Review Article
Journal of Pierre Fauchard Academy (India Section), *Vol 35(3), DOI: 10.18311/jpfa/2021/27610, September 2021 p. 78-86*
ISSN (Print) : 0970-2199
ISSN (Online) : 2405-772X

Impact of Drilling Speed in Implantology: A Review

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Abstract

Background: Drilling speed during osteotomy in implant site preparation is an important factor that affects heat generation, cell vitality and primary stability and consequently Osseointegration of the implant. A thorough understanding of this impact is important for taking suitable precautions for successful dental rehabilitation. **Aim:** The objective of this study is to review the available literature regarding the impact of drilling speed on heat generation and other related parameters that influence the success of dental implants. **Material and Methods:** Suitable research papers relevant for study were identified through electronic database of available dental literature in PubMed and MEDLINE for all articles published till February, 2021. Peer-reviewed dental and PubMed indexed journals were selected. Search was done using certain relevant key words and terms. **Results:** The initial search revealed a total of 281 articles which were then screened and a total of 61 articles were selected based on the inclusion criteria. Focus was laid on the studies related to drilling speed and its impact on osseointegration, heat generation during osteotomy, drilling speed and bone viability, drilling speed and primary stability of implant and particle size of the bone collected. Heat generation during implant placement is affected by multiple factors with drilling speed being one of them. **Conclusion:** Researchers have reached contradictory conclusions regarding the impact of drilling speed on heat generation during osteotomy and other parameters. However, studies in the recent past are favoring low speed drilling owing to the advantage of perfect control of the drilling depth and the possibility of collection of a considerable amount of viable granular bone grafts during the procedure.

Keywords: Bone Viability, Drilling Speed, Heat Generation, Osseointegration, Primary Stability

1. Introduction

Oral rehabilitation with endo-osseous implants appears to be a safe and practical choice for a successful treatment plan, the outcome of which largely depends upon the progression of bone healing[1]. Healing of the osseous structure can result either by repair or regeneration[2]. Regeneration with future osseointegration of the implant is expected if certain surgical and biologic criteria are strictly adhered to[3].

Amongst the various factors influencing implant survival; careful preparation of the implant site is considered as an essential requisite for successful healing and consists of several precautions to be followed, including avoidance of overheating after wear during osteotomy[4].

Heat generation during osteotomy of recipient site damages the bony tissue by producing hyperemia, necrosis, fibrosis, osteocystic degeneration[5], and finally increases the osteoclastic activity[6-8] thus affecting osseointegration which is a key for the success of this type of treatment.

Rotary drills or burs required for implant site preparation are often associated with bone necrosis resulting from thermal and mechanical damage[9-10]. Due to the frictional heat generated in the rotary osteotomy; intrabony temperature change occurs leading to overheating and subsequent heat transmission to the bone[11-12], which is detrimental for osseointegration and the success rate of implant rehabilitation[10,13].

Drilling at high speed (from 800 to 1500rpm) is recommended for most of the implant systems with irrigation to prevent over-heating of bone and preserve cell viability, to prevent thermal necrosis, and to reduce the time required for osteotomy[14-17]. The low-speed needs increased drilling time leading to more frictional heat production and overheating of the implant site during

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drilling[4,14]. However recent studies have shifted the focus back towards low-speed drilling on account of various likely benefits[18-20].

It is important to note that "drilling speed" is only one of the many parameters that may influence the heat generation and consequently the bone vitality, Osseointegration, primary stability and possibly also the particle size of the bone harvested during implant placement.

2. Material and Methods

2.1 Search Design

A comprehensive search of the dental literature in PubMed and Medline was executed for all available articles published till February, 2021. Emphasis was on peer-reviewed and PubMed indexed dental journals. The search strategy involved the inclusion of the following phrases as 'speed during implant placement; effect of drilling speed on heat generated during implant osteotomy; effect of low speed and high speed drilling in implant osteotomy; drilling speed and heat generation; drilling speed and bone viability; drilling speed and osseointegration; drilling speed and primary stability; and drilling speed and bone collected during osteotomy.' More emphasis was laid on articles comparing different drilling speeds. The references were noted and full-text articles and relevant review articles were searched electronically.

