Piezoelectric surgery: applications and protocols

Applications of ultrasonic waves in medicine

Therapeutic ultrasound was introduced and systematically studied after World War II. In Italy, these methods spread immediately and several research scholars resolutely contributed to experimental and clinical research in this field.

The safety of the application of therapeutic ultrasound is proven beyond doubt. The action of ultrasound on the human body is multifaceted, as it reaches the subcutaneous layers, generating the following:

- **Mechanical** effects, due to vibration movement (a few millions vibrations per second) of the ultrasonic wave-traversed tissue particles
- **Thermal** effects, due to energy absorption by the biological tissue and energy reflection in the interface zones between tissues with different acoustic impedance. For example, the passage of ultrasonic waves via soft tissues results in an increase in absorption temperature due to viscosity, thermal conductivity, and chemical absorption
- **Chemical** effects, when the action changes the body's pH and cell membrane permeability, resulting in molecular changes

Radiology is the discipline involving the maximum application of ultrasound. Ultrasound is a technique based on reflection of interfaces between different acoustic means crossed by an ultrasound beam. Typically, the same piezoelectric crystal is used as both the emitter and the receiver. It essentially receives echoes from the surfaces perpendicular to the beam trajectory. During use, the transducer is placed in contact with the skin using a gel, which acts as a sound conductive material, and the electrical impulses are supplied to the transduction crystal using a high frequency alternating voltage generator. Usually, frequencies of 1.5 and 20 MHz are used, and after the impulse is emitted, the piezoelectric crystal is automatically predisposed to the opposite emission effect, transforming any echo received into an electric vibration.

Furthermore, ultrasound has been applied in the field of urology for breaking calculi. Until recently, surgery was often the only therapeutic modality for elimination

of kidney stones. Over the past few years, considerable technological progress has facilitated the successful adoption of partially or completely noninvasive methods to destroy these solid concretions using a 'crushing through contact' technique, facilitated, for example, by reaching the calculi via an endoscopic route.

Additionally, ultrasound has widely been used in orthopedics. Conservative shock wave treatments are used in all diseases of the locomotor system that require an antalgic effect: typically, in sciatica and neuritis cases (reduced intensity and irradiation along the cutaneous projection of the nerve trunk to be treated); in periarthritis cases, where ultrasound therapy breaks down calcifications and promotes the reabsorption of calcium salt depositions.

Owing to piezoelectric surgery devices, ultrasound has recently been introduced in orthopedic surgery. The piezoelectric transducer is useful in hand and spinal surgery, where performing osteotomies are required in narrow areas and in close proximity to the blood vessels and nerves. The use of ultrasound facilitates the surgeon to employ a safer technique owing to the selectivity of the piezoelectric terminal for hard tissues.

Further, ultrasound can be applied in the fields of dermatology and plastic surgery.

In vascular surgery, mini ultrasonic generators and detectors are used, mounted at the apex of catheters; these generators and detectors render it possible to establish the composition of the atherosclerotic plates and to crush by unclogging the arteries.

Finally, ultrasound has been used in the field of ophthalmology with cataract procedures, where the crystalline lens is removed by spraying and vacuuming the residues.

Recently, ultrasound has been applied with piezoelectric surgery in otolaryngology and maxillofacial surgery.

Physics of ultrasonic waves

The term 'ultrasound' refers to a particular type of 'elastic' mechanical wave that is characterized by a frequency of >20,000 Hz.

Sound is an acoustic mechanical wave, i.e., it is the perturbation produced by any vibrating body in the material medium (gases, liquids, or solids) with which it comes in contact. This vibration causes the oscillation of the particles inside the medium—with the particles moving closer and away from each other—thereby producing compression bands (zones in which the particles are close) and rarefaction bands (zones in which the particles are distant from each other). Thus, a propagation of the wave without any actual movement of matter is obtained, because the movement of particles is merely an oscillation surrounding the equilibrium point.

The graphic representation of this trend is presented using a sinusoidal wave, which is a trace that represents the moving closer/moving away of these particles in time surrounding their point of equilibrium.

Similar to all waves, ultrasonic waves are characterized by several parameters:

- **Amplitude (a)** of a sound is the maximum pressure between highest and lowest points during the compression phase: it is indicative of the force that the wave exerts on the particles of the medium and thus of the magnitude of particle displacement from the equilibrium point
- **Wavelength (l)** is the distance between the corresponding points of two consecutive pressure waves, i.e., the distance between two synchronized points (for example, two successive compression or rarefaction bands); therefore, it is the distance at which the pressure curve repeats itself
- **Frequency (f)** of a sound is the number of compression and rarefaction cycles conducted in the unit of time, i.e., the number of times that the wave repeats itself per second in a fixed point of the traversed medium (cycles/s or Hz), and it coincides with the frequency with which the source vibrates

Based on what has been previously described, ultrasonic waves cannot propagate in vacuum in the absence of matter; this is the most important difference between ultrasonic waves and electromagnetic waves.

Generation of ultrasonic waves

Ultrasonic waves are generated by exploiting the phenomenon of piezoelectricity, characteristic of the crystalline structure materials called 'transducers' (such as quartz, barium titanate, and lead zirconate titanate). It involves the possibility of causing a dimensional vari-

ation (piezoelectric effect) by applying voltage at the ends of the crystal or the possibility of generating a difference in voltage at its ends (direct piezoelectric effect) by producing a variation in the crystal size. The frequency at which a crystal vibrates when activated by a potential difference is defined as 'resonance frequency' and is typically related to the thickness of the crystal itself: for example, a crystal with a thickness of approximately 1 mm has a resonance frequency of 2 MHz; to obtain frequencies of 10 MHz, it is necessary to use 0.2 mm thick crystals. A piezoelectric crystal can be stimulated to emit ultrasonic waves in a continuous or pulsed manner. In the first case, an electrical voltage is continuously applied to the crystal, which varies in a sinusoidal manner and causes continuous oscillation. In the second case, the electrical impulse is applied in a different manner, for a very short duration, following an interval during which the transducer returns to its resting state; the resulting ultrasound beam is a succession of short ultrasonic 'wave trains', with a length equal to the number of complete oscillations included within them. This length is defined as the spatial length of the pulse.

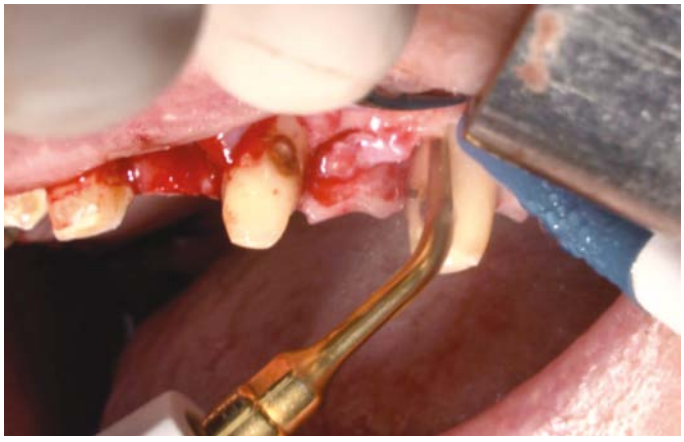
6.1 Preparation of the operating room with the trolley of the piezoelectric unit.

Oral piezoelectric surgery

Piezoelectric bone surgery is a new osteotomy and osteoplastic technique that uses a special ultrasonic surgical device with variable modulation, designed to exceed the precision and safety limits of the normal manual or motorized instruments used in bone surgery (6.1).

This new surgical procedure is based on the technological invention that allows specific electronic control of the ultrasonic vibrations, facilitating the cutting of the bone deeply without overheating.

