J Stomatol Oral Maxillofac Surg xxx (2019) xxx–xxx

Available online at
ScienceDirect
www.sciencedirect.com

Elsevier Masson France
EM|consulte
www.em-consulte.com/en

Original article

Implementation of a digital chain for the design and manufacture of implant-based surgical guides in a hospital setting

T. Pajot [a,*], L. Benichou [a], E. Moreau [b], V. Tallon [b], J.-P. Meningaud [c], R.H. Khonsari [d], S. Ketoff [a]

[a] Service de Chirurgie maxillo-faciale, Hôpital Paris Saint-Joseph, 185, rue Raymond losserand, 75014 Paris, France
[b] Service de Pharmacie, Hôpital Paris Saint-Joseph, 185, rue Raymond losserand, 75014 Paris, France
[c] Service de chirurgie maxillo-faciale et chirurgie plastique, Hôpital Universitaire Henri-Mondor Hospital, Assistance Publique–Hôpitaux de Paris, 51, avenue du Maréchal de Lattre de Tassigny, 94010 Créteil, France
[d] Service de chirurgie maxillo-faciale et chirurgie plastique, Hôpital Universitaire Necker–Enfants Malades, Centre de Références Maladies Rares MAFACE, Filière Maladies Rares TeteCou; Université Paris Descartes, Université de Paris, Assistance Publique–Hôpitaux de Paris, 149, rue de Sèvres, 75015 Paris, France

ARTICLE INFO

Article history:
Received 26 July 2019
Accepted 16 September 2019

Keywords:
Dental implant
3D printing
Regulation
Computer-assisted surgery

ABSTRACT

The digital revolution has led to many recent developments in implantology that have considerably facilitated implant planning and the creation of surgical guides. The purpose of this article is to explain how we set up a digital workflow in a large city hospital and how we met the requirements of the European regulations on the production of custom-made devices in a medical establishment. The internal manufacture of a surgical guide complied with European regulation EU/2017/45 concerning medical devices. This regulation allowed the hospital to create these medical devices locally without CE marking. However, the hospital must be declared as a manufacturer of medical devices and comply with the general requirements in terms of safety and performance related to the manufacture and use of medical devices. In addition, hospitals are large structures involving many different actors. Each step of the digital workflow, which included both the patient course and the creation of the surgical guide, was thus adapted to European regulations by considering local constraints.

1. Introduction

Implantology is essential for the rehabilitation of edentulous patients. Since the 1960s and Per Ingvar Brånemark's work on osseointegration [1], this sector has undergone many changes, especially since the digital revolution at the end of the 20th century and the development of three-dimensional printing.

Before the advent of digital technology, the conventional planning steps for creating a surgical guide were numerous and tedious. Nowadays, only three steps are required: optical impression, digital planning and 3D printing (Fig. 1).

The purpose of this article is to explain how we have implemented a digital workflow in the maxillofacial surgery department of a large city hospital, and how we have tackled the complex European regulations on the production of custom-made medical devices in hospitals.

2. How to implement a digital workflow in a city hospital

From initial consultation to surgery, various steps involving many health professionals are needed: computer science department, purchases, pharmacy, financial department for invoicing, sterilization, consultation, hygiene team, risk management, nursing assistants, operating room nurses, and finally, the surgeon. In order to best implement this workflow, a contact person was designated and had the duty of coordinating the various people involved in the manufacture of the guide in order to optimize and accelerate the implementation of this activity.

The implementation of this workflow revolved around three main axes:

- regulations: verification that the manufacturing process is in line with European legislation, which will allow the surgical guide to be used legally and thus will ensure patient safety;
- implementation of the patient course: this pertains to the various appointments necessary for the patient;
- design and production of the surgical guide.

