Digital Tools in the Interdisciplinary Orthodontic Treatment of Adult Patients

Alexandru S. Ogodescu, Cosmin Sinescu, Emilia A. Ogodescu, Meda Negrutiu, and Elisabeta Bratu

***Abstract*—**Orthodontic treatment of adult patients with complex dental problems is done in interdisciplinary teams where different specialist of dental medicine have to manage a vast quantity of data. In such complicated cases good diagnostic tools and easy communication are essential. Computer science has an increasing impact in almost every aspect of the orthodontic practice, research and education. The paper will present, discuss and evaluate the applications of computer technology in interdisciplinary orthodontics like digital photographs, virtual study models, cone beam computed tomography, three-dimensional craniofacial imaging, communication, virtual reality, software for prediction and treatment planning, video imaging, manufacture of orthodontic appliance, web-based digital orthodontic records and network-attached storage device. In conclusion all this digital tools and the new digital paradigm will change the way of imaging, diagnosing, documenting and will propel well the interdisciplinary orthodontic treatment of adult patients in the future.

***Keywords*—**Interdisciplinary adult orthodontics, computerized diagnostic tools, digital patient records, virtual reality, simulation and manufacture in orthodontics, network-attached storage.

I. Introduction

THE evolution of dental specialties allowed for an enhancement in the quality of treatment performed to adult patients.

In the past orthodontics was performed mainly to children and adolescents, generally in solo practice in relative isolation. Now, the orthodontist has emerged as a member, and frequently the leader, of an interdisciplinar team seeking to improve the overall results for adult patients with complex dental problems [1].

In the last years an increasing number of adults have been referred to orthodontists not only to correct their primary malocclusions but also for adjunctive orthodontic treatment to correct problems brought on by periodontal disease, edentulous areas or hopeless teeth. The number of adult patients is continuously growing and today represents more than *40% of new patients* in most orthodontic offices [2].

Unlike orthodontics for children and adolescents, for adults that often have mutilated dentition with association of primary and secondary dento-maxillary malocclusions with various diseases of the stomatognathic system, the therapeutically targets and rules are not the same as in the growing patients.

In the management of compromised adult malocclusions the orthodontist must interact *interdisciplinary* with the periodontist, oral and maxillofacial surgeon and the restorative dentist to perform excellence [3, 4].

Fig.1 Adult patient with advanced periodontal disease and dento-

maxillary malocclusion before (left) and after (right) the interdisciplinary therapy

By respecting protocols and interdisciplinary collaboration rigors many cases that initially seem to be compromised could reach a functional and aesthetic balance (Fig.1, Fig.2)

Fig.2 Periodontally compromised adult patient with secondary dento-maxillary malocclusions before (left) and after (right) the interdisciplinary orthodontic treatment

This new concept of interdisciplinary collaboration between orthodontics and other specialties of dental medicine is best synthesized by the word TEAM (Fig.3).

T.E.A.M. = TOGETHER EVERYONE ACHIEVES MORE

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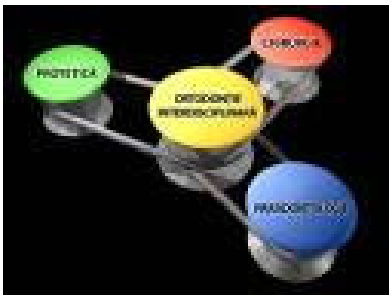


Fig.3 Interdisciplinary orthodontics gear [2]

To have good results in such complicated cases it is very important to have those diagnostic tools that facilitate an easy communication between the different specialists and with the patients for weighing the risks and benefits of all treatment options.

Adult orthodontic treatment often involves compromise and compromise solutions can be performed only through *continuous communication* between the various specialists involved in the treatment.

In the past the application of computer science to orthodontics was limited to creation of databases with some data from patients obtained with classic diagnostic methods on photographs, radiographs or plaster models.

Today the evolution of the digital technology has changed computers from having a limited, supporting role mainly in managing databases to one being indispensable in orthodontic treatment.

