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Perspective

55 Years of Clinical Innovation and Technological Developments in Plastic, Reconstructive and Aesthetic Surgery for the Cranio-Maxillo-Facial Complex

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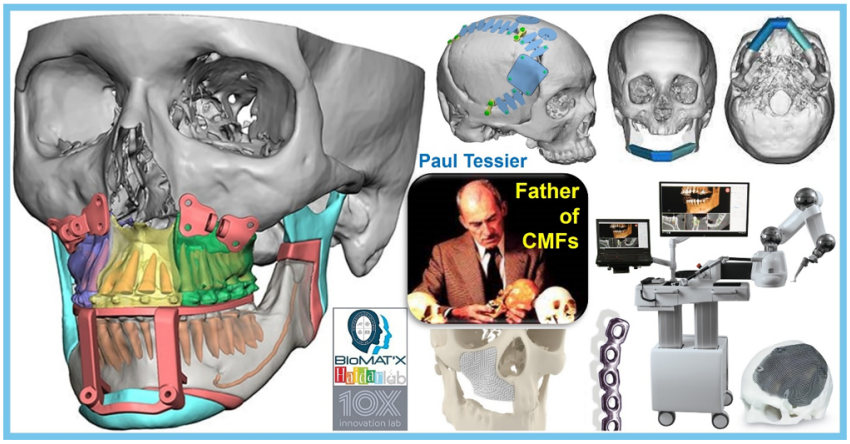
Graphical Abstract



Keywords: *Artificial Intelligence; Aesthetic Surgery; Computer-Assisted Surgery; Cosmetic Surgery; Congenital Abnormalities; Cranio-maxillofacial Surgery; Innovation; 3-D Printing; Plastic and Reconstructive Surgery; Digital Medicine; Rapid Prototyping Technology; Robotics, Research; Image-Guidance Systems; Virtual Planning; Orthognathic Surgery*

CranioFacial and/or Cranio-Maxillo-Facial Surgery (CMFs), as a speciality, did not exist before the year 1967 [1]. Fifty-five years ago, in a Rome-based meeting, French national Paul Tessier (August 1917 - June 6, 2008) via highlighting the challenges of the anatomic and biologic barriers between the cranium and the face (could be bridged), introduced the concepts of CranioFacial Surgery, to significantly impact the quality of life of patients [1]. Before then, NeuroSurgeons collaborated with Oro-Dental and Maxillo-Facial Surgeons to manage and treat facial disfigurations, skull base pathology and trauma cases [2]. Today, CMFs is a distinct surgical and not tissue-specific sub-specialty that deals with congenital, pathologic, acquired (traumatic), and/or iatrogenic deformities of the head, skull, face, neck, jaws, and associated structures, including the bone, skin, nerve, muscle, teeth, amongst other related tissues and anatomy [1-3]. Tessier went on to develop critical methods and techniques such as for the correction of cranio-facial clefts, orbital hypertelorism (trans- and sub-cranial), and Treacher Collins syndrome, and found vital organizations [4] such as the European Association of Oral and Maxillofacial Surgeons and the International Society of Craniofacial Surgery and was an honorary member of the Royal College of Surgeons of England (RCS), the American College of Surgeons (ACS), and the American Society of Plastic Surgeons (ASPS). Tessier, is the "father of CMFs".

The recent origin(s) of CMFs emanate from the demanding need to manage the devastating traumatic injuries that took place during World Wars I and II, hence, despite the ample advances, CMFs can be still considered to be in its infancy, until today [1,3-6]. An example of such innovative advances, and perhaps the biggest to many in the field, was the development of small bio-resorbable titanium plates and screws used to rigidly fix (internal) and maintain the 3-dimensional (3-D) bony shape of the craniofacial skeleton, and thereby help restore the normal facial framework with a faster recovery post-surgery [1-3]. Indeed, over the years, CMFs techniques, methods, materials, and tools have been developed to better manage and treat facial trauma, tumors and congenital pediatric oro-dental and cranio-maxillo-facial conditions, and their consequences [2,3]. For instance, modern, refined, and sophisticated functional radiologic imaging testing, whether using computed tomography (CT) scans and/or magnetic resonance imaging (MRI)-in comparison to X-ray imaging tests, helped provide a better and closer understanding of the anatomy of the cranio-maxillo-facial skeleton thereby allowing us to better (or more precisely and predictably) manipulate and repair the underlying clinical and surgical problem [7-9]. This is especially important when such complex clinical problems and conditions require an inter- and multi-disciplinary care (including techniques, methods, tools, and materials) to have an impact [2,7,9]. Patients suffering from congenital, post-ablative/-traumatic facial discrepancies, is perhaps a fine example [2,7,9]. Herein, it is worth-mentioning that the origin and continual evolution of the CMFs sub-speciality intersect and benefit, to a great deal, with/from other diverse specialities and sub-specialities including oro-dental and maxillo-facial surgery, plastic and reconstructive surgery, aesthetic and cosmetic surgery, orthognathic surgery, otolaryngology, ophthalmology, neurosurgery, and general surgery, with each bringing new insight(s)/perspective(s) to the practise of CMFs, in diagnosis/diagnostics and management and/or treatment [2,3,7-9].