In 1997, the intuition of Prof. Tommaso Vercellotti to use microvibrations produced by an ultrasound device in bone surgery was triggered by the extraction of an ankylotic canine root in a patient who had lost the stump owing to a fracture (6.2). The surgery was performed using a common tartar scaler, whose insert had been sharpened, almost similar to that of a scalpel blade. The walls of the alveolus were not damaged, and it was possible to proceed with an immediate implant and achieve a perfect osteointegration. Therefore, Vercellotti decided to apply this technique to maxillary sinus surgery; however, he acknowledged the limits of using thin and sharp instruments, considering the low power, with the high risk of membrane perforation. The limited power was an insurmountable constraint for cutting bone walls with a thickness of >1 mm, resulting in ex-



6.2 Extraction of ankylosed root using a piezoelectric insert.

cessive overheating. Therefore, via a series of studies and researches, the piezoelectric unit was developed, characterized by a low frequency overmodulation that renders a unique nature to the ultrasonic mechanical vibration.

The typical resonance frequency of the insert is superimposed by a forced oscillation with a frequency between 10 and 60 Hz. The insert thus presents a movement composed of two oscillations that have the same direction but different frequencies. This results in vibrations with optimal energy for bone cutting, even at low power levels, thereby reducing heat production both on the insert and the bone.

Features of piezoelectric cutting

Piezoelectric surgery was designed as a means to overcome the limitations of traditional bone surgery instruments.

In summary, the techniques of osteotomy comprise cutting (osteotomy) or reshaping (osteoplastic) actions for the bone surface. The practical combination of osteotomy and osteoplastic techniques leads to an increase in bone surgeries in the different fields.

Although there are only two bone surgery techniques, numerous surgical instruments are available to perform them.

It should be noted that there are two types of instruments:

- Manual instruments (chisels, hammers, saws, etc.), characterized by a remarkable cutting efficiency and linked to the mechanical force, which is instantly exercised and thus not adequately controllable
- Motor-powered instruments, characterized by a high cutting capacity due to an electrical or pneumatic energy; typically, the micromotors used in bone surgery transform the electrical energy into mechanical energy, and the cut is the result of a microvibration produced by the movement of milling cutters or by the oscillation movement in the case of bone saws

For example, bone cutters produce a cutting action only if the force of rotation can be used; this torque produces the cutting action only if high pressure is exerted on the handpiece, and it is precisely this pressure that renders the surgical maneuver less controllable and therefore more insecure.

In the anatomical situations wherein an osteotomy is performed starting from the cortical bone, it is evident that the force required to exploit the torque in the more mineralized bone structure is suddenly excessive in the passage to the trabecular bone. In this situation, the remarkable pressure produces an instant loss of control over the surgical instrument, which can be harmful considering the proximity of vital anatomical structures such as vascular bundles or nerve-like tissues. Moreover, when producing the cutting action, traditional motorized instruments generate macrovibrations that in turn reduce surgical safety.

In contrast, the action of piezoelectric cutting is the result of linear microvibrations of ultrasonic nature, with a width of only 20–60 μm in the longitudinal direction, which facilitates the surgical field to be controlled in all anatomical situations.

The characteristics of piezoelectric cutting are divided into physical and clinical characteristics.

The **physical characteristics** are as follows:

- Microvibration
- Hammering action (hammer effect)
- Cavitation effect of the saline solution

The vibrating insert will have a maximum longitudinal vibration and maximum vertical oscillation. Depending on the type of lock, the oscillation varies between 60 and 200 μm at maximum power.

The **hammering action**, fundamental characteristic of the instrument, is generated by the alternation of two types of ultrasonic waves with different wavelength—one short and the other long. The hammering effect, which facilitates maintaining the insert constantly clean, therefore only in direct contact with the bone, is due to the alternation of these two waves.

Indeed, in the absence of this effect, the pulverized bone would accumulate at the end of the insert, which would be read by the instrument as non-mineralized tissue; therefore, all the kinetic energy present would be transformed into heat, resulting in necrosis of the underlying and surrounding tissues (📷 6.3).

The **cavitation** occurs in a fluid when a body moves in it at a speed higher than a certain limit (depending on the fluid, temperature, and pressure). It is a physical phenomenon characterized by the formation of vacuum bubbles (very low pressure steam), which subsequently, via implosion, leads to a mechanical cleaning action that drains the field of blood.

The fluid (water or physiological solution) is used to dispose of excessive heat and to clean and lubricate the cut.

From these **three physical characteristics**, the following three clinical characteristics of the piezoelectric cut are derived:

- Micrometric cut due to microvibration effect
- Selective cutting
- Site drained of blood

Micrometric cutting renders the instrument a high degree of surgical control and precision as well as increased intraoperative safety, thereby reducing stress for the surgeon.

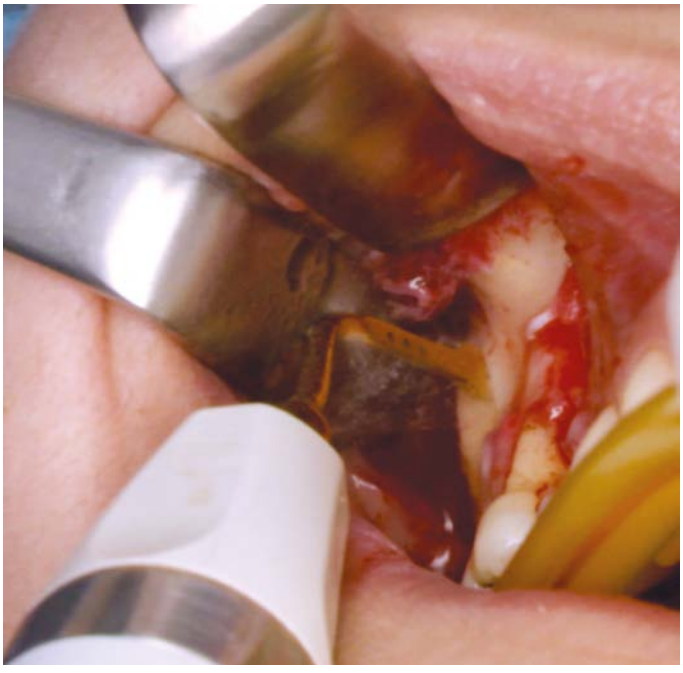
Selective cutting is a consequence of the instrument's low modulated working frequency. This characteristic renders the cut effective on type I, II, and III bones and slightly effective on type IV bones, which are poorly mineralized, as well as on the soft tissues.

Owing to the selected frequencies between 27 and 29.5 kHz, the piezoelectric terminal is active on hard tissues and limits the risk of soft tissue damage (to be active on soft tissues, it should work at twice the frequency used for mineralized tissues). Through intermittence, the generator produces ultrasonic vibrations at lower amplitudes. This is called a 'piezo-modulated' signal. This amplitude-modulated signal automatically developed during surgical procedures allows for optimal tissue relaxation and cellular repair, with a precise cut and better healing.

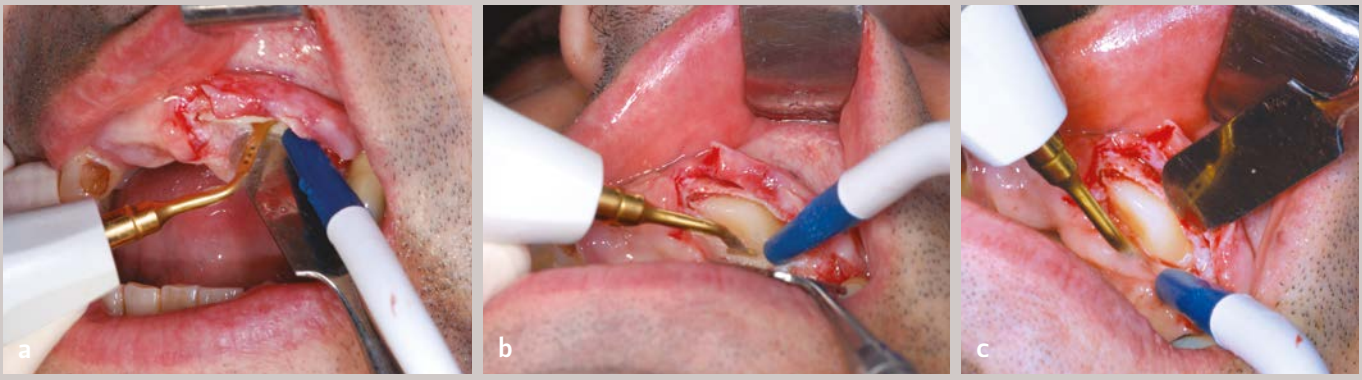
The robust terminals, combined with limited vibration amplitudes, produce cuts of the highest precision. In the end, the great maneuverability of the handpiece, combined with the points with shapes adapted to the anatomical context, facilitates the control of the most difficult surgeries.