The Internet, the actual CAD/CAM (computer – aided design and computer – aided manufacturing) technologies and the development of high speed communication modalities have enabled group practices, with multiple locations, to access records in outlying locations electronically. We speak today about *digital orthodontic office* [5]. We think that this paperless technology has a good impact on the environment. But are we able to use and apply all the developments of the computer science in the everyday orthodontic practice or research? How safe are all this digital records?

Everyday we see that the introduction of computer science and the digital technology has improved our lives making things better, easier to use, cheaper and more reliable.

Steadily we introduced the digital technology in the way we managed our practices. At the beginning we used the personal computers in the front office to manage the business part of our offices. After this we put the computers chair-side for better communication with the patients, for behavioral management and to increase the efficiency of the patient's record keeping. Today more and more of us in the interdisciplinary orthodontic treatment of adults and generally in orthodontics use digital imaging technology and computerized treatment planning tools to help for better care and communication with our patients.

Orthodontics is in a large manner similar to computer science because we have to spend most of our time to solve problems and to think logic and straightforward for solutions.

II. Problem Formulation

Computer technology is having an increasing impact on the practice of orthodontics, with digital imaging and radiography, three-dimensional virtual models and various CAD-CAM technologies affecting everyday practice. Virtual reality will be used in telemedicine, education, patient care, treatment planning and a host of other areas. The applications are only limited by our imagination [6].

The orthodontic records like study models, panoramic and cephalometric radiographs or the patient's intraoral and facial photographs are used to collect data in order to establish a diagnosis, to develop a problem list and a therapeutic concept.

These records, however, can be damaged or lost and need to be stored and maintained many years (Fig.4)

Fig.4 Veiled cephalometric radiograph, 6 month after exposure, become blurry and unusable. This would not happen if we would scan the radiograph or use a digital x-ray machine.

When you initiate an orthodontic treatment and damage some records you cannot have the initial clinical situation that changed during the treatment. If the clinical initial situation is digital you can restore it at any moment with the same excellent quality (Fig.5)

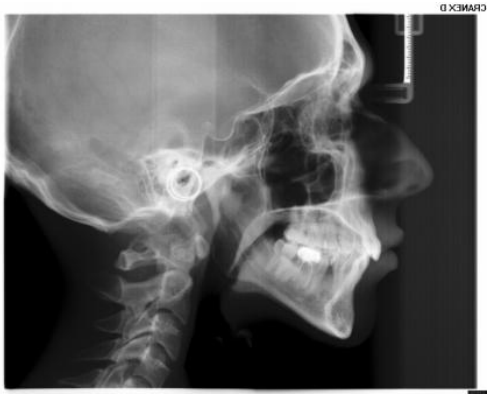


Fig.5 The digital cephalometric radiograph with excellent anatomical details even after many years

Also in our didactic work with students these records can be destroyed accidentally and need to be replaced every year. All this problems belong to the past in the *digital decade* [7].

Because adult orthodontics is a complex science with many data from different dental specialties you must integrate this

amount of information in order to elaborate a diagnosis and a treatment and also to observe the evolution of all this parameters during the treatment.

All this models, radiographs, photographs and files occupy a huge space that grows over the years and requires new storage spaces while the digital format is more easily archived and accessed.

The analyses of the records are done manually using different measuring tools. This is a time consuming process, not always very exact (depending on the ability of the clinician) and also the amount of information that you can obtain is limited. To correlate all this information is not always easy. Today we have a lot of *computerized diagnostic tools* but before using them we should ask a question: are those accurate?

Today more and more orthodontists are aiming toward a *paperless practice*. But without papers, as the data becomes digital, the protection of this data is very important. So in parallel with the development of digital orthodontic tools and environment we must develop and apply good *backup protocols* for this crucial data. This issue will be also discussed in this paper.

Also in research you must process a lot of information and it is very difficult to manage this data without using the latest developments in computer science [8, 9, 10].

The objective of this study was to evaluate the different applications of computers in orthodontics and to compare the accuracy of measurements carried out using dedicated software on digital models and cone-beam computed tomography (CBCT) with measurements made by hand on conventional plaster models.

