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INSPIRA NETWORK

ANTIMICROBIAL BENEFITS OF COPPER IN MANDIBULAR OSTEOGENIC DISTRACTION WITH EXTRAORAL PINS – A REPORT OF FIVE CLINICAL CASES AND A LITERATURE REVIEW

BENEFICIOS ANTIMICROBIANOS DEL COBRE EN LA DISTRACCIÓN OSTEOGÉNICA MANDIBULAR CON DISTRACTORES EXTRAORALES: INFORME DE CINCO CASOS CLÍNICOS Y REVISIÓN DE LA LITERATURA

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ABSTRACT

Infections at pin sites of extraoral distractors in mandibular osteogenic distraction (OD) remain a significant complication. Copper exhibits broad-spectrum antimicrobial activity and has been proposed to reduce pin-site infections.

We present a review of the literature, regarding the case of three adult patients (ages 29, 35, 42) with mandibular micrognathia and obstructive sleep apnea syndrome treated with bilateral sagittal mandibular OD, and two pediatric patients (ages 7, 9) with Goldenhar syndrome treated with vertical branch OD. Smooth 0.5 mm copper wire was circumferentially adapted to the extraoral pins of Orthomax Cibey distractors. Standard perioperative antibiotic prophylaxis and postoperative care were applied. Clinical and radiographic follow-up at 1 week, 3 weeks, 1 month, 3 months, and 6 months showed no pin-site infections in any patient. Adaptation of copper wire to extraoral distractor pins is a simple, cost-effective technique that may effectively prevent pin-site infections in mandibular OD.

Keywords: Copper, mandibular distraction osteogenesis, osteogenic mandibular distraction, pin-site infection.

RESUMEN

Las infecciones en los puntos de inserción de los distractores extraorales en la distracción osteogénica mandibular (DOM) siguen siendo una complicación significativa. El cobre presenta una actividad antimicrobiana de amplio espectro y se ha propuesto que reduce las infecciones en los puntos de inserción de los pines.

Presentamos una revision de la literatura, a propósito del caso de tres pacientes adultos (de 29, 35 y 42 años) con micrognatia mandibular y síndrome de apnea obstructiva del sueño, tratados con DOM sagital bilateral, y dos pacientes pediátricos (de 7 y 9 años) con síndrome de Goldenhar tratados con DOM de rama vertical. Se adaptó circunferencialmente un alambre de cobre liso de 0,5 mm a los pines extraorales de los distractores Orthomax Cibey. Se aplicó profilaxis antibiótica perioperatoria y cuidados postoperatorios estándar. El seguimiento clínico y radiográfico a la semana, a las 3 semanas, al mes, a los 3 meses y a los 6 meses no mostró infecciones en los puntos de inserción de los pines en ningún paciente. La adaptación de alambre de cobre a los pines distractores extraorales es una técnica simple y rentable que puede prevenir de manera efectiva las infecciones en el sitio de los pines en la DOM.

Palabras clave: Cobre, osteogénesis por distracción mandibular, distracción mandibular osteogénica, infección en el sitio de inserción del dispositivo.

INTRODUCTION

Copper was the first metal to be discovered and manipulated by humans, probably due to its abundance in Earth's crust and the ease of extracting its minerals[1]. It occurs naturally and does not require casting[2]. Pure copper metal has been used in the manufacture of various utensils, art objects and coins. In the periodic table, copper is placed above silver and gold. Its main mineral, chalcopyrite, is mined in Chile, Canada and the United States. Due to the ease with which it can be machined and moulded to form wires; it is ideal as a conductor of electricity. On the other hand, its water resistance allows it to be used as a pipe-making material. Moreover, copper can be used in high-temperature superconductors[1]. It is an essential micronutrient in almost all living organisms, including humans; it is involved in fundamental metabolic processes such as vascular growth, collagen deposition and wound re-epithelialization[2,3].