* Corresponding author at: 03 rue Royer Collard, 75005 Paris, France
E-mail addresses: dr.pajot@gmail.com, th.pajot@hotmail.fr (T. Pajot).

https://doi.org/10.1016/j.jormas.2019.09.009
2468-7855/

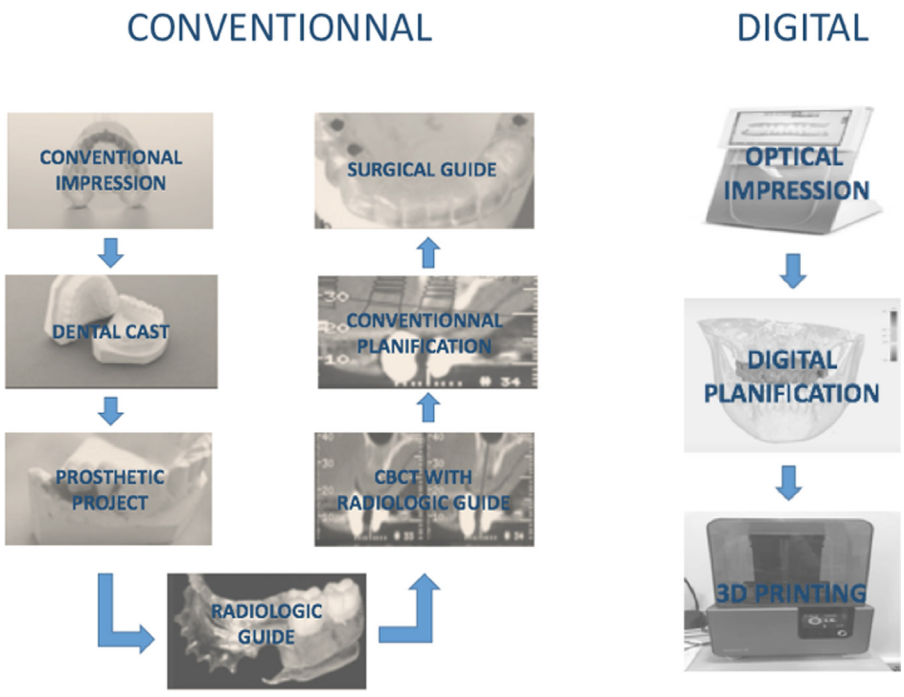

Fig. 1. Summary of conventional and digital planning.

3. Current regulation on custom-made medical devices

The models obtained from 3D printing, such as implant surgical guides, are considered as medical devices (MD). Their manufacture and use are therefore subjected to a framework set by European regulation.

We are currently in a transition phase between European Directive 93/42/EEC and European Regulation EU/2017/45. To date and until May 26th 2020, the regulation on medical devices complies with the European directive; after this date it will be replaced by the regulation. In the meantime, manufacturers may choose a CE marking procedure according to Directive 93/42/EEC or Regulation 2017/745. Of note, certificates issued under the Directives will remain valid until the end of their period of validity, at most 5 years after their issue.

Those regulations integrate the notion of the level of risk associated with the use of the MDs and divide these MDs into classes depending on various criteria [2,3] (Fig. 2).

In the 2017 regulations, the definition of the surgical template of the implant does not change and is still considered as a custom-made device 'intended to be used only for a specific patient and exclusively in response to the needs and health status of that patient' and thus not 'mass produced'. In these conditions, the MD is considered by the regulation as associated with a medium risk level (IIa) [4].

4. Medical device manufactured in a hospital establishment

This new regulation is important because it incorporates an essential and new element: specific provisions governing the manufacture of a medical device in a hospital establishment (Chapter II, Article 5, Sections 4 and 5). As such, the marketing of the surgical template (considered here as its manufacture and use within the health care organization) will be subject to its own regulations, which will be different from the various general provisions relating to the marketing of conventional medical devices.

Three points are specially important in this new regulation:

- declaration to the Agence Nationale de Sécurité du Médicament et des Produits de Santé (French national agency for the safety of health products, ANSM). In order to manufacture and use the surgical guide, the hospital must declare itself as a manufacturer of MDs to the ANSM. In this specific context, the MD can only be used in the hospital in which it was designed and manufactured;
- no need for CE marking. Surgical guide manufactured hospitals do not require CE marking to be implemented, thus avoiding long and cumbersome administrative steps;
- compliance with the conditions of Appendix I of European Regulation. Even if the surgical template does not require CE marking, it must nevertheless meet the same requirements in terms of safety and performance related to the manufacture and use of MDs. These requirements are listed in Appendix I and consist in:
  - risk management, that is managing each step of the manufacturing process, analyzing the risks, evaluating them and implementing solutions to check them;
  - performance evaluation and comparison to data from the literature;
  - vigilance and traceability.

All its information concerning the manufacture and use of the guide must be available for the ANSM in the event of an inspection.

