Konya Mühendislik Bilimleri Dergisi, c. 12, s.3, 801-821, 2024
Konya Journal of Engineering Sciences, v. 12, n. 3, 801-821, 2024
ISSN: 2667-8055 (Elektronic)
DOI: 10.36306/konjes.1430115

THE EFFECT OF CUTTING FORCES ON BONE RELATED OPERATIONAL PROCESSES: A LITERATURE REVIEW

[1,*] Yusuf Çağlar KAĞITCI, [2] Süleyman NEŞELİ

[1]Konya Technical University, Vocational School of Technical Sciences, Mechanical and Metal Technologies Department, Konya, TÜRKİYE
[2]Selcuk University, Technology Faculty, Mechanical Engineering Department, Konya, TÜRKİYE
[1]yckagitci@ktun.edu.tr, [2]sneseli@selcuk.edu.tr

(Received: 01.02.2024; Accepted in Revised Form: 13.06.2024)

ABSTRACT: Cutting mechanics must be known in terms of solving the mechanistic problems to be encountered as a result of the operational processes on the bone. In today's applications, operational procedures such as milling, drilling, cutting and screwing can be performed on the bone as a surgical procedure. The uncontrollable cutting forces that occur as a combination of the microstructure of the bone and the geometric features of the cutting tools and the resulting localized heat (fracture and necrosis) may cause bone damage. The fracture of the cutting tool or the cut bone due to the cutting force depends on the intensity and direction of the forces applied during the operation. In this study, a review of the studies in the literature on what the factors causing bone damage and their effects are reduced. In addition, the information given in this study will be useful as a one-stop document for technicians, engineers and researchers who need information on tool design, cutting force measurements in bone processing operations (in surgical applications such as milling, drilling, cutting, etc.) of cutting forces.

Keywords: *Bone Cutting, Bone Temperature, Cutting Force, Cutting Parameters, Machining*

1. INTRODUCTION

Machining technology, which is one of the most important fields with a great impact on the production industry in the world, has been and will continue to be effective in areas such as health, automotive, defense, aerospace, machinery manufacturing in the economies of developed countries [1]. Cutting mechanics is extremely important in machining technology. Chip formation, cutting tool and cutting forces are among the important stages to be emphasized in cutting mechanics. In order to be able to process materials in the desired dimensions, cutting tool manufacturers and academicians in this field are working on the development of cutting tool geometry and materials in manufacturing systems [2]. Selecting the ideal cutting tool during chip removal is an important condition for maximum productivity. Although a suitable cutting tool is selected, if the cutting parameters are not suitable, productivity decreases [3]. In order to obtain good efficiency in the machining process, it is possible to know the properties of the part to be machined and to select the machining parameters properly. Machinability provides the ease of machining the material with the ideal cutter and the correct cutting conditions. The most important step in machinability is the cutting force [4]. The basis of the chip removal process is plastic deformation, which leads to high strain rates and temperature generation during forming [5]. Plastic deformation in the cutting plane affects the cutting forces and the power consumed, as well as the chip geometry [6].

There is a relationship between the power spent during the chip removal process and the applied cutting forces. Because large forces are required to separate the chip from part [7]. These forces are one of the factors affecting machine costs. At the same time, cutting forces have a significant effect on heat generation, cutting tool life, part surface quality and geometric dimensions of the workpiece. Cutting forces vary depending on parameters such as rigidity of the machine, cutting parameters, tool geometry,

***Corresponding Author:** Yusuf Çağlar KAĞITÇI, yckagitci@ktun.edu.tr

workpiece material [8]. The fact that there are so many variables affecting the cutting forces has led scientific researchers to study the force generation [9, 82, 131].

One of the most important applications of cutting mechanics is in the health sector. These applications are generally performed in orthopedics and dental fields. Cutting and drilling operations on bone are the most important surgical applications that can affect the health and healing process of patients after surgery [117]. Today, cutting and drilling of bone in orthopedic operations are performed with surgical cutting systems [117, 118, 120, 132]. During cutting, heat may be generated due to friction between the surgical saw blade/piercing tip [51, 118, 119, 135, 136,137] and the bone. This heat generated in the bone is known to adversely affect the healing process after the operation. The side effects of the heat generated in the bone during cutting or drilling can lead to deterioration of bone tissue [10], infection of the bone, decrease in the mechanical strength of the bone [11] and delayed postoperative healing times [12]. The heat generation on the bone can vary according to the speed of the cutting tool and the force applied by the user. At the same time, this heat has detrimental effects on existing bone tissue [12, 13, 14, 15]. When bone is heated to 50°C, irreversible changes in the mechanical properties of bone can be observed [16]. In addition, mechanical deformation with a cutting tool can cause microcracks that can lead to osteocyte apoptosis (cell death) [17].

Another application that can be performed on bone is drilling [121, 122, 123, 124, 125, 127, 134]. Drilling in bone has important surgical applications, especially in the placement of screws during the repair of fractures in orthopedic fields [126, 128, 129, 130]. One of the biggest problems encountered during drilling is heat generation. The amount of drilling depth, drilling geometry, cutting tool used, variations in cortical thickness, drilling speed, pressure applied to drilling and bone density affect the temperature rise [18].

2. MATERIAL AND METHODS

2.1. Anatomy of Bone

Bone is a tissue that protects and supports vital organs in the human body, and at the same time, it is rich in calcium and can regenerate itself and is home to bone marrow. It has different sizes shaped to provide the basic functions of the body [19]. After teeth, bones are the hardest structures in the body and are, above all, important building blocks of the skeletal system [20]. They form the main part of the skeleton of most vertebrates [21]. Besides their mechanical role, bones are the site of production of a wide variety of indispensable cells for the organism. Bone is the mineral reservoir of the organism and plays an active role in the regulation of calcium levels in the blood [22].

In terms of bone structure, there are periosteum, cortical bone (compact bone), cancellous bone (spongy or trabecular bone), endosteum, bone marrow, blood vessels and nerve [23, 24, 25, 26]. Although the layers of cortical bone and trabecular bone differ greatly in their microstructure, function and location, they are both composed of the same basic mineral and organic materials [27]. Spongy bone, protected by a layer of cortical or compact bone, is composed of lamellae (honeycomb-like tissue membranes) known as trabecular [24]. Trabecular bone is composed of various bone cells (osteocytes, osteoblasts and osteoclasts) [28]. Bone marrow produces red blood cells and is located within the trabecular bone.

In the macro dimension of bone, 33% of bone tissue is composed of organic and 67% of inorganic substances. Inorganic substances include calcium phosphate, calcium carbonate, magnesium phosphate, calcium fluoride and alkali salts [29, 30, 31, 32]. Microscopically, bone is composed of support cells expressed as osteoblasts and osteocytes and osteoclast cells responsible for bone remodeling [33]. There are two different forms of bone tissue: cortical and cancellous (porous, spongy). Cortical bone is a firm, hard tissue with very few gaps and forms the outermost part of the bone. Cortical bone, which provides support for movement and is the strongest bone tissue, constitutes 80% of the skeletal system [31]. Cancellous bone (spongy or trabecular bone) is a bone tissue that comprises 20% of the skeletal weight, forms the inner cavity of the bone with its resemblance to a lattice structure, and is more porous and lighter than compact bone [34].

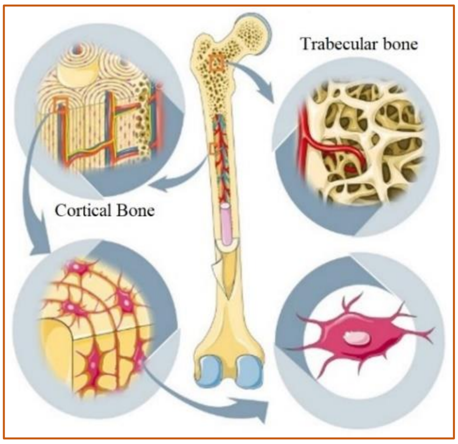

Figure 1. Anatomy of the bone (Created from smart servier medical art [116]

Cortical bone consists of osteons and haversian system. The osteon, which forms the basic structure of the bone, is a structure consisting of concentric circular lamellae that surrounds the blood vessels and the havers canal [24, 32]. Havers canals are centric canals extending longitudinally on the bone. These canals are surrounded by concentric circular lamellae [32]. The space on the lamellae, called lacunae, creates a larger surface area for osteocytes to settle [31, 35]. Lacunae are spaces between the lamellae, connected by a network of canals 0.2 μm in diameter, which house osteocyte cells and are called canaliculi [36]. Inside the bone there are branched thin canaliculi called canaliculi.

Osteocytes connect with each other through these canaliculi. The intercellular fluid of osteocytes is contained in the lacunae and canaliculi. This fluid, which spreads from the blood vessels into the canaliculi, ensures the survival of osteocytes [37, 38, 39]. The vessels running perpendicular to the length of the bone are located in the spaces called Wolkman canals. Havers canals are connected to each other by Wolkman canals. There are nerve and blood vessels within the Havers canals. As bone development increases, the osteon havers system develops. The membrane that surrounds the compact bone from the outside is the periosteum. The membrane surrounding the inner side of the canal is the endosteum [40]. Figure 2 shows the micro-sized structure of bone.

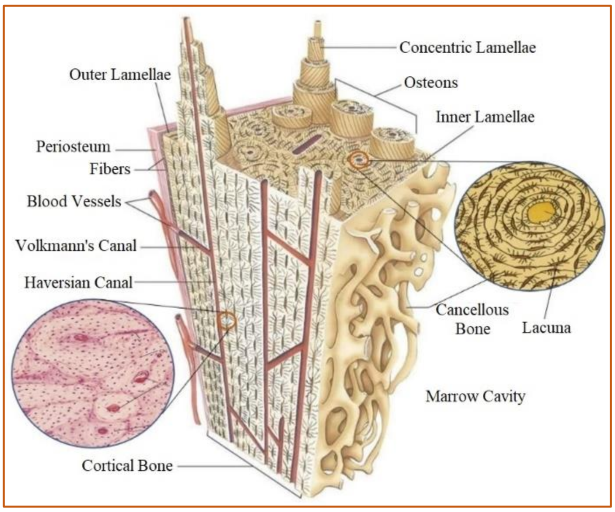

Figure 2. Microscopic structure of bone (Modified from Lesliee P. Gartner [40, 106])

2.2. Bone Operations

In bone operations, different technologies and cutting tools may be preferred in case of bone removal in different parts of the body. In such surgical operations, situations such as wrapping of soft tissues, nerves and blood vessels should be taken into consideration in the careful removal of bones. Studies are being carried out in this field [137,138].