Therefore, this type of surgery allows to operate in fields of high anatomical risk, because it does not damage the soft tissues (for example in areas close to nerves, mucous membranes, membranes, blood vessels, and the central and peripheral nervous system).

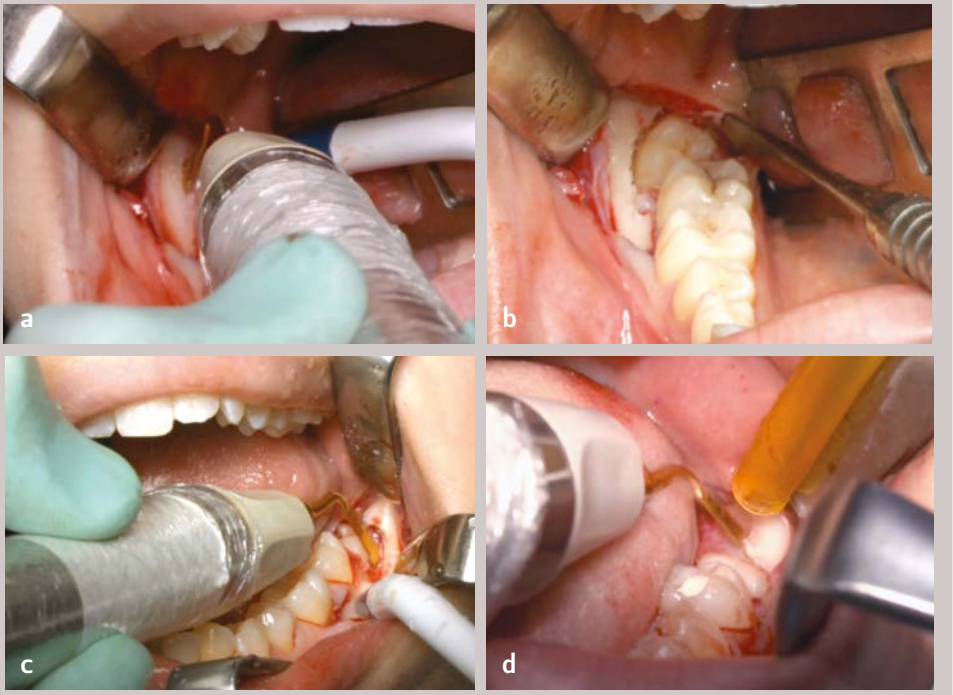
The **drained site** (see 6.5c) is a consequence of the irrigation subject to cavitation. The piezoelectric terminal exerts a hemostatic effect at the level of the cutting surfaces (partially due to the appearance of nascent oxygen). The cavity is characterized by the appearance of microbubbles when the liquid comes in contact with the tip subjected to ultrasonic vibrations. Imploding bubbles result in a pickling effect. This phenomenon renders it possible to have an optimal visibility, and it becomes easier for the operator to recognize and distinguish the different anatomical areas during the surgery. In addition, blood transfer is restricted, work area cleaning is facilitated by bone residues, and heat rises, which could cause tissue degradation, are avoided (6.4–6.14; 6.15 and 6.16–6.20).



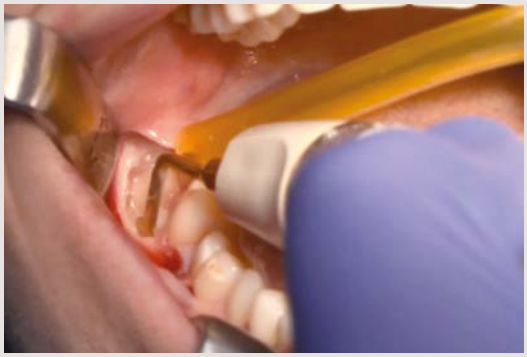
6.3 Hammering effect that keeps the insert clean.



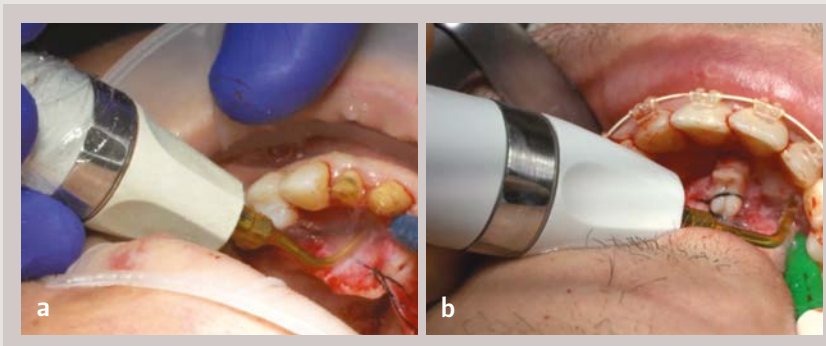
6.4 Extraction of impacted canine using a piezoelectric insert.



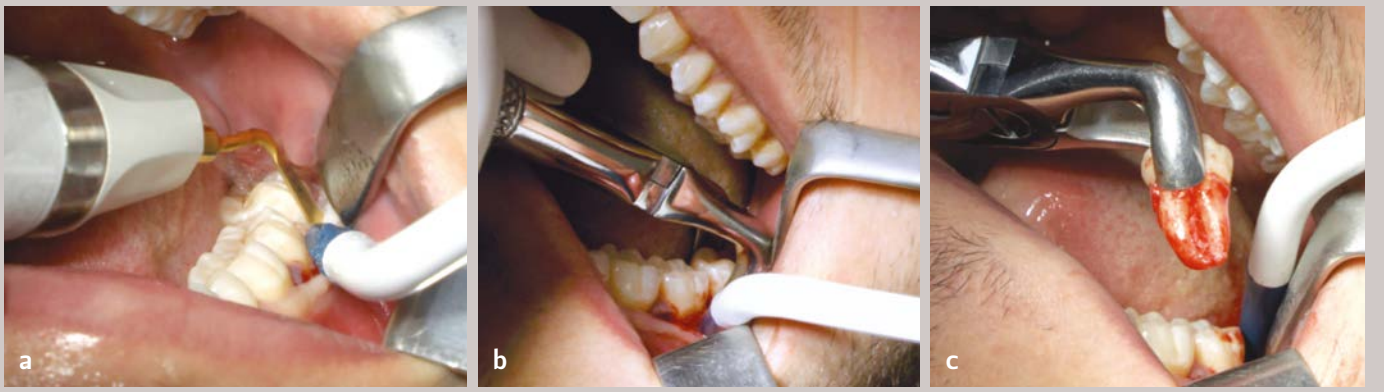
6.5 (**a**) Osteotomy of a completely impacted third molar tooth; (**b**) osteotomy of the impacted third molar tooth performed using a piezoelectric insert; (**c**) drained site during the osteotomy of the impacted third molar tooth; (**d**) osteotomy of the completely impacted third molar tooth.



