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TAILORED CONDYLECTOMY: IN-HOUSE 3D SOLUTIONS FOR MANAGING ACTIVE CONDYLAR HYPERPLASIA

CONDILECTOMÍA A MEDIDA: SOLUCIONES 3D PRECISAS PARA TRATAR LA HIPERPLASIA CONDÍLEA ACTIVA

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ABSTRACT

Background: Condylar hyperplasia (CH) is a progressive mandibular condyle overgrowth leading to facial asymmetry and malocclusion. While SPECT imaging is commonly used for diagnosis, its limitations underscore the need for complementary diagnostic methods. Proportional condylectomy has emerged as an effective treatment, addressing both pathological growth and vertical excess in a single procedure.

Methods: Six patients with active unilateral CH underwent proportional condylectomy guided by in-house 3D virtual surgical planning (VSP). Preoperative CBCT and SPECT confirmed diagnosis, with DICOM data processed using *Brainlab iPlan CMF* and *Meshmixer* to generate mirrored hemimandible references and osteotomy planes. Patient-specific cutting guides were 3D-printed for precise piezosurgical osteotomies via a preauricular approach. Postoperative outcomes were assessed via CBCT superimposition (*CloudCompare*) and clinical evaluation.

Results: All procedures were completed successfully without complications. Postoperative CBCT analysis revealed a mean deviation of 0.235 mm from the planned resection, with discrepancies limited to non-critical regions. All patients achieved functional stability (>35 mm mouth opening) and significant symmetry improvement. Transient occlusal pre-contacts were corrected with orthodontics.

Conclusion: Proportional condylectomy, supported by in-house 3D planning and cutting guides, offers a precise, single-stage solution for active CH. This protocol enhances surgical accuracy, reduces costs, and minimizes the need for secondary procedures. Further studies with larger cohorts and long-term follow-up are warranted.

Keywords: Condylar hyperplasia, proportional condylectomy, 3D virtual surgical planning, in-house 3D printing, mandibular asymmetry.

RESUMEN

Introducción: La hiperplasia condílea es un sobrecrecimiento progresivo del cóndilo mandibular que provoca asimetría facial y maloclusión. La condilectomía proporcional se ha revelado como un abordaje eficaz, que trata tanto el crecimiento patológico como el exceso vertical en un único procedimiento.

Métodos: Seis pacientes con hiperplasia condílea activa unilateral se sometieron a una condilectomía proporcional guiada utilizando guías de corte diseñadas e impresas “in-house”. Los datos DICOM se procesaron con *Brainlab iPlan CMF* y *Meshmixer* para generar la imagen especular de la hemimandíbula sana y diseñar los planos de osteotomía. Se imprimieron en 3D guías de corte específicas del paciente para realizar osteotomías precisas mediante un abordaje preauricular. Los resultados postoperatorios se evaluaron mediante superposición CBCT (*CloudCompare*) y evaluación clínica.

Resultados: Todos los procedimientos se completaron con éxito sin complicaciones. El análisis postoperatorio reveló una desviación media de 0,235 mm de la resección planificada, con discrepancias limitadas a regiones no críticas. Todos los pacientes consiguieron estabilidad funcional (> 35 mm de apertura bucal) y una mejora significativa de la simetría. Los contactos prematuros oclusales transitorios se

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corrigieron con ortodoncia.

Conclusiones: La condilectomía proporcional, con el apoyo de la planificación 3D "in-house" y las guías de corte, ofrece una solución precisa en una sola fase para la hiperplasia condílea activa. Este protocolo mejora la precisión quirúrgica, reduce los costes y minimiza la necesidad de procedimientos secundarios. Se requieren estudios adicionales con cohortes más amplias y seguimiento a largo plazo.

Palabras clave: Hiperplasia condílea, condilectomía proporcional, planificación 3D in-house, guías de corte, asimetría mandibular.