III. PROBLEM SOLUTION

For each case treated with interdisciplinary orthodontics we applied the following steps:

1. Acquisition of images and enhancement: digital photographs, optimal scanning of radiographs, photographs and dental casts.
2. Digitization: to reduce the common sources of error in cephalometric or cast measurements we use computer-aided methods like multiple digitization or computer aided point identification.
3. Measurements and analysis with dedicated software.

We used also digital facilities like image histograms to correct image problems or morphing and warping for photorealistic treatment predictions.

Today smile analysis and smile design is a key factor in orthodontic diagnosis and treatment. Using digital videography and computer technology the clinician can evaluate the patients dynamic anterior tooth display and incorporate smile analysis into routine treatment planning. Esthetic smile design is a multifactorial decision-making process that allows the clinician to treat patients with an individualized, interdisciplinary approach [11].

Today all the orthodontic records of adult patients can be in digital format and also they are some software solutions in order to analyze them (Fig.6, 8, 12).

Fig.6 The intraoral digital photographs of a patient with a partial transposition between the upper canine and first premolar, with the persistence of the temporary canine

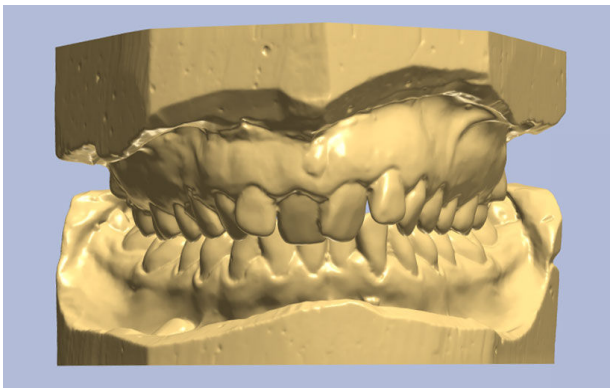
A. Digital Photography

Digital photography is today widely used to document orthodontic adult patients. The digital single lens reflex (SLR) cameras were tested for use in intra- and extra-oral photography and proved to generate perfect images when used with the recommended macro-lens and macro-flash (Fig.6).

The large possibilities offered by the recent image processing software allow a better diagnosis of the adult patient malocclusions. Because the digital images are so precise often in front of the computer screen you can see more details than during the clinical examination. The analyze of digital photographs and tools like image magnification or contrast enhancement holds promise for the detection of white spot lesions (W.S.L.) or better management of the dental surfaces after the debonding of fixed orthodontic appliances [12].

B. Digital Models

The introduction of digital models has provided the orthodontist with a viable alternative to plaster models with the added advantages of electronic storage of data, minimal storage space required, simple and accurate cataloguing and a



rapid transmission of records for consultation [13].

Fig.7 Digital model scanned with the laser scanner of the firma 3Shape

In our studies we used digital models generated by scanning of plaster casts into the computer using 3D optical scanners. For some studies we used the laser scanner of the firma 3Shape A/S from Copenhagen, Denmark (Fig.7) [l4, 15].

For our patients we use the optical 3D-Scanner Activity 101 from the Firma Smart Optics Sensorentechnik GmbH, Germany (Fig.8).

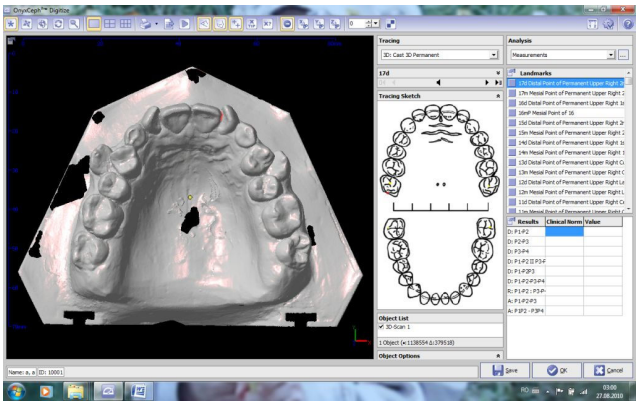


Fig.8 Digital model scanned with the Activity 101 Scanner

The measurements on the 3D models were performed using the OnyxCeph^{3TM} software developed by the firma Image Instruments GmbH, Germany.