As trained CMFs clinicians, we are well-suited to comprehend the anatomic and biologic complexities of the cranio-maxillo-facial complex, understand the fundamental relationship between the underlying bone and the overlying soft tissue, and consequently, improve our methods, techniques (and armamentarium) and hence, the standard of care for our patients [2,3,5,7,9]. Indeed, a wide range of technologies resulting from Research, Development, and Innovation (R&D&I) changed and continues to change the way we operate, and to appreciate the possibilities of the future, as surgeons, we must look back at our past, and the evolution of CMFs [10-13]. As mentioned in the précis above, oro-dental and maxillo-facial surgery preceded CMFs; established since the beginning of the last century [1-3]. From the use of anesthesia in simple extractions to the later the use of wires in treating mandibular fractures, to micro-vascular free-flap techniques used to import a living tissue along with its nutrient artery and vein (to efficiently restore or reconstruct voids in the jaw created by tumor resection), the evolution of oral and maxilla-facial surgery took time and effort. The first scientific writings in the area of orthognathic surgery can be traced back to Simon P. Hullihen in 18496, published in the *American Journal of Dental Sciences* and later in the year 1912 when one of the first books oriented to maxillo-facial surgery appeared and was written by Vilray Blair, then updated in 1917 [5]. Later, in 1927, the German surgeon Wolfgang Rosenthal described mandibular lengthening using the distraction osteogenesis (DO) technique which originated as a method to repair skeletal deformities and large, non-healing, segmental bone defects resulting from injuries suf-

fered by Russian soldiers during World War II [11]. [DO is a method of biologically creating *de novo* or new bone between two surgically-cut bone surfaces that are separated in a controlled manner by incremental (gradual) traction [11]. Today, DO is used in the cranio-facial region to manage developmental and acquired deformity resulting from trauma and pathology] [11]. In 1926, the German surgeon Martin Wassmund presented maxillary advancement in a patient suffering from hypoplasia [4,7]. Then, in 1960s, substantial advances contributed to the development of the specialty, when Robert Hall innovated the first high-speed rotating part in 1964, Per-Ingvar Branemark carried out the first implant interventional procedures in humans in 1965, Hugo Obwegeser published his techniques in orthognathics and orthognathic surgery in 1966 and Paul Tessier presenting his first cranio-facial surgeries and patient cases in 1967, in Rome, as highlighted earlier above [3,4,7-9]. Fifty-five years later, great advances in oro-dental and maxillo-facial surgery and CMFs are evident, where the surgeon can attempt to restore the effected defect(s) as accurately as possible, ensures a living blood supply to these tissues via micro-vascular techniques and employs suture(s) finer than a human hair to delicately connect the artery of the transplanted tissue to have a defined blood supply of its own, boosting its healing capability [10-15]. Overall, reconstructive, and aesthetic surgery, today, not only seeks to rebuild, restore, or return to normal those soft and hard tissues that have been rendered abnormal, dysfunctional or deformed due to an event, yet also to improve facial appearance [10-15]. The event may be brought on by trauma, congenital abnormalities, the resection of a tumor, or the result of a disease process. For example, cleft lip and palate are reconstructed by CMFs to re-arrange and -place these tissues into proper alignment, appearance and function (of the lip, palate, jaw, and face). In trauma cases, affecting the nose, eye sockets, jaws, ears and skin of the victim/patient, CMFs restores and re-creates these tissues, either by re-arranging local tissues or by importing new skin and bone from other body parts such as the hip, lower leg, or shoulder, among many options [10-15]. Henceforth, for a comprehensive care of the patient, CMFs involves much more than oro-dental and maxillo-facial surgery and the surgeon interactively interacts with other disciplines, specialities, and sub-specialities, including orthodontics, biomaterials, and nanobiotechnology, among others, to produce an optimal outcome [10-18].

