is a great tool in translating customer needs into specifications into each phase. Based in Japan, QFD quickly spread to U.S. where it gained most of the popularity.

There are many precious case studies, papers and articles about using QFD in different areas, but there are limited applications in medical devices.

This study subjects a SME in Turkey, who has ongoing research about the most important aspects to supply in dental implant industry before entering the market. Since the resources are limited, a study is going on to find the most important processes complying with customer needs and transferring them to manufacturing operations. Study includes a two-step QFD approach to for translating customer needs into quality characteristics. First step starts with extensive clinical and marketing research to figure out customer needs. This constructed the first WHATs of QFD chart. Then the results were surveyed of a group of eight people, ranging from pioneers, specialists and newly dentists in a 1-10 scoring system and respective average importance degrees were calculated. Then, general processes were filled into HOWs section and the most important process related to these characteristics were identified following by building of House of Quality (HOQ). Second step contains using QFD in dental implant manufacturing. This step starts with another meeting between engineers and customers to find out design characteristics. This time customer needs turn into WHATs and design characteristics became HOWs. This step continues with transferring such aspects into manufacturing most important manufacturing operation is found.

Lastly the relations between quality controls and manufacturing operations were inspected and the most important element is determined. Results are R&D, short length, CNC machining and geometric inspections in the most important process, quality characteristic, manufacturing process and quality controls respectively.

ÖZET

Kalite fonksiyon yayılımı (KFY) müşteri taleplerini her faz için gerekliliklere çevirme konusunda çok iyi bir araçtır. Japonya'da temeli atılan KFY hızlıca Birleşik Devletlere yayılmış ve popülerliğinin çoğunu burada kazanmıştır.

KFY'nin farklı alanlarda kullanımı ile ilgili birçok değerli vaka analizi, yazı ve makale bulunmakta; ancak tıbbi cihazlar konusunda kullanımı konusunda kısıtlı bilgi bulunmaktadır.

Bu çalışma Türkiye'de pazara girmeden önce dental implant endüstrisine sağlanabilecek en önemli özellikleri araştıran bir KOBİ'yi konu almaktadır. Kaynakların kısıtlı olması dolayısı ile, müşteri istekleriyle en çok uyum sağlayan prosesleri bulmak ve bu proseslerin ürüne aktarılması konusunda çalışma yapılmaktadır. Çalışma müşteri isteklerinin kalite karakteristiklerine çevrilmesi için iki adımlı bir KYF yaklaşımını konu almaktadır. İlk adım müşteri isteklerinin anlaşılabilmesi için geniş kapsamlı bir klinik ve pazar araştırması ile başlamaktadır. Bu çalışma sonucunda KFY tablosunun ilk NEleri oluşturulmuştur. Sonra, sonuçlar çalışma alanında önü olanlar, uzmanlar ve yeni diş hekimlerinden oluşan sekiz kişilik bir grup tarafından 1-10 puanlama sistemi ile değerlendirilmiş ve ilgili ortalama önem dereceleri hesaplanmıştır. Sonrasında NASILlar kısmına genel prosesler girilmiş ve bu karakteristikler ile ilgili en önemli proses bulunarak Kalite Evi kurulmuştur. İkinci adım KFY'yi dental implant imalatında kullanmayı içermektedir. Bu adım mühendisler ve müşterilerin tasarım karakteristiklerini bulmak için toplantı gerçekleştirilmesi ile başlamıştır. Bu sefer müşteri istekleri Nelere dönüşürken tasarım karakteristikleri NASILları oluşturmuştur. Bu adım ilgili özellikleri imalata aktarmayla devam etmiş ve en önemli imalat operasyonu bulunmuştur.

Son olarak kalite kontrol ve imalat operasyonları arasındaki bağlar incelenmiş ve en önemli eleman bulunmuştur. Sonuçlar sırasıyla AR-GE, kısa uzunluk, CNC imalat ve geometrik kontrollerin en önemli proses, kalite karakteristiği, imalat prosesi ve kalite kontrol alanlarında sırasıyla en önemli olarak belirlenmeleri ile sonuçlanmıştır.

1. INTRODUCTION

Resources are limited. This is one of the things that cannot be changed. Because there is no other way to change this fact, allocating resources efficiently becomes incredibly important. With businesses getting more and more complex, it is getting harder to do such thing. When non-technical things like customer needs are added, it becomes nearly inextricable. Any process or step that’s been insufficiently allocated may lead to hazardous consequences. This study searches for a simple method to allow efficient allocation of resources.

Our culture necessitates white and even spread teeth. Even a tiny bit of deformation appears to be an eyesore. Decays, discoloration, crooked or lost teeth are hidden, and smiles are never to be shown. Patients no matter what age they are, or where they live are under the same stress. Edentulism, or the loss of teeth is one of the most observed disease today; mostly due to ease of access to the sugary junk foods; hence the rise of sugar consumption. Since there’s no way known to recover a lost tooth, many efforts were given to intervene and mimic the functions of teeth. Dental implantology was born from these efforts.

The history of dental implants can be traced back to ancient Egypt (Gaviria et al., 2014). Archeological findings have showed that ancient civilizations tried to replace missing teeth using carved stone, shells, bones and gold. The concept of early osseointegration was introduced by Branemark in Europe in 1950’s, which started shaping the today’s implant industry (Rajput et al., 1963). He discovered that bone could grow in harmony with the titanium (Ti) (Gaviria et al., 2014). With the clinical experience himself developed, in 1965 first patient was treated with the system carrying his name (Gottlander & Steenberghe, 2009). After more than six decades, dental implantology has developed into a well-recognized and used therapeutic advance in treatment of edentulism.

Research and development gave way into new designs and treatments in implant manufacturing, making it easier and affordable for patients every day. In Europe, 2009, four companies capture nearly 60% of the market. It has been estimated that markets for dental implants reach nearly $8.1 billion in 2015 (Durkan, 2013).

Dental implants are no news for Turkey; yet the number of companies that manufacture dental implants are no more than a handful. With other international players, it's crucial for a Turkish company to decide what to supply in dental implant industry to sustain profitability, while keeping eye on the customer needs. Even with adequate implants, sustaining customer needs is not possible. Dental implant sector contains services and other aspects that customers require to be satisfied. Since resources are limited, every aspect cannot get all they need. So, a decision strategy should be chosen to satisfy customer needs. This is where QFD comes in.

QFD can be used as a decision-making tool with keeping eye on customer-oriented to find the best way to meet customer needs for allocating resources. According to Akao, who developed this technique with Katsuyo Ishihara, QFD is "a method for developing a design quality aimed at satisfying the customer and then translating the customers' demands into design targets and major quality assurance points to be used throughout the production stage" (Akao, 1990).

QFD was originally proposed to develop products with higher quality to respond customer needs. Hence, the early functions of QFD are product development, quality management, and customer needs analysis. Later, functions of QFD have been expanded to other areas like planning, engineering, decision-making, management, timing, and costing (Chan & Wu, 2002).

QFD incorporates satisfaction of customer requirements into every development activity, and it has been applied in the development of many products. Contrary to common usage, QFD lacks case studies in dental products.

The purpose of this thesis is to select the most suitable method for manufacturing dental implants with Quality Function Deployment method. It is aimed to serve a product that has good healing time, durability and stability preferable without complicated processes while keeping quality to cost ratio at maximum.

The rest of this study is organized as follows. In section 2, a brief description and application of QFD is presented. Section 3 includes literature review of QFD and contains information about applications to numerous challenges. In section 4, a brief information about implantology with explaining critical design aspects. Section 5 includes the study and application of mentioned challenge. In section 6 results were shown. Finally, the conclusions are provided in the last section.

2. QUALITY FUNCTION DEPLOYMENT

2.1. Introduction

Today, customers are driving the market more than ever. With logistical and technological advances, they have much more options to choose from; making not the strongest one to survive, rather the most innovative one to if not survive, stay on top of the market. This pushes the companies to focus on a development-based approach and makes QFD a gem in realizing products that meet customer needs.

Quality Function Deployment (QFD) is a product development methodology that "deploys" the Voice of the Customer throughout the product development process. A cross-functional team implements QFD by creating a series of one or more matrices, relating customer needs to an extensive set of product features (Hauser, Griffin, Klein, Katz, & Gaskin, 2010).

American Supplier Institute (ASI) states that QFD is "a system for translating customer or user requirements into appropriate company requirements at every stage from research, through product design and development, to manufacture, distribution, installation and marketing, sales, and service" (Xie et al., 2003).

QFD enables the entire product development team to prioritize their development activities in a systematic way. It helps them work together to translate customer needs into product design in a synergic way, improving communication among the members of the product development team; resulting a product that is thoughtfully designed right from the beginning while cutting down the need for later rework and reducing development time and costs.