Significant results have been gained from academic studies conducted in various areas and applications pertaining to cutting force, which is a crucial component influencing heat generated and other bone damages.

Many researchers have published experimental and theoretical research on bone machining over the years. In bone cutting, there is a small amount of work on tool design and a large number of studies on bone drilling operations focused on operational drilling parameters. Despite the importance of operational operations on bone and the growing interest in this topic, there has been no compilation or update of relevant studies that include both bone cutting operations and bone milling operations. A study that includes bone milling operations will contribute to bone machining and will guide research that will provide new ideas. The aims and objectives of this study can be summarized as follows:

- To review the studies on the cutting operational processes on bone.
- To examine the effects of cutting forces on bone machining operations, measurement of cutting forces and related research in terms of cutting tools.
- To observe the thermomechanical damage that occurs in the operational processes on bone and the studies carried out for their solution.

3. RESULTS AND DISCUSSION

3.1. Orthogonal Bone Cutting and Force

In orthopedic surgeries, bone cutting is performed for screw placement or plate fixation in cases where the bone is broken. With orthogonal cutting of bone, cutting properties such as forces, chip formation and surface quality can be easily analyzed according to cutting conditions. Orthopedic surgery requires bone processing. Success in this process depends on surface integrity, precision during the operation and the extent of damage to the bone [41]. The high level of cutting forces applied during cutting will cause micro-sized cracks and fractures in the surrounding bone tissues [42, 43]. It will also cause thermal necrosis on the bone with increased friction and temperatures [44].

Considering all machining operations, orthogonal machining is three-dimensional due to the geometry of the cutting tool and its position relative to the part with which it interacts, both in industrial applications and in surgical applications in healthcare [45, 46, 47]. In the study of cutting mechanics, cutting forces are important in terms of material properties, chip morphology and surface integrity [48]. Therefore, the cutting forces in orthogonal machining are extremely important and need to be emphasized. Figure 3 shows the orthogonal cutting process and cutting forces.

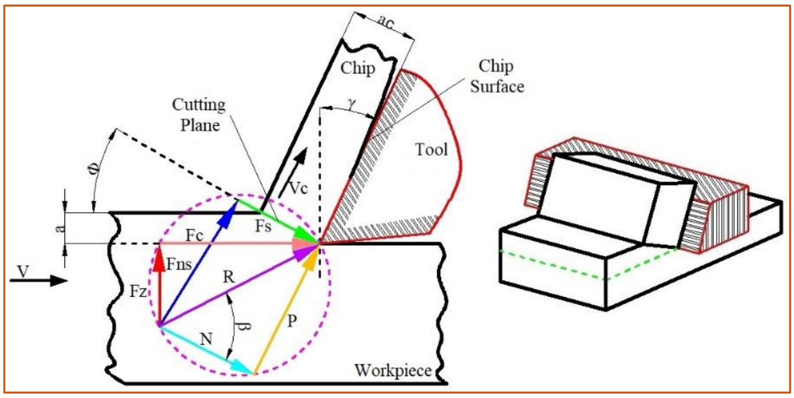

Figure 3. Representation of cutting forces in orthogonal cutting (Modified from Stephenson et al, [49])

In the cutting process, the workpiece approaching the cutting edge of the tool at the cutting speed (v) is compressed on the chip surface of the tool, causing deformation (shape change) with plastic shear along the shear plane. Under favorable conditions, a continuous and stable amount of deformation occurs along the slip plane, and the deformed material (chip) slides down the rake face of the tool at a uniform speed (chip velocity-Vc) in the form of a continuous chip. The chip thickness a before deformation increases to chip thickness ac during deformation. In this movement, sliding occurs along some specific plane under the influence of the chip angle (γ), the position of the sliding is given by the sliding angle (Φ). As long as h and γ are known, ac can be measured for a chip cut under stable conditions. Since vertical cutting behaves as a two-dimensional problem rather than a three-dimensional problem, it is a widely used method in experimental and theoretical studies to derive the equations governing the mechanics of cutting [133].

The first studies on orthogonal bone cutting were carried out by Jacobs et al. in a microscopic image-supported investigation of different sized chip types, where the cutting force increased linearly with the feed rate and varied with the angle of inclination [50]. Wang et al. cut bone at small depths of cut under different cutting conditions with an oscillating saw blade using a perpendicular cutting pattern and observed serrated chip formation structures using SEM [51]. Different cutting technologies can be applied or developed to minimize the damage that may occur in processes related to bone cutting. To better understand the bone cutting mechanism, Bai et al. investigated the chip mechanism in orthogonal cutting of cortical bone and analyzed the force signals for different cutting directions [52]. Qasemi et al. investigated both numerically and experimentally the shear force and temperature changes by milling cortical bone in different directions and observed that the errors in temperature and shear force prediction were low. Thus, they concluded that there is a good agreement between numerical and experimental results [53]. For orthogonal cutting of bone, numerical analysis is performed using finite element analysis structure [54, 55, 56, 57]. When the studies are supported by experimental studies, they show striking results. Creating the conditions of the experimental environment requires an additional cost, and at the same time, situations such as the creation of precautions and conditions that need to be taken in the experimental environment may occur. Finite element analysis can be important in terms of helping experimental studies in this situation.

The studies will allow the effects of different parameters to be examined in terms of both cutting force and chip morphology as a result of orthogonal cutting of the bone. Therefore, it will support the importance of the relationship between the effective parameters and the microstructure of the cortical bone. Thus, it will provide important information on the intervention of machining parameters on cutting damage on bone tissue and optimization of cutting operations. It will be a reference for the design of tools used for surgical purposes depending on the parameters.

3.2. Bone Milling Processes

In milling operations, cutting occurs when the cutting tool of different geometry rotates around its own axis and the workpiece moves linearly. The cutting tools used in the operational process have more than one cutting edge. In addition, each blade has a certain and equal chip removal capacity. In addition to its high processing efficiency, milling has high elasticity in operations such as plane surface, step and channel milling with a good degree of surface completeness and precision. With the changes in cutting tool and control technology, milling has been preferred as the machining method. Thus, the operations to be performed can be carried out with different easily designed, computer-aided, multi-axis machines and cutting tools [58].

When bone is broken or damaged due to diseases in orthopedic surgery, it is subjected to cutting, drilling and milling for different operations. A complete understanding of bone cutting mechanics is required due to accident situations, diseases due to increased human aging, and the demand for optimized bone cutting methods. In orthopedics, cutting is done either with a tool with a rotary motion (drilling, milling) or with a linear motion (planar cutting with a chisel). Mechanical operations such as drilling, milling, sawing and chiseling performed on bone are similar to applications performed on other materials [59]. Among mechanical operations on bone, the most typical surgical bone processing operations commonly performed in orthopedic surgery are drilling and milling [60, 61, 62]. Bone milling is a common procedure in orthopedics, total knee replacement (TKR), cranial and spinal surgery, and is used for bone resection [60]. Since the mechanical milling cutter is the most commonly used tool in orthopedic surgical procedures, more emphasis is placed on the milling process. Some studies on bone milling are given in Table 1.

Table 1. Studies on bone milling.

Ref.	Authors	Sample Preparation	Manufacturing	Force Measurement Method	Experiment Number
[63]	Rabiee et al. (2023)	Fresh	CNC Milling Machine	Piezoelectric Dynamometer	54
[64]	Tahmasbi et al. (2022)	Fresh	CNC Milling Machine	Piezoelectric Dynamometer	54
[53]	Qasemi et al. (2022)	Frozen	CNC Milling Machine	Piezoelectric Dynamometer	9
[65]	Zheng et al. (2022)	Frozen	CNC Milling Machine	Piezoelectric Dynamometer	16
[66]	Ying et al. (2022)	Fresh	CNC Milling Machine	Piezoelectric Dynamometer	
[67]	Qi-sen et al. (2020)	Frozen	Milling Machine	-	16
[68]	Liao et al. (2019)	Frozen	CNC Milling Machine	Piezoelectric Dynamometer	21
[69]	Sui et al. (2013)	Frozen	Milling Machine	Dynamometer	-
[70]	Sugita et al. (2009)	Frozen	Milling Machine	Dynamometer	-
[71]	Itoh et al. (1983)	Frozen	Milling Machine	Piezoelectric Dynamometer	-
[72]	Wiggins et al. (1978)	Frozen	Milling Machine	Dynamometer	-
[50]	Jacobs et al. (1974)	Frozen	Milling Machine	Two Component Dynamometer	-

3.3. Cutting Parameters and Effects in Milling

In milling operations, solution-oriented approaches are essential for measuring cutting force. Obtaining the workpiece at the desired tolerance values through the milling process is a gradual process that includes functions such as the speed to be given to the spindle, cutting tool diameter, number of teeth and angle values. Cutting force can be related to cutting tool geometry and chip thickness. The purpose here is to determine the force applied to the cutting tool in order to eliminate the resistances that occur during machining during the milling process. Thus, an ideally created, machinable cutting environment is provided. The milling process can be considered a precision solution compared to other operational processes. Thus, it leads to innovative developments in machining processes with applications in fields such as biomedical, automotive, electronics and aerospace industries. Its use in dental and orthopedic fields through milling has added a different dimension to machining. There are studies showing that the changes in robotic surgery in recent years provide more decisive results than traditional surgery with small touches [73, 74, 75, 76]. It is important that milling has variable factor factors. Maximizing the performance of the process depending on the processing performed requires taking these variable factors into consideration. These factors are the dominant cutting parameters underlying the cutting process. Cutting parameters can be considered multidimensionally considering the material to be processed. These are the determinants that can affect machining, such as the cutting tool and its geometry, speed, feed and depth of cut.

