

A novel methodology in design and fabrication of lingual orthodontic appliance based on rapid prototyping technologies

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ABSTRACT: This paper reviews a novel lingual orthodontic technique based on custom-made brackets and custom-made series of pre-bent wires using rapid prototyping technologies. Most adults prefer rearmament with invisible appliances because they want to achieve a treatment objective without aesthetic impairment. For many adults, the stigma discouraged them from undergoing orthodontic care. A solution to this problem is to hide the braces on the inside of the teeth.

The manufacturing process of the new appliance differs fundamentally from any other lingual appliance or laboratory procedures. The whole appliance is made using CAD/CAM technology. The set-up model is scanned with a 3D scanner and the brackets are designed on the computer.

Rapid-Prototyping Technology is used for the actual manufacturing of the lingual brackets. Indirect bonding with a single bonding tray is possible for the whole jaw. Direct bonding is feasible too. Furthermore, bending arch wire is one of the most difficult part in orthodontic. In this system, computer-operated bending of arch wire using robots is used to manufacture precise-shaped arch wires.

1 INTRODUCTION

In the past, the path to perfectly aligned teeth meant a smile marred by a mouthful of metal brackets and wire. For many adults, the stigma discouraged them from undergoing orthodontic care. A solution to this problem is to hide the braces on the inside of the teeth. However, this simple idea poses unique challenges and difficulties (www.solid-scape.com/top_services_case_study).

In addition, there is also a demand for invisible orthodontic treatment among younger patients. Many adolescents now realize that braces which do not show are an option, and they are asking for them. Orthodontists want to use appliance systems that deliver both high patient satisfaction and clinically excellent results. A fixed appliance system designed to achieve these goals is necessary to meet the growing demand for aesthetic treatment. Lingual braces are not visible from the outside. There is little or no aesthetic impairment. Even when labial brackets are made from tooth-color plastics or ceramics, they are still visible. This is why many patients avoid fixed appliance therapy (Wiechmann et al. 2008).

T.O.P. Service fur Lingualtechnik GmbH (Bad Essen, Germany) overcame the challenges of lingual orthodontic treatment and introduced its Incognito system. The company's unique approach to positioning, optimizing results and improving patient comfort relies heavily on custom appliances produced with rapid manufacturing technology (www.solid-scape.com/top_services_case_study).

The manufacturing process of the Incognito appliance differs fundamentally from any other lingual appliance or laboratory procedures. The whole appliance is made using state-of-the-art CAD/CAM technology (Wiechmann 2002, Wiechmann 2003 and Mujagic et al. 2005). The set-up model is scanned with a 3D scanner and the brackets are designed on the computer. The bracket/arch wire system consists entirely of individualized components. The bracket bases and bodies, the position of the bracket body on the bases, the bracket-slot orientation (edgewise or ribbon wise), the direction of the arch wire insertion (vertical/horizontal) and the arch wire geometry are individually adjusted to each tooth, the malocclusion and to the orthodontist's prescription.



Figure 1. Lingual braces are mounted on the inner surface of the tooth to conceal them.



Figure 2. Custom lingual brackets have a profile of 2 mm (0.08 in.) and an arch wire slot guaranteed at 5 micron (0.00016 in.) precision.

2 HIDDEN BRACES

Lingual (tongue side) orthodontic appliances (Fig. 1) are mounted on the inner surfaces of the teeth. Like the labial (lip side) appliances, the brackets are bonded to the tooth surface, and an arch wire connects the brackets. Unlike labial appliances, lingual braces require precise bracket positioning and high precision in the brackets' arch wire slots. Additionally, since the appliance is on the inside, the lingual brackets must have a smaller profile so that they do not cause discomfort or speech impairment.

T.O.P. Service's early success arose from its innovations in bracket placement. The Transfer Optimized Positioning system improved positional accuracy and decreased the patient's time in the orthodontist's chair. However, T.O.P. Service determined that it needed further improvements to decrease treatment times, optimize results and diminish patient discomfort. In 2001, T.O.P. Service reinvented its processes and introduced custom lingual brackets. Designed patient-by-patient and tooth-by-tooth, these brackets deliver precision and control for improved results. The small profile also improves patient comfort by minimizing tongue irritation (www.solid-cape.com/top_services_case_study).