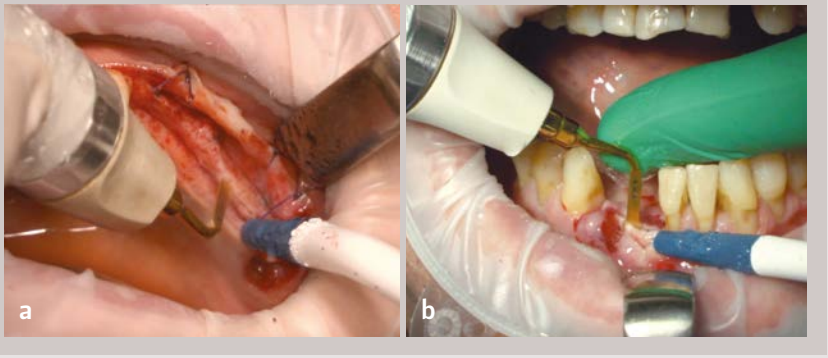
6.6 Cutting precision and drained site in the avulsion of the third molar tooth.



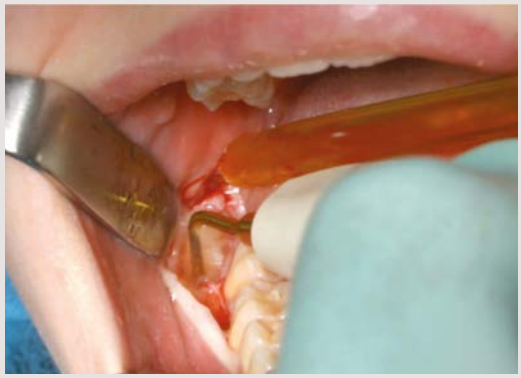
6.7 (**a**) Diamond insert for removal of a palatal cystic lesion; (**b**) extraction insert for the orthodontic surgical recovery of impacted palatal canine.



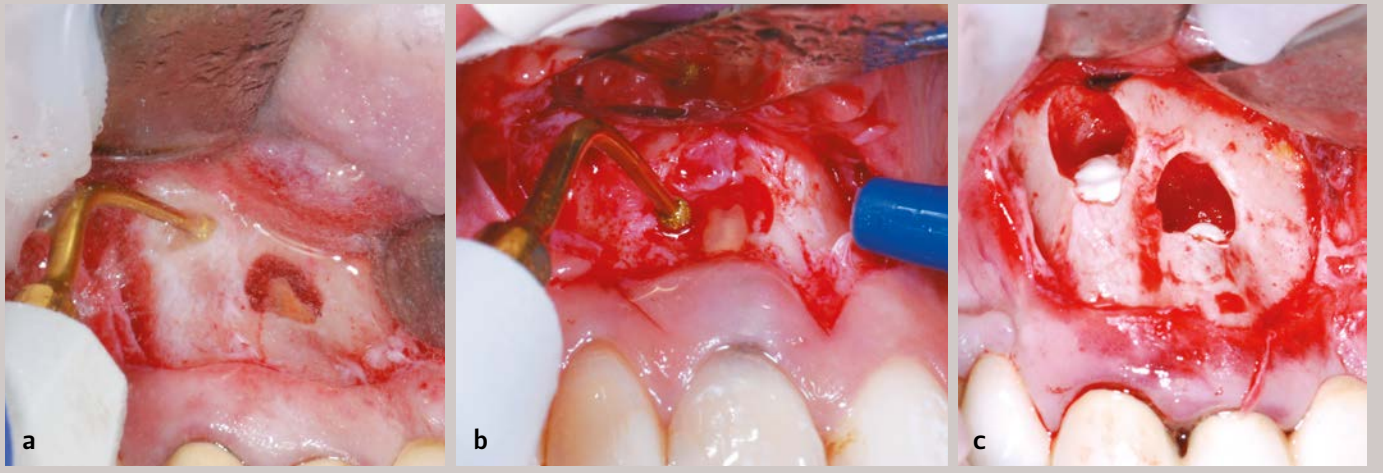
6.8 (**a**) Ostectomy of the extruded third molar tooth; (**b, c**) avulsion with forceps for the lower third molar tooth.



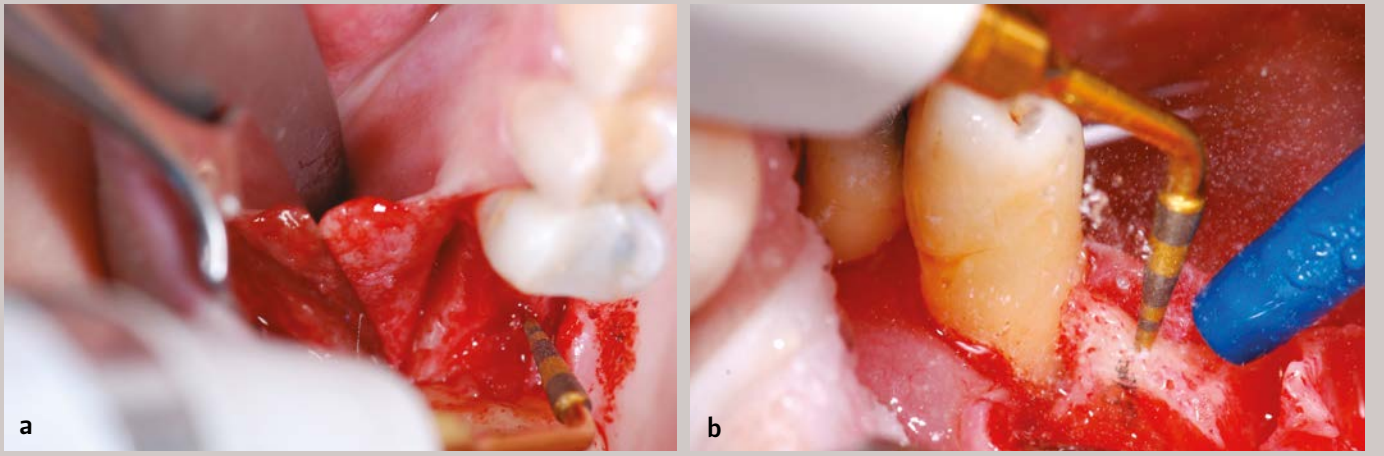
6.9 (**a**) Cutting accuracy of a piezoelectric insert in the split-crest procedure; (**b**) use of a piezoelectric insert for crest expansion.



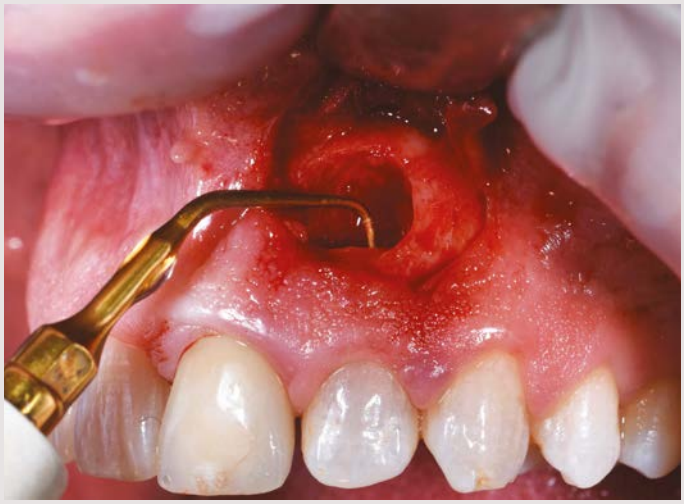
6.10 Selectivity of the piezoelectric insert for hard tissues while preserving soft tissues.