Considering the layers that make up the structure of bone in the material category to be processed in milling, efficiency in milling should be increased with different cutting strategies. This reduces the burden on the patient. The high degree of hardness of the bone may cause it to have a tendency to break against the forces acting on it. In addition, the increase in heat generated by the cutting force applied to the bone during processing will cause an increase in the temperature in the processing area. This situation, caused by large cutting force, will expose you to structural problems such as tissue, bone and even tool damage. It is of great importance to optimize the machining parameters for different cutting situations and at the same time to monitor these cutting situations. Ying et al. [66] chose an artificial neural network-based method to detect the cutting force and condition using audio signals during the bone milling process. They concluded that the data obtained with the force model they created to determine the cutting force was compatible with the experimental results, and the state and depth error estimates were 3.6% and 7-13%. Denis et al. [77] analyzed the effects of bone milling parameters (feed speed and spindle speed) on temperature, milling forces and surface smoothness. They stated that increasing the feed rate and decreasing the speed would limit the temperature increase. They concluded that milling forces increased with increasing feed rate, and surface smoothness varied between 0.15 and 0.29 mm, which was sufficient for bone growth.

Feldmann and colleagues [78] conducted research on orthogonal cutting of cortical bone. In his studies, cutting forces, bone chip formation and temperature increase were measured at two different rake angles (10° - 40°) and different cutting depths. He found that there was a linear correlation between cutting forces and bone chip and workpiece temperature increase. It was also concluded that the high rake angle in the tools and the increase in cutting depths significantly reduced the cutting forces and temperature increase. Wiggins and Malkin [72] conducted a study on the mechanics of orthogonal processing of bone. He conducted experiments on machine forces and energies for three different cutting directions, rake angles, and depths of cut. It was observed that the energy consumed due to cutting increased linearly with the chip surface area. In addition, he concluded that the greatest force and energy were made transversely to the osteon direction, and the smallest force and energy were made along (parallel) the osteon direction. Rabiee et al [63] performed micro milling of fresh cortical bone. The changes of cutting depth, tool rotation speed, feed rate, tool diameter parameters on cutting force and temperature were investigated experimentally and statistically. They found that cutting parameters related to micro milling affect the force value by 46%, feed rate by 46%, rotation speed by 34%, depth of cut by 15%, tool diameter by 4%, and cutting direction by 1%. They concluded that the cutting parameters affected the temperature value by 80.3% of the tool diameter, 9.2% of the rotation speed, 8.9% of the feed rate, and 1.5% of the depth of cut. In their study, Tahmasbi et al. [64] found that the cutting parameters in milling affected the force value by 51.4% of the cutting depth, 22.9% of the feed rate, 19% of the rotation speed, 4.8% of the cutting direction, and 1.9% of the tool diameter. The studies carried out according to the technical specifications of the cutting tools used in processing bone are listed in Table 2. Studies on cutting parameters used in bone processing are listed in Table 3.

Table 2. Studies on cutting tool technical specifications in bone processing.

Ref.	Authors	Bone Type	Rake Angle (°)	Clearance Angle (°)
[63]	Rabiee et al. (2023)	Bovine Shank	14	
[53]	Qasemi et al. (2022)	Bovine Femur	7	10
[65]	Zheng et al. (2022)	Porcine Femur	16.7	15
[52]	Bai et al. (2020)	Human Femur	10	5
[67]	Qi-sen et al. (2020)	Bovine Femur	10	
[68]	Liao et al. (2019)	Bovine Femur	10	10
[79]	Liao et al. (2016)	Bovine Femur	8	8
[70]	Sugita et al. (2009)	Porcine Femur	14	
[80]	Yeager et al. (2008)	Bovine Femur	(-30, -20, -10, 0, 10, 20, 30)	11
[81]	Plaskos et al. (2003)	Bovine Femur	0, 20, 40	10
[77]	Denis et al. (2001)	Human Tibia	20	25
[82]	Krause, (1987)	Bovine Femur	(-30, -15, -20, -10, -5, 0)	10
[72]	Wiggins et al. (1978)	Bovine Tibia, Human Tibia	-30, 40	10

Table 3. Studies on cutting parameters in bone processing.

Dates	Authors	Bone Type	Rotational Speed (Rpm)	Feed Rate (mm/min)	Depth of cut (mm)
[63]	Rabiee et al. (2023)	Bovine Shank	1000-2000-3000	10-30-50	0.4 - 0.6 - 0.8
[64]	Tahmasbi et al. (2022)	Bovine Femur	1000-2000-3000	100-200-300	1-2-3
[53]	Qasemi et al. (2022)	Bovine Femur	1000-2000-3000	300-400-500	1
[65]	Zheng et al. (2022)	Porcine Femur	1000-1500-2000-2500	24-36-48-60	4
[66]	Ying et al. (2022)	Porcine Femur	1000-3000-5000	90-120-150	0.5 - 1
[76]	Tian et al. (2021)	Porcine Femur	1000-2000-3000	30-75-120	0.1 - 0.3 - 0.5
[105]	Qasemi et al. (2020)	Bovine Femur	1000-2000-3000	10-30-50	10
[67]	Chen et al. (2020)	Bovine Femur	9000 -12 000 -15 000	180 - 240 - 300	0.5 - 1
[83]	Thounaojam et al. (2020)	Bovine Femur	800 - 850 - 900 - 950	250 - 300 - 350 - 400	0.1 - 0.15 - 0.2 - 0.25
[84]	Wu et al. (2015)	Porcine Femur	3000-3500-4000-4500-5000-5500	30 - 60 - 90 - 120	0.3 - 0.5 - 0.8 - 1 - 1.2 - 1.5
[85]	Mitsuishi et al. (2004)	Human Femur Porcine Femur	8000	300	3

It has been observed that the forces acting on the tissue attached to the bone decrease as the rotation speed of the cutting tool increases. It has been observed that the increase in feed rate, tool diameter and depth of cut causes an increase in cutting force [53, 63, 64]. In studies, it has been observed that the temperature increase in bone milling increases with the increase in rotation speed, depth of cut and feed rate [53, 63]. With the increase in tool diameter, the contact of the large surface of the tool with air during cutting will facilitate cooling. In addition, thanks to the dominant state of milling power, the removal of chips from the cutting environment is a positive advantage. The result of these two situations will be effective in temperature changes [63]. Studies on technical data of cutting tools used in bone processing are listed in Table 4.

Table 4. Studies on cutting tool parameters in bone processing.

Ref.	Authors	Bone Type	Materials	Tool Diameter (mm)	Flute Number	Helix Angle (°)
[63]	Rabiee et al. (2023)	Bovine Shank	-	0,6 - 0,8 - 1	-	30
[64]	Tahmasbi et al. (2022)	Bovine Femur	High Speed Steel (HSS)	4 - 6 - 8	-	
[53]	Qasemi et al. (2022)	Bovine Femur	High Speed Steel (HSS)	4	4	30
[65]	Zheng et al. (2022)	Porcine Femur	Cemented Carbide	3	4	55
[66]	Ying et al. (2022)	Porcine Femur	-	5	12	30
[67]	Qi-sen et al. (2020)	Bovine Femur	Cemented Carbide	2 - 4	2	35
[105]	Qasemi et al. (2020)	Bovine Femur	High Speed Steel (HSS)	2 - 3.5 - 5	4	-
[68]	Liao et al. (2019)	Bovine Femur	Solid Carbide	4	2	30
[70]	Sugita et al. (2009)	Porcine Femur	High Speed Steel (HSS)	10	2	30
[85]	Mitsuishi et al. (2004)	Human Femur Porcine Femur	-	10	2	30
[77]	Denis et al. (2001)	Human Tibia	Hard metals	10	2	20

3.4. Effects of Temperature in the Machining Operation

Bone milling, drilling, etc. Procedures are generally performed in surgical procedures or medical practices such as orthopedics and dentistry. There is a risk of necrosis (death or damage to bone tissue) during bone milling, drilling, cutting, but this risk may vary depending on various factors. Temperature may be one of these factors. Temperature may have indirect effects on bone tissue. For example, surgical instruments that use high temperatures can cause thermal effects on bone tissue, which can lead to damage to bone tissue. Therefore, during surgical procedures, it must be ensured that the instruments are at the appropriate temperature and are controlled. More surgical skill, the cutting force effect of the procedures and the appropriate use of tools, and a careful approach during surgery are important to preserve the health of bone tissue. For this reason, operational procedures on bone should be performed by an expert healthcare professional and necessary medical precautions should be taken.

In operations such as milling and drilling, overheating occurs at the interface of the cutting tool and bone due to the contact surface due to friction. Depending on the result of this process, when the temperature on the bone exceeds the required threshold value, it causes irreversible damage to the bone tissues. With this damage, blood cells that nourish the bone are damaged and necrosis (bone death) occurs.

Measurement of the thermal properties of bone is important for calculating the temperature rise in bone during a cutting process using analytical and numerical modelling. The heat capacity and thermal conductivity of bone are important factors affecting the temperature rise during the cutting process. The extent of necrosis depends on the temperature increase and its duration. In literature, age, bone type, etc. are used for bone tissue. Depending on the conditions, thermal conductivity values vary between 0.2 W/mK and 13 W/mK [86, 54]. In his study, Davidson found the thermal conductivity of fresh bovine cortical bone to be 0.53 W/mK - 0.58 W/mK and concluded that bovine cortical bone can be considered thermally isotropic [87].