3 CUSTOM LINGUAL BRACKETS

Each orthodontic appliance requires up to 16 brackets. T.O.P. Service begins with a malocclusion model, which is used to digitally design brackets, and finishes with investment cast brackets made from dental gold.

The lingual brackets (Fig. 2) measure $5 \times 3 \times 2$ mm ($0.200 \times 0.118 \times 0.079$ inch) and they have only a 0.4 mm (0.016 inch) wall thickness.

Production of these small, detailed brackets is complicated by the arch wire slot. Measuring only 0.46×0.64 mm (0.018×0.025 inch), the arch wire slot must be extremely precise. According to Ralf Paehl, Dipl.-Ing, head of research and development, "To impart multidirectional forces to the bracket, the rectangular slot must hold the arch wire, which can be round or rectangular, without any slippage." This precision is so critical that T.O.P. Service guarantees ± 5 micron (0.0002 inch) slot tolerances for each of the custom brackets that it makes.

In its reinvention of the process, T.O.P. Service faced the challenge of developing a method to rapidly manufacture the high-precision, fully customized brackets. After evaluating all possibilities, the company selected a Solidscape Model Maker™ II system for creation of investment casting patterns. According to Paehl, the key criteria in the evaluation were resolution, surface finish, castability and precision (www.solid-cape.com/top_services_case_study).

4 THE MANUFACTURING PROCESS

Production of lingual appliances begins with malocclusion models of the patient's teeth. These models are cast from impressions taken by the orthodontist. One model becomes the setup after it is manipulated to align the teeth to the target positions. This setup is reverse engineered with a white light scanner (Fig. 3) to create a digital model that is loaded into T.O.P. Service's design software.

Selecting from a library of brackets, T.O.P. Service technicians position the brackets and adjust their features for optimal results (Fig. 4). The bracket design is output as an STL file for building patterns for investment casting.

The T66 Benchtop, which can build with 13 micron (0.0005 inch) layers, constructs the

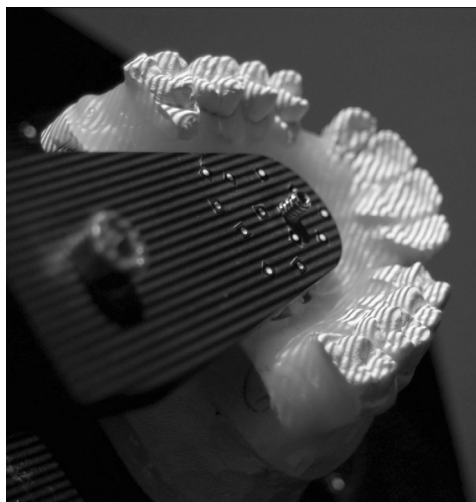


Figure 3. White light scanning captures a digital representation of the malocclusion model.

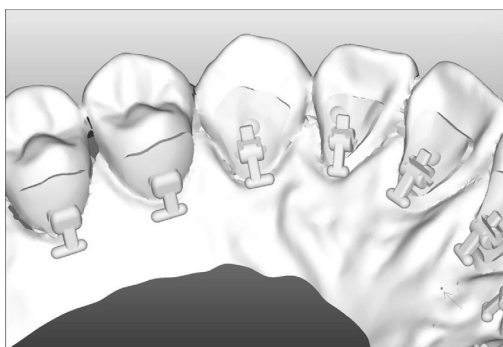


Figure 4. Custom lingual brackets are designed and positioned with CAD software.

bracket patterns (Fig. 5) with proprietary thermoplastic ink jetting technology. The thermoplastic, which has wax-like properties, is deposited as small droplets. For precise layer thickness and flatness, a cutter mills the horizontal plane. When complete, the patterns are post processed by dissolving the support material and wiping off any debris.