2.2 Inclusion and Exclusion Criteria

To determine which of the articles and studies need to be made a part of the study, the following inclusion criteria was used. Studies specifically related on effect of drill speed on implant osteotomy were included. Both *in vitro* and *in vivo* study articles related to impact of drilling speed on heat generation, primary implant stability, bone viability and particle size of bone harvested during the implant drilling were considered. Both abstract and full text articles were incorporated for the study. Systematic reviews, contemplative reviews and targeted articles were included. Research articles comparing implant osteotomies at different drilling speeds were included.

Articles displayed in the search results which didn't conform to the inclusion criteria and those that specifically studied other parameters and not the variables forming the main basis of this review, were excluded. Articles not complying with the keywords considered were sifted off. Case reports, letters to the editor, and opinion articles were excluded.

3. Results

The initial search using multiple terms mentioned under search strategy resulted in a total of 281 articles of which 61 articles were found to be fulfilling the criteria and were selected. The articles not conforming to these criteria were excluded from the study. The articles selected either in general terms were related to the studies on impact of the drilling speed on the selected variables as mentioned above or specifically studied interaction in respect of the dental implants like drill speed during implant placement; effect of drilling speed on heat generated during osteotomy; drilling speed and heat generation, correlation of drilling speed and osseointegration; drilling speed and primary stability; drilling speed and bone viability and particle size of bone collected. Rest of the articles which were excluded did not specifically study the relationships between drilling speed and the selected parameters.

4. Discussion

4.1 Drilling Speed and Heat Generation

The success of endo-osseous implants is largely dependent on the bone viability post implant site preparation and perhaps the most pertinent factor that affects the viability and vitality of the bone at implant site and that needs to be considered is the sensitivity of the bone to the heat generated during bone drilling[9]. Heat generation during bone drilling is a frequent occurrence related to various factors such as bone density, irrigation system, drill sharpness, drilling depth, feed rate, drill wear and drilling speed, drilling load and many others[10,13,14,21] (Table 1) [Tehemar 1999, p. 130].

Since a multitude of reasons affect heat generation during bone drilling, the overall impact will depend on the combination of the various factors taken as variables in the particular study.

The sensitivity of the bone tissue towards heat has been examined in a number of studies. Previous studies conducted by Mathews & Hirsch[22] and Rhinelander *et al.*[23] on heat generation during implant osteotomy to evaluate the critical bone temperature beyond which bone necrosis may occur[4] had revealed that temperatures deleterious to bone tissue range from 56°C to 70°C as alkaline

Table 1. Factors Affecting Heat Generation During Implant Site Drilling

Operator	Manufacturer	Site	Patient
Drilling pressure	Drill design	Cortical thickness	Age
Drilling status	Irrigation system	Site condition	Bone density
Drilling motions	Drill sharpness	Drilling depth	
Drilling speed	Implant systems		
Drilling time			

Note: Reprinted from "Factors Affecting Heat Generation During Implant Site Preparation: A Review of Biologic Observations and Future Considerations" by SH Tehemar, 1999, Int J Oral Maxillofac Implants, 14: 130.

phosphatase is denatured at that level[22,23]. Thereafter, in a series of studies carried out by Eriksson, Albrektsson, and colleagues in tibial metaphysis of rabbits[11,24,25]; it was determined that bone is a lot more sensitive to heat, and can withstand threshold temperature of 44°C for only 1 minute without impairing bone regeneration. Heating the test implants to 47°C or 50°C for 1 minute resulted in remarkably decreased bone formation in the area 0.5 mm away from the periphery of the test implants[24,25].