When the temperature on the bone rises above 47°C for one minute, the process of thermal tissue necrosis begins [88]. Here, the necrosis process depends on the thermal properties of the tissue and the duration of exposure to temperature [89, 90, 91]. Nerves exhibit high sensitivity to temperature changes [92]. It has been observed that thermal damage may occur in nerve tissues close to the punctured bone [93]. It states that the critical temperature for thermal damage to occur is approximately 43°C. Below this temperature, no damage occurs no matter how long the tissue is exposed to the source [94, 95, 96, 91]. Numerical and experimental results have shown that necrosis extends to approximately 0.1 mm below the surface [70]. It has been shown in the literature that increasing the temperature above 50°C causes the death of osteocytes, and by increasing the temperature above 70°C, degeneration of proteins and enzymes as well as biochemical damage may occur in the cells [82, 97]. Studies have been carried out in the literature on the effects of necrosis on cutting tool properties, cutting parameters, and changes depending on bone types in operational operations such as bone drilling, cutting, etc., and are still being carried out.

3.5. Effects of Bone Specimen Preparation and Processing Direction

Considering the studies on bone, it has been observed that cortical and spongy bone structures were examined. It has been observed that human bone [98, 99], animal bone [100, 101] and composite blocks [102, 62] were used as bone structure. Among animal bones, cattle and pig bones are preferred. Studies show that there are similarities between human bones and animal bones in terms of mechanical and physical properties [103, 104, 64]. The mechanical properties between human bone and bovine bone are shown in Table 5. The bone types used in the studies are listed in Table 6.

Table 5. Comparison of human bone and bovine bone properties [53, 64, 100, 104].

Bone Characteristic	Bone Type	
	Human	**Bovine**
Tensile strength (MPa)	130-200	140-250
Compressive strength (MPa)	40-145	45-150
Young's modulus	10-17	10-22
Density (Kg/m3)	1800-2000	1950-2100
Poisson’s ratio	0.4	0.33
Shear Modulus	3	3

Some processes are carried out to make bone samples ready for use before experiments. In these processes, the bone sample can be prepared before the experiment or preserved (freezing) in a different environment until the time of the experiment. The freezing process allows bones to be stored without causing any change in mechanical properties [107]. Multiple studies have examined the effects of freezing on the mechanical properties of bone. The intention is, in part, for freezing to be a preferred preservation method for bone [36]. In the studies conducted, the bone was examined by subjecting it to the freezing process or by processing it without freezing. While there was evidence that there may be differences in limited publications, it was observed that there was no difference in many studies. Therefore, researchers should consider freezing as a suitable preservation technique [108, 109]. In their studies, they stored rat femur samples at -20 °C, -70 °C, -196 °C and tested them later. Freezing at -20 °C and -70 °C did not change the torsional strength or stiffness properties of the femurs. They concluded that there was no statistically significant difference in the strength parameters (torque and energy) of the samples tested fresh or after being stored at -20 °C, -70 °C, -196 °C. Goh et al [110] state that there is no significant change in the bending and torsional properties of cat humeri (forelegs) and femurs when stored at -20 °C for 21 days. In their study, Salai et al. [111] found no change in the biomechanical properties of bone in tests performed after 5 years of storage at -80 °C. In their study, Linde and Sorensen [112] examined the effects on pressure behavior of human bone samples by applying multiple freeze-thaw cycles (freezing, freeze- dissolution). As a result, they found that the mechanical behavior of samples frozen for 1, 10 and 100 days was not significantly different from the behavior measured 24 hours after death, and the mechanical properties were not affected by multiple freeze-dissolution cycles.

Van Haaren et al. [113] in their study revealed that deep freezing at -20°C had no effect on the biomechanical properties of goat bone over a 12-month storage period. They concluded that the bones used in the studies can be preserved for up to 1 year without any negative effects by freezing. Borchers et al. [114] examined the mechanical effects of freezing bovine bones at -20 °C and -70 °C. He performed tests on 24 samples in total. It was concluded that the elastic modulus and strength were not significantly affected by the freezing process when the samples examined in the study were compared to fresh ones. Hamer et al. [115] found that freezing human femur bone to −70 °C did not change the mechanical properties measured in a non-conventional bending test. A review of literature studies indicates that freezing is unlikely to significantly alter the mechanical properties of cortical or trabecular bone.

Due to the semi-brittle structure and anisotropic behavior of the bone, the difference it shows during cutting may occur due to the position of the osteon fibers that form the bone structure. Osteons within the bone structure are distributed along the axis of the cortical bone. Cutting direction can be evaluated to investigate the effect of cutting direction with respect to bone osteon orientation. During the bone milling process, the relative position between the cutting plane and the osteon fibers can be among the main factors affecting machine mechanics. In operational procedures performed on bone, it may show a distinct feature in cutting directions at different depth values. In their studies, many scientific researchers examined the bone by cutting it in three different situations, taking into account variable cutting parameters. These are the osteonal perpendicular direction (transverse), the osteonal parallel direction (Parallel), and the cutting edge direction parallel to the osteon direction (across). The examinations reveal that the change in direction due to bone processing has significant effects on cutting force, temperature and chip morphology, depending on the cutting parameters. Studies on this subject are shown in Table 6.

Table 6. Studies on bone types and bone processing

Ref.	Authors	Bone Type	Cutting direction		
			Parallel	Across	Transverse
[72]	Wiggins et al. (1978)	Bovine Tibia, Human Tibia	✓		
[82]	Krause, (1987)	Bovine Femur		✓	✓
[77]	Denis et al. (2001)	Human Tibia	✓		✓
[81]	Plaskos et al. (2003)	Bovine Femur	✓	✓	✓
[80]	Yeager et al. (2008)	Bovine Femur	✓	✓	✓
[70]	Sugita et al. (2009)	Porcine Femur		✓	
[69]	Sui et al. (2013)	Bovine Femur	✓	✓	✓
[79]	Liao et al. (2016)	Bovine Femur	✓	✓	✓
[68]	Liao et al. (2019)	Bovine Femur	✓		✓
[52]	Bai et al. (2020)	Human Femur	✓	✓	✓
[53]	Qasemi et al. (2022)	Bovine Femur	✓	✓	
[64]	Tahmasbi et al. (2022)	Bovine Femur	✓	✓	

3.6. Analysis Studies on Bone Milling

In line with the examination of the studies on bone milling, it has been observed that different types of analysis are applied and these are mathematical modeling, experimental study, finite element analysis. The applicability of the methods varies in terms of repeatability of the processes, ease of simulation, low application cost and comparison with different materials. It is critical to predict cutting forces and mechanical damage during machining processes. It is critical to create tools that can accurately simulate the change in forces and temperature rise during bone processing [48]. Modeling these processes is very difficult and requires effort. This shows its importance in terms of the accuracy of the process. Considering the integrity of the process, an accurate modeling will contribute to the understanding of the cutting process on the bone and the selection of process parameters. It also facilitates the analysis process with a validated and efficient dominant model. Variables related to the cutting process, bone structure, factors in the cutting operation will determine the choice in the analysis. In some studies, it has been observed that isotropic and anisotropic structures that can help in modeling bone tissue have been examined [56]. Studies on this subject are shown in Table 7.

Table 7. Experimental procedure for bone milling.

Ref.	Authors	Experiment	Modelling	Analysis	Optimization
[50]	Jacobs et al. (1974)	✓		✓	
[53]	Qasemi et al. (2022)	✓		✓	
[63]	Rabiee et al. (2023)	✓	✓	✓	✓
[64]	Tahmasbi et al. (2022)	✓	✓	✓	✓
[65]	Zheng et al. (2022)	✓	✓	✓	✓
[66]	Ying et al. (2022)	✓	✓	✓	
[67]	Qi-sen et al. (2020)	✓	✓	✓	
[68]	Liao et al. (2019)	✓	✓	✓	
[69]	Sui et al. (2013)	✓	✓	✓	
[70]	Sugita et al. (2009)	✓		✓	
[71]	Itoh et al. (1983)	✓			

4. CONCLUSIONS

Bone structure, which is of vital importance in the human body, may be exposed to problems due to use (disease) or some environmental negativities (accidents, etc.) throughout life. In the fields of orthopedic surgery and dentistry, treatment methods can be applied with different operations by cutting the bone such as sawing, drilling, milling and grinding methods. The industrial production of cutters used in this type of operational processes contributes greatly to medical applications. Known concepts such as integrity and machinability in the machining process will provide ease of application in medical fields. Reducing the cutting time on the bone will shorten the surgical time. Thus, it can be associated with the integrity of bone tissue and minimization of processing-related damage, including necrosis.

By using the data obtained from the studies, it will reduce the damage to the bone tissue and will also help in determining the geometries of the surgical instruments that can be designed. It will also contribute to the improvement of process parameters with the applications to be made.

Although the choice of different tool geometries and cutting parameters in literature reviews has hindered the evaluation of results related to bone processing, new studies will shed positive light on the selection and application of effective values.

An accurate modeling of bone processing will contribute to a better understanding of bone machinability and analysis of the bone cutting process. The verification process performed with the created model is important in determining the values to be determined. Cutting and temperature-related complexities can be resolved by mathematical modeling or finite element analysis. The important issues here are defining the appropriate geometry and boundary conditions, correctly specifying the mechanical and physical properties of the bone structure, and also modeling the bone structure, which are difficulties that may be encountered. Accurate modeling of the mechanical behavior of bone is important in achieving simulation results. Studies on isotropic and anisotropic structures will be a reference in examining bone structure.

The hard (cortical) and soft (trabecular) layers that make up the bone tissue, which exhibits an anisotropic structure, constitute an important place in the human body. It is of great importance in research because the biggest task at the foundation of the body is in the long bones. When we look at the studies, cortical bone, which may have tissue damage, takes priority in many cutting operations. Cortical bone is the priority layer in surgical operation. Due to its structure, it is a layer that needs to be focused on during bone procedures.

To eliminate the damage that may occur in the surrounding tissues with the cutting process, it is the correct and proper penetration of the cutter to be applied surgically. This can be achieved by controlling the cutting force and evaluating the effectiveness of the cutting tool and cutting parameters.