The next step is to attach cast pipes to the patterns and assemble them to make the casting tree. The tree is then embedded in a “speed plaster” to create the investment casting shell. The shell is heated to 690°C (1,274°F) to burn out the patterns and then dental gold is cast into the investment. This process, which is computer controlled,

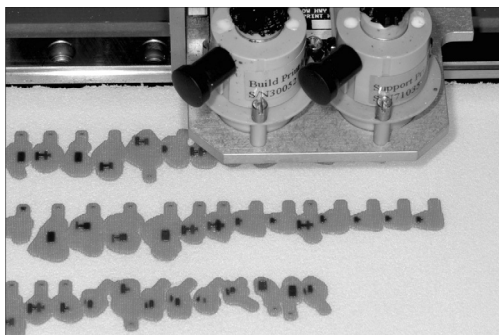


Figure 5. Bracket patterns for investment casting being constructed in a T66 Benchtop.



Figure 6. Investment cast lingual brackets after shell removal.

takes only two hours. Paehl stated that he has 100 percent casting yield. “Short duration, low temperature burnout and no residual ash are critical in our process. The Solidscape patterns give us all three,” said Paehl.

After cooling, the shell is broken away to yield the metal brackets (Fig. 6). The runners (cast pipes) are then removed, and the brackets are tumbled in a polishing compound to smooth the surfaces.

To complete the process, the brackets are mounted to the malocclusion model (Fig. 7), and a transfer tray, which captures the brackets, is cast. T.O.P. Service’s rapid manufacturing process, from treatment planning to shipment of the lingual appliance, takes only 10 to 15 days (www.solid-escape.com/top_services_case_study).



Figure 7. Custom lingual brackets bonded to malocclusion model prior to casting of transfer tray.

5 CASE STUDIES

The following illustrated five clinical cases treated using the Incognito System to show its versatility and applicability (Wiechmann et al. 2008).

5.1 Case A (Fig 8)

The patient was a 22 years old female having slight crowding on the lower arch and moderate crowding on the upper arch and 23 was buccally placed (Figs. 8a, c, e, g, h). The plan for the lower arch was non-extraction and alignment and extraction of 24 for the upper arch and alignment with lingual appliance. The treatment started with alignment of the upper arch with 0.016 × 0.022 inch SE NiTi arch wire and lower arch with 0.016 inch SE NiTi arch wire (Figs. 8g, h). The alignment and space closure for the upper arch was continued with 0.016 × 0.024 inch stainless steel arch wire with extra torque from 13 to 23 (Figs. 8i, j). Finally, the teeth were finished with 0.0182 × 0.0182 inch TMA arch wires (Figs. 8k, l). The teeth were then retained with fixed lingual retainers (Figs 8b, d, f, m, n), the whole treatment took 9 months to complete.

5.2 Case B (Fig 9)

The patient was a 46 years old female having crowding and proclination of upper and lower anterior teeth, with minimal overbite (Figs. 9a, c, e, g, i, j). The plan was extractions of 15, 25, 35 and 45 and alignment and space closure with lingual appliance. The treatment started with alignment of the up per arch with 0.016 × 0.022 inch SE NiTi arch wire and lower arch with 0.016 inch SE NiTi arch wire with retractions of premolars to relieve crowding (Figs. 9i, j). Space closure was then performed with 0.016 × 0.024 inch stainless

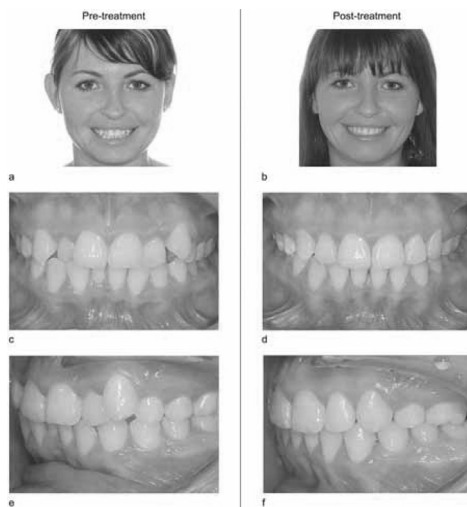


Figure 8a–f. Case A, 22-year-old female, with crowding. Upper arch extraction 14, and lower arch non-extraction therapy.