Are those measurements precise?

Generally computers are very accurate in measuring things. Actually this is exactly what they do the best since they are infinitely precise, mathematically based beings.

In our studies, like in many others from the recent orthodontic literature about digital models, we found that the measurements of dental dimensions by the software package were very precise, and this is probably the truth at almost all quantitative orthodontic software [14, 15, 16].

For this study we scanned a total number of 227 teeth using an optical three-dimensional scanner (Activity 101, Firma Smart Optics Sensortechnik GmbH, Germany).

The measurements on the 3D models where performed using the OnyxCeph^{3TM} software developed by the Firma Image Instruments GmbH, Germany.

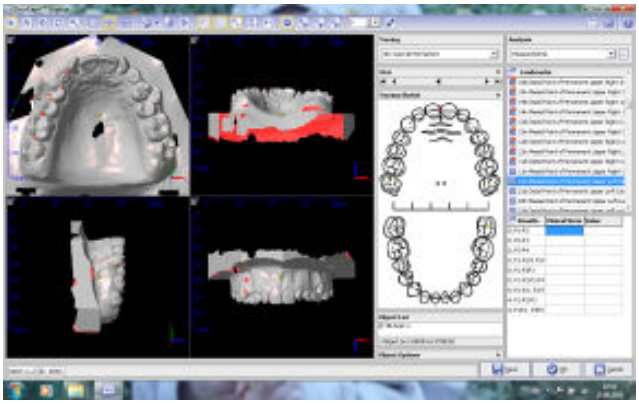


Fig.9 Digital model analyzed with the OnyxCeph^{3TM} software

All of the teeth have no interproximal caries, restorations or stripping and no evident tooth wear. The same teeth were measured on the scanned plaster models with a digital caliper by the same investigator. The teeth were measured from occlusal and facial view (Fig.9).

After performing statistical analysis (Student's t test for paired data) they are no major differences between the measurements carried on digital and plaster models.

Digital models can be used in conjunction with CAD-CAM technologies to individualize the brackets to the adult patients crown morphology. So we will obtain a more stable tooth/bracket interface and a better biomechanical control on the specific tooth movements in interdisciplinary orthodontics [17].

3D databases from digital models and virtual model analysis are useful tools for diagnosis and treatment planning but also for education and research, facilitating statistical analysis.

C. Digital Radiography

After photography and models the introduction of digital radiography is another important digital tool in the actual concept of virtual reality in orthodontics.

The actual possibility to transmit the digital radiographic images via modem to other specialists is a very important aspect in the interdisciplinary orthodontics. Many times the specialists involved in the therapy of this complex cases need to have full access to the whole documentation of the patient and today in many instances the documents are carried by the patient from one dental office to another. Sometimes on the way the documentation is deteriorated or lost and there is no possibility to see again the initial or intermediary clinical situation. For this reason sending digital images directly over phone lines virtually eliminates the chances of losing or destroying films.

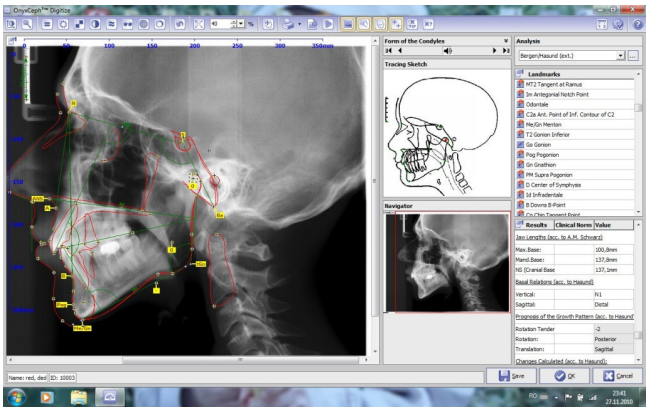


Fig.10 Cephalometric analyze of a digital radiography using a dedicated software

The actual possibility to send images electronically to another dental office allows for consultation between different