As a result, when we look at the studies on bone tissue, there are deficiencies in both modeling and application. Bone type and structural differences, as well as changes in cutting conditions, affect the test results. These differences are contradictory in some studies. This may create difficulties in comparing some result values. This situation can be resolved with new studies. It should be supported by new studies on the fracture mechanics that occur during bone milling and on bone chip morphology. It will meet the need in this field with new studies on bone milling with different tool geometries, materials and cutting parameters.

Declaration of Ethical Standards

The authors prepared the study in accordance with all ethical guidelines.

Funding / Acknowledgements

This article is Ph.D. Yusuf Caglar Kagitci's thesis. We would like to thank Selçuk University Scientific Research Projects Unit (Project No: 22111001) for their support of this study.

Data Availability

Not applicable

5. REFERENCES

[1] S. Neseli, S. Tasdemir, S. Yaldız, "Prediction of surface roughness on turning with artificial neural network," *Journal of Engineering and Architecture Faculty of Eskisehir Osmangazi University,* vol. 22, no. 3, pp.65-75, 2009, https://dergipark.org.tr/en/pub/ogummf/issue/30159/325473.

[2] B. Bakır, "Effects of geometry carbur end mill on machinability for CNC machines," *Master Thesis, Marmara University Institute of Science and Technology*, İstanbul, 2005.

[3] E. Yılmaz, "Determining the appropriate tool selection by comparing experimental cutting performance of tool holders produced by two different methods from tool steel (AISI 4340)," *Master Thesis, Marmara University Institute of Science and Technology*, İstanbul, pp. 2, 2019.

[4] M. P. Groover, "Principles of modern manufacturing," *J.Wiley & Sons,* 2011.

[5] A. Kurt, S. Sürücüler, A. Kirik, "Developing a mathematical model for the cutting forces prediction," *Journal of Polytechnic,* vol. 13, no. 1, pp. 15-20, 2010, https://dergipark.org.tr/en/pub/politeknik/issue/33052/367852.

[6] B. Yılmaz, "Design of the dynamic chip breaker with pneumatic driven and investigation of the effects on machining parameters," *Master Thesis, Gazi University Institute of Science and Technology,* Ankara, pp. 10-50, 2016.

[7] M. C. Çakır, "Modern machining methods," *Dora Yayıncılık*, 2010.

[8] İ. Çiftçi, H. Gökçe, "Optimization of cutting tool and cutting parameters in machining of molybdenum alloys through the Taguchi Method," *Journal of the Faculty of Engineering and Architecture of Gazi University,* vol. 34, no. 1, pp. 201-213, 2019, Doi:10.17341/gazimmfd.416482.

[9] M. Aydın, U. Köklü, "A study of ball-end milling forces by finite element model with Lagrangian boundary of orthogonal cutting operation," *Journal of the Faculty of Engineering and Architecture of Gazi University,* vol. 33, no. 2, pp. 517-527, 2018, https://doi.org/10.17341/gazimmfd.416360.

[10] A. R. Eriksson, T. Albrektsson, "The effect of heat on bone regeneration: an experimental study in the rabbit using the bone growth chamber," *Journal of Oral and Maxillofaccial Surgery,* vol. 42, no. 11, pp. 705-711, 1984, https://doi.org/10.1016/0278-2391(84)90417-8.

[11] J. Christie, "Surgical heat injury of bone," *Injury,* vol. 13, no. 3, pp. 188-190, 1981, https://doi.org/10.1016/0020-1383(81)90236-9.

[12] F. G. Pallan, "Histological changes in bone after insertion of skeletal fixation pins," *Journal of Oral Surgery, Anesthesia, And Hospital Dental Service*, vol. 18, pp. 400-408, 1960, PMID: 14429940.

[13] H. C. Thompson, "Effect of drilling into bone," *Journal of Oral Surgery, Anesthesia, And Hospital Dental Service*, vol. 16, no. 1, pp. 22-30, 1958, PMID: 13492103.
[14] L. S. Matthews, C. Hirsch, "Temperatures measured in human cortical bone when drilling," *The Journal of Bone and Joint Surgery,* vol. 54, no. 2, pp. 297-308, 1972, doi:10.2106/00004623-197254020-00008.
[15] S. T. Larsen, L. Ryd, "Temperature elevation during knee arthroplasty," *Acta Orthopaedica Scandinavica*, vol. 60, no. 4, pp. 439-442, 1989, https://doi.org/10.3109/17453678909149314.
[16] W. Bonfield, C. H. Li, "The temperature dependence of the deformation of bone," *Journal of Biomechanics,* vol. 1, no. 4, pp. 323-329, 1968, https://doi.org/10.1016/0021-9290(68)90026-2.
[17] B. Noble, "Bone microdamage and cell apoptosis," *European Cells and Materials,* vol. 6, pp. 46-56, 2003, doi:10.22203/eCM.v006a05.
[18] H. K. Parsa, "An investigation into the temperature distribution resulting from cutting of compact bone using a reciprocating bone saw," *Master Thesis, Department of Mechanical and Electronic Engineering Institute of Technology, Sligo,* pp. 26-27, 2006.
[19] R. Bielby, E. Jones, D. McGonagle, "The role of mesenchymal stem cells in maintenance and repair of bone," *Injury,* vol. 38, no. 1, pp. 26-32, 2007, https://doi.org/10.1016/j.injury.2007.02.007.
[20] C. Baycu, "Histology-Unit 7, Open Education Faculty Publications, Anadolu University," no. 480, pp. 124-144, Eskisehir, 1995.
[21] T. Udiljak, D. Ciglar, S. Skoric, "Investigation into bone drilling and thermal bone necrosis," *Advances in Production Engineering Management,* vol. 2, no. 3, pp. 103-112, 2007.
[22] U. Kneser, D. J. Schaefer, E. Polykandriotis, R. E. Horch, "Tissue engineering of bone: the reconstructive surgeon's point of view," *Journal of Cellular and Molecular Medicine,* vol. 10, no. 1, pp. 7-19, 2006, https://doi.org/10.1111/j.1582-4934.2006.tb00287.x.
[23] H. Ogura, K. Ohya, "Physiology and pharmacology of hard tissues-effect of chemicals on the formation and the resorption mechanism of tooth and bone," *Nihon yakurigaku zasshi*, vol. 105, no. 5, pp. 305-318, 1995, doi: 10.1254/fpj.105.305.
[24] K. W. S. Ashwell, "Concise body atlas: the compact guide to the human body," *London: Quad Quarto Publishing Group*, 2017.
[25] A. G. Robling, A. B. Castillo, C. H. Turner, "Biomechanical and molecular regulation of bone remodeling," *Annual Review of Biomedical Engineering,* vol. 8, pp. 455-498, 2006, https://doi.org/10.1146/annurev.bioeng.8.061505.095721.
[26] G. J. Tortora, B. Derrickson, "Principles of Anatomy and Physiology," *Hoboken: Wiley,* pp. 1146, 2017.
[27] J. A. Buckwalter, M. J. Glimcher, R. R. Cooper, R. Recker, "Bone biology: Structure, blood supply, cells, matrix, and mineralization," *Journal of bone and joint surgery,* vol. 77, pp. 1256-1275, 1995a, https://doi.org/10.2106/00004623-199508000-00019.
[28] M. F. A. Akhbar, A. W. Sulong, "Surgical drill bit design and thermomechanical damage in bone drilling: A review," *Annals of Biomedical Engineering Society,* vol. 49, pp. 29-56, 2021, https://doi.org/10.1007/s10439-020-02600-2.
[29] İ. V. Odar, "Anatomy Textbook 1," Hacettepe-Taş Kitapçılık Ltd. Şti., pp. 565, Ankara, 1986.
[30] L. Bayliss, D. J. Mahoney, P. Monk, "Normal bone physiology, remodeling and its hormonal regulation," *Surgery,* vol. 30, no. 2, pp. 47-53, 2012.
[31] J. A. Buckwalter, M. J. Glimcher, R. R. Cooper, R. Recker, "Bone biology," *J Bone Joint Surg Am.,* vol. 77, pp. 1256-1275, 2010.
[32] B. Clarke, "Normal bone anatomy and physiology," *Clinical Journal of the American Society of Nephrology,* vol. 3, pp. 131-139, 2008, doi: 10.2215/CJN.04151206.
[33] U. Kini, B. N. Nandeesh, "Physiology of bone formation, remodeling, and metabolism," *Radionuclide and Hybrid Bone Imaging,* pp. 29-57, 2012, doi:10.1007/978-3-642-02400-9_2.
[34] C. E. Metzger, D. B. Burr, M. R. Allen, "Anatomy and structural considerations," *Encyclopedia of Bone Biology,* pp. 218–232, 2020, https://doi.org/10.1016/B978-0-12-801238-3.62234-1.