This metal has been used as a disinfectant for centuries. However, in the 1930s, the advance of antibiotics massively overshadowed and considerably reduced research on the antimicrobial effects of metals, including copper. However, the increase in multi-resistant bacteria has meant that antibiotic treatments are no longer as effective in eradicating some infectious diseases completely. The need to eliminate superbugs and the spread of antibiotic resistance have forced the scientific community to search for new treatment approaches in the medical and environmental fields, including the use of iodine, silver, zinc and copper[3,4]. Copper was officially recognised by the United States Environmental Protection Agency (EPA) as the first effective antimicrobial metal: it could kill 99.99% of pathogenic bacteria within 2 hours of contact. The bactericidal property of copper surfaces is known as 'contact killing'[4].

Currently, copper alloys have applications for the prevention of infections in hospitals and health facilities[2]. Copper may be found in handles, doors, pipes and inanimate contact surfaces, or in medical devices[4]. Researchers have studied the effect of copper as a microbial contact agent on resistant bacteria; it demonstrates antibacterial activity under all conditions against *Escherichia coli*, *Clostridium difficile*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa* and *Staphylococcus aureus*[2,4]. Researchers have suggested different copper antimicrobial mechanisms, including membrane damage and DNA degradation. Most bacteria exposed to copper have survival and adaptation systems that only protect them for a couple of minutes before they die. Therefore, long-term bacterial resistance and survival to copper exposure have not been observed[4]. Copper also acts as a surface antifungal agent. However, there has been less research on its antifungal activity compared with its antibacterial activity; it mainly damages the membranes of fungi such as *Candida albicans* and *Saccharomyces cerevisiae* via contact. Finally, the mechanism of copper toxicity is independent of the type of virus: it has demonstrated effectiveness against influenza viruses, human immunodeficiency virus (HIV) and severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2)[4,5].

During the First World War, severe facial traumas were treated with metal alloys, such as osteosynthesis elements and stabilising arcs, among others. At the end of the 17th century, a dental surgeon became a fundamental member of an army's health team. This medical professional used devices to treat facial fractures, and these experiences greatly benefited the evolution of oral and maxillofacial surgery[6]. As maxillofacial surgery has developed, there has been increased use of metals such as titanium for treatment; this metal is chemically inert, low cost and widely available[7]. Per-Ingvar Brânemark studied the blood flow of the femur of rabbits by placing intraosseous titanium chambers; he discovered that when they were removed, the titanium was firmly attached to the bone. This discovery led to the concept of osteointegration, with Brânemark recognized as the father of modern dental implantology. After this initial observation, it took years to confirm that titanium could integrate into living tissue took years[8]. Despite the great advance in the use of titanium, surgical steel and other alloys are still used in the manufacture of devices developed for craniofacial anomalies, including osteogenic distractors[9]. These devices promote histogenesis by combining osteotomy with gradual traction forces[10].

There have been many authors who, following the technique of Dr. Gavriil Ilizarov[11-13], have reported various surgical techniques and devices to achieve osteogenic distraction (OD) of the jaws, most notably McCarthy[14-18], among others.

The distraction devices can be extraoral, intraoral or subcutaneous[10]. The incidence of OD complications is 34.4 % in the intervention population[19]. The main complications are dental injuries, hypertrophic scar, mandibular nerve injuries, infections, an inappropriate distraction vector and pseudoarthrosis[20]. Infections range from superficial cellulitis to osteomyelitis in 8.3-9.5 % of patients[19,20]. The most common complication of external/extraoral distractors being the over-infection of the pin site, where the stem emerges, the active end of the device[9,20]. The aim of this study was to conduct a literature review based on 5 clinical cases in which copper wires adapted to the extraoral pins of the OD were used to prevent bacterial colonisation and consequent infection of the surgical site.