CLASS	*RSIK LEVEL*
Class I	*Low risk level*
Class IIa	*Medium risk level*
Class IIb	*High risk level*
Class III	*Very high risk level*

Fig. 2. Risk level of medical devices.

Please cite this article in press as: Pajot T, et al. Implementation of a digital chain for the design and manufacture of implant-based surgical guides in a hospital setting. J Stomatol Oral Maxillofac Surg (2019), https://doi.org/10.1016/j.jormas.2019.09.009

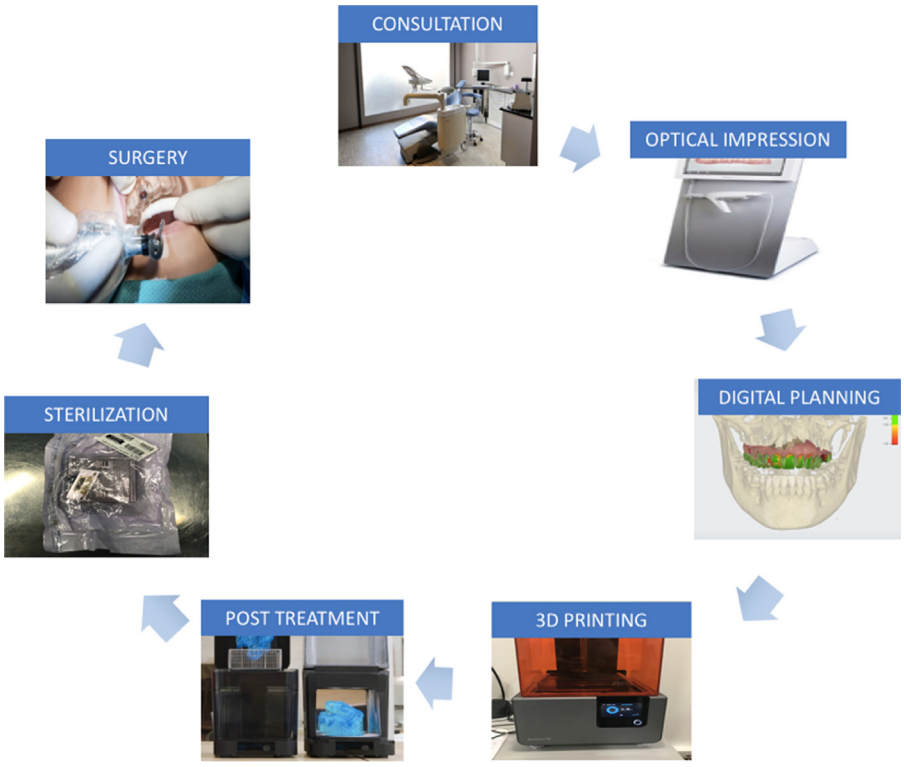

Fig. 3. Digital workflow in a large European city hospital.

Compliance with legislation must be achieved in close collaboration between the hospital itself and hospital pharmacy.

5. Digital workflow in a city hospital: practical details

Each step of the digital chain used to design and manufacture MDs has to comply to the European Regulation and hospital structure (Fig. 3).

5.1. Patient course

5.1.1. 1st consultation: implantology clinic

During this step, the treatment plan is established, based on clinical and radiological data.

5.1.1.1. Material required: Cone Beam (CBCT). A CBCT within the hospital is not essential since this activity can be externalized to a radiology center. However, a local CBCT machine facilitates patient management, and ensures that the CBCT is carried out under good conditions (occlusion, complete dental arch).

5.1.1.2. Adaptation to the hospital structure. This step does not involve any particular management in a hospital sector. However, it requires the invoicing department to introduce an invoicing code for the surgical guide and to be able to quote it to the patient.

5.1.2. 2nd consultation: 3D clinic

This second consultation is the patient's entry point into the digital flow. Once the prosthetic project has been completed and the quote accepted, optical impressions are collected.

This step is critical for the accuracy of implant planning, but it implies that the patient returns to the hospital for a second consultation. The consultation time should be set at 45 minutes in order to be able to collect good quality optical impressions and take pictures for follow-up, check various parameters involved in patient management and create a file in which all data will be stored.