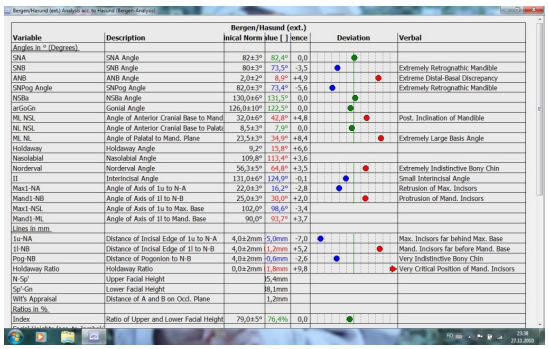
dental professionals in almost instantaneous fashion and this *interoperability* is very important for the success of the interdisciplinary team.

The digital storage of the information allows printing copies for patients and dentists at the same quality after many years.

Also specific annotations can be printed on each image.

The digital cephalometric radiograph can be analyzed more precisely using dedicated software. To our cases we used the OnyxCeph^{3TM} software developed by the Firma Image Instruments GmbH, Germany (Fig.10).

Because of the ability to optimize the display of an image the orthodontist may choose to enlarge areas of greatest diagnostic values, for example in the positioning of the specific landmarks. This was done until now manually using a magnifier. What is really amazing at this software is that after pointing the requested landmarks on the cephalometric radiograph you can choose a lot of measurements and analysis that can be done to your case and you will get a final label with the actual value, the deviation from the standard values and also the clinical significance of the findings (Fig.11).



Variable	Description	Bergen/Hasund (ext.) inical Norm alue [ ] ence		Deviation	Verbal
Angles in ° (Degrees)					
SNA	SNA Angle	82±3°	82,4°	0,0	
SNB	SNB Angle	80±3°	73,5°	-3,5	Extremely Retrognathic Mandible
ANB	ANB Angle	2,0±2°	8,9°	+4,9	Extreme Distal-Basal Discrepancy
SNPog	SNPog Angle	82,0±3°	73,4°	-5,6	Extremely Retrognathic Mandible
NSBa	NSBa Angle	130,0±6°	131,5°	0,0	
arGoGn	Gonial Angle	126,0±10°	122,5°	0,0	
ML NSL	Angle of Anterior Cranial Base to Mand	32,0±6°	42,8°	+4,8	Post. Inclination of Mandible
NL NSL	Angle of Anterior Cranial Base to Palat	8,5±3°	7,0°	0,0	
ML NL	Angle of Palatal to Mand. Plane	23,5±3°	34,9°	+8,4	Extremely Large Basis Angle
Holdaway	Holdaway Angle	9,2°	15,8°	+6,6	
Nasolabial	Nasolabial Angle	109,8°	113,4°	+3,6	
Norderval	Norderval Angle	56,3±5°	64,8°	+3,5	Extremely Indistinctive Bony Chin
11	Interincisal Angle	131,0±6°	124,9°	-0,1	Small Interincisal Angle
Max1-NA	Angle of Axis of 1u to N-A	22,0±3°	16,2°	-2,8	Retrusion of Max. Incisors
Mand1-NB	Angle of Axis of 1l to N-B	25,0±3°	30,0°	+2,0	Protrusion of Mand. Incisors
Max1-NSL	Angle of Axis of 1u to Max. Base	102,0°	98,6°	-3,4	
Mand1-ML	Angle of Axis of 1l to Mand. Base	90,0°	93,7°	+3,7	
Lines in mm					
1u-NA	Distance of Incisal Edge of 1u to N-A	4,0±2mm	5,0mm	-7,0	Max. Incisors far behind Max. Base
1l-NB	Distance of Incisal Edge of 1l to N-B	4,0±2mm	1,2mm	+5,2	Mand. Incisors far before Mand. Base
Pog-NB	Distance of Pogonion to N-B	4,0±2mm	0,6mm	-2,6	Very Indistinctive Bony Chin
Holdaway Ratio	Holdaway Ratio	0,0±2mm	1,8mm	+9,8	Very Critical Position of Mand. Incisors
N-Sp'	Upper Facial Height		5,4mm		
Sp'-Gn	Lower Facial Height		8,1mm		
Wit's Appraisal	Distance of A and B on Occl. Plane		1,2mm		
Ratios in %					
Index	Ratio of Upper and Lower Facial Height	79,0±5°	76,4%	0,0	