Given the high sensitivity of the bone to changes in temperature, it becomes imperative to study the impact of various factors that affect heat generation during osteotomy. Accordingly, a multitude of studies have been conducted to assess the impact of drilling speed which is a likely factor with possible impact on heat generation. However, researchers have reached contradictory conclusions while studying the impact of drilling speed on heat generation and incremental temperature rise.

Thompson studied the thermal changes and initial histologic responses to drilling in bone without use of coolant at varying speeds ranging from 125 to 2000 rpm and concluded that temperature elevated from 38.3°C to 65.5°C at 2.5 mm and 5 mm from drill site with increase in drilling speed[26]. Clinically, a cooling system combining both internal and external cooling can be a better course of solution for treatment planning for osteotomy and reaming systems[27].

Matthews and Hirsch studied the effect of temperature increased as a function of drilling speed (345 rpm to 2900 rpm) and applied force (2 kg, 6 kg & 12 kg) in bone analogue[22]. They concluded that it was variation in the drilling force that is more responsible for rise in temperature than other drilling parameters in bone analogue. Increased force decreases heat generation. This was the first study to look at influence of load. Nam *et al.* studied the effect of combining two different drilling speeds (600 and 1200 rpm) and applied pressure (500 and 1000 g) on implant during osteotomy on heat generation in bovine ribs and concluded that the temperature rise is notably dependent on the force applied[28]. Acceptable results were seen with the low speed (600 rpm) and high pressure (1000 g) group, and with the high speed (1200 rpm) and low pressure (500 g) group which produced temperature rise upto 40-45°C. The temperature increase was more noticeable during the initial 5-10 seconds[28]. Intermittent drilling was considered a better alternative than continuous drilling.

Eriksson *et al.* conducted an *in vivo* study where they calculated rise in temperature during drilling in femoral cortex of rabbits, dogs and humans. With drilling speed of 20000 rpm under irrigation, temperatures of 40°C in rabbits, 56°C in dogs and 89°C in patients were noted 0.5 mm adjacent to the drill site[29]. The results clearly indicated the disparity of temperature rise in patients as compared to animals. Animal experiments cannot be extrapolated to clinical situations where high temperatures are experienced while drilling in human cortical bone[29].

Brisman studied the outcome of speed, pressure, time and temperature increase while drilling bovine cortical bone during implant osteotomy at 1800 and 2400 rpm speed and varying loads of 1.2 and 2.4 kg[30]. It was deduced that raising both the speed as well as the load results in effective osteotomy with insignificant or minimal rise in temperature.

The heat generated during the drilling procedure caused harmful thermal effects on the bone as concurred by Perrone[31].

Krause *et al.* did a study on mid diaphysis of mature bovine bone and concluded that use of irrigation can prevent overheating and thus the risk of thermal necrosis[32]. Reduction of cutting angle and shape of bur also influenced rise in temperature. Iyer *et al.* in their study evaluated heat production during *in vivo* osteotomy preparation in rabbit tibia at low (maximum 2000 rpm), intermediate and high speeds, and concluded that drilling speed is inversely proportional to heat generation[33].

Sharawy and his colleagues evaluated heat generated during drilling at 1225 rpm, 1667 rpm and 2500 rpm and concluded that heat generation was inversely related to drilling speed[4]. They concluded that slow speed requires longer drilling time thereby producing higher frictional heat. On the other hand, drilling at 2500 rpm reduced the osseous damage that helps augment the primary healing of dental implants[4]. It was inferred that the degree of non-vital zone adjoining the implant surface after surgery decreases at high speed as confirmed by Cardioli *et al*[12].

In contrast to the above studies, Watcher and Stoll performed both *in vivo* and *in vitro* osteotomies in sheep where the load of oscillatory saw and irrigation varied[34]. It was noted that under continuous applied load, the increase in temperature was significant while in case of intermittent load, the temperature rise could be balanced. Intensive irrigation helps control the rise in temperature[34]. Reingewirtz and his colleagues in their study showed that from 400 rpm to 10000 rpm, temperature elevation is relatable with drilling speed and thus advised pre drilling protocol[35]. In Type III & IV bone, high drill speed can be employed along with cryogenic spray while for Type I & Type II bone, low rotation speed was recommended (400-600 rpm). Lavelle and Wedgwood concluded that internal irrigation helped in controlling frictional heat better than external or no irrigation upto 350 rpm[8].