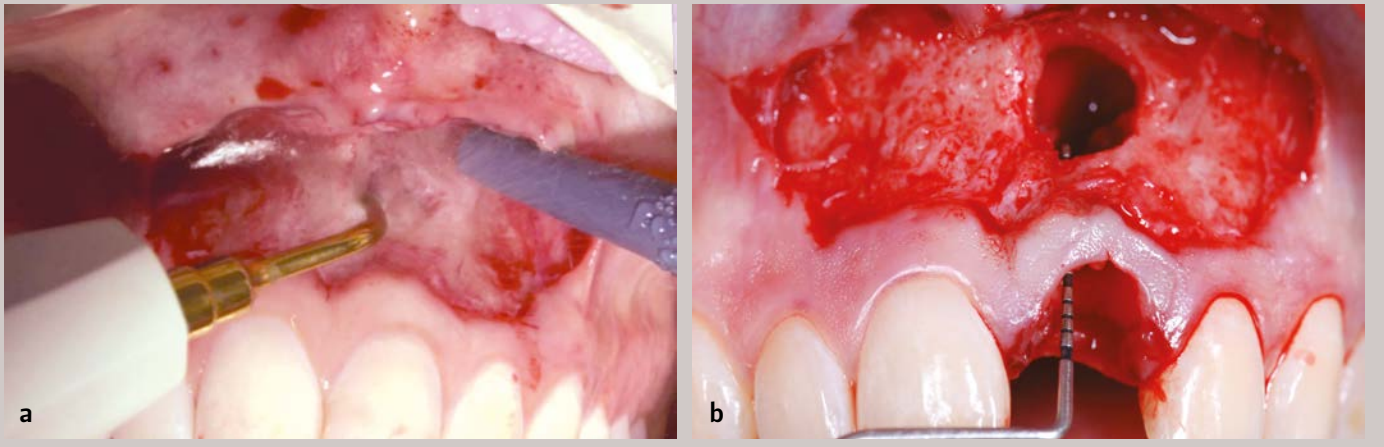
6.11 (**a, b**) Apicectomy using a diamond insert; (**c**) apicectomy showing cutting precision and a clean and drained site.



6.12 Diamond insert for implant site preparation.



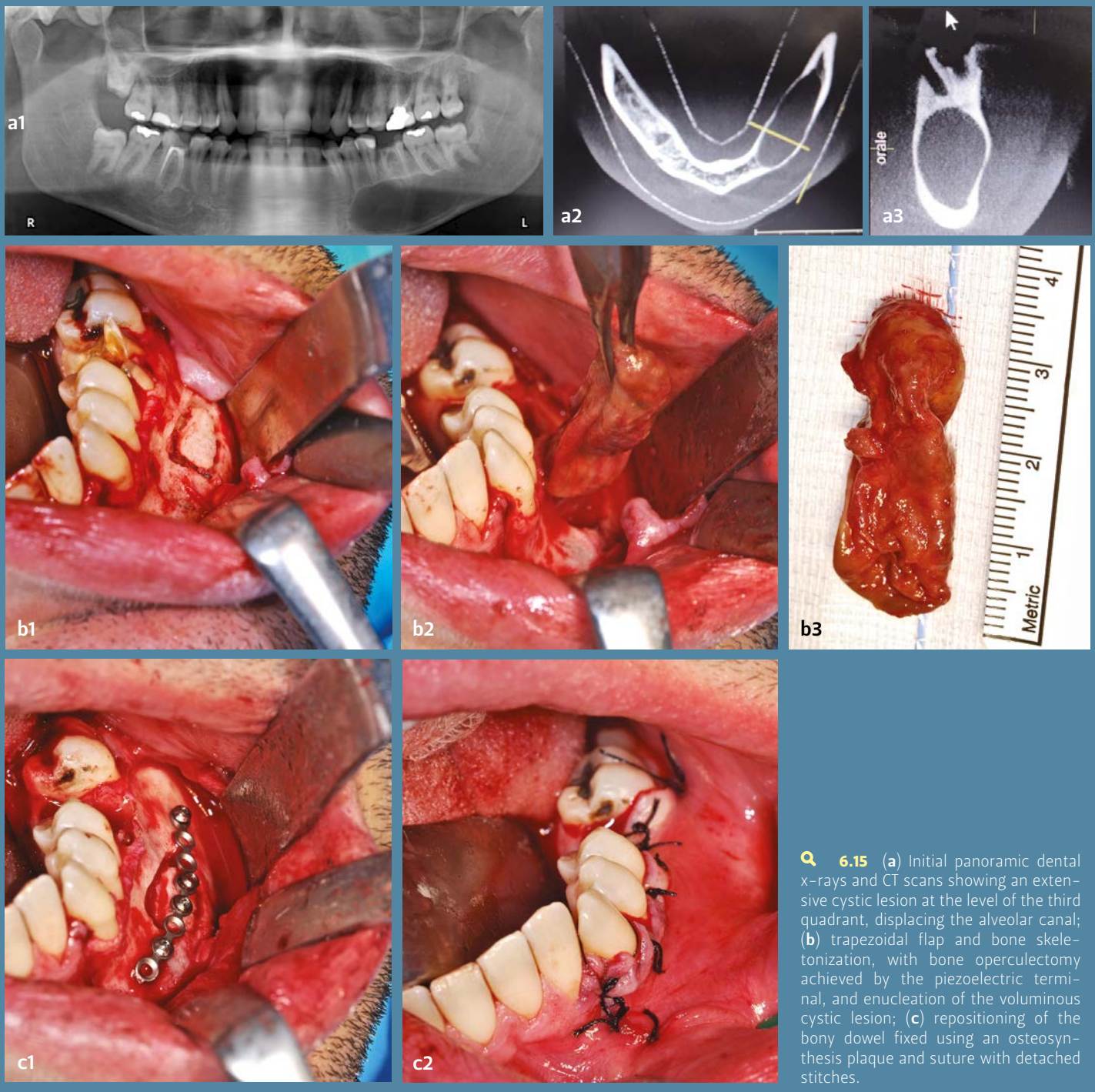
6.13 Insert for the endodontic surgery.



6.14 (**a**) Diamond insert for the removal of a cystic lesion; (**b**) cystic lesion removed.