CASE REPORT

Patient demographic information

We present case reports of five patients, two male paediatric patients aged 7 and 9 years, two male adult patients aged 29 and 35 years, and one female adult patient aged 42 years. The two paediatric patients had Goldenhar syndrome and hemifacial microsomia type I, according to Pruzansky's classification, and the three adult patients had skeletal class II, micrognathia and obstructive sleep apnoea and hypoapnoea syndrome. The patients were referred to a private professional maxillofacial surgery practice in 2019 and 2024 for assessment and management of severe mandibular hypoplasia. Osteogenic mandibular distraction was performed in each patient. For the two paediatric patients with Goldenhar syndrome, a vertical mandibular branch OD was performed (Figure 1), and in the three adult patients with micrognathia, a bilateral sagittal mandibular branch OD was performed (Figure 2). The distractors employed were Orthomax Cibey (Ortho Max® Manufacturing Company Pvt. Ltd., Vadodara, Gujarat, India) 20 mm mandibular X0101-20 for each patient (Table I). These five cases were selected because they fulfilled strict inclusion criteria: use of copper-adapted distractors, complete clinical and radiographic follow-up of at least six months, and absence of systemic comorbidities that could bias the results. During the study period, our institution treated a larger cohort of patients with mandibular distraction; however, only these five met all the criteria for inclusion. In our overall caseload, we documented instances of infection in mandibular distraction procedures performed without copper wire adaptation, but none of the five patients reported here developed pin-site infections.

Diagnostic evaluation

A clinical and imaging study was performed prior to the surgical intervention; it comprised a clinical facial analysis, panoramic radiography, lateral and posteroanterior cephalometry and computed tomography (CT). The obtained files were analysed with the Romexis software to obtain a multiplanar and three-dimensional reconstruction. Romexis® software (Planmeca Oy, Helsinki, Finland) was used for case planning and 3D reconstruction, and CAD/CAM cutting and positioning guides were fabricated based on the virtual plan, ensuring precise osteotomy and accurate distractor placement. Before performing the intervention, each case was carefully analysed to determine the distraction vector and the type of OD device.

Therapeutic intervention and Surgical Technique

After surgical planning, the procedures were performed in each patient under general anaesthesia. Each patient was subjected to osteogenic mandibular distraction (Figure 1.A). Once the procedure was completed, a 0.5 mm diameter smooth copper wire was fitted, with a circular path, to cover at least 2 cm of the stem of the OD. Note that the stem is the active extraoral end that allows the device to rotate to achieve the separation of the osteotomised area. Each copper wire that was positioned remained in contact with the patient's skin without damaging it and with sufficient retention achieved through careful adaptation, thus avoiding the displacement of this material (Figure 2.A).

Each patient was given intravenous antibiotic treatment, cefazolin 1 g, 30 minutes prior to surgery. Postoperatively, each patient received intravenous cefazolin 1 g every 8 hours during the 2 days of hospitalisation. Subsequently, an outpatient regimen of amoxicillin 1 g was continued every 12 hours for 7 days. This regimen follows the institutional protocol for maxillofacial surgery in our center, aiming to cover both skin flora and oral bacterial contamination. Cefazolin was selected for perioperative prophylaxis, while amoxicillin was prescribed for postoperative coverage; the choice was based on clinical guidelines applied in our institution rather than on empirical criteria

In addition, each patient was advised to rinse their mouth with colutorium 0.12 % chlorhexidine three times a day for 14 days, and to take non-steroidal anti-inflammatory drugs to manage pain and inflammation. The distraction rods were deliberately left exposed for the entire 6-month consolidation phase, rather than being cut or removed after activation, to ensure device stability and prevent micromovements. This approach, although potentially increasing the risk of secondary infection, was chosen to preserve biomechanical security and was well tolerated in this series.

Monitoring and results

The patients were monitored clinically and radiographically in the immediate postoperative period (Figure 1.B), and then 1 week, 3 weeks, 1 month, 3 months (Figure 2.B), 6 months and annually. There were no adverse intraoperative and postoperative events or complications in the short and long term. None of the three patients developed a local skin infection related to the external puncture site of the distractor until the removal of the OD devices 6 months after the procedure.

DISCUSSION

OD is a method used for bone elongation; the application of gradual mechanical traction allows the correction of bone deformities and deficiencies. The effectiveness of the treatment is influenced by the patient's age, the surgical technique used, distraction speed and rhythm, the latency period, the duration of the containment period and the type of distraction device used. However, the specific parameters of OD are not completely standardised, which leads to significant variability between different patient groups[10].