2.2. Historical Development of QFD

General concept of QFD was intoruced in Japan by Dr. Shigeru Mizuno and Yoji Akao in 1966 (Shen et al., 2000a). Earlier concepts show a basic process chart containing some of QFD's main characteristics. After trials for converting design characteristics into control points for manufacturing control charts, Akao defined the system as hinshitsu tenkai (quality development). After a suggestion made by Akao, primitive ideas of QFD had been applied in Kobe Dockyard of Mitsubishi Heavy Industries; with a quality table that showed correlation between customer needs and pairing engineering characteristics. Akao then formulated all gathered information from this experience into a technique called as hinshitsu kino tenkai (quality function deployment).

After successful implementation at Mitsubishi Heavy Industries, Toyota's Hino Motor adopted the technique. Taken magnificient results, Toyota group then adopted the technique in all departments. Evolving into an extraordinary technique, QFD was introduced to the U.S. nearly after 10 years after of development (Chan & Wu, 2002). By that time, U.S. organizations were unexpectedly hit from the pace of development in both quality and cost savings in Japanese organizations and they were implementing many techniques adopted by the Japanese. From a retrospective view, it would be safe to say it's not surprising that Ford Motor Company was one of the first companies who learned QFD based on the shared history of W. Edwards Deming. Based on the learnings, L. Sullivan of Ford Motor, who also founded American Supplier Institute (ASI) played a major role of the widespread of QFD in the U.S. Early adopters of QFD in the U.S. included Ford, General Motors, Chrysler, AT&T, Procter and Gamble, Hewlett-Packard, Digital Equipment, ITT, Baxter Healthcare, 3M Company, Motorola, NASA, and Xerox (Chan & Wu, 2002).

The term QFD is used to translate customer requirements to specifications, linking customers and companies. It provides insights into the design and manufacturing phase, making it easier to resolve problems early in the design phase. In early 1980's QFD evolved from TQC, mainly from the belief that requirements should be met prior to design phase.

After world War II Japanese manufacturers bought the equipment and technologies and reverse engineered them, making cheap but highly durable products, but customer response to these products were poor because final products were unable to respond to their needs (Ayoola Oke, 2013). This was the perfect opportunity for QFD to grow in the design process itself. With tremendous amount of effort and developments in computing made it easier to analyze data for collecting and interpreting customer needs.

2.3. Overwiev

QFD begins with house of quality matrix, shown in figure 1. QFD methodology is used to focus on the most important product attributes. Once the house of quality is built and attributes are prioritized, QFD deploys organizational function for translation into each level.

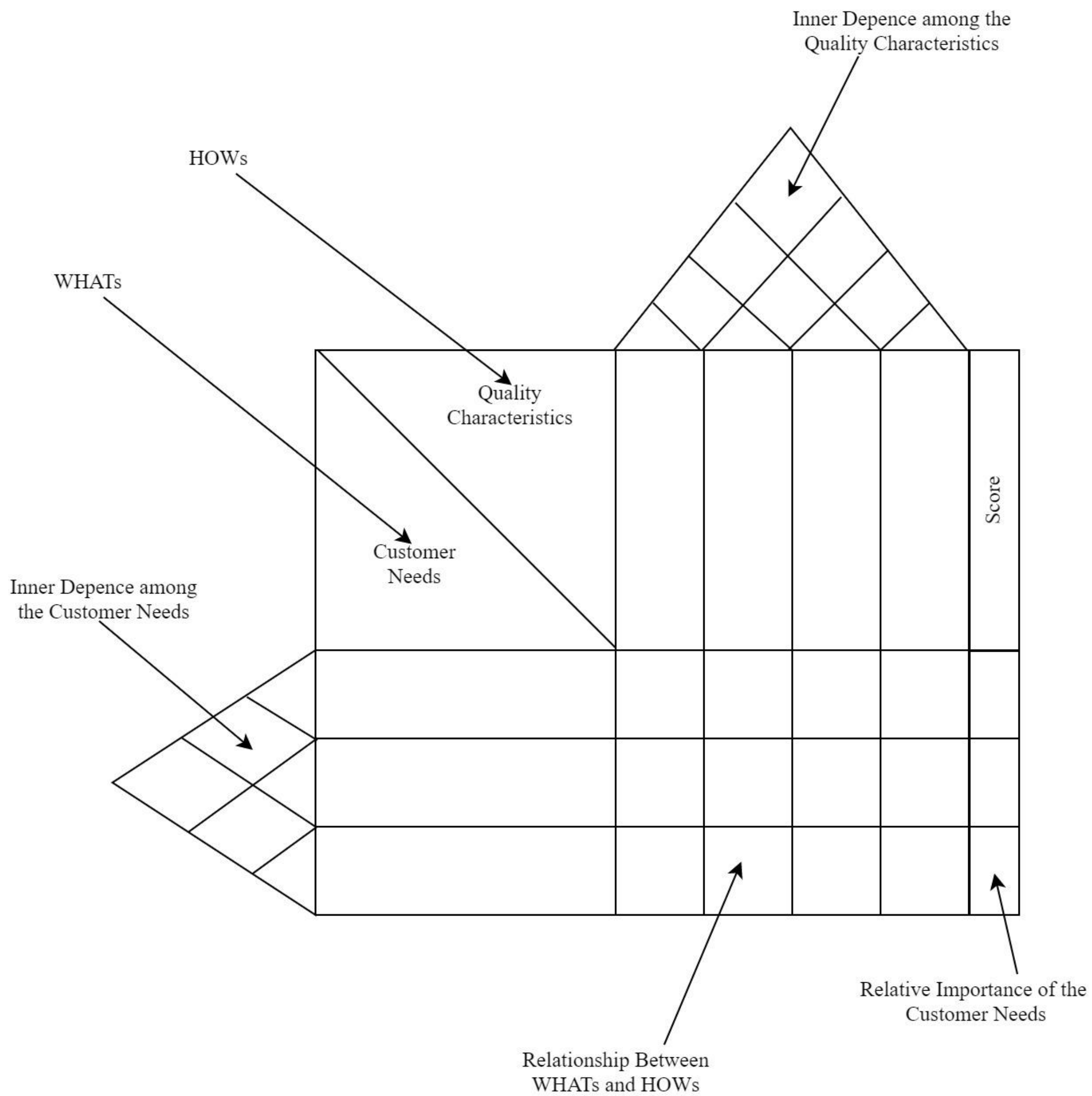


Figure 1. House of Quality

QFD begins with house of quality matrix, shown in figure 1. QFD methodology is used to focus on the most important product attributes. Once the house of quality is built and attributes are prioritized, QFD deploys organizational function for translation into each level.

HOQ consists of six elements, namely:

Customer needs (WHATs). Also known as voice of the customer, this part is the initial input for the HOQ, highlighting which product characteristics should be paid attention to. Customer needs are usually collected by individual interviews or focus groups; though one-to-one interviews is more cost effective (Hauser & Griffin, 1993). To organize customer needs, Affinity diagram is a sufficient and effective technique (Talbot et al., 2011).

Quality characteristics (HOWs). Product characteristics are also known as design requirements, engineering characteristics or product features. They can also be developed using the affinity diagram. They translate the language of the product to the engineer; therefore, it sometimes called as the voice of the company. Product characteristics explain how company satisfies customer needs. Since they are used in engineering, product characteristics should be measurable.

Relative importance of the customer needs. Since the collected data from the customers are in bulk, they should be rated in order to work on the most important areas. This step shows the tradeoffs and what should be disregarded when working through the process. Point scales are generally used for ratings.

Relationships between WHATs and HOWs. This step shows the affection between product characteristics and customer needs. Ratings can be given in symbols or points (Bahil & Chapman, 1993).

Inner dependence among the customer needs. This part is called “the porch” of the HOQ (Bahil & Chapman, 1993). It is likely to have related needs of customer. This step shows their effect on each other. It may be supporting or adverse.

Inner dependence among the product characteristics. This part is called “the roof” and it states the relations between various product characteristics. This is one of the most crucial steps; because, by identifying the relations, the company can see how a change affects another one. This enables to have an early intervention between different departments in the company

To capture the interrelationships within all processes, QFD uses many matrices aside from HOQ as shown in seen Fig 2. (Bahil & Chapman, 1993).