Clinical case 1

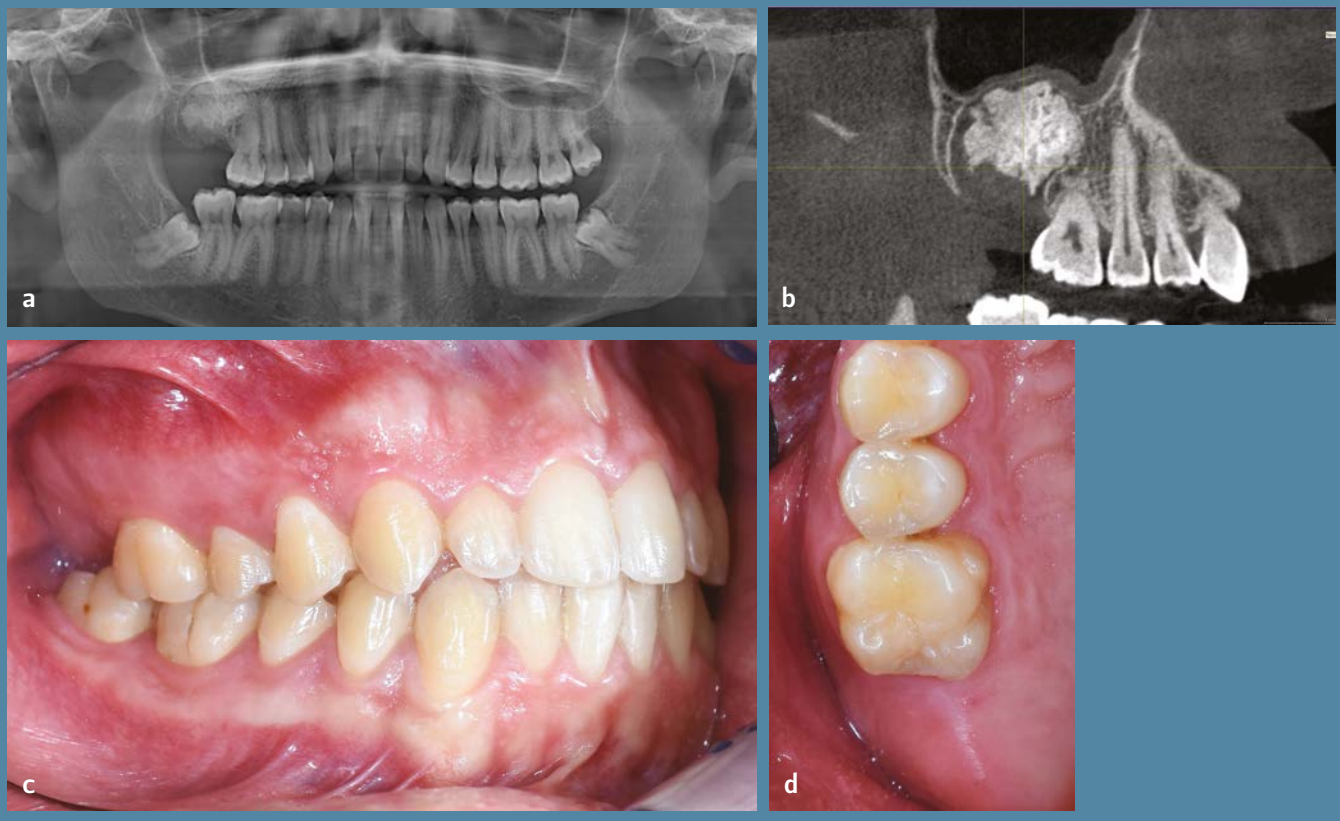
A 35-year-old asymptomatic male patient underwent a panoramic dental x-ray performed during the first visit and it revealed a large area of osteolysis in correspondence with the left mandibular body. Therefore, a cone-beam computed tomography (CBCT) was required to confirm the extensive lesion, which had relocated the alveolar canal to the bottom during the evolutionary process.



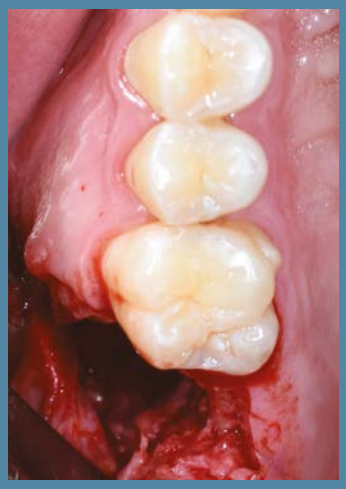
6.15 (**a**) Initial panoramic dental x-rays and CT scans showing an extensive cystic lesion at the level of the third quadrant, displacing the alveolar canal; (**b**) trapezoidal flap and bone skeletonization, with bone operculectomy achieved by the piezoelectric terminal, and enucleation of the voluminous cystic lesion; (**c**) repositioning of the bony dowel fixed using an osteosynthesis plaque and suture with detached stitches.

Clinical case 2

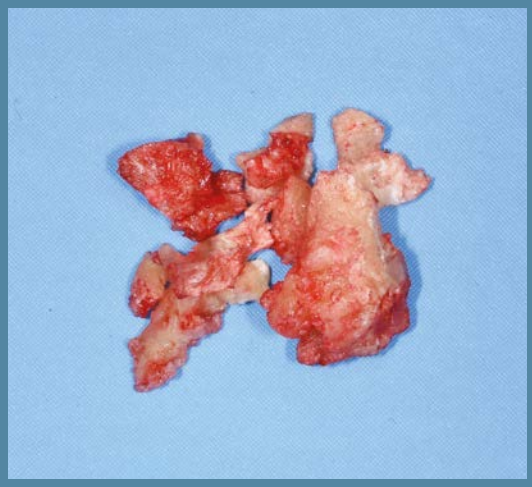
A 27-year-old male patient was diagnosed with an odontoma at the first quadrant several years ago. From the radiological evaluation, an increase in the volume of the lesion compared with the past radiographs was noted , which is in a relation of continuity with the maxillary sinus. Therefore, a CBCT scan was performed that revealed the wide extension of the lesion. We preformed its enucleation using the piezoelectric handpiece.



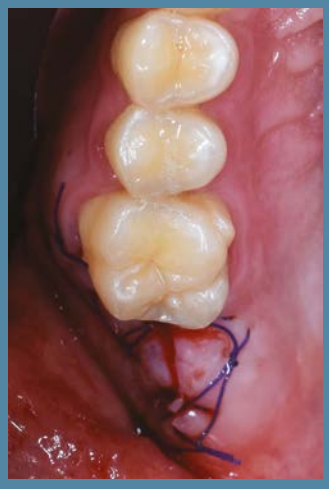
6.16 (**a**) Initial panoramic dental x-ray showing the presence of a radiopaque mass in the area of the first quadrant; (**b**) CBCT scan showing the remarkable size of the lesion, which is in continuity with the maxillary sinus. Initial clinical situation: (**c**) lateral view; (**d**) occlusal view.



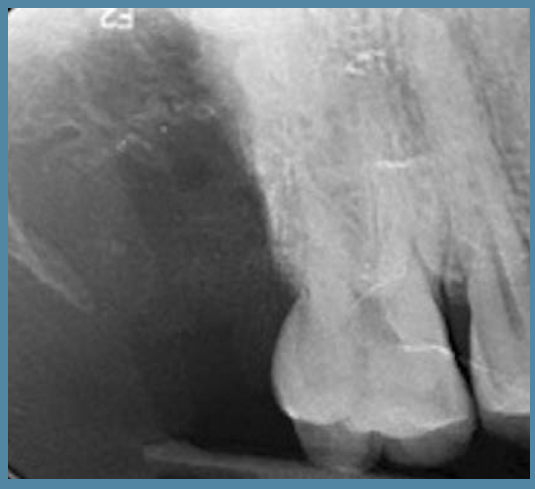
6.17 Removal of the lesion by the piezoelectric terminal with reduced surgical invasiveness.



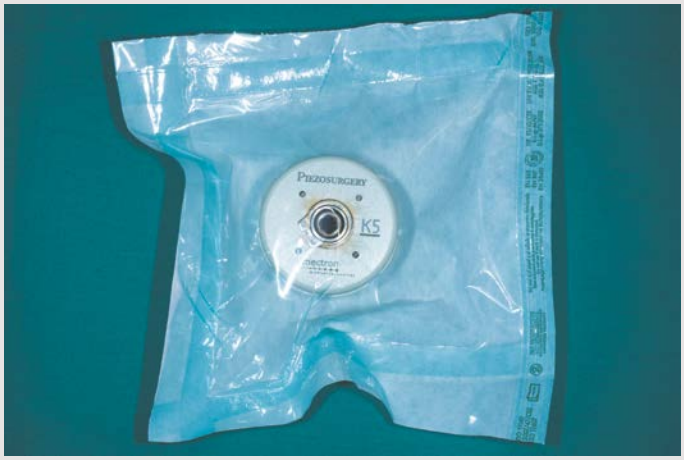
6.18 An enucleated odontoma.



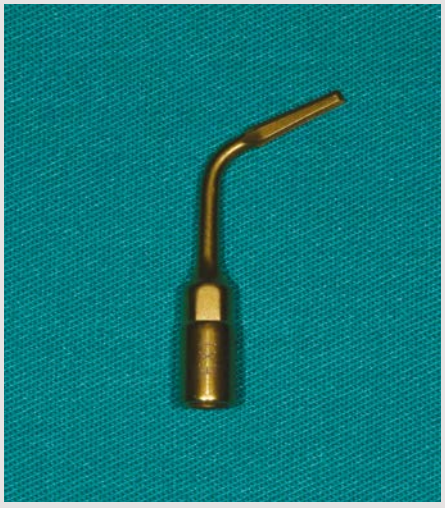
6.19 Suture with detached stitches.