[35] O. R. William, "Functional anatomy and physiology of domestic animals. Fourth edition," pp. 179-198, 2009.
[36] S. C. Cowin, "Bone mechanics handbook, second edition," *Taylor & Francis*, pp. 8,15, 2001.
[37] J. M. Bassert, T. Colville, "Clinical anatomy and physiology for veterinary technicians," pp. 95-118, 2002.
[38] L. E. Lanyon, "Osteocytes, strain detection, bone modeling and remodeling," *Calcif Tissue Int.* vol. 53, pp. 102-107, 1993, https://doi.org/10.1007/BF01673415.
[39] S. Standring, "Gray's anatomy: The anatomical basis of clinical practice. Forty-first edition," *Elsevier press.* pp. 81-123, 2016.
[40] Leslie P. Gartner, "Color Atlas and Text of Histology Seventh Edition," *Wolters Kluwer*, 2018.
[41] S. Li, A. Zahedi, V. Silberschmidt, "Numerical simulation of bone cutting: hybrid SPH-FE approach. Numerical methods and advanced simulation in biomechanics and biological Processes," *Elsevier*, Amsterdam, Netherlands, pp. 187-201, 2018, https://doi.org/10.1016/B978-0-12-811718-7.00010-1.
[42] M. E. Launey, P. Y. Chen, J. McKittrick, R. O. Ritchie, "Mechanistic aspects of the fracture toughness of elk antler bone," *Acta Biomater.*, vol. 6, no. 4, pp. 1505-1514, 2010, https://doi.org/10.1016/j.actbio.2009.11.026.
[43] V. Ebacher, P. Guy, T. R. Oxland, R. Wang, "Sub-lamellar microcracking and roles of canaliculi in human cortical bone," *Acta Biomaterialia*, vol. 8, no. 3, pp. 1093-1100, 2012, https://doi.org/10.1016/j.actbio.2011.11.013.
[44] J. D. Currey, "Mechanical properties and adaptations of some less familiar bony tissues," *J. Mech. Behav. Biomed. Mater.*, vol. 3, no. 5, pp. 357-372, 2010, https://doi.org/10.1016/j.jmbbm.2010.03.002.
[45] A. Molinari, R. Cheriguene, H. Miguelez, "Contact variables and thermal effects at the tool chip interface in orthogonal cutting," *International Journal of Solids and Structures*, vol. 49, no. 26, pp. 3774-3796, 2012, https://doi.org/10.1016/j.ijsolstr.2012.08.013.
[46] X. Soldani, C. Santiuste, A. Muñoz-Sánchez, H. Miguélez, "Influence of tool geometry and numerical parameters when modeling orthogonal cutting of LFRP composites," *Composites Part A: Applied science and Manufacturing*, vol. 42, no. 9, pp. 1205-1216, 2011, https://doi.org/10.1016/j.compositesa.2011.04.023.
[47] M. E. Merchant, "Basic mechanics of the metal cutting process," J. Appl. Mech., vol. 11 (A), pp. 168-175, 1944, https://doi.org/10.1115/1.4009380.
[48] M. Marco, M. Rodríguez-Millán, C. Santiuste, E. Giner, M. H. Miguélez, "A review on recent advances in numerical modelling of bone cutting," *J. Mech. Behav. Biomed. Mater.*, vol. 44, pp. 179-201, 2015, https://doi.org/10.1016/j.jmbbm.2014.12.006.
[49] D. A. Stephenson, J. S. Agapiou, "Metal cutting theory and practice, third edition," *CRC Press Taylor & Francis Group LLC*, Boca Raton, 2016.
[50] C. H. Jacobs, M. H. Pope, J. T. Berry, F. Hoaglund, "A study of the bone machining process-orthogonal cutting," *Journal of Biomechanics*, vol. 7, no. 2, pp. 131-136, 1974, https://doi.org/10.1016 /0021-9290(74)90051-7.
[51] H. Wang, U. Satake, T. Enomoto, "Serrated chip formation mechanism in orthogonal cutting of cortical bone at small depths of cut," *Journal of Materials Processing Technology*, vol. 319, 118097, 2023, https://doi.org/10.1016/j.jmatprotec.2023.118097.
[52] W. Bai, L. Shu, R. Sun, J. Xu, V. V. Silberschmidt, N. Sugita, "Mechanism of material removal in orthogonal cutting of cortical bone," *Journal of the Mechanical Behavior of Biomedical Materials*, vol. 104, 103618, 2020, https://doi.org/10.1016/j.jmbbm.2020.103618.
[53] M. Qasemi, V. Tahmasbi, M. M. Sheikhi, M. Zolfaghari, "An effect of osteon orientation in end milling operation of cortical bone based on FEM and experiment," *Journal of Manufacturing Processes*, vol. 81, pp. 141-154, 2022, https://doi.org/10.1016/j.jmapro.2022.06.068.
[54] K. Alam, "Experimental and numerical analysis of conventional and ultrasonically assisted cutting of bone," *Doctoral Thesis, Loughborough University*, 2009.

[55] T. H. C. Childs, D. Arola, “Machining of cortical bone: Simulations of chip formation mechanics using metal machining models,” *Mach. Sci. Technol.*, vol. 15, no. 2, pp. 206-230, 2011, https://doi.org /10.1080/10910344.2011.580699.

[56] C. Santiuste, M. Rodríguez-Millán, E. Giner, H. Miguélez, “The influence of anisotropy in numerical modeling of orthogonal cutting of cortical bone,” *Composite Structures,* vol. 116, pp. 423-431, 2014, https://doi.org/10.1016/j.compstruct.2014.05.031.

[57] P. Zawadzki, R. Talar, “Model of a chip formation mechanism of cortical bone using a tool with a negative rake angle-analysis, modelling, and validation,” *The International Journal Advanced Manufacturing Technology,* vol. 130, pp. 4187-4205, 2024, https://doi.org/10.1007/s00170-023-12921-w.

[58] H. Sağlam, “Tool condition monitoring based on multi-element force measurements using artificial neural networks in milling,” *Master Thesis, Selçuk University, Institute of Science and Technology,* Konya, 2000.

[59] K. Alam, A. V. Mitrofanov, V. V. Silberschmidt, “Finite element analysis of forces of plane cutting of cortical bone,” *Computational Materials Science,* vol. 46, no. 3, pp. 738-743, 2009, https://doi.org/ 10.1016/j.commatsci.2009.04.035.

[60] M. Conward, “Effects of haversian and plexiform components on the machining of bovine cortical bone,” *Doctoral Thesis, Rensselaer Polytechnic Institute, Troy*, pp. 27-29, New York, 2018.

[61] N. B. Dahotre, S. S. Joshi, “Machining of bone and hard tissues,” *Springer,* New York, 2016.

[62] K. I. Al-Abdullah, H. Abdi, C. P. Lim, W. A. Yassin, “Force and temperature modelling of bone milling using artificial neural networks,” *Measurement,* vol. 116, pp. 25-37, 2018, https://doi.org/10. 1016/j.measurement.2017.10.051.

[63] A. H. Rabiee, V. Tahmasbi, M. Qasemi, "Experimental evaluation, modeling and sensitivity analysis of temperature and cutting force in bone micro-milling using support vector regression and EFAST methods,” *Engineering Applications of Artificial Intelligence,* vol. 120, 105874, 2023, https://doi.org/10.1016/j.engappai.2023.105874.

[64] V. Tahmasbi, M. Qasemi, R. Ghasemi, R. Gholami, “Experimental study and sensitivity analysis of force behavior in cortical bone milling,” *Medical Engineering & Physics,* vol. 105, 103821, 2022, https://doi.org/10.1016/j.medengphy.2022.103821

[65] Q. Zheng, Y. Lin, X. Chen, L. He, C. Zhang, Y. Hu, W. Fu, “Optimization of cranial bone milling parameters in craniotomy: a milling force model and ıts experimental validation,” *Journal of Mechanics in Medicine and Biology,* vol. 22, no. 7, 2250059, 2022, https://doi.org/10.1142/S0219519422500592.

[66] Z. Ying, L. Shu, N. Sugita, “Bone Milling: On Monitoring Cutting State and Force Using Sound Signals,” *Chin. J. Mech. Eng.*, vol. 35, pp. 61, 2022, https://doi.org/10.1186/s10033-022-00744-x.

[67] Q. Chen, Y. Liu, Q. Dong, "Modeling and experimental validation on temperature diffusion mechanism in high-speed bone milling,” *Journal of Materials Processing Technology,* vol. 286, 116810, 2020, https://doi.org/10.1016/j.jmatprotec.2020.116810.

[68] Z. Liao, D. Axinte, D. Gao, "On modelling of cutting force and temperature in bone milling," *Journal of Materials Processing Technology,* vol. 266, pp. 627-638, 2019, https://doi.org/10.1016/j.jmatprotec.2018.11.039.

[69] J. Sui, N. Sugita, K. Ishii, K. Harada, M. Mitsuishi, “Force analysis of orthogonal cutting of bovine cortical bone,” Machining Science and Technology, vol. 17, no. 4, pp. 637-649, 2013, https://doi. org/10.1080/10910344.2013.837355.

[70] N. Sugita, O. Takayuki, M. Mamoru, “Analysis and estimation of cutting-temperature distribution during end milling in relation to orthopedic surgery,” *Medical Engineering & Physics,* vol. 31, no. 1, pp. 101-107, 2009, https://doi.org/10.1016/j.medengphy.2008.05.001.

[71] S. Itoh, Y. Ito, T. Shikita, “Basic study on bone cutting forces for developing surgical instruments,” *Bulletin of JSME,* vol. 26, no. 222, pp. 2295-2301, 1983, https://doi.org/10.1299/ jsme1958.26.2295.

[72] K. L. Wiggins, S. Malkin, “Orthogonal Machining of Bone,” *ASME. J Biomech Eng.* vol. 100, no. 3, pp. 122-130, 1978, https://doi.org/10.1115/1.3426202.

[73] N. Sugita, F. Genma, Y. Nakajima, M. Mitsuishi, “Adaptive controlled milling robot for orthopedic surgery,” *Proceedings 2007 IEEE International Conference on Robotics and Automation,* pp. 605-610, 2007, Doi: 10.1109/ROBOT.2007.363053.

[74] J. H. Zhu, J. Deng, X. J. Liu, J. Wang, Y. X. Guo, C. B. Guo, “Prospects of robot-assisted mandibular reconstruction with fibula flap: comparison with a computer-assisted navigation system and freehand technique,” *J. Reconstr. Microsurg.,* vol. 32, no. 9, pp. 661-669, 2016, Doi:10.1055/s-0036-1584805

[75] I. J. Kwon, S. M. Kim, S. J. Hwang, “Development of autonomous robot osteotomy for mandibular ramal bone harvest and evaluation of Its accuracy: A phantom mandible-based trial,” *Applied Sciences,* vol. 11, no. 6, pp. 2885, 2021, https://doi.org/10.3390/app11062885.

[76] H. Tian, J. Pan, Y. Gao, X. Dang, B. Tian, D. Meng, Y. Yao, “Prediction modeling and sensitivity analysis of robot bone milling temperature operated by a doctor,” *Mathematical Problems in Engineering,* vol. 2021, 6806689, pp. 1-17, 2021, https://doi.org/10.1155/2021/6806689.