Recently, implant osteotomy at drilling speed of 50 rpm without irrigation has been propagated as a substitute for the conventional technique[18-20]. Drill guides can control the need for irrigation[36,37]. Additionally uncontaminated bone can be collected which can then be used as an autograft[14,39]. Drilling at low speed has proven to be advantageous than the high-speed drilling with irrigation[14]. The low-speed drilling gives more specific information on the path of the drill so that ramifications can be made if required[39]. Thus, implant site preparation is better monitored by drilling at low speed[14].

Sun-Jong Kim *et al.* did a comparative study involving two conventional drill systems with low-speed drill systems at 50 rpm without irrigation in pig cortical bone under constant load of 10 kg[18]. They deduced that speed drilling at 50 rpm without irrigation even with conventional drill systems did not result in overheating. Drilling at 50 rpm without irrigation does not produce heat exceeding 47ºC thus it is preferable during implant site preparation[18].

Ji-Hyeon Oh *et al.* in a study assessed heat generation during the low-speed drilling procedure without irrigation in 10 artificial bone blocks simulating human D1 bone to imitate the clinical conditions involved in osteotomy[39]. Drilling of 5 artificial bone blocks at 50 rpm without irrigation and another 5 artificial bone blocks at 1500 rpm with irrigation (control group) was done. The change in temperature was noted using thermocouples. The average maximum temperature change in test group was 40.9ºC and 39.7ºC in the control group thus confirming that drilling at low speed does not lead to temperature increase[39].

Delgado-Ruiz RA *et al.* studied bone temperature changes during implant osteotomy with a single-drill protocol but keeping drill design and drill speed as variables (50, 150, and 300 rpm) in artificial type IV bone[40]. Control group had drill speed at 1200 rpm. A single-drill procedure at low speed without irrigation increased the temperature but well below the 47°C. It was concluded that in the above scenario drilling speed was the only parameter affecting the time required for osteotomy and more time was required with low speed[40].

Some studies favour low speed drilling[10,14,18-20,36-37,39-40] and while others advocate drilling at high speed with irrigation[4,12,32,33,44]. Drilling at low speed without irrigation or biological drilling is beneficial as vital bone can be collected for use as autograft[14,38]; involves low risk of invading structures during osteotomy[38]; provides possibility of controlling and correcting direction of drilling in case of deflection of its path[18]; and similar osseointegration rate[41] and peri-implant bone level changes were noted[42,43] as with high speed conventional drilling procedure. Drawbacks include increased time for osteotomy preparation[18] and over preparation of the implant site due to rocking of drill sometimes[44].

There is a lack of consensus about the drilling speed range that ought to be ideally used during low-speed drilling for osteotomy as pointed out by Delgado-Ruiz RA *et al.*[40]

4.2 Drilling Speed, Bone Viability and Osseointegration

Success of osseointegration depends on avoidance of heat generation[12] and type of bone at the implant osteotomy site[45,46].

Sarendranath *et al.* conducted a histological and histomorphometrical outcomes i.e. Bone to implant contact [BIC] and Bone area fraction occupancy [BAFO] of a simplified drilling technique at low speed (400 rpm) compared with those of a conventional drilling technique in canine tibias of dogs[41]. Bone was assessed after 3 and 5 weeks and showed similar osseointegration with both protocols[41].

Landazuri *et al.* concluded that two varying drilling speeds of 50 rpm and 1500 rpm did not affect bone regeneration and osseointegration pattern in the rabbit tibia using the flapless guided surgery for a brief healing period[47].