5.1.2.1. Material required: intra-oral scanner. Different technologies are used to collect optical impressions. In practice, the technology used by a specific camera has little or no impact on the quality of the optical impressions, but determines the ergonomics of the system (size and volume of the camera, weight) and gives access to certain features (color). The camera available in our hospital was 3Shape TRIOS (Copenhagen, Denmark), a color camera using confocal microscopy with video acquisition. All elements involved in the digital flow should be connected to the internet network of the hospital. This facilitates the planning after the 3D consultation, by sending the data directly to the planning software and then the surgical template file to the 3D printer.

5.1.2.2. Adaptation to the hospital structure. A shared hard drive specific to the maxillofacial surgery department should be created in coordination with the Information Technology department. All members of the medical staff in the department will therefore be allowed consult patient data from any computer in the hospital.

5.2. Production and use of the surgical template

Different steps are required to create and use the surgical template:

- digital planning;
- printing and post-processing;
- sterilization;
- surgery.

5.2.1. Digital planning

Once the scan and optical impression data have been collected, planning can be started. This phase is essential since most of the

Please cite this article in press as: Pajot T, et al. Implementation of a digital chain for the design and manufacture of implant-based surgical guides in a hospital setting. J Stomatol Oral Maxillofac Surg (2019), https://doi.org/10.1016/j.jormas.2019.09.009

surgical procedure depends on this stage. Indeed, once the guide is positioned, the surgeon only follows the plan. This step can be performed by a resident and then validated by a senior surgeon.

5.2.1.1. Material required: planning software. All softwares available on the market do not provide the same options. One must ensure that the user can design the guide and print the surgical guide virtually. The software we used was Implant Studio (3Shape, Copenhagen, Denmark).

5.2.1.2. Adaptation to the hospital structure. In case of technical problems or planning difficulties, it is important that the planning software support company can take control of the computer to assist the surgeon. However, confidentiality constraints require the establishment to have a secure network to protect patient data. A Virtual Private Network (VPN) can be used. This network is called virtual because it connects two 'physical' local networks via an unreliable link (Internet) and private because only computers on both sides of the VPN can access the data, thanks to an encryption system that makes the data unavailable to others. Thanks to this process, the support company can intervene and take control of the computer remotely, and thus help the surgeon in his planning process while ensuring the security of the data stored on the hospital server.

5.2.1.3. Adaptation to European legislation. The planning software is considered as a full-fledged MD according to the latest regulations. As such, it requires CE marking.

5.2.2. 3D printing and post-processing

Once the guide has been virtually designed, the printing phase begins. The volume recovered after printing will then undergo a post-processing step corresponding to rinsing/cleaning the guide and exposing it to UV radiation in order to make it both more rigid and more solid.

5.2.2.1. Material required: 3D printer. Many 3D printing technologies are available on the market but the stereolithography photopolymerization technique is the most described in the literature, due to its reasonable price and the small size of the machines. The usual accuracy of this technique is 0.1 mm per 100 mm, representing an error rate of 0.1% - similar to that of laboratory-made guides in terms of implant deviation - largely sufficient for the production of surgical guides [5–7].

The printer used was Form 2 (Formlabs, Sommerville, MA, USA), which uses stereolithography technology. In addition to the above-mentioned characteristics, this printer allows the use of the biocompatible resin Dental SG (Formlabs, Sommerville, MA, USA), which is sterilizable by autoclave or gamma radiation. Moreover, this printer is compatible with the Form Wash and Form Cure devices, both from Formlabs, which allow semi-automatic rinsing and cleaning of the guide with isopropyl alcohol and then exposure to UV radiation.

5.2.2.2. Adaptation to European legislation. Physical and chemical properties risks related to the surgical guide depend on the materials (resin and drill sleeve). Therefore, those intermediate components are also considered to be MDs and must therefore have CE marking. Moreover, the manufacturer must be able to provide traceability data both for the manufacture and marketing of medical devices. A traceability sheet was therefore created containing the patient's identification, the batch number of the resin and drill sleeve, and the version of the printing software for each guide.

The manufacturer (here, the hospital establishment) must prove that its final MD is biocompatible. Even if the resin used is biocompatible, biocompatibility tests must be carried out not on the material itself but on the final MD (in order to ensure that no cytotoxic products appear during the manufacture of the guide). This includes the entire manufacturing process. Indeed, if the material is not cytotoxic, it may be broken down into cytotoxic products during the manufacturing or sterilization process. Since implant-oriented surgical guides are devices that can come into contact with bone, three tests are required for biocompatibility assessment: cytotoxicity tests, skin sensitization tests and skin irritation tests [4].