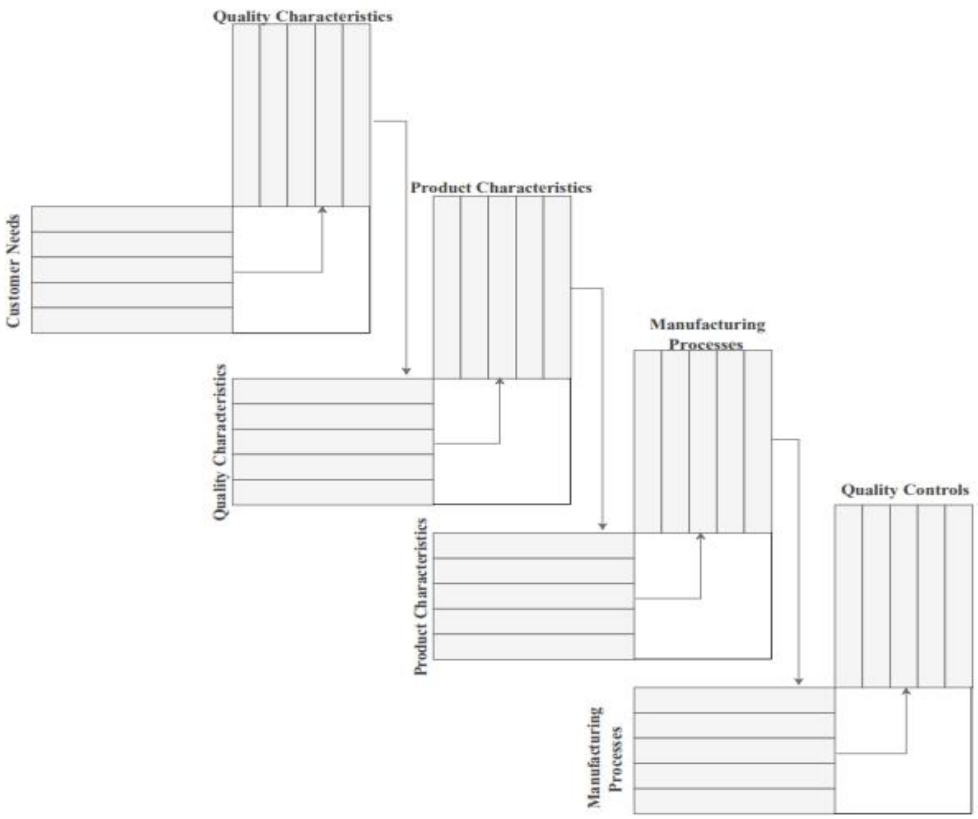


Figure 2. The QFD waterfall chart

These four phases of QFD are:

Quality characteristics: This phase begins with collecting customer needs and translating them into product specifications. In this phase, evaluation of any competitors' products that may fulfill customer needs can be beneficial. Quality characteristics are generally based on performance specifications of the product.

Product characteristics: In this phase, the most important product specifications are translated into product characteristics. The result feeds next step.

Manufacturing processes: This phase examines the relationship between product characteristics and manufacturing processes, developing the process flow and critical process characteristics.

Quality Controls: This last step is used to identify the appropriate process parameters and controls.

QFD analysis completes after the fourth phase.

3. LITERATURE REVIEW

3.1. QFD in Manufacturing Industries

There are dozens of studies in the literature relevant to QFD applications. Zairi and Youssef studied seven companies based in the UK for their efforts in introducing QFD for new product development with outcomes and challenges (Zairi & Youssef, 1995). Bahill and Chapman inspected the use of QFD in a toothpaste company for a new product while giving extensive insights and approaches for QFD (Bahil & Chapman, 1993). Barnett inspected the manufacturing industry in Australia and gave insights about QFD technique for use in such industries (Barnett, 2010). Barad and Gien used QFD to apply a contingency approach over improvement priorities of SMEs. The essence of the QFD method is to get inspired from customer needs and then translate it into technical product characteristics. By cluster analysis, they have found several improvement models of the sampled enterprises (Barad & Gien, 2001). King inspected the implementation of QFD in a small and large company (King, 1987). Jugulum and Sefik used TQM in conjunction with QFD, QPD, SPC, TRIZ and Taguchi method for improving strategic manufacturing strategies, products and processes to help themselves survive in the global market (Jugulum & Sefik, 1998). Crowe and Chang studied a case in a powdered metals manufacturer. They have studied extended use use of QFD to manufacturing strategy development. They have argued how basic QFD concepts and methods coulb be used for a company to stay in line with business strategy (Crowe & Cheng, 1996). Scheurrell studied extended steps from HOQ’s matrixes and shows a practical approach for using QFD in a new product development (Scheurell, 1994). Moen presented a new customer and process focused poor quality cost model to enable companies making long term decisions regarding satisfaction of customers (Moen, 1998). Partovi presented a method based on QFD and AHP for process selection and evaluation for manufacturing systems (Partovi, 2007b).

Park and Kim illustrated a modified HOQ model which employs a multi-attribute decision method for assigning relationship ratings between customer requirements and design requirements as an alternative to conventional relationship scale (Park & Kim, 1998). Mrad reported a case in a big computer company, using conventional QFD with a cross functional team for the company's workstation (Mrad, 1997). Fung et al. proposed a hybrid system incorporates QFD, AHP and fuzzy set theory for analyzing customer needs and translating them into the relevant design, engineering and product attributes. It offers an analytical and intelligent tool for translating ambiguous voice of customer (Fung et al., 2006). Curtis and Ellis inspected QFD in R&D for speeding up the processes (Curtis & Ellis, 1998). Shen et al. studied procedures and methods for successful benchmarking in QFD for quality improvement. They have presented a road map for strategic competitor selection to SME's or companies in developing countries (Shen et al., 2000b). Lowe et al. presented a tool derived from QFD to evaluate feasibility of a process to manufacture products (Lowe et al., 2000). Xavier and Hunt studied a typical bricks and mortar company that's been threatened by the explosive growth of the Internet and increasingly turbulent economic environment, implementing methodologies such as Hoshin and QFD to their transformation process (Xavier & Hunt, 2002). Bhattacharya et al. studied a AHP/QFD model in determination of robots' performance enhancement from requirement perspective (Bhattacharya et al., 2005). Ramaswamy et al. reported a study performed in SMEs in selecting and prioritizing various techniques for the implementation of JIT in a seasonal order-manufacturing environment through the QFD technique (Rajam et al., 2002). Parkin et al. analyzed the activities to introduce QFD into an OEM based on UK. The have aimed to address the imbalance by using a case study detailing how the OEM has implemented the first six steps of a proposed 16-step QFD process, presenting a discussion of the first six steps program (Parkin et al., 2002).

Other uses of QFD include forming teams (Zakarian & Kusiak, 1999), improving quality of teaching (Lam & Zhao, 1998), reducing traffic accidents (Sohn, 1999), using QFD to attract more soccer fans (Partovi & Corredoira, 2002) and capital budgeting (Partovi, 2007a).

3.2. Using QFD for Medical Devices

Although there are many applications of QFD, only a handful of applications to medical devices are found in the literature review. Hauser studied a case in a spirometry company using QFD to reduce product costs and introduce a new design (Hauser, 1993). Talbot et al. studied the use of QFD and AHP in design process of a company's glucose monitoring department (Talbot et al., 2011). Zadry et al. studied using QFD in long spinal boards (Zadry et al., 2015). Booysen et al. studied anaesthetic mouthpiece development through QFD (Booysen et al., 2006). Kriewall and Widin studied the use of QFD for hearing aids (Kriewall & Widin, 2005). Melgoza et al. studied QFD and TRIZ in customized tracheal stent for solving contradictions related to material and geometry (Melgoza et al., 2012).

No literature for the use of QFD in dental implant manufacturing is found in literature search.

3.3. Other Uses of QFD

QFD is an approach for achieving a solution to a broad range of problems. Recently, Babbar et al. developed a model integrating environmental concerns for supplier selection and order allocation based on Fuzzy QFD in beverages industry (Babbar et al., 2018). Wang and Hsieh studied a two-stage patent analysis based on the quality function development (QFD) method which adopts customer requirement and technology viewpoints to explore key technologies (Wang & Hsieh, 2017). Torabi et al. studied a hybrid SWOT-QFD systematic framework for choosing the most influential sustainability criteria in accordance with the manufacturer's strategies (Torabi et al., 2018). Tian et al. proposed a multi-phase QFD-based hybrid fuzzy MCDM approach for performance evaluation for smart bike-sharing programs in Changsha (Tian et al., 2018). Hsieh researched identify the most potential principles of social media, combining Quality Function Deployment of House of Quality (QFD-HOD) method and the Multiple Criteria Decision Making (MCDM) (Hsieh, 2016).

Akbaş and Bilgen studied using QFD and TOPSIS methodology for choosing the ideal gas fuel at WWTPs (Akbaş & Bilgen, 2017). Lee et al. analyzed the healthcare service requirements using fuzzy QFD (Lee et al., 2015).

It can be clearly seen that QFD is a tool for working in virtually any problem. There are much more exhibits of QFD uses in different fields not posted in this report.