[77] K. Denis, G. V. Ham, J. V. Sloten, R. V. Audekercke, G. V. der Perre, J. D. Schutter, J. P. Kruth, J. Bellemans, G. Fabry, “Influence of bone milling parameters on the temperature rise, milling forces and surface flatness in view of robot-assisted total knee arthroplasty,” *International Congress Series,* vol. 1230, pp. 300-306, 2001, https://doi.org/10.1016/S0531-5131(01)00067-X.

[78] A. Feldmann, P. Ganser, L. Nolte, P. Zysset, “Orthogonal cutting of cortical bone: Temperature elevation and fracture toughness,” *International Journal of Machine Tools and Manufacture,* vol. 118-119, pp. 1-11, 2017, https://doi.org/10.1016/j.ijmachtools.2017.03.009.

[79] Z. Liao, D. A. Axinte, "On chip formation mechanism in orthogonal cutting of bone," *International Journal of Machine Tools and Manufacture,* vol. 102, pp. 41-55, 2016, https://doi.org/10.1016/j. ijmachtools.2015.12.004.

[80] C. Yeager, A. Nazari, D. Arola, “Machining of cortical bone: surface texture, surface integrity and cutting forces,” *Machining Science and Technology,* vol. 12, no. 1, pp. 100-118, 2008, https://doi.org/10. 1080/10910340801890961.

[81] C. Plaskos, A. J. Hodgson, P. Cinquin, ”Modelling and optimization of bone-cutting forces in orthopedic surgery,” In: Ellis, R.E., Peters, T.M. (eds) Medical Image Computing and Computer Assisted Intervention - MICCAI 2003. MICCAI 2003. *Lecture Notes in Computer Science,* vol, 2878, Springer, Berlin, Heidelberg, 2003, https://doi.org/10.1007/978-3-540-39899-8_32.

[82] W. R. Krause, “Orthogonal bone cutting saw design and operating characteristics,” *J Biomech Eng,* vol. 109, no. 3, pp. 263-271, 1987, https://doi.org/10.1115/1.3138679.

[83] A. Thounaojam, A. K. Birru, “Bone machining: An analysis of machining parameters such as cutting speed, feed and depth of cut using bovine bone,” Jurnal Tribologi, vol. 24, pp. 39-51, 2020, https://jurnaltribologi.mytribos.org/v24/JT-24-39-51.pdf

[84] D. Wu, L. Zhang, S. Liu, "Research on establishment and validation of cutting force prediction model for bone milling," *2015 IEEE International Conference on Robotics and Biomimetics (ROBIO)*, Zhuhai, China, pp. 1864-1869, 2015, doi: 10.1109/ROBIO.2015.7419044.

[85] M. Mitsuishi, S. Warisawa, N. Sugita, "Determination of the Machining Characteristics of a Biomaterial Using a Machine Tool Designed for Total Knee Arthroplasty,” *CIRP Annals,* vol. 53, no. 1, pp. 107-112, 2004, https://doi.org/10.1016/S0007-8506(07)60656-8.

[86] S. Karmani, “The thermal properties of bone and the effects of surgical intervention,” *Current Orthopaedics,* vol. 20, no. 1, pp. 52-58, 2006, https://doi.org/10.1016/j.cuor.2005.09.011

[87] S. R. H. Davidson, D. F. James, “Measurement of thermal conductivity of bovine cortical bone,” *Medical Engineering & Physics,* vol. 22, no. 10, pp. 741-747, 2000, https://doi.org/10.1016/S1350-4533(01)00003-0

[88] A. Alan, H. S. Vatansever, G. G. Alsan, G. Eskismiir, G. Giray,"Effect of thermal energy produced by drilling on the facial nerve: histopathologic evaluation in guinea pigs," *The Journal of Laryngology & Otology,* vol. 119, no. 8, pp. 600-605, 2005, doi:10.1258/0022215054516250.

[89] R. K. Pandey, S. Panda, "Drilling of bone: a comprehensive review," *Journal of Clinical Orthopaedics and Trauma,* vol. 4, no. 1, pp. 15-30, 2013, https://doi.org/10.1016/j.jcot.2013.01.002.

[90] Z. Sun, Y. Wang, K. Xu, et al., "Experimental investigations of drilling temperature of high-energy ultrasonically assisted bone drilling," *Medical Engineering & Physics,* vol. 65, pp. 1-7, 2019, https://doi.org/10.1016/j.medengphy.2018.12.019.

[91] P. Zawadzki, A. Patalas, R. Labudzki, R. Talar, "Measurement of thermal conductivity of the cortical bone: experimental studies and comparative analysis," *International Conference on Applied Sciences (ICAS 2022),* pp. 2540, 012035, 2023, doi:10.1088/1742-6596/2540/1/012035.

[92] N. McDannold, N. Vykhodtseva, F. A. Jolesz, K. Hynynen, "MRI investigation of the threshold for thermally induced blood-brain barrier disruption and brain tissue damage in rabbit brain," *Magnetic Resonance in Medicine,* vol. 51, no. 5, pp. 913-923, 2004, https://doi.org/10.1002/mrm.20060.

[93] N. Hosono, T. Miwa, Y. Mukai, S. Takenaka, T. Makino, T. Fuji, "Potential risk of thermal damage to cervical nerve roots by a high-speed drill," *J Bone Joint Surg Br.,* vol. 91-B, no. 11, pp. 1541-1544, 2009, https://doi.org/10.1302/0301-620X.91B11.22196.

[94] M. W. Dewhirst, B. L. Viglianti, M. Lora-Michiels, M. Hanson, P. J. Hoopes, "Basic principles of thermal dosimetry and thermal thresholds for tissue damage from hyperthermia," *Int J Hyperth,* vol. 19, no. 3, pp. 267-294, 2003, https://doi.org/10.1080/0265673031000119006.

[95] B. L. Viglianti, M. W. Dewhirst, J. P. Abraham, J. M. Gorman, E. M. Sparrow, "Rationalization of thermal injury quantification methods: Application to skin burns," *Burns,* vol. 40, no. 5, pp. 896-902, 2014, https://doi.org/10.1016/j.burns.2013.12.005.

[96] H. Ye, S. De, "Thermal injury of skin and subcutaneous tissues: A review of experimental approaches and numerical models," *Burns,* vol. 43, no. 5, pp. 909-932, 2017, https://doi.org/10.1016 /j.burns.2016.11.014.

[97] Q. Wang, H. Tian, X. Dang, et al., "Temperature distribution simulation, prediction and sensitivity analysis of orthogonal cutting of cortical bone," *Proceedings of the Institution of Mechanical Engineers, Part H, Journal of Engineering in Medicine,* vol. 236, no. 1, pp. 103-120, 2022, doi:10.1177/09544119211049869.

[98] D. Vashishth, K. E. Tanner, W. Bonfield, "Contribution, development and morphology of microcracking in cortical bone during crack propagation," *Journal of Biomechanics,* vol. 33, no. 9, pp. 1169-1174, 2000, https://doi.org/10.1016/S0021-9290(00)00010-5.

[99] R. P. Singh, P. M. Pandey, C. Behera, A. R. Mridha, "Effects of rotary ultrasonic bone drilling on cutting force and temperature in the human bones," *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine,* vol. 234, no. 8, pp. 829-842, 2020, doi:10.1177/0954411920925254.

[100] M. F. A. Akhbar, A. R. Yusoff, "Comparison of bone temperature elevation in drilling of human, bovine and porcine bone," *Procedia CIRP,* vol. 82, pp. 411-414, 2019, https://doi.org/10.1016/j.procir. 2019.03.220.

[101] Z. Liu, J. Sui, B. Chen, et al., "Study on cutting force of reaming porcine bone and substitute bone," *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine,* vol. 236, no. 1, pp. 94-102, 2022, doi:10.1177/09544119211043758.

[102] B. Kianmajd, D. Carter, M. Soshi, "A novel toolpath force prediction algorithm using CAM volumetric data for optimizing robotic arthroplasty," *Int J CARS* 11, pp. 1871-1880, 2016, https://doi.org/10.1007/s11548-016-1355-x.

[103] R. K. Pandey, S. S. Panda, "Optimization of bone drilling parameters using grey-based fuzzy algorithm," *Measurement,* vol. 47, pp. 386-392, 2014, https://doi.org/10.1016/j.measurement.2013.09. 007.

[104] G. Singh, V. Jain, D. Gupta, A. Ghai, "Optimization of process parameters for drilled hole quality characteristics during cortical bone drilling using Taguchi method," *Journal of the Mechanical Behavior of Biomedical Materials,* vol. 62, pp. 355-365, 2016, https://doi.org/10.1016/j.jmbbm.2016.05. 015.

[105] M. Qasemi, M. M. Sheikhi, M. Zolfaghari, V. Tahmasbi, "Experimental analysis, statistical modeling and optimization of effective parameters on surface quality in cortical bone milling process," *Journal of Mechanics in Medicine and Biology,* vol. 20, no. 4, 1-17, 1950078, 2020, doi:10.1142/S0219519419500787.

[106] Leslie P. Gartner, "Textbook of Histology, Fourth Edition International Edition," *Elsevier,* 2017.

[107] A. Dhamodharan, "Analysis of bone cutting mechanics in orthopedic surgery," *Doctoral Thesis, Loughborough University, Oklahoma State University, Bachelor of Technology in Mechanical Engineering,* Coimbatore, India, 2012.

[108] B. Kaye, C. Randall, D. Walsh, P. Hansma, "The effects of freezing on the mechanical properties of bone," *The Open Bone Journal,* vol. 4, pp. 14-19, 2012, 10.2174/18765254012 04010014.

[109] R. R. Pelker, G. E. Friedlaender, T. C. Markham, M. M. Panjabi, C. J. Moen, "Effects of freezing and freeze-drying on the biomechanical properties of rat bone," *J Orthop Res.,* vol. 1, no. 4, pp. 405-411, 1983, https://doi.org/10.1002/jor.1100010409.

[110] J. C. Goh, E. J. Ang, K. Bose, "Effect of preservation medium on the mechanical properties of cat bones," Acta Orthopaedica Scandinavica, vol. 60, no. 4, pp. 465-467, 1989, https://doi.org/10.3109/17453678909149321.