Printing and post-treatment require different resins and isopropyl alcohol. Their use is subject to special regulations and must therefore be carried out in a dedicated and adapted room.

5.2.3. Sterilization

The surgical guide must be sterilized in order to be used. A specific sterilization form has been set up containing the name of the patient (since it is a custom-made MD), the date of the operation, and the surgeon responsible for the operation.

5.2.3.1. Adaptation to the hospital sector and European legislation. In a hospital, the sterilization process is standardized. However, this process does not necessarily correspond to the recommendations of the manufacturer regarding the resins. As part of the risk management process, it is therefore necessary to verify that the sterilization process does not lead to deformation and that it is effective.

5.2.3.2. Evaluation of the deformation of the guide. We assessed deformation by printing 10 surgical guides as well as the study model for the same patients. Before sterilization, it was verified that the surgical guide was properly adapted to the study model before autoclaving according to the hospital process. Sterilized guides were then retrieved and checked. We could confirm that sterilization using the standard protocol of our hospital was possible.

5.2.3.3. Microbiological evaluation of the guide. We performed a study in coordination with the microbiology department of our hospital. We printed a surgical guide that underwent the usual local sterilization process. The bags containing the sterilized guides were then opened in a sterile atmosphere under a laminar flow hood in the microbiology department. The guide was then sectioned into different parts and grinded until the formation of a homogeneous liquid, which was then deposited on various culture media, in aerobic and anaerobic atmospheres: blood agar, Drigalski agar and Sabouraud agar. Since no germs were detected after 7 days of culture, it was decided that the microbiological safety of the guides was satisfactory.

5.2.4. Surgery

Once sterilized, the guide is carried to the operating room in a sterile package and is then ready to be used.

6. Discussion

6.1. Financial questions

'Homemade' approaches are new in the field of computer-assisted surgery and more particularly in implantology. They are made possible due to the introduction of affordable and high-quality 3D printers on the market. The financial question related to the implementation of this work flow is major since it constitutes a main obstacle in most hospitals.

Please cite this article in press as: Pajot T, et al. Implementation of a digital chain for the design and manufacture of implant-based surgical guides in a hospital setting. J Stomatol Oral Maxillofac Surg (2019), https://doi.org/10.1016/j.jormas.2019.09.009

The acquisition of the various elements necessary for the digital flow (intra-oral scanner, computer for planning, planning software, 3D printer) varies between 40,000 and 60,000 euros depending on the devices chosen. By evaluating the depreciation of the equipment over a period of 5 years, the licenses to be renewed every year for certain software and consumables, we obtain a production cost per guide of approximately 300 euros if 50 guides are produced per year (600 euros if 25 guides are produced and 150 euros if 100 guides are produced).

This investment is therefore an important and often difficult one to make in a hospital structure in the current economical context in France. However, various advantages related to the use of this digital work flow must be taken into account:

6.1.1. Invoicing of the guide to the patient

The surgical guide is an option available to the patient that can be billed to the patient and thus reducing the cost for the hospital.

6.1.2. Reduction of procedure time

The use of surgical guides significantly reduces surgical time, for instance for free fibula transfers [8]. Indeed, as the drilling axes have already been planned and cannot be modified during surgery, the operator can concentrate on the rest of the procedure without having to remodel the flap after harvesting.

6.1.3. Increase of precision and reduction of post-operative complications

The use of surgical guides in general secures the placement of implants. In the context of microsurgical reconstruction, the use of guides reduces the rate of post-operative complications (scar issues, infection and bleeding) [9–12]. Moreover, this technique seems to improve osseointegration and reduces marginal bone loss [13–15].

6.1.4. Autonomy regarding prosthetic laboratories

The time required to obtain a surgical template for dental implants (including printing and post-processing) internally is two hours and thirty minutes after the planning is completed.

This time lapse is much longer when using an external company. It certainly varies according to the options chose: generally 10 to 15 days when the company carries out the planning and printing and around 5 days if the company only carries out the printing. The internal printing of surgical guides therefore allows much greater responsiveness and reduces the time between patient consultations and surgery.

6.2. Teaching and academia

6.2.1. Handling complex cases

The recruitment of patients in a maxillofacial department is different from private practice. Cases are often more complex and significant rehabilitations are more common. Planning these cases is difficult for an external company since it requires medical and surgical experience. Moreover, for complex cases, the digital flow facilitates communication with the correspondents manufacturing the prosthesis.