This is why the background of a cranio-maxillo-facial surgeon includes full dental education, amongst others [2]. Thus far, from the systematic development of scientific evidence, the increase in the number of qualified surgeons and the growth of researchers in the area have also allowed for the innovation, design, development and support of new ideas, new technologies and inventions in deformity surgery, reconstructive surgery, facial aesthetic surgery, oral and dental surgery and other areas that are strongly incorporated into the current training of oral and maxillofacial surgeons as well as CMFs [10,12,15-18]. Indeed, the incorporation of biomaterials, biomimetics, platelet concentrates, 3-D printing (and recently, hybrid 3-D printing combined with electro-spinning), tissue engineering, regenerative medicine, cell-, protein-and gene-therapy, controlled pharmaceutic delivery systems, nanotechnology, virtual surgery, robotics, augmented reality, and artificial intelligence are today the basis for technological developments, focusing their innovation on improving the quality of life of patients, their families and their health care providers [10-18]. Certainly, plastic, reconstructive, and aesthetic surgery today aims to restore unique human qualities such as appearance, speech (palate), hands, to improve interaction with others and thereby positively impact the quality of life. Herein, computer-assisted surgery (CAS), image-guidance systems, 3-D printing technologies (including/incorporating 3-D computer-aided design/computer-aided manufacturing, additive manufacturing, surgical occlusal splints, custom-made guides, templates, and fixation plates) can be applied to plastic surgery and cranio-maxillo-facial operations to better plan and control the change of the bony skeleton of the skull, face, and jaws [19,20]. Furthermore, modern digital technologies, such as the aforementioned CAS, that incorporate various forms of advanced simulation, imaging, software, analysis, and planning, are changing the way that surgeons operate; revolutionizing the ability of surgeons to visualize, plan, and create rapid prototyped models and patient-specific implants for surgeons involved in the broad disciplines of CMFs, oral and maxillofacial surgery, plastic, reconstructive and aesthetic surgery as well as ENT/otolaryngology, with improved, superior, more precise, and predictable outcomes [19,20]. Herein, for instance, rather than improvise during surgery; surgical interventional steps can be pre-conceptualized, simulated, planned, and executed with superior outcomes and decreased patient morbidity, henceforth, impacting quality of life.

On the other hand, necessarily, rigorous scientific publication and technological development advance together, give the surgeon the great responsibility of constantly studying to keep up with these developments and deliver quality treatments to our patients. It is perhaps noteworthy herein to the younger generation that the completion of a surgical residency program implies qualification to act as a professional in the area and requires permanent updating to keep up with technological advances and innovation that are not the heritage of a certain place but are developed in different parts of the globalized World. With the lessons learnt from the COVID-19 pandemic and its aftermath, the World-wide adoption of live and virtual learning and instructional courses has greatly enhanced and promoted access to avenues, access, and opportunities by which direct mentorship and out-reach can ensue. For these reasons, the task of our academic institutions, training programs, associations and groups is also to generate instances that allow, besides investigating, the design, development, evaluation, optimization and translation of new technologies, innovations, techniques, methods, and skills that are required by our residents and surgeons and promote the evolutionary and revolutionary progress of CMFs based on valid scientific and clinical (and end-user) evidence. The summon is to continue to invest, advance, contribute and impact the progress of CMFs, with integrity and ethics, empathy, quality and evidence-based work, translational and impactful innovation, and continuous improvement of our surgical processes and tools so that we provide the benefit of optimal functional and aesthetic results, patient satisfaction and treatment preference, and precise translation of the treatment plan for a better quality of life, and thereby our specialty continues to grow in a sustainable and sustained way, for the decades and generations to follow. It was said that by standing on the shoulders of giants [4], our field has advanced to its current state, and such giant shoulders shall persist.

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