INTRODUCTION

Condylar hyperplasia (CH) is a non-neoplastic, progressive overgrowth of the mandibular condyle, leading to facial asymmetry, malocclusion, and temporomandibular joint dysfunction[1,2]. The etiology remains unclear, though hormonal, genetic, and traumatic factors have been implicated[3]. Unilateral condylar hyperplasia (UCH) predominantly affects young individuals, with a higher incidence in females. Clinically, patients often present with progressive chin deviation, malocclusion, occlusal canting, and a posterior open bite, significantly impacting both function and facial aesthetics[4].

Accurate diagnosis hinges on differentiating active from inactive forms of UCH, as this distinction directly influences treatment decisions. Imaging modalities such as cone-beam computed tomography (CBCT), and single-photon emission computed tomography (SPECT) are central to this process. CBCT provides detailed three-dimensional visualization of condylar morphology, enabling assessment of structural asymmetry, while SPECT quantifies metabolic activity to identify hyperactive growth centers. A 10 % asymmetry in condylar uptake on SPECT is traditionally considered diagnostic of active UCH, warranting surgical intervention. However, recent studies challenge the reliability of SPECT as a standalone diagnostic tool, reporting sensitivity and specificity values of 81 % and 63 %, respectively, with a high false-positive rate (30 % of cases). These findings suggest that SPECT may detect metabolic activity unrelated

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to growth, such as inflammation or asymmetric joint loading, underscoring the need for complementary diagnostic methods[5,6].

The clinical progression of asymmetry remains the cornerstone for interpreting imaging findings. Longitudinal assessment of mandibular changes—through serial CBCT scans, clinical photographs, or dental casts—is critical to confirm active growth. For instance, morphometric analyses have shown that true active UCH exhibits measurable structural changes (>1 mm/year) in the chin and mandibular body, while false-positive SPECT results often lack such progression. This aligns with the growing consensus that SPECT should not be the sole basis for surgical decisions but rather one component of a comprehensive diagnostic workflow[7].

Treatment strategies vary based on disease activity. Active unilateral condylar hyperplasia (UCH) typically requires condylectomy to arrest pathological growth, while inactive forms may be managed with orthognathic surgery alone[6]. High condylectomy—resection of the superior 3–5 mm of the condylar head—has been the traditional approach, often combined with orthognathic surgery to correct resultant deformities. However, proportional condylectomy has emerged as a superior alternative, as it removes the hyperactive growth center while simultaneously addressing vertical excess, thereby reducing the need for secondary procedures[8,9]. Advances in virtual surgical planning (VSP), computer-aided design and manufacturing (CAD/CAM), and 3D-printed cutting guides have further refined these techniques, enabling precise, patient-specific osteotomies that optimize both functional and aesthetic outcomes.

This article presents a standardized protocol for treating UCH using proportional condylectomy with in-house designed and manufactured surgical guides in a tertiary hospital setting. The study was approved by the Ethics Committee of La Paz University Hospital as part of an undergraduate thesis (TFG) exploring 3D planning for cutting guides and anatomical models in maxillofacial surgery pathologies. We integrate virtual surgical planning (VSP) and point-of-care 3D printing to enhance accuracy and reproducibility. Our protocol emphasizes minimally invasive techniques and postoperative orthodontic management to achieve stable occlusal and aesthetic outcomes.

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By leveraging hospital-based 3D printing capabilities, we aim to streamline the surgical workflow, reduce costs, and improve accessibility to advanced care. This protocol not only aligns with current evidence supporting proportional condylectomy but also introduces innovations in guide design and intraoperative validation, offering a reliable solution for UCH that minimizes the need for additional surgeries.

MATERIAL AND METHODS

Patient selection

Six patients were treated from January 2024 to March 2025 at the Maxillofacial Surgery Department of La Paz University Hospital. The cohort included 4 females and 2 males, with ages ranging from 13 to 17 years (mean age: 15.2 ± 1.5 years). All patients had a diagnosis of active condylar hyperplasia and met the following inclusion criteria:

- Progressive asymmetry of the lower face.
- CT scan showing unilateral condylar enlargement.
- SPECT scan revealing a difference greater than 10 % in condylar uptake.