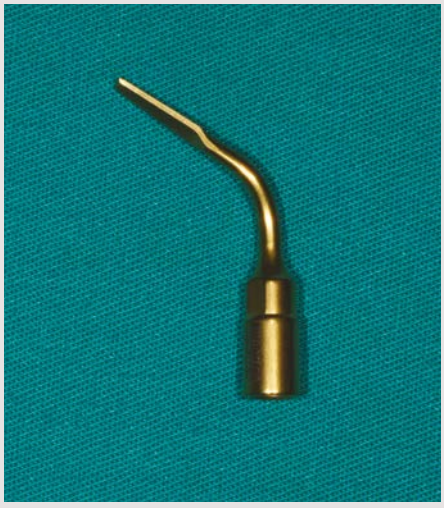
6.20 Intraoral postoperative x-ray highlighting complete odontoma removal.



6.21 A torque wrench for clamping the inserts.



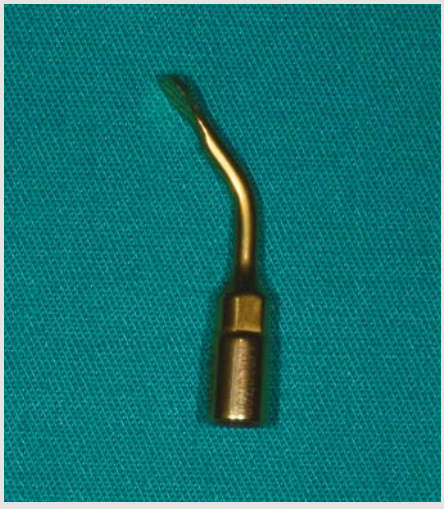
6.22 An extraction insert.



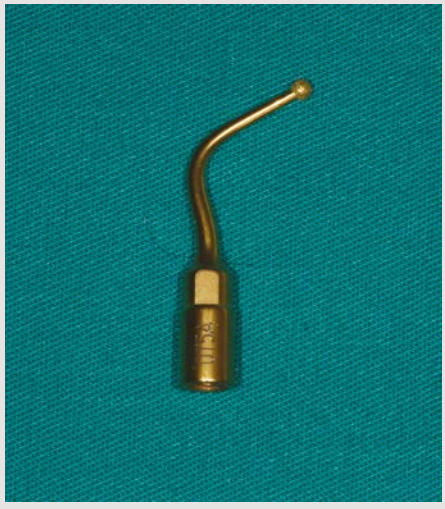
6.23 An extraction insert in rear sections.

6.24 A diamond insert for micrometric osteotomy.

6.25 An insert for the ostectomy of the impacted third molar tooth.



6.26 An insert for osteoplasty.



6.27 An insert for atraumatic osteotomy.

Piezoelectric unit

It is composed of the following (see 3.46 and 3.47, pp. 36–37):

- A generator, for the generation of the electric field that deforms the ceramic pads
- A transducer, for the transfer of energy
- Two connectors (for the handpiece connection) that allow the automatic recognition of the connected handpiece
- Two types of handpieces—one for surgery and one for conventional treatments
- Numerous inserts, each of which has been assigned for a particular procedure
- A torque wrench that allows to tighten the inserts on the handpiece using a defined force to obtain the optimal transmission of energy (6.21)
- Two silent peristaltic pumps
- A pedal to remotely guide the device

In general, the inserts are classified as follows:

- Sharp inserts
- Diamond inserts (with different grain sizes)
- Non-cutting-smoothing inserts, which are not for cutting

The **cutting inserts** are coated with titanium nitride, providing greater surface hardness and maximum cutting power. The **diamond inserts** have a diamond surface that allows performing osteotomy on thin bones or in anatomically delicate areas. They produce a cut that is clinically less efficient and histologically more traumatic than sharp inserts. The **non-sharp inserts** have a steel surface, so they are not coated with nitride. They are used with a low power close to vital anatomical structures, such as membranes and nerves (6.22–6.27).

Piezoelectric extractive techniques

The extraction technique is optimal when root removal occurs without causing damage to the alveolar walls; however, this is difficult, particularly in the presence of ankylosed roots, without the risk of removing a large amount of bone.

With traditional techniques using rotary instruments, a periradicular osteotomy is performed with burs that remove the alveolar bone, in particular the vestibular cortical bone, often compromising the possibility of inserting an implant immediately, and regenerative techniques must be used.

However, with the use of a dedicated piezoelectric insert, ankylotic tooth removal occurs by consuming the root surface, thereby maintaining the integrity of the alveolar bone even when the vestibular wall is extremely thin (6.28–6.33).

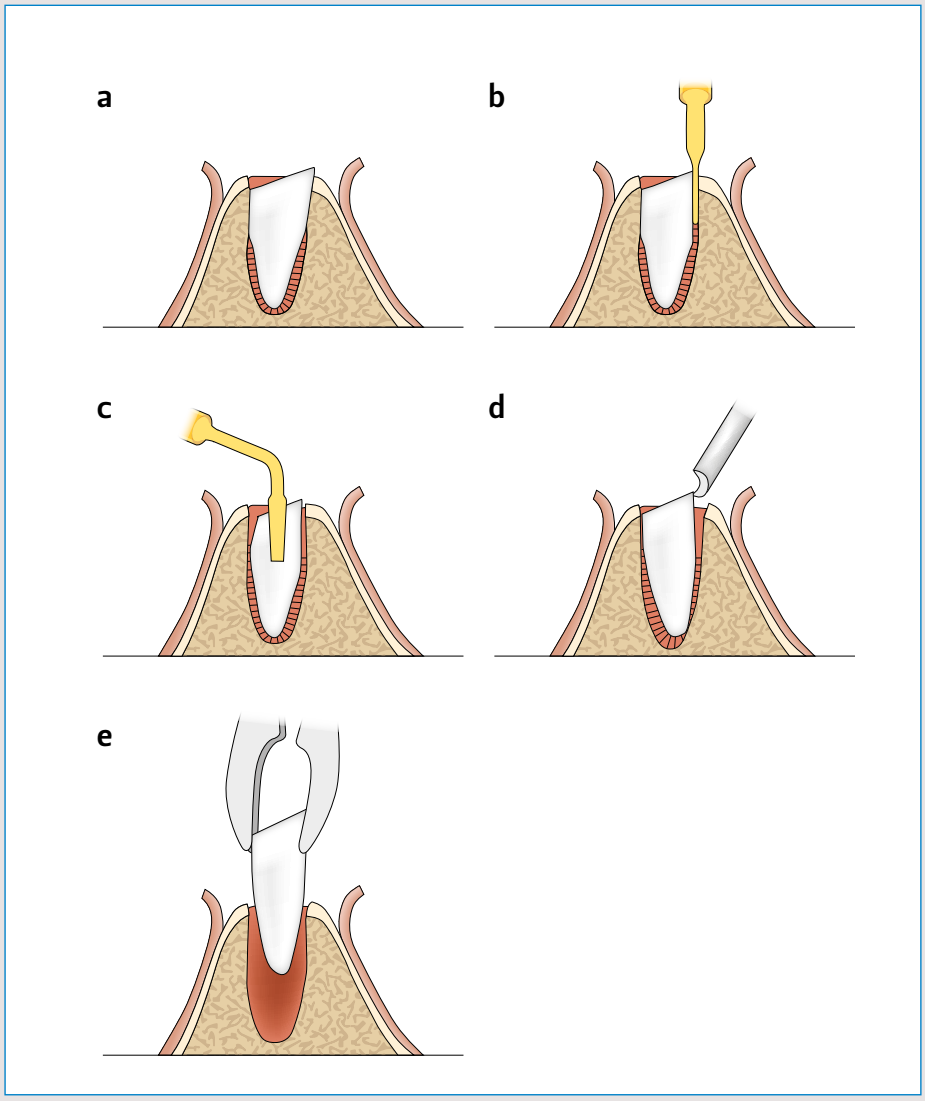
Moreover, in **orthodontic surgical recovery**, the approach to the crown of the impacted tooth with a special insert allows the ability to preserve the integrity of the enamel, and additionally the absence of bleeding allows easy execution of adhesion techniques for applying the orthodontic bracket.