[111] M. Salai, T. Brosh, N. Keller, et al., "The effects of prolonged cryopreservation on the biomechanical properties of bone allografts: A microbiological, histological and mechanical study," *Cell Tissue Banking,* vol. 1, pp. 69-73, 2000, https://doi.org/10.1023/A:10 10163800026.

[112] F. Linde, H. C. Sorensen, "The effect of different storage methods on the mechanical properties of trabecular bone," *Journal of Biomechanics,* vol. 26, no. 10, pp. 1249-1252, 1993, https://doi.org/10.1016/0021-9290(93)90072-M.

[113] E. H. van Haaren, B. C. van der Zwaard, A. J. van den Veen, I. C. Heyligers, P. I. Wuisman, T. H. Smit, "Effect of long term preservation on the mechanical properties of cortical bone in goats," *Acta Orthop,* vol. 79, no. 5, pp. 708-716, 2008, https://doi.org/10.10 80/1745367 0810016759.

[114] R. E. Borchers, L. J. Gibson, H. Burchardt, W. C. Hayes, "Effects of selected thermal variables on the mechanical properties of trabecular bone." *Biomaterials,* vol. 16, no. 7, pp. 545-551, 1995, https://doi.org/10.1016/0142-9612(95)91128-L.

[115] A. J. Hamer, J. R. Strachen, M. M. Black, C. J. Ibbotson, I. Stockley, R. A. Elson, "Biomechanical properties of cortical allograft bone using a new method of bone strength measurement. A comparison of fresh, fresh-frozen and irradiated bone," *The journal of bone and Join Surgery,* vol. 78, no. 3, pp. 363-368, 1996, https://doi.org/10.1302/0301-620X.78B3.0780363.

[116] https://smart.servier.com/ [date: 20.12.2023]

[117] A. Chatterjee, G. G. Kar, "Cutting Tools Used in Orthopedic Implantology. In: Banerjee, A., Biberthaler, P., Shanmugasundaram, S. (eds) Handbook of Orthopaedic Trauma Implantology," *Springer,* Singapore, 2022, https://doi.org/10.1007/978-981-15-6278-5_46-1.

[118] J. Y. Giraud, S. Villemin, R. Darmana, J. Ph. Cahuzac, A. Autefage, J. P. Morucci, "Bone Cutting," *Clinical Physics and Physiological Measurement,* vol. 12, no. 1, pp. 1-19, 1991, doi:10.1088/0143-0815/12/1/001.

[119] W. R. Krause, "Orthogonal Bone Cutting: Saw Design and Operating Characteristics," *ASME. J Biomech Eng.,* vol. 109, no. 3, pp. 263-271, 1987, https://doi.org/10.1115/1.3138679.

[120] W. Phanindra Addepalli, S. A. Sawangsri, C. Ghani, "A qualitative study on cutting tool materials for bone surgeries," *Materials Today: Proceedings,* vol. 47, no. 10, pp. 2457-2462, 2021, https://doi.org/10.1016/j.matpr.2021.04.549.

[121] G. Augustin, T. Zigman, S. Davila, T. Udilljak, T. Staroveski, D. Brezak, S. Babic, "Cortical bone drilling and thermal osteonecrosis," *Clinical Biomechanics*, vol. 27, no. 4, pp. 313-325, 2012, https://doi.org/10.1016/j.clinbiomech.2011.10.010.

[122] G. Augustin, S. Davila, K. Mihoci, et al., "Thermal osteonecrosis and bone drilling parameters revisited," *Arch. Orthop. Trauma Surg.*, vol. 128, pp. 71-77, 2008, https://doi.org/10.1007/s00402-007-0427-3.

[123] K. N. Bachus, M. T. Rondina, D. T. Hutchinson, "The effects of drilling force on cortical temperatures and their duration: an in vitro study," *Medical Engineering & Physics*, vol. 22, no. 10, pp. 685-691, 2000, https://doi.org/10.1016/S1350-4533(01)00016-9.

[124] M. T. Hillery, I. Shuaib, "Temperature effects in the drilling of human and bovine bone," *Journal of Materials Processing Technology*, vol. 92-93, pp. 302-308, 1999, https://doi.org/10.1016/S0924-0136(99)00155-7.

[125] W. Wendong, S. Yikai, Y. Ning, Y. Xiaoqing, "Experimental analysis of drilling process in cortical bone," *Medical Engineering & Physics*, vol. 36, no. 2, pp. 261-266, 2014, https://doi.org/10.1016/j. medengphy.2013.08.006.

[126] F. Pupulin, G. Oresta, T. Sunar, P. Parenti, "On the thermal impact during drilling operations in guided dental surgery: An experimental and numerical investigation," *Journal of the Mechanical Behavior of Biomedical Materials*, vol. 150, 106327, 2024, https://doi.org/10.1016/j.jmbbm.2023.106327.

[127] U. A. Pangnguriseng, S. Imade, S. Furuya, K. Nakazawa, K. Shiraishi, M. Sato, T. Kawamura, Y. Uchio, "Effect of bone density on the drill-hole diameter made by a cannulated drill bit in cancellous bone," *Journal of Orthopaedic Science*, 2024, https://doi.org/10.1016/j.jos.2024.04.001.

[128] H. Y. Lin, J. H. Yang, Y. T. Li, C. H. Chou, S. J. Tsai, H. H. Chang, C. P. Lin, "Comparison of the physical, thermal, and biological effects on implant bone site when using either zirconia or stainless-steel drill for implant bone site preparation," *Journal of the Formosan Medical Association*, pp. 1-7, 2024, https://doi.org/10.1016/j.jfma.2024.01.011.

[129] I. Dörsam, A. Bauroth, L. Keilig, C. Bourauel, F. Heinemann, "Definition of a drilling protocol for mini dental implants in different bone qualities," *Annals of Anatomy-Anatomischer Anzeiger*, vol. 231, 151511, 2020, https://doi.org/10.1016/j.aanat.2020.151 511.

[130] R. Jimbo, N. Tovar, R. B. Anchieta, L. S. Machado, C. Marin, H. S. Teixeira, P. G. Coelho, "The combined effects of undersized drilling and implant macrogeometry on bone healing around dental implants: an experimental study," *International Journal of Oral and Maxillofacial Surgery*, vol. 43, no. 10, pp. 1269-1275, 2014, https://doi.org/10. 1016/j.ijom.2014.03.017.

[131] S. Li, A. Abdel-Wahab, E. Demirci, V. V. Silberschmidt, "Penetration of cutting tool into cortical bone: Experimental and numerical investigation of anisotropic mechanical behaviour," *Journal of Biomechanics*, vol. 47, no. 5, 2014, pp. 1117-1126, 2014, https://doi.org/10.1016/j.jbiomech.2013.12.019.

[132] P. Addepalli, W. Sawangsri, S. A. C. Ghani, "A scientometric analysis of bone cutting tools & methodologies: Mapping the research landscape," *Injury*, vol. 55, no. 4, 111458, 2024, https://doi.org/10.1016/j.injury.2024.111458.

[133] B. Takabi, B. L. Tai, "A review of cutting mechanics and modeling techniques for biological materials," *Medical Engineering & Physics*, vol. 45, 2017, pp. 1-14, https://doi.org/10.1016/j. medengphy.2017.04.004.

[134] L. Shu, S. Li, M. Terashima, W. Bai, T. Hanami, R. Hasegawa, N. Sugita, "A novel self-centring drill bit design for low-trauma bone drilling," *International Journal of Machine Tools and Manufacture*, vol. 154, 103568, 2020, https://doi.org/10.1016/j.ijmachtools.2020.103568.

[135] T. P. James, G. Chang, S. Micucci, A. Sagar, E. L. Smith, C. Cassidy, "Effect of applied force and blade speed on histopathology of bone during resection by sagittal saw," *Medical Engineering & Physics*, vol. 36, no. 3, pp. 364-370, 2014, https://doi.org/10.1016/j.medengphy.2013.12.002.

[136] S. Toksvig-Larsen, L. Ryd, A. Lindstrand, "Temperature influence in different orthopaedic saw blades," *The Journal of Arthroplasty,* vol. 7, no. 1, pp. 21-24, 1992, doi:10.1016/0883-5403(92)90027-n.

[137] T. Mizutani, U. Satake, T. Enomoto, "Bone grinding using coarse-grained diamond wheels to suppress thermal damage," *Precision Engineering,* vol. 78, pp. 163-170, 2022, https://doi.org/10.1016/j.precisioneng.2022.08.003.

[138] L. Zhang, B. L. Tai, A. C. Wang, A. J. Shih, "Mist cooling in neurosurgical bone grinding," CIRP Annals, vol. 62, no. 1, pp. 367-370, 2013, https://doi.org/10.1016/j.cirp.2013.03.125.

Konya Mühendislik Bilimleri Dergisi, c. 12, s.3, 801-821, 2024
Konya Journal of Engineering Sciences, v. 12, n. 3, 801-821, 2024
ISSN: 2667-8055 (Elektronic)
DOI: 10.36306/konjes.1430115

THE EFFECT OF CUTTING FORCES ON BONE RELATED OPERATIONAL PROCESSES: A LITERATURE REVIEW

[1,*] **Yusuf Çağlar KAĞITCI**, [2] **Süleyman NEŞELİ**

[1]*Konya Technical University, Vocational School of Technical Sciences, Mechanical and Metal Technologies Department, Konya, TÜRKİYE*
[2]*Selcuk University, Technology Faculty, Mechanical Engineering Department, Konya, TÜRKİYE*
[1]yckagitci@ktun.edu.tr, [2]sneseli@selcuk.edu.tr

Highlights

- Recognize the bone structure and the process performed on the bone.
- Observation of dominant parameters and their effects in operational procedures on bone.
- Evaluation of the interactions of cutting forces with variations of cutting parameters in bone milling.

***Corresponding Author:** Yusuf Çağlar KAĞITÇI, yckagitci@ktun.edu.tr