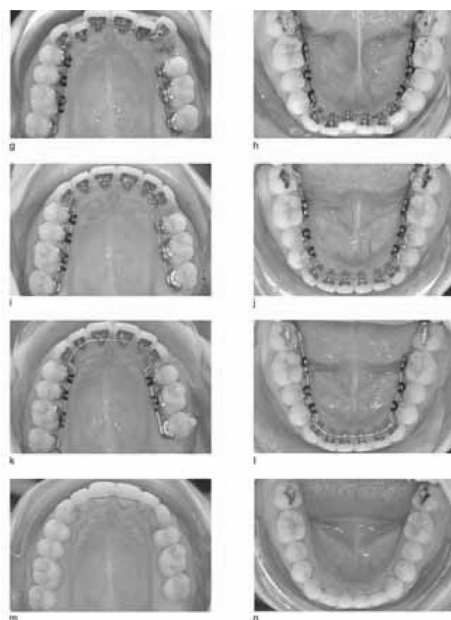


Figure 8g–n. Interim stages.

steel arch wires with extra torque from 13 to 23 (Figs. 9k, l). Finally, the teeth were finished with 0.0182 × 0.0182 inch TMA arch wires (Figs. 9m, n). The whole treatment took 16 months to complete (Figs. 9b, d, f, h, o, p).

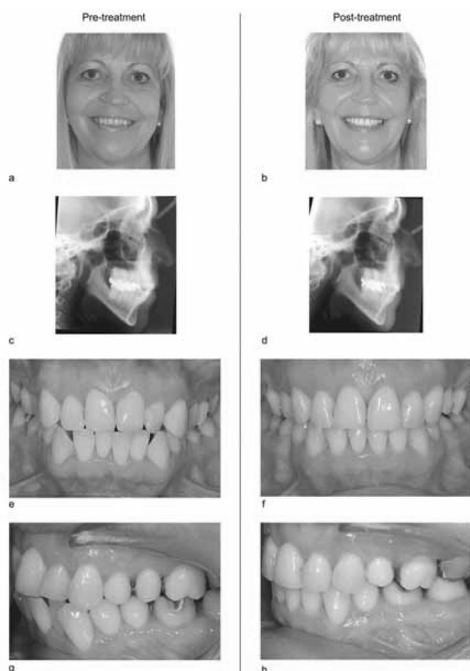


Figure 9a–h. Case B, 46-year-old female with crowding and bimaxillary protrusion. Extraction of all second premolars.

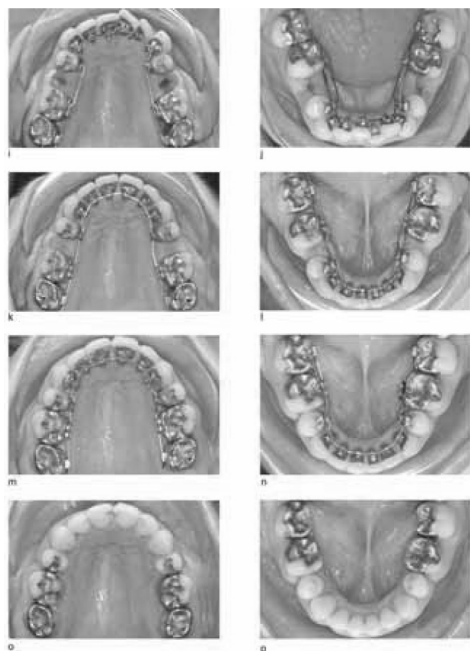


Figure 9i–p. Interim stages.

5.3 Case C (Fig. 10)

The patient was a 13 years old female having crowding and retroclination of upper and lower anterior teeth and deep overbite (Figs. 10a, c, e, g, i, j). The plan was nonextraction and alignment of both the upper and lower arches with lingual appliance. The treatment started with alignment of the upper and lower arch with 0.016 inch SE NiTi arch wires (Figs. 10i, j) and then alignment of the upper arch with 0.016 × 0.022 inch SE NiTi arch wire. Coordination of arches was then performed with class II elastics on 0.016 × 0.022 inch stainless steel arch wires (Figs. 10k, l, m). Finally, the teeth were finished with the same arch wires. The teeth were then retented with fixed lingual retainers and the whole treatment took 11 months to complete, note that only 2 arch wires were used on the lower jaw (Figs. 10b, d, f, h, n, o).