The exclusion criteria were as follows:

- Condylar enlargement associated with neoplastic growths.
- Bilateral condylar involvement (affecting both mandibular condyles).
- Previous facial or condylar surgical procedures.

Virtual planning

Preoperative CT scans provided DICOM data, which were imported into *Brainlab iPlan CMF software* for 3D segmentation of the mandible. The object was exported to the Meshmixer software as Standard Tessellation Language (STL) file. The healthy hemimandible was mirrored using to create a reference model for surgical planning.
The osteotomy plane was designed based on the mirrored healthy condyle, ensuring proportional condylectomy. Specifically, the plane was oriented to pass through the

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highest point of the condylar head, allowing for adequate bone remodeling of the residual condyle while preserving mandibular function (Figure 1). This approach facilitated anatomical reconstruction of the condylar morphology.

A custom surgical cutting guide was then designed, ensuring precise adaptation to the lateral condylar pole. The guide was 3D-printed using biocompatible "Surgical Guide" resin (*Formlabs, Somerville, MA*) to transfer the virtual plan accurately to the surgical field.

Surgical Procedure and postoperative care

All surgeries were performed under general anesthesia by the same surgical team. A preauricular endaural approach was used, with careful dissection to protect the facial nerve. The temporomandibular joint capsule was accessed, and the condylar head was exposed. The 3D-printed guide was secured to the hyperplastic condyle with an 11-mm screw, and a piezosurgical osteotomy was performed following the virtual plan (Figure 2).

Following surgery, all patients underwent a combined regimen of physiotherapy and orthodontic treatment aimed at restoring mandibular function and occlusion. Physiotherapy was initiated immediately postoperatively, focusing on mandibular opening exercises to achieve a normal range of motion within 10 days. Orthodontic treatment involved the placement of orthodontic appliances with three main objectives: 1) to eliminate premature contacts on the operated side, 2) to correct maxillary canting as much as possible, and 3) to achieve stable occlusion.

RESULTS

All surgical procedures were completed successfully without intraoperative complications. No instances of facial nerve palsy—whether transient or permanent—were documented during follow-up. Mandibular function was preserved in all cases, with patients achieving normal mouth opening exceeding 35 mm at the 1-year evaluation. Notably, none of the subjects reported persistent pain in the operated joint.

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The resected bone volume ranged between 7 and 13 mm (mean resection: 9 mm). The postoperative evaluation was performed by superimposing a 3D model generated from a CBCT scan taken three months after surgery onto the virtual surgical plan using *CloudCompare* for deviation analysis. The quantitative assessment showed a mean surface deviation of 0.235 mm indicating strong overall agreement between the planned and actual outcomes. The color-coded deviation map revealed that areas with the greatest discrepancies were located in anatomically non-critical regions not influencing the surgical planning objectives (Figure 3). These localized differences likely resulted from segmentation artifacts during CBCT processing while the surgically relevant zones maintained submillimeter accuracy confirming the precision of the executed plan. I addition, quantitative analysis of clinical outcomes revealed improvements in facial symmetry parameters: mandibular midline deviation improved from by an average of 5.3 mm (range 4-7 mm) and occlusal plane canting was reduced by 3-5 degrees.

While all patients developed initial postoperative occlusal pre-contacts on the operated side, these were effectively managed through orthodontic intervention with elastics. At 1-year follow-up, patients exhibited significant improvement in facial symmetry, occlusal plane correction, and functional stability. During the follow-up period (mean 14 months), none of the patients required additional surgical interventions such as genioplasty or orthognathic surgery. However, longer-term studies will be necessary to evaluate potential need for secondary procedures as patients complete skeletal growth, and final occlusal outcomes are assessed.