4. DESIGN ASPECTS OF DENTAL IMPLANTS

International Organization for Standardization defines a dental implant as a device designed to be placed surgically within or on the mandibular or maxillary bone to provide resistance to displacement of a dental prosthesis or to provide orthodontic anchorage (EN 1642:2011) and dental implant system as the dental implant components that are designed to mate together, consisting of the necessary parts and instruments to complete the implant body placement and abutment components (EN ISO 10451:2010). These components are shown in Figure 3 below.

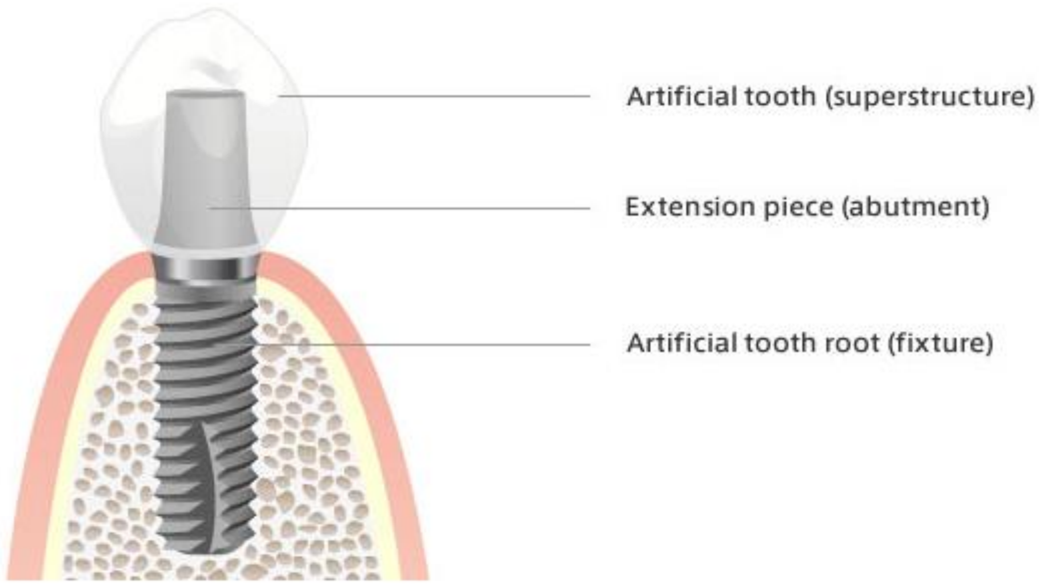


Figure 3. General structure of a dental implant parts

Dental implants come in many sizes and shapes. Common design choices consist of:

Implant length (Long, short)

Implant diameter (Narrow, wide)

Thread shape (V shape, square, buttress, reverse buttress)

General geometry (cylindrical, tapered
Internal connection (external hexagon, Morse taper)
Surface treatment (Sand-blasted, sand-blasted and acid etched etc.)

Each of these features are explained below:

Implant length can be specified as the length between the bottom of implant and crestal level. Long implants are used in conditions such as immediate implantation, implantation in defected bones and poor bone quality sites. Since it'll take long to drill long holes in preparation of implant bed; long implants adhere a risk of overheating implant site in before implantation.

Implant diameter represents the most distant size of the external shape. It can differ from the size of prosthetic platform. Optimal diameter selection should allow bone to implant engagement to be sufficient.

The thread design plays a crucial role in optimizing force distribution at bone to implant interface and contact. Greater depths enhance bone to implant contact and stabilize implant in pre-healing phase in poor bone quality areas but makes them harder to insert into dense bone.

Implant geometry commercially have two different options: cylindrical and tapered. The shape can play a major role in primal stability and can affect bone loss after implantation (Torroella-Saura et al., 2015).

Figure 4. Cylindrical (a) and tapered implants (b) (Torroella-Saura et al., 2015)

Internal connection is where dental abutment connects to implant. Implant connection must be precise and stable; since the replica of the missing teeth is placed to the abutment which is placed to implant via connection socket. Mostly first generations of dental implants are manufactured with external connections. This type of connection allows some micro motion and less rigidity (Durkan, 2013). Morse taper design is an internal connection with a conical design with a polygon in the end for easy indexing. It offers a very close contact between implant and abutment, preventing the rotation of the abutment. Titanium is a great material for implants with its biocompatibility. But, healing in implants come from the surface to the bone, so surface topography is a crucial aspect when it comes to long term success. There are a lot of different approaches to modify surfaces. Commonly used techniques are sand-blasting, acid etching, sand blasting with acid etching, and derivatives of sand-blasting. Sand-blasting technique is mostly done with titanium dioxide, but recent applications include calcium phosphate; since it makes a non-toxic alternative to titanium dioxide (Citeau et al., 2005). In acid etching, surface of the implant is etched with strong acids (Degidi et al., n.d.), since acids involved in modification implants must be thoroughly rinsed to ensure no residues left from this operation.

Sand-blasting and acid etching combines the two mentioned techniques, first parts are blasted and treated with acid; creating more complex micro surfaces compared to the two treatment techniques mentioned before.

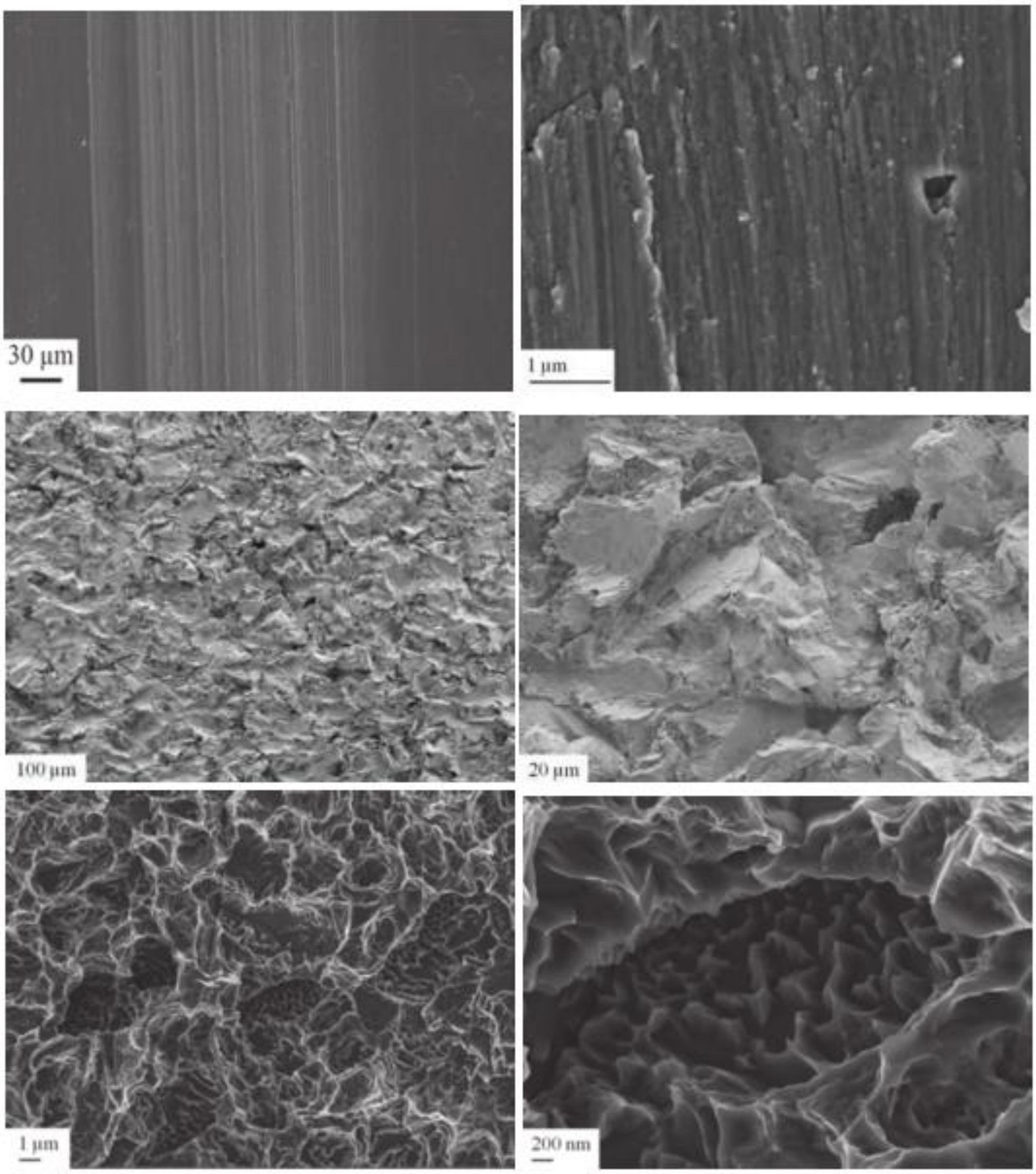


Figure 5. Scanning electron micrograph of machined, sand-blasted, sand-basted and acid etched surface (Ballo et al., 2011)

Dental implants are medical devices and they are ensured to be protected strictly with both local and global regulations than ever before, mostly due to a scandal led by a company named PIP breast implants. In 2010, PIP breast implants were withdrawn from the UK after it was found that the company fraudulently used unapproved silicone gel and their implants were far more likely to rupture[1]. Now, implantable devices are regulated with 93/42/EEC medical devices directive in Europe, which is to be replaced with a far more strict 2017/745 medical device regulation. There are other authorized bodies around the world, namely The Food and Drug Administration in the U.S., Korea Food and Drug Administration in Korea and so on. These bodies accredited several bodies to inspect and certify companies' conformance on regulations on their behalf. Without adequate certification, a company cannot manufacture or sell medical devices in these regions. To get certified, a company needs to go under auditing process for conforming essential requirements of a body that is constructed with relative standards for the product. For dentistry, there are more than a hundred standards affecting the product[2]. In Europe, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs Health Technology and Cosmetics gathered a harmonized list for medical devices[3]. For a company to stay in market, there's another challenge in conforming these standards and regulations.