Yeniyol S *et al.* studied the consequence of drilling speed on early bone healing in dog tibiae by recording BIC and BAFO while using drilling speed of 100 rpm, 500 rpm and 1000 rpm[48]. The BIC for the 100 rpm drilling speed increased significantly after 1 to 3 weeks. BAFO results were comparable for 100 rpm and 500 rpm groups initially but the values noted for the 1000 rpm group were comparatively higher after 3 weeks[48].

Eduardo Anitua evaluated the efficiency of low-speed drilling on the viability and vitality of the particulate bone obtained[14]. While conducting the study in five patients, he concluded that the crushed bone grafts obtained can be helpful if immediate augmentation of bone is needed[14]. The bone with biological drilling showed "alive cells, maintained bone architecture and size of bone particles was significantly higher" (Anitua, 2018, p.101). The disadvantage of high-speed bone drilling is that absence of cells in bone makes it impossible to help in expansion of osteoblasts as proved in another study by Anitua E and his colleagues[38].

Giro *et al.*[19] carried out implant drilling at 50 rpm without irrigation and 900 rpm with irrigation in dogs[19]. A notable increase in BIC and BAFO was observed as time elapsed at 2 and 4 weeks. Both techniques did not affect osseointegration[19].

Gaspar *et al.* assessed instantaneous histological variations in rabbit tibias at low speed with no irrigation and at 800 rpm with irrigation and deduced that both preserve bone-cell entity[20].

Tabrizi *et al.* while studying the impact of drilling speed (1000 rpm and 1500 rpm) and bone depth (10mm and 13mm) during implant osteotomy on bone viability in 100 human participants. It was observed that increased drilling speed or depth does not influence the mean percentage of bone cell vitality but notably increasing both depth and drilling speed can cause reduced vital bone percentage[10].

Iyer *et al.* histologically studied the postoperative effects of the rate and quality of healing at three speeds in the mandible after 2, 4, and 6 weeks[49]. It was concluded that the rate of healing and quality of new bone formation was better after high speed drilling in the first 6 weeks[49].

Marzook *et al.* in their research aimed to verify the significance of implant drill speed on heat generation and bone viability at the recipient site of femur bone in 20 rabbits with 3 varying drill speeds of 1000 rpm, 1500 rpm and 2000 rpm. It was concluded that drilling at high speed with irrigation produced less heat and bone viability was not much affected in contrast with lower speed[50].

Seo *et al.* in their study concluded that favorable outcome can be expected with 50 rpm, 800 rpm and 1200 rpm drilling speeds in mandible but higher drilling speed presented the best biological response[51].

Witek *et al.* conducted their study using narrow diameter and wide diameter short implants to systematically analyze the osseointegration by a multifaceted surgical approach[52]. While experimenting with skeletally mature female sheep and plateau-root-form healing chamber titanium implants; they used drilling speed, function of time and irrigation as variables at three different drill speeds of 50 rpm, 500 rpm and 1000 rpm. It was observed that the narrow 3.5mm implant showed higher values of BIC at a drilling speed of 50 rpm with irrigation at 6 weeks, while at 500 and 1000 rpm, not much variation was observed with or without irrigation. The wide 6-mm diameter implant with 500 & 1000 rpm drilling speed gave better outcomes under irrigation. BAFO results showed no significant difference[52].

As can be seen, studies are not completely in agreement regarding impact of drilling speed on osseointegration and cell viability. There are studies that favour low speed drilling[10, 14, 18 - 20, 36, 37, 39, 40] and those that favor high speed drilling[4, 12, 32, 33, 44, 50 - 52]; however, most of the studies show that there is no significant difference in osseointegration in case of drilling using either one of the protocols (conventional or low speed).

4.3 Drilling Speed (DS) and Primary Stability (PS)

Primary stability at the time of implant placement is crucial for perpetual success of dental implants[51 - 53]. It is associated with bone integration or absence of mobility[5]. Density of bone and bone strength, surgical protocol used, and implant thread design are few of the main factors affecting primary stability[54 - 57].