The incidence of complications associated with OD is 34.4 % in the population that received the intervention[19]. Meling et al.[21] compared external and internal OD complications and found no statistically significant differences between the groups, with most infections manifesting locally. Swennen et al.[10] conducted a literature review with respect to the craniofacial skeleton, considering mandibular, maxillary, bimaxillary, midfacial and/or cranial OD. They found that 19.6 % of all patients presented some degree of infection, either minor local, pin or severe. A pin-tract infection (PTI) is the most common complication of external distractors, especially in prolonged applications. The common infectious agents include *Staphylococcus epidermis*, *S. aureus* and *E. coli*, commensals of the skin and mucous membranes[22]. Preventive bactericidal methods such as metal alloys with nanoparticles of silver, zinc or titanium, and coatings with antibiotics or chemicals such as hydroxyapatite with chlorhexidine are being explored to reduce infections[22].

Researchers have highlighted the biocidal effect of copper against various pathogens, including bacteria[23,24], fungi and viruses[25]; it is much stronger compared with aluminium and stainless steel[26]. Considering the continuous emergence of antimicrobial resistance, there is a need to reduce antibiotic consumption in health care[24]. Copper has emerged as a non-pharmacological alternative for the prevention and treatment of infections. Sustained exposure to high cooper concentrations is lethal for microorganisms tolerant to antimicrobial agents. Copper's rapid and multifactorial mechanism of action involves DNA denaturation, which significantly reduces the probability of that microorganisms will develop resistance[4,27].

Solid copper surfaces are very effective, killing 99.9 % of pathogenic bacteria within 2 hours of contact. These surfaces prevent repeated recolonisation and inhibit bacterial growth between routine cleaning activities[4,28]. The antibacterial nature of copper contact surfaces has been instrumental in reducing environmental pollution in the health sector[29]. This approach replaces metallic objects with copper alloys to significantly reduce bacterial colonisation and to effectively prevent healthcare-associated infections at a low cost[25,30]. Studies have shown that continuous limitation of the bioload at surgical sites results in a 58 % decrease in the rate of acquisition of hospital infections. When copper alloys are used, this rate decreases up to 10% more, favouring the prevention of these nosocomial infections[29].

Another way to use copper in a clinical setting is in impregnated textiles[31], which have a wide spectrum of antimicrobial and antifungal properties[32]. Copper oxide can be impregnated in personal protective equipment, such as respiratory masks, and wound dressings to promote healing[33], and incorporated into bed sheets, the coverings of intensive care beds[29] and clinical uniforms[25]. Copper is considered safe for dermal use. Indeed, it is unlikely to produce adverse reactions considering the fact that it was used for years in intrauterine devices (IUDs) as an effective and long-lasting contraceptive method[24,26,32]. Copper socks are used as a preventive measure and to treat manifestations of tinea pedis (athlete's foot), and are recommended for use in people over 65 years of age or people with decompensated diabetes[32].

In biomedicine, copper nanoparticles and their organic complexes have attracted attention for their physicochemical characteristics and pharmacokinetic properties in recent years.

Elevated intracellular copper levels in different types of cancer suggest its potential for the development of new oncological therapies and biomedical imaging applications, especially in the treatment and diagnosis of tumours[34,35].

In orthopaedics and traumatology, many authors have explored strategies to reduce the incidence of implant-associated infections. For example, Shirai et al.[36] and Chai et al.[37] conducted studies in animal models on alloys of titanium and stainless steel with copper, respectively. The implants in both studies were exposed to *S. aureus* and *E. coli*. These alloys significantly inhibited inflammation and infection, demonstrating strong antimicrobial activity and biocompatibility, suggesting their use as a promising biomaterial[36,37]. Similarly, Prinz et al.[38] used copper-coated nails for the surgical fixation of a tibia fracture inoculated with bacteria in an animal model. Ti6Al4V nails were coated with copper, then subjected to electrolytic oxidation with plasma to create a porous oxide layer. Subsequently, copper ions were deposited galvanically on the surface by using a bath saturated with copper acetate. After coating, the nails were polished with glass spheres to produce a smooth surface. The results showed that the copper released by the implant was locally restricted to the fracture site, and it completely prevented biofilm-forming bacteria from adhering to the titanium implant. There were more calluses observed through radiographic examination, indicating bone formation stimulated by the release of copper ions, allowing the prevention of bacterial infection and the stimulation of regenerative processes[38]. These experiments involve a strategy of chemical bonding of copper to different materials; this process is time-consuming, laborious, complex and relatively inefficient. By contrast, in the five cases described in this study, a physical bonding method was used. It involved an adaptation of copper wire to extraoral rods, allowing a more effective procedure that optimised time and resources, considering that copper is a widely available and economical metal.