1- **URL**: https://www.nhs.uk/conditions/pip-implants/
2- **URL**: https://www.iso.org/ics/11.060/x/
3- **URL**: https://ec.europa.eu/growth/single-market/european-standards/harmonised-standards/medical-devices_en

5. STUDY

5.1. Defining the Most Important Company's Function Using the House of Quality

In this study, decision making will be done using QFD. A SME located in Turkey conducted a research about the most important aspects and held meetings with potential clients in implant dentistry before entering the market. To find adequate needs, company conducted a literature research in terms of important aspects of success factors in dental implantology. To date, in dentistry, critical factors for a successful dental implant treatment were reported in many studies. Clinical reasons behind the choice of an implant procedure from alternative treatment options were examined in details and risk criteria were analyzed. Jokstad et al. (2004) analyzed the quality of dental implants and presented relationship between characteristics of dental implants and clinical performance. In recent years, qualitative studies have investigated patient experience of their healthcare in medicine and dentistry (Kashbour et al., 2015). Kashbour et al. (2015) reviewed the findings of the previous qualitative studies relating to patients' experience of dental implant treatment. Later, a market research is conducted to see what their prospective customers need besides a successful implant. Since company has different processes, a house of quality built with main processes corresponding with customer needs to see which process needs to be prioritized and if there are some inter-relations with each customer need and main processes respectively.

Based on research different characteristics were identified as stated below:

Easy to place: Dental implants should be easy to place. Harder applications may have adverse effect on jawbones and could lead to unwanted trauma. It can be vague, since the term “ease” can vary from different people (Jockstad et al., 2004), for simplification purposes easy placement is assumed with simple dental protocol.

Shorter healing time: Healing times are a major part of patient comfort (Kashboud et al., 2015). A complete healing cycle of a dental ranges from weeks to months.Shorter healing periods decrease sthe time for the patient to get back on their normal lives; hence significantly increase comfort of the patient.

Firm primary stability: Primary stability is an important part for avoiding micro movements; hence the it reduces inflammation after surgery. A firm primary stability is associated with a successful long-term outcome (Javed et al., 2013). Also, it leads to immediate loading so firm first stability is a thing to keep focus on.

Applicable to immediate-loading: Immediate-loading is the technique such specialist places a restoration within 48 hours of implant placement (Cochran et al., 2004). Immediate-loading protocol is closely linked to primary stability. If primary stability is not achieved, immediate-loading cannot be applied in single-tooth restoration operations.

Should not cause periodontal soft tissue resorption: Periodontal soft tissue stabilizes teeth and functions as a barrier between the oral cavity and the inside of the body. Periodontal soft tissue resorption may lead to bacterial leak and cause periodontal soft tissue diseases. Healthy peri-implant tissues are a determining factor in long-term success (Menini et al., 2018)

Should not cause bone resorption: Bone resorption is the destruction of bone tissue, whereby bone tissue loss occurs and is carried out by osteoclasts and mononuclear cell (Pejeva et al., 2017). Jawbone is the only aspect that a dental implant holds onto. Losing valuable bone may lead more than just implant failure. Bone resorption may lead to loss of surrounding healthy bone tissue; hence losing multiple teeth.

Extraordinary fatigue strength: Dental implants bear the occlusal load in each chewing cycle. Biting loads differ, posterior jaw takes on about three times of load in respect to anterior (Flanagan, 2017). Apart from heavy bite loads (Zhao & Ye, 1994), average human chews 0.94–2.5 times per second (Farooq & Sazonov, 2016), making resilience against fatigue may be extremely beneficial in implant survival in the long term.

Stable long-term performance: Dental implants have a 90%–95% the success rate of over the 10 years (Raikar et al.). They should last for decades if not for lifetime. Stability of long-term performance helps dentists, patients and even the manufacturer with reduced need for another operation and reduced need for keeping spare parts for years.

Easier indexing when placing upper structure (dental abutment): Implant position is extremely important for locating upper structure. When using hexagon shaped connection, specialist has six positioning -with sixty degrees apart- options (Durkan, 2013); whereas a dodecagon shaped connection gives twelve positioning options.

Surgical kit has to be convenient and easy to follow: Surgical kit contains tools to drill jawbone for implant bed preparation and auxiliary items inserting dental implants; such as drivers, parallel pins, depth gauges and so on. It is one of the most useful aspects in implantation. Reducing complexity of surgical kit and steps need to be taken for implantation may lead to better outcomes and less stress for both the specialist and the patient.

Easily identifiable packaging: Different implants are suitable for different applications. Dental implants are supplied as sterile, so when their package has been opened; it should be used right away or thrown away. A mistake in identifying dental implant will lead to unnecessary waste at minimum and wrong treatment application at maximum. To avoid such thing, companies use color and/or shape coding to their packages, reducing the risk for wrong identification.

Affordable pricing: Implant pricing indirectly affects patient. An affordable pricing will make the operation more affordable; hence more patients can benefit from implant treatment making it a win-win situation for both sides.

Company's current reputation: A bad reputation could cause instant-death for companies. Especially when it comes to health, almost all specialists avoid risks by applying trustworthy, reputable companies. An innovative product may suddenly raise awareness build a good reputation for a good start.

Company's trust to last: Long lasting expectation of a dental implant gives way for the need of company's trust to last. Any adverse effects and/or needs that can take place in the future should be met from company.

Knowledgeable personnel: Knowledgeable personnel can assist dental specialists in dental implant selection for significant cases; thus reducing the risk of further complications.

Quick response time for supply needs: Dental implants are not a thing to stock in mass amounts for doctors. Also, implant needs can change from one operation to another. A quick support from company eases the difficulties like these, making the company preferable.

Exceptional machining: Machining is the first step to define the product. Exceptional machining links to an exceptional product in geometric characteristics; leading to easier and more convenient usage.

Quality materials: Even though chemical and physical properties of dental implants have been standardized, pioneering raw material suppliers build more trust and backs company’s overall reputation.

Cleanliness: Every manufacturing step leads to a risk of leaving a residue behind, posing a risk for human health. Thoroughly cleaned products dramatically reduces chances of implant failures and negative impact on tissues.

Company consolidated these aspects in five areas, hence configuring customer needs in performance, usage, cost, service and quality shown in table below.