5.4 Case D (Fig. 11)

The patient was a 16 years old male having class II skeletal and dental relationships and proclination of upper teeth, the mandible was short and deep overbite (Figs. 11a, c, e, g, i, j). The plan was

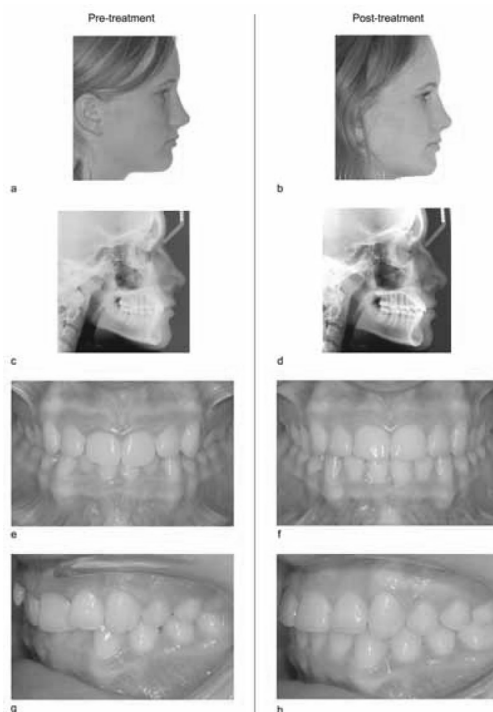


Figure 10a–h. Case C, 23-year-old female, with crowding and retroclined anterior teeth. Non-extraction therapy.

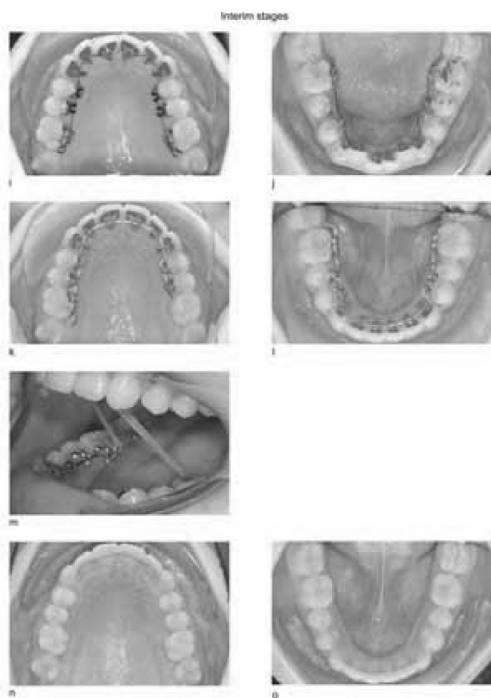


Figure 10a–o. Interim stages.

nonextraction and alignment of both the upper and lower arches with lingual appliance with correction of jaw relationship with an integrated Herbst appliance. The treatment started with alignment of the upper and lower arches with 0.016 inch SE NiTi arch wires (Figs. 11i, j). Anterior bite planes were included with the upper brackets 13 to 23 (Fig. 11i). The alignment was continued with 0.018 × 0.025 inch SE NiTi arch wires. Jaw relationship correction was then performed with the integrated Herbst appliance on 0.018 × 0.025 inch stainless steel arch wires, with one mandibular advancement to the edge incisal relationship (Figs. 11k, l, m, n). Finally, the teeth were finished with the same stainless steel arch wires. The teeth were then retained with lower fixed lingual retainer and upper removable plate and the whole treatment took 23 months to complete (Figs 11b, d, f, h, o, p). The before and after lateral cephalometric radiograph were included to show the growth of the mandible (Figs. 11c, d).