Almeida *et al*. studied the influence of drilling speed on primary stability of tapering implants placed at drilling speeds of 800 rpm in simulated Type II and 1500 rpm in Type IV bone[55]. It was deduced that it is the quality of bone and not the drilling speed that affects primary stability as also concluded by Javed *et al*.[56]

Georgios E. Romanos *et al*. in an *in-vitro* experiment studied the influence of "drilling speed on the PS of narrow diameter implants with different thread designs placed in dense and soft simulated bone" (Romanos 2004, p.1350) and concluded that a low drilling speed (800 rpm) is preferable in dense artificial simulated bone as opposed to high drilling speed (2000 rpm) in soft artificial simulated bone for better initial stability[58].

Frictional heat generated by drilling results in changes in intrabony temperature which results in bone necrosis. High drilling speed and depth are mainly responsible for temperature rise during implant osteotomy[4, 10]. Bone vitality helps in measuring the range of cell injury caused due to heat generation[10]. High drill force and speed can reduce osseous heating by reducing the intrabony drill operation time and heat production[59].

Ozcan *et al*. in their experimental animal study with sheep focused on comparing different osteotomy drilling speed procedures on temperature of cortical bone, implant stability and bone healing; while using 4 different drilling speeds of 50 rpm without saline cooling and 400 rpm, 800 rpm, 1200 rpm and 2000 rpm with saline cooling[60]. It was concluded that there is not much effect of drill speed for implant osteotomy and its irrigation on the temperature of the cortical bone, primary and biological implant stability and bone and tissue volume. However, at 50 rpm drill speed, high cortical bone temperature and long preparation time with the highest primary stability was noted[60].

Above studies are inconclusive as to the final understanding of the effect of drilling speed on primary stability of the implant. Results show that the impact may vary depending on bone and implant type and therefore this is an area still wide open for further research. Biological drilling can be performed in clinical situations but care should be taken in cases with high bone densities.

4.4 Drilling Speed and Particle Size

There are not many studies regarding evaluation of the impact of drilling speed on particle size of the bone collected. Chang-hee Jeong *et al*. evaluated the influence of implant drilling speed on the structure of particulate bone collected while drilling in bovine mandible. Low speed drilling produced more percentage of large particles[61].

Tabassum *et al*. carried out a research using standard drilling protocol with saline irrigation and low-speed drilling (200 rpm) without saline irrigation in 20 patients[61]. Osteogenic efficacy of autogenous bone particles harvested at low-speed drilling samples yielded better results[62].

It is important to point out that a single study is not sufficient to draw any conclusions and therefore further studies in the area are warranted. In addition, it is crucial to remember that there is huge difference between the bone densities of osseous study models, animals and humans. Most of the studies to analyse the impact of the variables considered for this study were done on bovine femoral bone, rabbit tibia, bovine mandible, bovine cortical bone, pig jaw, rabbit femur, osseous study models etc. but there are very few studies in humans. There is shortage of data for assessing heat generation in living models as it can jeopardize the bone vitality which is both an ethical and legal concern.

5. Conclusion

Bone drilling speed is a crucial parameter that affects heat generation during implant osteotomy thereby having an impact on the bone viability and osseointegration, in addition to its impact on particle size of bone collected and primary stability of the implant.

1. Both high speed drilling with irrigation and low speed drilling without irrigation can be performed for implant placement. Recent studies are more in favor of low speed drilling without irrigation even though it increases the drilling time on account of its benefits. The exact range of low speed drilling protocol that produces the best results needs to be explored.
2. Most of the studies prove that no significant difference has been noted in achieving osseointegration either by conventional method or by intermittent low drilling speed.
3. Majority of the studies favour low drilling speed for achieving better primary stability because of perfect control of the drilling depth and possibility of collecting granular bone grafts for immediate augmentation of bone.

Low drilling speed without irrigation does have advantages as compared to high speed but extensive histological and bone vitality studies are required to be conducted in humans at a larger scale with a longer follow up period for better understanding the effect of drilling speed on heat generation and other parameters during osteotomy.

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