Fig.11 The final chart of the cephalometric values, with the verbal explication of the clinical significance of the determined values

Of course in all this digital software the standard values are from international literature and studies and does not always correspond with the actual norms of our patients. Studies for *determination of the growth and development standards* of our actual population are very important and we are working on this (Dr. Emilia Ogodescu) [18, 19]. These digital tools are very important in the studies of the growth and development of the stomatognathic system because they help to manage precisely a waste quantity of information and define better such a complex phenomena as growth is.

Fig.12 The 3D CBCT imaging allows a good view of all anatomic elements, particularly the alveolar bone around the teeth in transposition and the relative position of the tooth

Another important tool - *Cone Beam Computed Tomography (CBCT)* is ideally suited for dento-maxillofacial scanning and offers a lot of useful information for the interdisciplinary orthodontic diagnoses (Fig.12, 13).

The new GALILEOS cone beam technology (Sirona Dental Systems, Inc.) has a perfect combination of software (GALAXIS 3D imaging software), 3D volume reconstruction and 3D diagnostics [20].

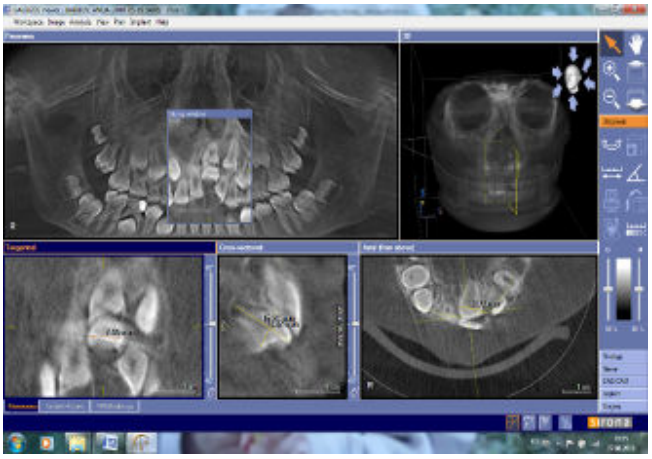


Fig.13 The 3D imaging allows a good view of the position of the supernumerary teeth, the relationship with the surrounding structures and even linear measurements can be done with the dedicated software proven to have a good accuracy.

For example the case of an 11 years old girl with a delayed eruption of the two permanent central upper incisors. Clinically there is only a tumefied alveolar process. What is inside? What produced the disturbance in the normal eruption? On the panoramic radiograph we observe 4 supernumerary teeth and 2 incisors but it was very difficult to decide the teeth that should be extracted mainly because the supernumeraries have completely developed roots. So we decide to recommend a CBCT (fig.14, 15).

Fig.14 Initial clinical situation with 4 supernumeraries

Fig.15 Due to the advancements in computer technology the CBCT comes with exceptional anatomical details of the investigated region.

Always when we recommend a CBCT we must take into consideration the risk from ionizing radiation that result from this examination especially because we often work on growing children.

In a recent study the authors concluded: depending on the size of the scanned field, the effective doses with CBCT vary significantly. A scan of 13 cm height, which is sufficient in most growing patients, with a fast scanning mode results in a dose approximately two times than a conventional set of orthodontic radiographs. Whole head scanning without a neck shield to allow the study of the cervical vertebrae was found to produce an almost 4-fold increase in the radiation compared with three routine orthodontic radiographs [21].

Even in the digital decade always when indicating a radiographic examination we must follow the *ALARA principle* ("as low as reasonably achievable").