5.5 Case E (Fig.12)

The patient was a 35 years old female having narrowed upper arch, anterior open bite crowding and proclination of upper anterior teeth (Figs. 12a, c,

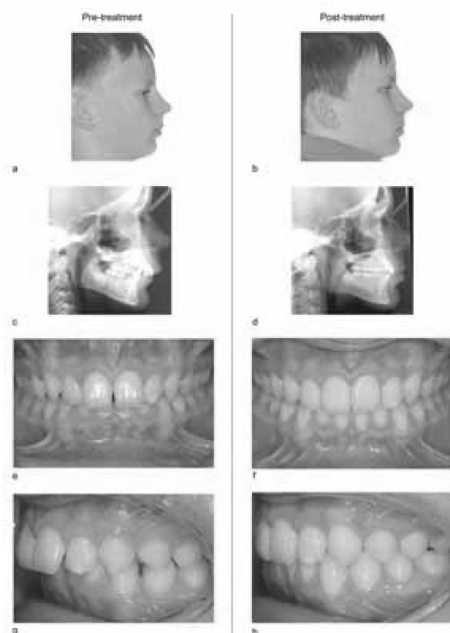


Figure 11a–h. Case D, 16 year-old-male, with Class II dental and skeletal malocclusion. Non-extraction treatment in combination with Herbst appliance.

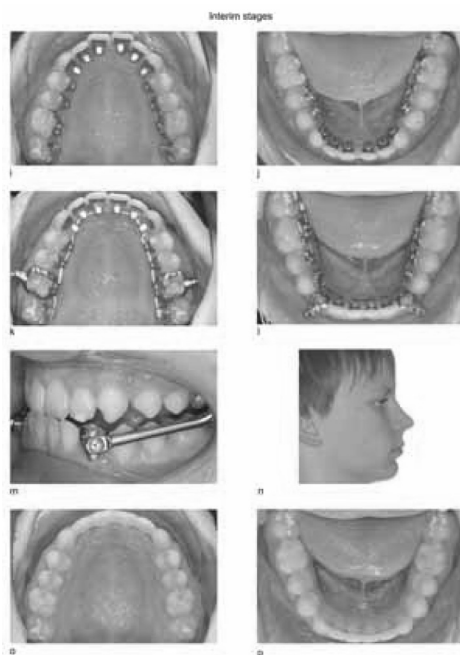


Figure 11i–p. Interim stages.

d, g, i, k, l). The plan was expansion of maxilla using the maxillary expander and extractions of 14, 24 and alignment and space closure with lingual appliance using micro-implant anchorage. Maxillary expansion was performed with 2 turns a day for two weeks and retained for 6 months (Fig. 12k).

The treatment started with alignment of the upper arch with 0.016 × 0.024 inch SE NiTi arch wire and lower arch with 0.016 inch SE NiTi arch wire with retractions of upper canines to relieve crowding, a palatal arch was incorporated with the lingual appliance (Fig. 12 m).

Space closure was then performed with 0.016 × 0.024 inch stainless steel arch wire in the upper and 0.016 × 0.022 inch stainless steel arch wire in the lower with the aid for 4 micro-implants placed on the buccal and palatal of the left and right sides of the maxilla.

Class III elastics were used to finalize the jaw relationship correction (Figs. 12n, o). Finally, the teeth were finished with upper 0.0182 × 0.0182 inch TMA arch wire and 0.016 × 0.022 inch stainless steel arch wire in the lower (Figs. 12p, q). The whole treatment took 16 months to complete (Figs. 12b, e, f, h, j, r, s).