Table 1: Designated aspects

Main Area	Characteristic
Performance	Easy to place
	Shorter healing time
	Firm primary stability
	Applicable to immediate-loading
	Should not cause periodontal soft tissue resorption
	Should not cause bone resorption
	Extraordinary fatigue strength
	Stable long-term performance
Usage	Easier indexing when placing upper structure (dental abutment)
	Surgical kit has to be convenient and easy to follow
	Easily identifiable packaging
Cost	Affordable pricing
Service	Company’s current reputation
	Company’s trust to last
	Knowledgeable personnel
	Quick response time for supply needs
Quality	Exceptional machining
	Quality materials
	Cleanliness

After designating the aspects, company conducted a survey to a total of eight people, ranging from pioneers, specialists and newly dentists; asking what they expect from a dental implant company to supply in regarding aspects in a 1-10 scoring system. For privacy reasons, names are omitted and each person is indicated as customer. Results are shown below:

Table 2: Results for customer #1

Main Area	Characteristic	Importance degree
Performance	Easy to place	8
	Shorter healing time	8
	Firm primary stability	9
	Applicable to immediate-loading	6
	Should not cause periodontal soft tissue resorption	10
	Should not cause bone resorption	10
	Extraordinary fatigue strength	9
	Stable long-term performance	10
Usage	Easier indexing when placing upper structure (dental abutment)	6
	Surgical kit has to be convenient and easy to follow	8
	Easily identifiable packaging	7
Cost	Affordable pricing	8
Service	Company's current reputation	8
	Company's trust to last	8
	Knowledgeable personnel	8
	Quick response time for supply needs	8
Quality	Exceptional machining	9
	Quality materials	9
	Cleanliness	10

Table 3: Results for customer #2

Main Area	Characteristic	Importance degree
Performance	Easy to place	8
	Shorter healing time	8
	Firm primary stability	8
	Applicable to immediate-loading	8
	Should not cause periodontal soft tissue resorption	10
	Should not cause bone resorption	10
	Extraordinary fatigue strength	9
	Stable long-term performance	10
Usage	Easier indexing when placing upper structure (dental abutment)	6
	Surgical kit has to be convenient and easy to follow	9
	Easily identifiable packaging	6
Cost	Affordable pricing	8
Service	Company’s current reputation	8
	Company’s trust to last	9
	Knowledgeable personnel	9
	Quick response time for supply needs	9
Quality	Exceptional machining	8
	Quality materials	9
	Cleanliness	10

Table 4: Results for customer #3

Main Area	Characteristic	Importance degree
Performance	Easy to place	9
	Shorter healing time	8
	Firm primary stability	8
	Applicable to immediate-loading	7
	Should not cause periodontal soft tissue resorption	10
	Should not cause bone resorption	10
	Extraordinary fatigue strength	8
	Stable long-term performance	9
Usage	Easier indexing when placing upper structure (dental abutment)	7
	Surgical kit has to be convenient and easy to follow	8
	Easily identifiable packaging	7
Cost	Affordable pricing	8
Service	Company’s current reputation	9
	Company’s trust to last	9
	Knowledgeable personnel	8
	Quick response time for supply needs	8
Quality	Exceptional machining	8
	Quality materials	9
	Cleanliness	10

Table 5: Results for customer #4

Main Area	Characteristic	Importance degree
Performance	Easy to place	9
	Shorter healing time	8
	Firm primary stability	9
	Applicable to immediate-loading	9
	Should not cause periodontal soft tissue resorption	10
	Should not cause bone resorption	10
	Extraordinary fatigue strength	8
	Stable long-term performance	10
Usage	Easier indexing when placing upper structure (dental abutment)	8
	Surgical kit has to be convenient and easy to follow	9
	Easily identifiable packaging	8
Cost	Affordable pricing	9
Service	Company's current reputation	8
	Company's trust to last	8
	Knowledgeable personnel	9
	Quick response time for supply needs	10
Quality	Exceptional machining	10
	Quality materials	9
	Cleanliness	10

Table 6: Results for customer #5

Main Area	Characteristic	Importance degree
Performance	Easy to place	9
	Shorter healing time	7
	Firm primary stability	9
	Applicable to immediate-loading	6
	Should not cause periodontal soft tissue resorption	10
	Should not cause bone resorption	10
	Extraordinary fatigue strength	10
	Stable long-term performance	10
Usage	Easier indexing when placing upper structure (dental abutment)	7
	Surgical kit has to be convenient and easy to follow	9
	Easily identifiable packaging	8
Cost	Affordable pricing	10
Service	Company’s current reputation	10
	Company’s trust to last	8
	Knowledgeable personnel	8
	Quick response time for supply needs	10
Quality	Exceptional machining	9
	Quality materials	8
	Cleanliness	10

Table 7: Results for customer #6

Main Area	Characteristic	Importance degree
Performance	Easy to place	7
	Shorter healing time	9
	Firm primary stability	9
	Applicable to immediate-loading	9
	Should not cause periodontal soft tissue resorption	10
	Should not cause bone resorption	10
	Extraordinary fatigue strength	8
	Stable long-term performance	10
Usage	Easier indexing when placing upper structure (dental abutment)	7
	Surgical kit has to be convenient and easy to follow	8
	Easily identifiable packaging	7
Cost	Affordable pricing	9
Service	Company’s current reputation	9
	Company’s trust to last	7
	Knowledgeable personnel	8
	Quick response time for supply needs	8
Quality	Exceptional machining	8
	Quality materials	8
	Cleanliness	10

Table 8: Results for customer #7

Main Area	Characteristic	Importance degree
Performance	Easy to place	9
	Shorter healing time	8
	Firm primary stability	8
	Applicable to immediate-loading	8
	Should not cause periodontal soft tissue resorption	10
	Should not cause bone resorption	10
	Extraordinary fatigue strength	9
	Stable long-term performance	10
Usage	Easier indexing when placing upper structure (dental abutment)	9
	Surgical kit has to be convenient and easy to follow	9
	Easily identifiable packaging	8
Cost	Affordable pricing	7
Service	Company’s current reputation	9
	Company’s trust to last	9
	Knowledgeable personnel	9
	Quick response time for supply needs	9
Quality	Exceptional machining	9
	Quality materials	9
	Cleanliness	10

Table 9: Results for customer #8

Main Area	Characteristic	Importance degree
Performance	Easy to place	8
	Shorter healing time	9
	Firm primary stability	8
	Applicable to immediate-loading	6
	Should not cause periodontal soft tissue resorption	10
	Should not cause bone resorption	10
	Extraordinary fatigue strength	9
	Stable long-term performance	10
Usage	Easier indexing when placing upper structure (dental abutment)	8
	Surgical kit has to be convenient and easy to follow	9
	Easily identifiable packaging	8
Cost	Affordable pricing	9
Service	Company’s current reputation	9
	Company’s trust to last	8
	Knowledgeable personnel	9
	Quick response time for supply needs	9
Quality	Exceptional machining	8
	Quality materials	10
	Cleanliness	10

Prioritization is another important aspect for sorting customer needs. After surveying customers, to prioritize, company followed a simple average approach for each aspect's importance degree. Table below shows average signifies the results:

Table 10: Average importance degrees

Main Area	Characteristic	Average Importance Degree
Performance	Easy to place	8,375
	Shorter healing time	8,125
	Firm primary stability	8,500
	Applicable to immediate-loading	7,375
	Should not cause periodontal soft tissue resorption	10,000
	Should not cause bone resorption	10,000
	Extraordinary fatigue strength	8,750
	Stable long-term performance	9,875
Usage	Easier indexing when placing upper structure (dental abutment)	7,250
	Surgical kit has to be convenient and easy to follow	8,625
	Easily identifiable packaging	7,375
Cost	Affordable pricing	8,500
Service	Company's current reputation	8,875
	Company's trust to last	8,250
	Knowledgeable personnel	8,500
	Quick response time for supply needs	8,875
Quality	Exceptional machining	8,625
	Quality materials	8,875
	Cleanliness	10,000

It can be clearly seen that each main area has its own unique important aspect. Since it's not feasible for company to allocate resources to every aspect, a decision making should be done for to focus on most important aspects that satisfies customer needs. This is where QFD comes in. For starters, company identified its key processes: R&D (including design processes), manufacturing (including quality control, surface treatment and packaging processes), purchasing, top management (including finances), human resources and marketing (including selling). To identify which key aspect is correlated to which process, the first QFD table was built using the logarithmic 9-3-1 weighting. If there's a strongly related connection, a full dot that represents 9 points is marked in the intersecting cells. Moderate relationships are given a 3, or an empty circle. Weak relationships are given a 1, or a triangle. If there is no relationship between such qualities, the cell is left blank. The result gives way to the first QFD table shown in the figure below:

WHATs vs HOWs Strong Relationship ● (9p) Medium Relationship ○ (3p) Weak Relationship △ (1p)	R&D (including design processes)	Manufacturing (including quality control, surface treatment and packaging processes)	Purchasing	Top Management (including finances)	Human Resources	Marketing (including selling)	Average Importance Degree
Easy to place	●	○					8,375
Shorter healing time	●	●					8,125
Firm primary stability	●	○					8,500
Applicable to immediate-loading	●	○					7,375
Should not cause periodontal soft tissue resorption	●	●	△	△			10,000
Should not cause bone resorption	●	●	△	△			10,000
Extraordinary fatigue strength	●	○	△	△			8,750
Stable long-term performance	○	●	△	△			9,875
Easier indexing when placing upper structure (dental abutment)	●	○					7,250
Surgical kit has to be convenient and easy to follow	●						8,625
Easily identifiable packaging	●	●				○	7,375
Affordable pricing	△	○	○	●		○	8,500
Company's current reputation	△	△	○	●	○	●	8,875
Company's trust to last	△	○		●	△	●	8,250
Knowledgeable personnel				○	●	△	8,500
Quick response time for supply needs		○	○	△	○	○	8,875
Exceptional machining		●	●	○	△		8,625
Quality materials	○	○	●	●			8,875
Cleanliness	△	●	○				10,000