DISCUSSION

The findings of this study highlight the effectiveness of proportional condylectomy guided by in-house 3D planning in the management of active condylar hyperplasia (CH). Our results align with existing literature, reinforcing that this approach not only arrests pathological condylar growth but also improves facial symmetry and occlusal stability in a single surgical intervention[8,9].

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Proportional condylectomy has emerged as a preferred alternative to high condylectomy due to its ability to simultaneously address vertical mandibular excess, reducing the need for secondary orthognathic procedures[9]. In our series, postoperative CBCT superimposition revealed a mean deviation of 0.235 mm between the planned and actual outcomes, confirming high surgical accuracy. Notably, discrepancies were primarily localized to non-critical regions, likely attributable to CBCT segmentation artifacts rather than surgical error. This precision underscores the reliability of virtual surgical planning (VSP) and 3D-printed guides in executing patient-specific osteotomies.

A key factor in achieving stable postoperative outcomes was the integration of early physiotherapy and orthodontic intervention. All patients developed transient occlusal pre-contacts, which were successfully corrected using intermaxillary elastics to guide condylar repositioning and molar intrusion. This collaborative approach minimized functional disturbances and enhanced occlusal plane leveling, consistent with prior reports[9]. Importantly, none of our patients experienced temporomandibular joint dysfunction or persistent pain, supporting the functional safety of proportional condylectomy.

In-house 3D solutions streamlined the surgical workflow while maintaining cost efficiency—a critical advantage for tertiary centers. The design of condyle-specific cutting guides not only improved osteotomy accuracy but also simplified intraoperative execution, reducing procedural variability. A key advantage of our approach using 3D-printed surgical guides is the assurance that the resected segment precisely matches our preoperative planning. This eliminates the measurement challenges inherent in traditional proportional condylectomy techniques, where intraoperative determination of resection dimensions was complex and prone to error due to limited visibility and anatomical distortion in hyperplastic condyles. Postoperative validation via CBCT superimposition (e.g., *CloudCompare* analysis) provided quantitative feedback, reinforcing the protocol's reliability.

Although our outcomes are promising, the small cohort and short follow-up period warrant cautious interpretation. Long-term studies are needed to assess condylar remodeling stability and potential relapse. Additionally, refining CBCT segmentation

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algorithms could further minimize non-clinically relevant deviations.

CONCLUSION

This study demonstrates that proportional condylectomy, supported by in-house 3D planning and multidisciplinary care, offers a precise, efficient, and cost-effective solution for active CH. By integrating advanced diagnostics, virtual planning, and point-of-care manufacturing, we propose a standardized protocol that optimizes both functional and aesthetic outcomes while reducing the burden of secondary surgeries.

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Figure 1. Virtual surgical planning in *Meshmixer* software showing: A: osteotomy plane design passing through the highest point of the healthy condyle; B: mirroring of the healthy hemimandible (blue) over the affected side (red), and C: 3D-printed cutting guide adaptation to the lateral condylar pole.