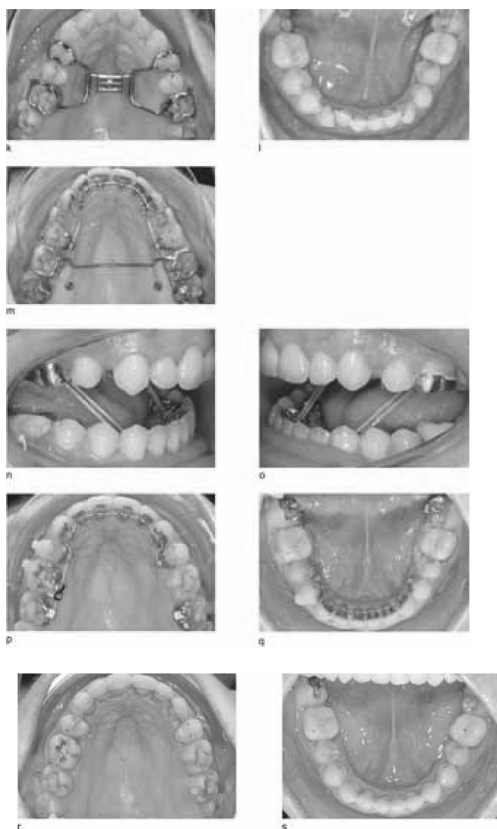


Figure 12k–s. Interim stages.

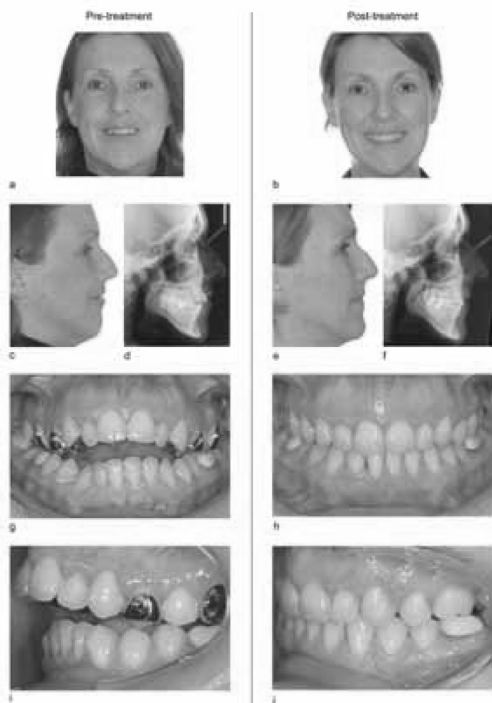


Figure 12a–j. Case E, 35 years-old-female, with Class III dental and skeletal malocclusion. Non-extraction treatment in combination with Herbst appliance.

6 CONCLUSIONS

Rapid-Prototyping-Technology is used for the actual manufacturing of the lingual brackets. Indirect bonding with a single bonding tray is possible for the whole jaw. Direct bonding is feasible too, thanks to extended individual bases. Furthermore, bending arch wires is one of the most difficult parts in orthodontics. In this system, computer operated bending of arch wires using robots are used to manufacture precise-shaped arch wires. Even super-elastic arch wires can be precisely shaped. This helps solving three major problems in lingual orthodontics:

1. Patient discomfort during the phase of adaptation: The appliance is designed as flat as possible, not much higher as a bonded retainer; this significantly improves the patient's comfort.
2. Inaccuracies during re-bonding: The customized bracket base covers the major part of the lingual tooth surface and therefore allows a direct re-bonding without the need for any other positioning aids.

3. Difficulties in finishing: Inaccuracies of the slots due to production and resulting varieties in the torque play are from now on part of the past, thanks to Incognito. Measuring rates show divergences of not more than 0.008 mm between the slots. The precise-shaped arch wires also make high standard finishing easily achievable.

The conception of the new Incognito bracket also proves to be advantageous to the clinical handling:

1. The vertical slot allows arch wire driven derotations without using power chains.
2. The conception of the Incognito bracket system according to the modular construction system permits, even for cases with extreme rotations and short clinical crowns, an optimal usage of the enamel tooth surface.
3. The Incognito system disposes of the high flexibility due to the Rapid-Prototyping Process. Each single bracket series is not only individually designed for the patient but the system also allows respecting the doctor's wishes.
4. The gold alloy, used for the new brackets, offers an alternative especially for patients showing a nickel allergy.

From December 2004, after three years of extensive clinical tests with more than 1000 arches bonded since November 2001, the Incognito system is available to all orthodontists having participated in a certification course. In 2007, more than 18,000 cases will be started worldwide.

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