In **extraction of the third molar**, including the cavitation effect of the saline solution, it is possible to reduce the bleeding, providing maximum visibility to the operator, even in the case of root fragment removal.

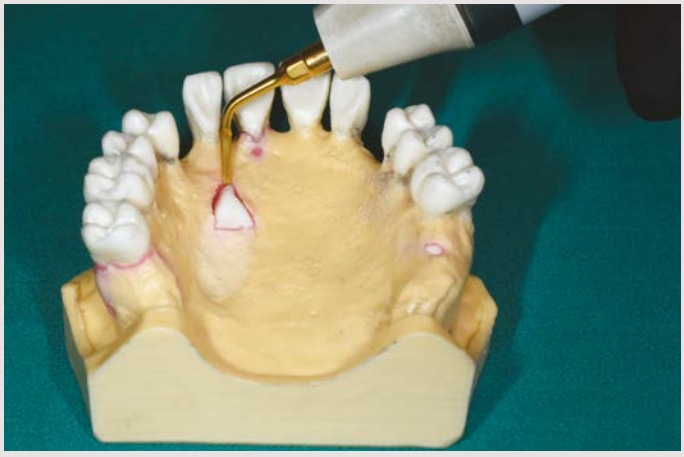
Bone bur cutters require 2–3 kg of pressure on the treatment handpiece, reducing operational sensitivity and surgical control. In contrast, the cut produced by the piezoelectric insert requires a pressure of approximately 500 g only, thereby improving control and sensitivity. The advantages of using the piezoelectric terminal are listed in 6.1.

Table 6.1 Advantages of using the piezoelectric terminal compared with rotating instruments

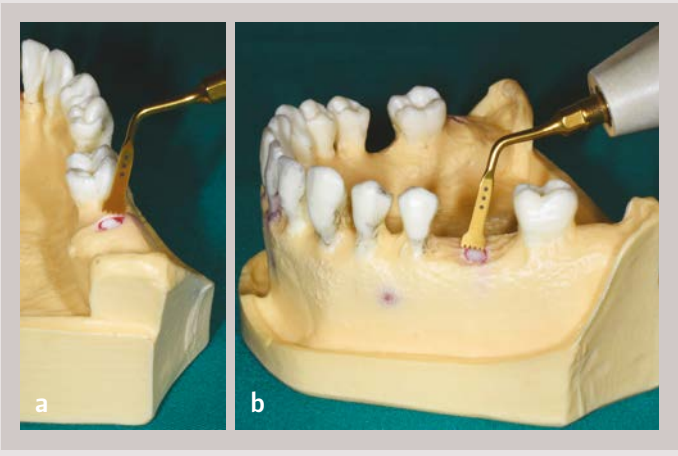
	Piezoelectric terminal	Traditional rotating instrument
Duration of the surgery	+	–
Trismus	–	+
Pain	–	+
Edema	–	+
Aggressiveness for hard tissues	–	+



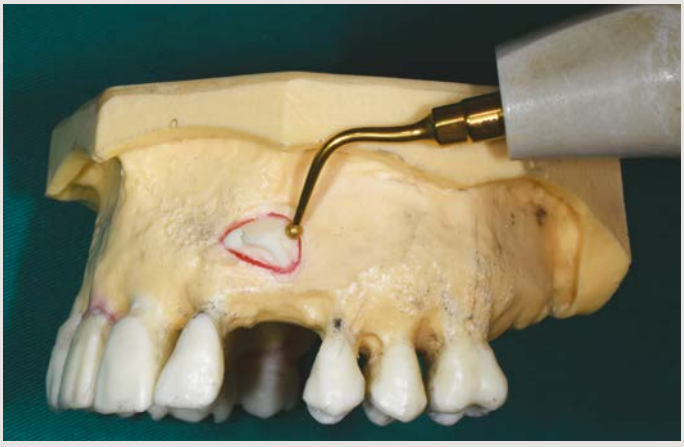
6.28 Technique for using the piezoelectric insert in extractions.



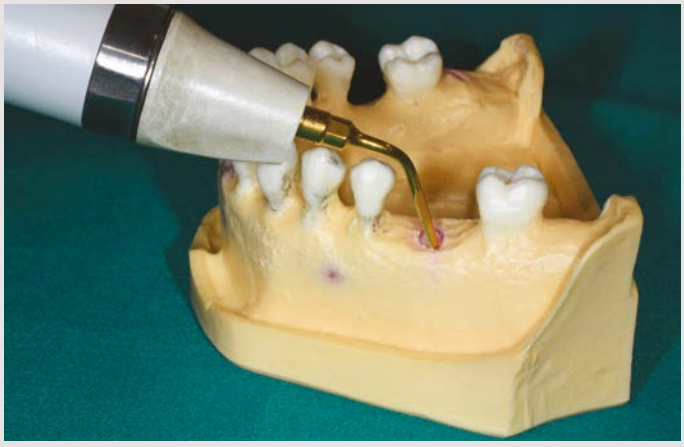
6.29 Use of the cutting insert for ostectomy.



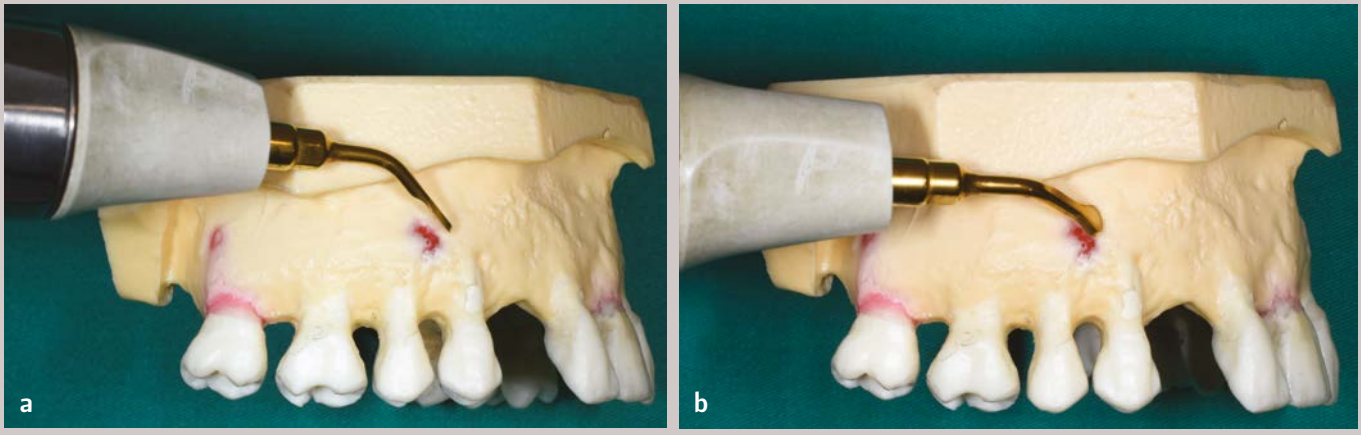
6.30 (**a**) Use of cutting insert for ostectomy of the impacted tooth; (**b**) lateral view.



6.31 Use of the diamond insert in the ostectomy of the impacted tooth.



6.32 Use of the insert for rear sections.



6.33 Use of the insert for osteoplasty.

RECOMMENDED READING

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