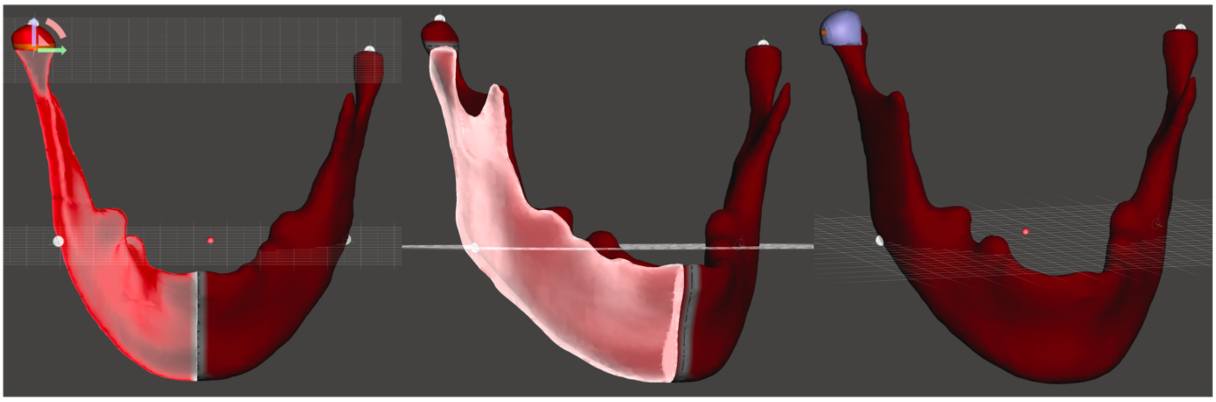

Figure 2. Intraoperative photographs demonstrating: A) precise fixation of the 3D-printed surgical guide to the hyperplastic condyle using an 11-mm screw, and B) the resected condylar fragment following piezosurgical osteotomy according to the virtual plan.

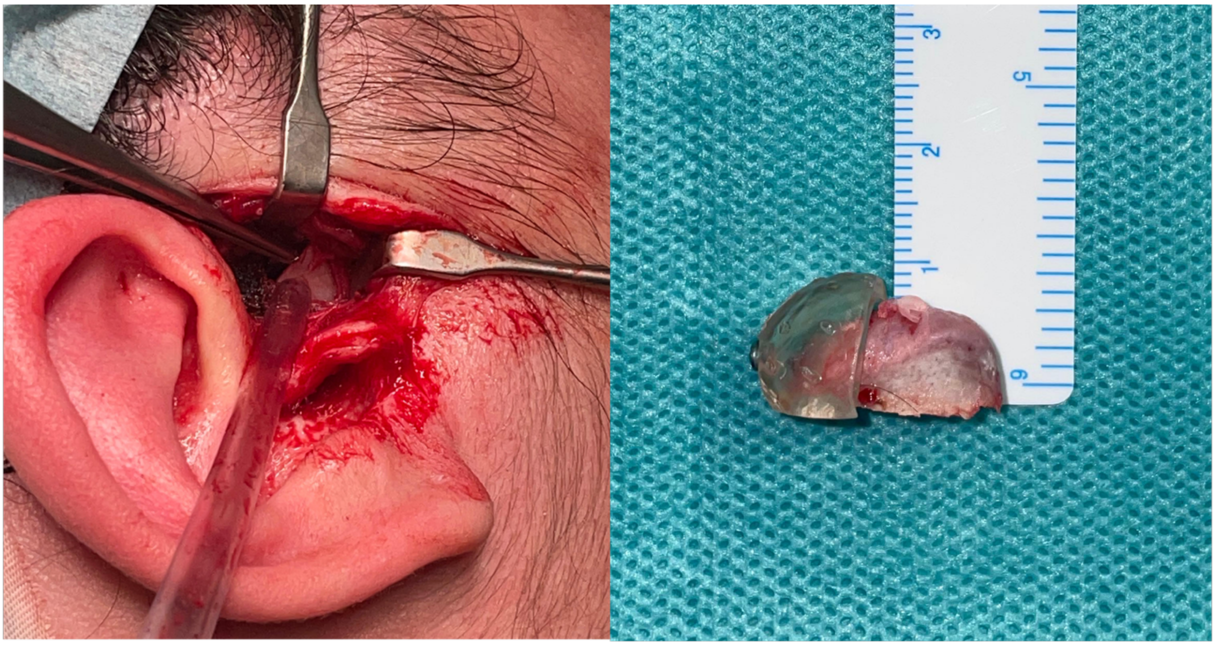

Figure 3. Postoperative validation using *CloudCompare* software: Color-coded deviation map showing the comparison between planned and actual surgical outcomes. The heat map indicates submillimeter accuracy (0.235 mm mean deviation) in critical anatomical regions (green/blue), with minimal discrepancies (yellow/red) confined to non-functional areas due to CBCT segmentation artifacts.