An important consideration concerns the management of stems after the activation phase. In our series, the stems were intentionally left exposed until the end of the consolidation phase. This decision aimed to ensure mechanical stability and avoid micromovements that could jeopardize bone formation. Although this strategy may increase the theoretical risk of secondary infection or patient discomfort, no major infections were observed in our five patients. In contrast, other authors advocate trimming or removing stems once activation is completed, reporting potential advantages in comfort and hygiene but at the cost of increased surgical manipulation. These alternative strategies should be compared in larger prospective studies to establish evidence-based recommendations.

The objective of using copper in maxillofacial orthopaedic surgical devices is to avoid colonisation by bacteria with consequent infection and failure of the surgical intervention due to its known antibacterial activity against a broad spectrum of bacteria and low incidence of resistance. Currently, there is no scientific evidence in humans about copper and its use in orthopaedic surgical materials, such as fixations, distraction devices, among others. The abovementioned studies were carried out in animal models. Shirai et al.[36] and Chai et al.[37] showed that titanium and copper alloys substantially reduced the incidence of pin tract infections. Shirai et al.[36] observed the formation of deep abscesses in only 2 of the 12 copper alloy pins. Of the five cases presented in this article, none presented signs or symptoms of infection until the removal of the OD devices, 6 months after the procedure.

At present, there is no universally accepted protocol for optimal pin site care. It is suggested to use large dressings installed at the ends of the external distractors to reduce the range of movement at the skin–pin interface and to use gauze or sponge cubes to apply direct pressure to the area[22]. The copper wire used in the five cases described in the present study fulfils the antibacterial contact function, decreasing the appearance of signs and symptoms associated with PTIs. Copper is used so that its properties of conductivity, malleability and flexibility characteristic are maintained while it acts as an antibacterial physical barrier and external stopper. Copper prevents complications associated with PTIs and thus reduces patient discomfort, hospitalisation times, re-interventions and the use of resources.

Prior to our study, the use of copper for OD in humans had not been reported in the literature. The cases reported in the present study have demonstrated that using copper wires adapted to an extraoral distractor for mandibular OD is an innovative technique. We propose using plain copper wires, 0.5 mm in diameter, circumferentially adapted to OD devices or extraoral stems, with the aim of reducing the incidence of infections associated with these devices. This approach represents a preventive, non-pharmacological, economical and accessible alternative to reduce the incidence of extraoral distractor infections in the postoperative period and thus to increase the success of the surgical procedure.

In summary, copper adaptation in extraoral mandibular distractors appears to be a safe and inexpensive preventive measure. The comparison of exposed vs. trimmed stems after

activation, as well as long-term follow-up of larger samples, remain important areas for future research.
The antimicrobial activity of copper may reduce the incidence of infections of extraoral distractors used in mandibular osteogenic distraction. Adapting copper wire to these devices is an effective, economical, accessible and easy-to-perform method for preventing infections.

CONCLUSIONS

Incorporating copper wires into the extraoral stems of mandibular distraction devices may represent a valuable preventive measure against pin-site infections, showing no cases of infection in our five-patient series.
Leaving the stems exposed throughout the consolidation phase ensured mechanical stability and complete device function; however, this strategy may increase patient discomfort and theoretical risk of secondary infection. Alternatives, such as trimming or removing the stems after activation, should be further evaluated and compared in controlled studies. The combined antibiotic protocol employed in our institution (perioperative cefazolin followed by postoperative amoxicillin) was effective in this series. Nevertheless, antibiotic selection should always be tailored to local epidemiology, institutional guidelines, and patient-specific risk factors.
Copper adaptation offers a simple, economical, and non-pharmacological adjunct to reduce the incidence of complications associated with mandibular distraction, warranting larger studies to validate its long-term effectiveness and reproducibility.