The CBCT is very useful for the three-dimensional quantification of the alveolar bone for Orthodontics, Periodontics or Implantology. The Galileos software for virtual implant planning enables the precise positioning of the implant (Fig.16).

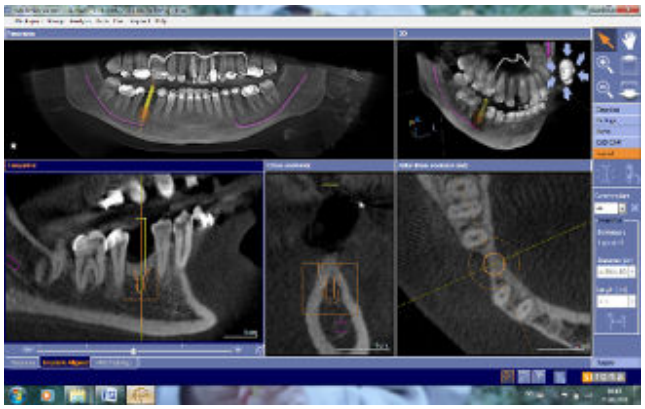


Fig.16 After the orthodontic treatment the implant site was evaluated by CBCT and the software for three-dimensional pre-surgical dental implant treatment planning

In the field of orthodontics the CBCT is probably the most revolutionary medical informatics innovations.

Thanks to it lower costs and lower dosage (compared with regular CT) it has made three-dimensional (3D) imaging a tangible reality for the dental field. If widely used, it will affect a very large area of the orthodontic practice in the future, from visual treatment objectives (VTO) to digital casts to 3D cephalometric analysis and incidental findings [22].

The digital radiography has a lot of benefits over the classic one beginning with the elimination of the necessary darkrooms, processor and flatbed scanner, all capital expenses.

With no need for chemical processing, the monthly costs of chemicals, upkeep of the processor, film mounts and film are eliminated. There is also a significant environmental benefit to this technology since the heavy metal waste stream that results from chemical processing is eliminated [23].

D. Virtual reality in orthodontics

To explore the human face the science goes from classic photography to digital two-dimensional (2D) and even to three-dimensional (3D). Based on the triangulation and fringe projection method the 3D facial scan is used to measure aesthetic facial parameters, to orthodontic diagnosis and to evaluate the craniofacial growth and development [19]. More studies and advances in manufacturing engineering and in the development of specific software for image processing must be done to make this method more suitable for everyday clinical use.

Computer science has an impact in almost every aspect of the orthodontic practice: diagnosis and treatment planning, communication at consultations and with other specialists, data base maintenance or practice management. Computer-assisted cephalometric analysis is today a point of interest for more and more orthodontists.

Orthodontic treatment for adult patients is often done for esthetic reasons. Using computer science we can create a computerized craniofacial model based on a large number of soft-tissue measurements, facial profile and proportionality, all for evaluation of the facial esthetics. The uses of computers in the management of this large amount of information provide relevant standards that are useful in the diagnosis and treatment of *the actual adult population* with dentofacial deformities.

Three-dimensional (3D) computer models of the human craniofacial structure have been constructed with computed tomography (CT). However, the high cost of CT and the radiation exposure are drawbacks to this method. Today using a technique, proven to be accurate, it is possible to produce a 3D head model on a personal computer based on cephalograms, facial photographs and dental cast models. This three-dimensional computer-generated head model will provide easy-to-understand information for patients and establish a diagnostic or therapeutic method for communication with other health care providers [24].

Virtual reality in orthodontics modifies a lot of the traditional techniques. We must not cut the plaster models to generate set-up models, we can create them virtually. There is

a great interest in develop specific software for prediction and treatment planning to correct the malocclusion, or for *simulation of tooth movements*. It allows the clinician to simulate the effect of the orthodontic treatments, and is also useful in engineering design of new brackets that fit better with the biomechanical conditions when treating periodontally compromised adult patients [17].

Video imaging is an important emerging technology in orthodontics, in planning orthognathic surgery, in educating patients about the esthetic effects of treatments and also in the education. There is a great interest in this technology and how to apply it to the orthodontic treatment of adults and for *computer generated video image predictions*.