6.2.2. Training

In an academic context, the availability of this technology is interesting for training purposes, particularly for residents. The planning phase is notably very useful, as various surgical options can be tested on the same patient virtually. These can then be discussed during a staff meeting with the surgeons of the department, evaluating the various advantages and disadvantages of each treatment option.

Conclusion

The implementation of a digital workflow for the design and manufacture of surgical guides within a hospital is complex and requires adapting each step to the local hospital structure and to European legislations. However, it is a very fruitful process as this tool considerably facilitate the work of surgeons and opens up new perspectives in patient management.

Disclosure of interest

The authors declare that they have no competing interest.

References

[1] Brånemark PI. Osseointegration and its experimental background. J Prosthet Dent 1983;50(3):399–410.
[2] European Parliament and Council. Directive 93/42/EEC concerning medical devices, as amended by directives 98/79/EC, 2000/70/EC, 2001/104/EC abd 2007/47/EC and by EC regulation No. 1882/2003.1993.
[3] European Parliament and Council Regulation UE/2017/745 concerning medical devices. 2017; 2013.(2).
[4] Montmartin M, Meyer C, Euvrard E, Pazart L, Weber E, Benassarou M. L'impression 3D à l'hopital: quelle réglementation en France? Rev Stomatol Chir Maxillofac Chir Orale 2015;116(5):303–8.
[5] Deeb GR, Allen RK, Hall VP, Whitley D, Laskin DM, Bencharit S. How accurate are implant surgical guides produced with desktop stereolithographic 3-dimentional printers? J Oral Maxillofac Surg 2017;75(12) [2559.e1-2559.e8].
[6] Pozzi A, Polizzi G, Moy PK. Guided surgery with tooth-supported templates for single missing teeth: A critical review. Eur J Oral Implantol 2016;9.
[7] D'haese J, Ackhurst J, Wismeijer D, De Bruyn H, Tahmaseb A. Current state of the art of computer-guided implant surgery. Periodontol 2000 2017;73(1):121–33.
[8] Arisan V, Karabuda CZ, Ozdemir T. Implant surgery using bone- and mucosa-supported stereolithographic guides in totally edentulous jaws: surgical and post-operative outcomes of computer-aided vs. standard techniques. Clin Oral Implants Res 2010;21(9):980–8.
[9] Becker W, Goldstein M, Becker BE, Sennerby L. Minimally invasive flapless implant surgery: a prospective multicenter study. Clin Implant Dent Relat Res 2005;7(Suppl. 1):S21–7 [4].
[10] Becker W, Goldstein M, Becker BE, Sennerby L, Kois D, Hujoel P. Minimally Invasive Flapless Implant Placement: Follow-Up Results From a Multicenter Study. J Periodontol 2009;80(2):347–52.
[11] Nikzad S, Azari A, Ghassemzadeh A. Modified flapless dental implant surgery for planning treatment in a maxilla including sinus lift augmentation through use of virtual surgical planning and a 3-dimensional model. J Oral Maxillofac Surg 2010;68(9):2291–8.
[12] Lazic Z, Golubovic M, Markovic A, Cepanovic M, Miccic T, Vlahovic Z. Immunohistochemical analysis of blood vessels in peri-implant mucosa: A comparison between mini-incision flapless and flap surgeries in domestic pigs. Clin Oral Implants Res 2015;26(7):775–9.
[13] Jeong SM, Choi BH, Xuan F, Kim HR. Flapless implant surgery using a mini-incision. Clin Implant Dent Relat Res 2012;14(1):74–9.
[14] Oh J-H, An X, Jeong S-M, Choi B-H. Digital Workflow for Computer-Guided Implant Surgery in Edentulous Patients: A Case Report. J Oral Maxillofac Surg 2017;75(12):2541–9 [cited 2017 Dec 31].
[15] Cosyn J, Hooghe N, De Bruyn H. A systematic review on the frequency of advanced recession following single immediate implant treatment. J Clin Periodontol 2012;39(6):582–9.

Please cite this article in press as: Pajot T, et al. Implementation of a digital chain for the design and manufacture of implant-based surgical guides in a hospital setting. J Stomatol Oral Maxillofac Surg (2019), https://doi.org/10.1016/j.jormas.2019.09.009