Figure 6. The first FD Table

The next step is multiplying each cell's value with corresponding importance rating of the customer demand and totaling the column for each characteristic. Total score will help ordering the importance of each characteristic. Typically measures with high score are chased; but that doesn't mean that low scored rankings should be thrown away. Rather, high scores indicate a requirement for a focus on that quality. For this company R&D, manufacturing (including quality control, surface treatment) and top management (including finances) are the most important three aspects shown in the figure below:

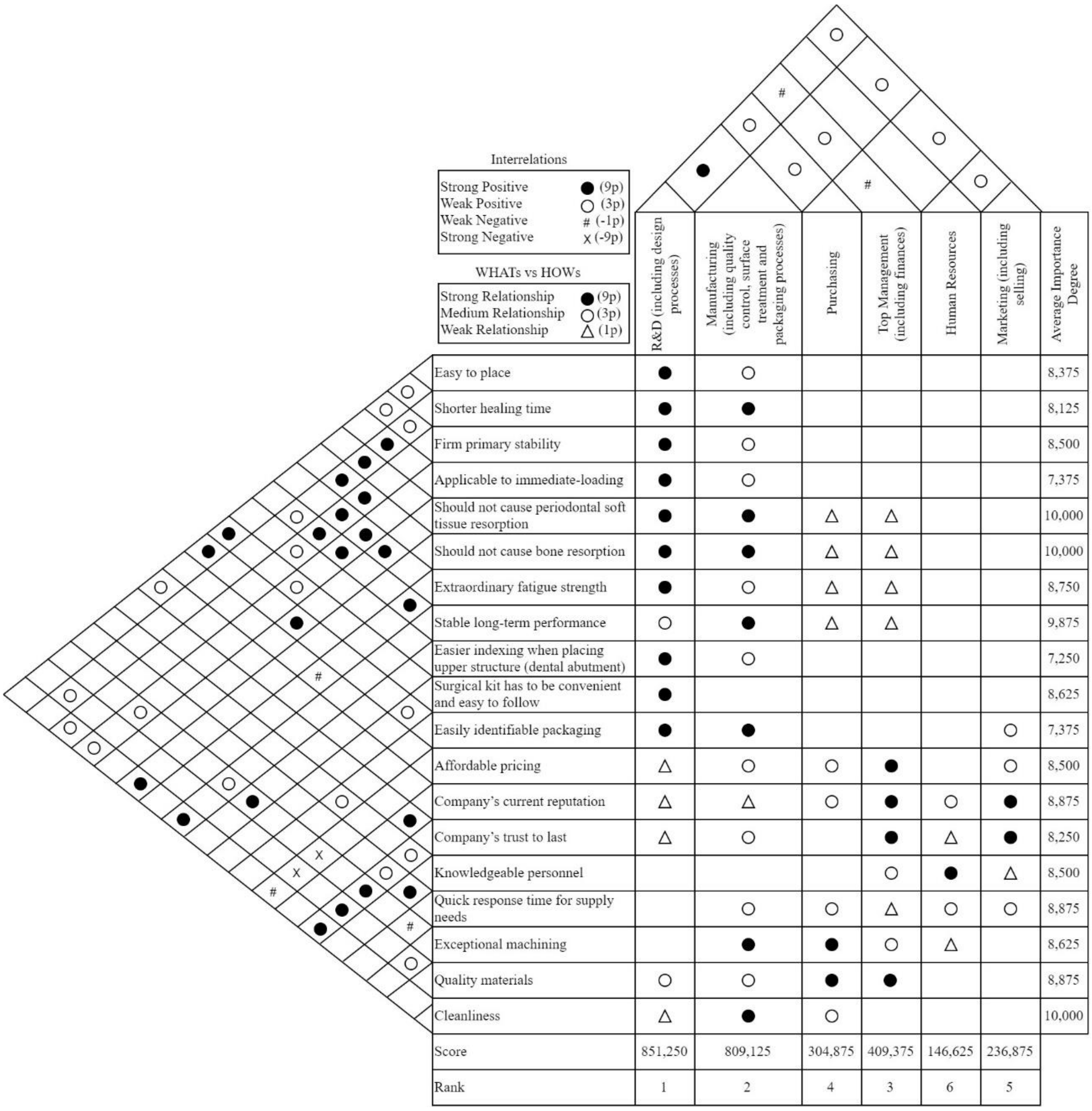
WHATs vs HOWs

Strong Relationship ● (9p)
Medium Relationship ○ (3p)
Weak Relationship △ (1p)

WHATs vs HOWs	R&D (including design processes)	Manufacturing (including quality control, surface treatment and packaging processes)	Purchasing	Top Management (including finances)	Human Resources	Marketing (including selling)	Average Importance Degree
Easy to place	●	○					8,375
Shorter healing time	●	●					8,125
Firm primary stability	●	○					8,500
Applicable to immediate-loading	●	○					7,375
Should not cause periodontal soft tissue resorption	●	●	△	△			10,000
Should not cause bone resorption	●	●	△	△			10,000
Extraordinary fatigue strength	●	○	△	△			8,750
Stable long-term performance	○	●	△	△			9,875
Easier indexing when placing upper structure (dental abutment)	●	○					7,250
Surgical kit has to be convenient and easy to follow	●						8,625
Easily identifiable packaging	●	●				○	7,375
Affordable pricing	△	○	○	●		○	8,500
Company's current reputation	△	△	○	●	○	●	8,875
Company's trust to last	△	○		●	△	●	8,250
Knowledgeable personnel				○	●	△	8,500
Quick response time for supply needs		○	○	△	○	○	8,875
Exceptional machining		●	●	○	△		8,625
Quality materials	○	○	●	●			8,875
Cleanliness	△	●	○				10,000
Score	851,250	809,125	304,875	409,375	146,625	236,875	
Rank	1	2	4	3	6	5	

Figure 7. The first QFD table with calculated scores and ranking

After scoring and ranking, interrelationships between the whats and the hows are investigated. This is done by adding a triangle to whats and hows qualities respectively. When the top triangle is added, the QFD chart resembles as a house, thus giving the top triangle the “roof” name. There are five possible relationships between the hows: a strong positive represented with a full black circle that counts as 9 points, a weak positive indicated with a circle that counts as 3 points, a weak negative represented with X that counts -3 points, a strong negative represented with # that counts -9 points and a none represented with empty cell that counts 0 point. This is a helpful approach in identifying correlations between the quality measures. The customer needs part has a similar approach. When examining the interrelationships between them, a triangle is added to the left most of the table. This is called as the “porch” in QFD methodology. Analyzing customer needs is a helpful approach in finding conflicting demands that may affect quality characteristics. The full House of Quality derived from this approach is shown in figure below:



	R&D (including design processes)	Manufacturing (including quality control, surface treatment and packaging processes)	Purchasing	Top Management (including finances)	Human Resources	Marketing (including selling)	Average Importance Degree
Easy to place	●	○					8,375
Shorter healing time	●	●					8,125
Firm primary stability	●	○					8,500
Applicable to immediate-loading	●	○					7,375
Should not cause periodontal soft tissue resorption	●	●	△	△			10,000
Should not cause bone resorption	●	●	△	△			10,000
Extraordinary fatigue strength	●	○	△	△			8,750
Stable long-term performance	○	●	△	△			9,875
Easier indexing when placing upper structure (dental abutment)	●	○					7,250
Surgical kit has to be convenient and easy to follow	●						8,625
Easily identifiable packaging	●	●				○	7,375
Affordable pricing	△	○	○	●		○	8,500
Company's current reputation	△	△	○	●	○	●	8,875
Company's trust to last	△	○		●	△	●	8,250
Knowledgeable personnel				○	●	△	8,500
Quick response time for supply needs		○	○	△	○	○	8,875
Exceptional machining		●	●	○	△		8,625
Quality materials	○	○	●	●			8,875
Cleanliness	△	●	○				10,000
Score	851,250	809,125	304,875	409,375	146,625	236,875	
Rank	1	2	4	3	6	5	

Figure 8. The full House of Quality

5.2. QFD Phases for Dental Implant Manufacturing

It can be seen that company needed to shift its focus more to R&D and allocate resources accordingly. In this phase, company aimed to transfer all knowledge from R&D to quality controls, thus spreading customer needs to whole organization and finding the most important aspect, ranging from product characteristics, manufacturing processes and quality controls in each iteration as in Bahill and Chapman (1993). Another meeting held between engineers and customers for finding out product characteristics on satisfying R&D demands. These are:

Short length – To prevent overheating implant site in preparation, easy placement and simple surgical kit
Double screw cutting – To increase movement for each pitch, thus easy placement
Self-tapping – For smoother advance in insertion
Narrow diameter – To allow less pressure when inserting the implant, easy placement and simple surgical kit
V shaped thread – To allow easier mounting
Conical geometry – For offering a better stability
Morse tapered interface – To reduce micro movements
Implant neck – For greater fatigue strength
Double hexagon connection – To allow more options for indexing
Color coded implant box – For easier package identification
Sand blasted surface – For easier manufacturing with less complications, reducing risk for periodontal tissue and bone complications
Implant set – A basic set that contains necessary items

Based on this information, another QFD chart exhibiting customer needs and product characteristics was built reiterating the first QFD table shown in the figure below:

WHATs vs HOWs Strong Relationship ● (9p) Medium Relationship ○ (3p) Weak Relationship △ (1p)	Short length	Double screw cutting	Self-tapping	Narrow diameter	V shaped thread	Conical geometry	Morse tapered interface	Implant neck	Double hexagon connection	Color coded implant box	Sand blasted surface	Implant set	Average Importance Degree
Easy to place	●	●	●	●	○							○	8,375
Shorter healing time	●			○		○							8,125
Firm primary stability	○	○		○	○			○					8,500
Applicable to immediate-loading	○	○			○		○						7,375
Should not cause periodontal soft tissue resorption	○										○		10,000
Should not cause bone resorption	○										○		10,000
Extraordinary fatigue strength	○	○			○	○	○						8,750
Stable long-term performance	○			○	○		○		○		○		9,875
Easier indexing when placing upper structure (dental abutment)							●		●				7,250
Surgical kit has to be convenient and easy to follow	●		○									●	8,625
Easily identifiable packaging										●			7,375
Affordable pricing													8,500
Company's current reputation													8,875
Company's trust to last													8,250
Knowledgeable personnel													8,500
Quick response time for supply needs	○	○	○	○	○	○	○	△					8,875
Exceptional machining	○				○	○	○						8,625
Quality materials												○	8,875
Cleanliness	○	○	○		○						○		10,000
Score	446,25	205,875	157,875	237,375	211,125	106,875	195,750	34,375	94,875	66,375	116,250	103,500	
Rank	1	4	6	2	3	8	5	12	10	11	7	9	

Figure 9. Reiterated QFD Chart

This table clearly shows what's important in R&D aspects. Company transferred this knowledge to manufacturing processes and advancing on QFD. This time hows in previous chart becomes whats and hows becomes the manufacturing processes. Respective processes are:

CNC manufacturing – Where main characteristics are given
Descaling – Degreasing material from oil and other residues
Lot inspection – Sampling the lots and inspecting against nonconformities
Surface treatment – Giving further surface treatment (Sand-blasting in this case)
Packaging – Once prior processes complete, implants are packaged and sealed in clean rooms to prevent it from contaminants
Sterilization – Implants are sterilized in gamma radiation
Based on these respective processes, another QFD chart was built below:

WHATs vs HOWs

Strong Relationship ● (9p)
Medium Relationship ○ (3p)
Weak Relationship △ (1p)

WHATs vs HOWs	CNC Machining	Descaling	Lot Inspection	Surface Treatment	Packaging	Sterilization	Score
Short Length	●		○				446,250
Double Screw Cutting	●		○				205,875
Self-tapping	●		○				157,875
Narrow Diameter	●		○				237,375
V Shaped Thread	●		○				211,125
Conical Geometry	●		○				106,875
Morse Taper Interface	●		○				195,750
Implant Neck	●		○				34,375
Double Hexagon Connection	●		○				94,875
Color Coded Implant Box					●		66,375
Sand Blasted Surface	△		△	●		△	116,250
Implant Set	●	○	○				103,500
Score	16261	311	5213	597	854	116	
Rank	1	5	2	4	3	6	

Figure 10. Importance Degree of Manufacturing Operations

This table reveals the most important process, in this case CNC machining gets the first row.

The final step of QFD compares manufacturing processes to quality controls. In this case, company planned the quality controls as follows:

Geometric inspections – Inspecting part with equipment such as calipers, micrometers etc.
Visual controls – Inspecting parts for any seen nonconformities
Microscope inspection – Inspecting magnified part for any residues and/or any nonconformities that cannot be seen without magnification
CMM inspection – Inspecting part’s internal connection for any nonconformities
Insertion torque inspection – Inserting the implant to a bone replica and interpreting the results
Biocompatibility validation – Necessary tests for proving biologic safety
Radiation emission validation – Sampling lots and sending them to an external laboratory to make sure no radiation is emitted from the implant
Atomic microscope validation – Sampling lots and sending them to an external laboratory for inspection of surface topography
Force distribution inspection – Sampling lots and sending them to an external laboratory to measure force distribution around implant and bone tissue.

Based on these respective controls, the QFD chart below was built:

WHATs vs HOWs Strong Relationship ● (9p) Medium Relationship ○ (3p) Weak Relationship △ (1p)	Geometric inspections	Visual controls	Microscope inspection	CMM inspection	Insertion torque inspection	Biocompability validation	Radiation emission validation	Atomic microscope validation	Force distribution inspection	Score
CNC Machining	●	●		○	○	○			○	16261
Descaling		○	○			●				311
Lot Inspection	●	●				△				5213
Surface treatment		○				○		●		597
Packaging		○				○	○			854
Sterilization						●	●			116,25
Score	193269	167275	932	48783	48783	62191	3608	5376	48783	
Rank	1	2	7	4	4	3	6	5	4	

Figure 11. Controls Corresponding with Processes

6. RESULTS

The most important aspects for dental implant manufacturing were found using QFD. Study shows that the most important process as R&D, following with manufacturing and top management as the top three and purchasing, marketing and human resources as the bottom three accordingly, shifting focus and allocating enough resources to R&D is vital in the beginning.

After shifting focus to R&D, reiterating QFD resulted with the most important design aspects, as short length leads in this iteration with the most score. Moving on and investigating which manufacturing process is the most important, the subsequent iteration resulting CNC machining as the most important one. This is somewhat expected, since manufacturing phase starts with CNC machining and the resulting part is strongly correlated with it.

Finally, quality controls went through the last iteration and resulted geometric inspection as the most important activity. This does not mean that the rest controls are not important. To explain, any failure in biocompatibility tests will make every step invalid, whereas any failure in the least ranked radiation emission validation would be a serious health hazard and prevent company from selling their products.

QFD simply allows company to see processes as which one requires attention or in this case resources the most. In this case allocating sufficient resources to geometric control equipment and quality training control operators seems to be one of the best solutions for the sake of resulting part.

7. CONCLUSION

Staying in market is getting harder especially in manufacturing sector. With competition getting rougher, companies should take correct steps to stay in the game. it's extremely important for a company to allocate sufficient resources for critical processes. Any mistake in such thing can affect more than the resulting product, it can stake company's relationship with customers, reputation and longevity. Other than these, a company needs to watch their customers for their ever-changing needs. Keeping focused on such matter guides through many aspects of design phases.

Allocating resources while keeping an eye on customer needs in an adequate way requires a systematic approach. QFD is a wonderful tool to fulfill such objective. It can guide a company through every phase while still correlated to their needs.

This study inspected QFD as a decision-making system in dental implant supply. A SME in Turkey founded by an ex-salesman who worked in the sector for many years, wanted to find the most important implant aspects before entering the market.

After designating customer needs through extensive clinical research and appraisal with market research, a list with consolidated aspects was created and presented to a group of eight dentists, resulting an average importance degree for each aspect, QFD was used in two different approaches.

First, it's used for obtaining knowledge for which process was the most important; hence needs the most importance in allocating resources, resulting R&D as the most important one. In this phase, house of quality was also built for easy access to any inter relations between customer needs and company's main processes.

Second, correlations between customer needs (Whats) and quality characteristics (Hows) are investigated, transferring the study into manufacturing processes. In each step, the most important qualities were identified. It shows that CNC machining as the most important process and geometric inspection as the most important activity.

This study only covered the body geometry and marketing aspects of a dental implant. Future research may include abutment and surgical drill designs, combined implant geometry, different materials in consideration (e.g. zirconium).

For simplification purposes, detailed processes were merged into bigger categories, like R&D including design processes, manufacturing as it merged with quality control, surface treatment and packaging, top management containing finances and marketing including selling activities. A detailed work can be done breaking up these categories and integrating other disciplines. Likewise, the resulting most important activity (quality controls in this case) has different aspects in it, like procuring quality control equipment that is correlated with finances and top management, and training personnel that is strongly correlated with human resources.

Another approach would be integrating more complex optimization techniques can be developed by integrating multi-criteria decision making with cost and technical difficulties rather than solely focusing on importance degrees.

Finally, work will be done with inter-relations included in the future.

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