Today with the use of computerized imaging techniques and the CAD/CAM technologies the orthodontists can integrate the computer in the manufacture process of orthodontic appliance. The best example is the Invisalign system where the series of trays are made using a computer-assisted simulation of the needed movements [25].

In education the introduction of computer science has a tremendous effect. Virtual reality in orthodontics by creation of diagnosis web sites provides the undergraduate and postgraduate students in orthodontics an accessible source of complete, good-quality study materials. Web-based digital orthodontic records were as effective in teaching clinical orthodontic diagnosis as were conventional records [26].

In the orthodontic research we cannot imagine any important result without the use of computer science even for epidemiological studies, for biomechanical or material studies.

E. NAS (Network-Attached Storage)

All this big quantity of information need to be protected otherwise it can be destroyed as easy as the previous versions of clinical records. The digital tools have a lot of advantages over the classical diagnostic tools but are *equally vulnerable to loss* as the last ones. For this reason if we want to have success with this paperless work environment and innovative imaging technology we have to apply *adequate backup protocols* for this crucial data.

They are two critical tasks in each backup design:

- To backup the information as frequently that can minimize the amount of data you need to enter manually if you have to restore the data. Generally you must backup once/day.
- The backup must be taken out of the office in order to remain with the information if the computers are stolen or if the office burns down.

A very good method to archive the information and to share files between multiple computers are the network-attached storage devices (NAS).

The NAS is a computer connected to the network that provides to other computers of the network file-based storage services. It can store any data that appears in the form of files, which is typically the situation in orthodontics.

Basically the *network storage device* is a server dedicated to the file sharing system. It has a lot of advantages: it allows storing and retrieving large amounts of data, it can be utilized from any location that has a network connection, it provides reliable operation and easy administration, do not require keyboard, mouse or monitor.

For our adult patients we have a NAS appliance on a network port. The unit holds 465 GO of data. Each night, incremental backups sweep the day's work onto the NAS.

All the diagnostic findings of our patients are copied on this device. Each patient receives a username (the patients ID) and a password and all the specialists that participate into the interdisciplinary orthodontic team know the patient's username and password and have access to the whole data of the patient during the treatment. The files can be viewed at any computer station via network. This improves the *interoperability* of the dental team and makes communication between the different dental specialists very easy.

Today when we all go a lot to congresses, holidays or meetings this system allows us to work on our cases not only in the office or at home but everywhere we go and there is a network connection.

Also for congresses or courses for the University we use this easy access to create or update our presentations.

In conclusion network attached devices are amazing solutions for file sharing for both clinical and home purposes.

Respecting the TEAM (together everyone achieves more) principle from interdisciplinary orthodontics we can say that today the computer and the computer science is the first partner in every team that tends to optimize the treatment effects for their patients [27].

IV. Conclusion

In the orthodontic treatment of adult patients computer science is very present.

The era of plaster models seems to come to an end. Today's orthodontic hardware and software facilitates rapid measurements on digital models without any distortion on the real morphology of the teeth.

The introduction of digital photographs, the virtual study models and CBCT may allow the use of a fully electronic patient record. This is particularly useful because these patients are treated in interdisciplinary teams, with many dental specialists that need a facile access to the whole documentation. With good management of this digital data, proper backup protocols, patients records will never again be lost or misplaced and can be used in a large variety of domains. This new *digital paradigm* will propel well the orthodontic treatment of adult patients in the future.

When we recommend a CBCT examination we have to compare between the increased amount of information obtained and the increased radiation dose for each person.

Orthodontics is undergoing a gradual transition from plaster decade to digital decade, mainly due to advancements in computer technology, changing the dental specialists to a new way of imaging, diagnosing, documenting and communicating between them and with the patients.

Each specialist in orthodontics and in other specialties from dental medicine should have good knowledge in bioinformatics and should be trained to use these new digital devices in order to provide better medical care for the complex cases.

All this digital technologies when applied correctly and in an interdisciplinary approach they *fertilize each other*, resulting in more precise diagnosis, improved treatment results and better communication.

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