ETHICAL APPROVAL

Ethical Approval: This study was performed in line with the principles of the Declaration of Helsinki, the identity of the patients remained anonymous according to the ethical principles.
Consent to participate: The use of the clinical cases with their respective images is supported by the informed consent obtained and signed by the patient and the adults legally

responsible for the individuals included in this study.

Consent to publication: The authors state that all the patients and the legal guardians of the participants in the human research gave their informed consent for the publication of the images shown in Figures 1a, 1b, 2a and 2b.

CONFLICT OF INTEREST

The authors declare that the research was carried out in the absence of any commercial or financial relationship that could be interpreted as a potential conflict of interest.

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Author contributions: All authors contributed to the conception and design of the study. S.D.A and F.F.P. prepared the material, collected and analysed the data. The disagreements were resolved by consensus and discussion with a third reviewer, P.T.C., who acted as judge to resolve the disagreements generated. All authors read and approved the final manuscript.

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Figure 1. Vertical osteogenic distraction of mandibular ramus. (1.A) Installation of the extraoral device. (1.B) Three-dimensional reconstruction based on computed tomography, with the extraoral distractors visualised in position in the immediate postoperative period.

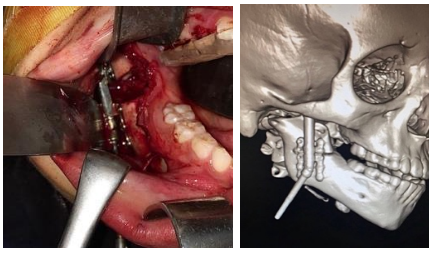

Figure 2. Sagittal osteogenic distraction of bilateral mandibular ramus. (2.A) The extraoral distractor in position together with adapted copper wires. (2.B) Three-dimensional reconstruction based on computed tomography, with the extraoral distractors visualised in position three months postoperative period.

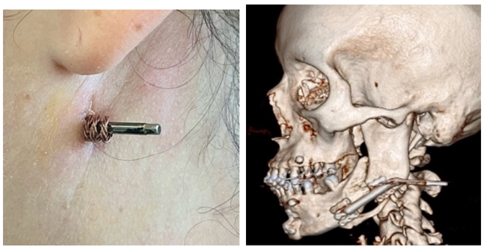

Table I. Epidemiological and descriptive data of the patients presented in this study and the surgical technique used.

Patient	Age (years)	Gender	Principal diagnosis	Comorbidities	Osteogenic distraction	Distractor type
1	7	Male	Goldenhar syndrome and hemifacial microsomia type I	No	Vertical mandibular branch	Orthomax Cibey 20 mm mandibular X0101-20 oral distractor
2	9	Male	Goldenhar syndrome and hemifacial microsomia I	No	Vertical mandibular branch	Orthomax Cibey 20 mm mandibular X0101-20 oral distractor
3	29	Male	Class II skeletal malocclusion, micrognathia and obstructive sleep apnoea and hypoapnoea syndrome	No	Sagittal of bilateral mandibular branches	Orthomax Cibey 20 mm mandibular X0101-20 oral distractor
4	35	Male	Class II skeletal malocclusion, micrognathia and obstructive sleep apnoea and hypoapnoea syndrome	Arterial hypertension, obesity	Sagittal of bilateral mandibular branches	Orthomax Cibey 20 mm mandibular X0101-20 oral distractor
5	42	Female	Class II skeletal malocclusion, micrognathia and obstructive sleep apnoea and hypoapnoea syndrome	Arterial hypertension	Sagittal of bilateral mandibular branches	Orthomax Cibey 20 mm mandibular X0101-20 oral distractor