38 3D, 4D, Mobile APP, VR, AR, and MR Systems in Facial Palsy

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Key Points

- 3D facial surface imaging systems are a fast, noninvasive instrument, which provides accurate measurement of the 3D movement of facial markings and can be used as an objective system for evaluating the effectiveness of various facial reanimation procedures, as well as for preoperative consultation.
- 4D imaging allows capturing the movement of a 3D surface over time and is therefore especially suited for dynamic measurements, such as facial expressions.
- Mobile apps are a new trend, which will continue to evolve and further support the plastic surgeon. At present, the areas of application in facial surgery remain limited to supporting the patient during rehabilitation, surgical simulations, or helping with the application of clinical scores (e.g., eFace).
- The use of VR/AR offers a fast and patient-safe training to acquire surgical skills and help plastic surgeons operate faster and more accurately and therefore improve patient outcomes and reduce surgical morbidity.

38.1 Introduction

In plastic and reconstructive surgery, many diagnoses are based on visual examinations; therefore, imaging technologies provide essential aids to support diagnosis and therapy. Objective analysis of facial movement is essential to quantify the extent of facial paralysis. This helps to predict the postoperative course of recovery and allows comparison of postoperative outcomes. Quantifying the degrees of facial palsy and the dimensions of facial movements has long been assessed with various grading systems.

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38.1.1 Subjective Diagnostic Tools

Subjective facial motion analysis tools like the House-Brackmann, Sidney, or Sunnybrook facial scoring system [1–4], and patient questionnaire, such as the Facial Clinimetric Evaluation (FaCE) Scale, are subject to evaluation by the examiner and may comprise investigator's rating [5]. The House-Brackmann scale for facial grading, introduced in 1985, is the North American standard used for evaluating facial function and classifying facial paralysis [3]. In further consequence, subsections for the diagnosis of facial synkinesia had been developed. These included the "Facial Grading System" [1], the "regional House-Brackmann facial nerve grading system" [6], the "Sydney facial grading system" [7], and patient questionnaires specifically aiming at synkinesia, such as the "Synkinesis Assessment Questionnaire" [8] and the "FaCE Scale Instrument" [5], were introduced. Subjective diagnostic tools for facial function are easy to use and inexpensive, but do not provide completely accurate facial function.

38.1.2 Objective Diagnostic Tools

Sawyer et al. highlight the importance of quantitative analysis of the healthy side in unilateral facial palsy to aid reconstruction of the paralyzed side, as well as the additional help for Mobius syndrome with bilateral facial palsy in recreating the smile [9]. Classic technologies include stereolithography, stereophotogrammetry, structured light, moiré topography, image subtraction techniques, light luminance scanning, laser scanning, and video systems [10].

Objective assessment of facial nerve function is crucial for adequate planning and evaluating therapeutic interventions in patients with facial palsy [11–13]. In particular, the three-dimensional analysis of facial function for pre- and postoperative examination, adequate surgical planning, and evaluation and research in facial surgery has become indispensable [12]. Diagnostic systems that rely on the technique of three-dimensional video analysis, like the "3D Video Analysis System" developed by Frey et al. [11, 13–15], provide both quantitative and qualitative data of facial function [16–18]. Three-dimensional analysis allows the most precise assessment of facial movement. Gross et al. found that two-dimensional analysis underestimates three-dimensional excursions by up to 43% [19].

Chuang et al. developed an objective scoring system for assessing smile excursion that is fast and easy to use. Since the mid-1990s, this has been used at Chang Gung Memorial Hospital for pre- and postoperative assessment of smile reconstruction outcomes [20].

38.1.3 Current Status

Several subjective and objective diagnostic tools have been reported for the quantification of facial nerve palsy. Multiple centers around the world have created their individual diagnostic instruments, but an international standard has not yet been created [21]. A brief summary of the subjective and objective diagnostic of a facial palsy grading system is provided in the following paragraphs. Quality assurance in facial reanimation surgery is essential and requires adequate tools to document the preoperative and postoperative status. Due to the versatile changes of the surface of three-dimensional nature of facial movements and expressions, these set challenging requirements for 3D and 4D systems [9, 10, 22–26].

This chapter introduces the technical aspects of 3D and 4D systems, mobile apps, and virtual technologies relevant for the facial palsy surgeon. Reflecting rapidly ongoing advances in optical systems and data-processing software, this chapter focuses on the typical features and strengths of each system, rather than on technical data, which tend to become outdated quickly.

38.2 Technical Aspects

Most 3D and 4D systems fall into three systems: structured light analysis, stereophotogrammetry, and optical-based analysis of images/frames of videoshots.

Laser- and optics-based technologies for surface imaging have evolved considerably over time and are increasingly used in medicine. Optics-based technologies for surface imaging include stereophotogrammetry and structured light. In the following section, the basic principles of these technologies are presented in more detail.

38.2.1 Structured Light

This technique is probably best known for the touchless 3D scanning of fingerprints. Visualization of three-dimensional surfaces utilizing structured light requires the projection of known patterns such as grids, dots, or horizontal bars onto the desired object. At least one camera from a different perspective is needed to capture the distortion of this structured light from its original pattern. The information is then processed for the geometrical reconstruction of the surface structure.

Imperceptible light, such as infrared light, can be used to avoid undesired interference of these patterns with other imaging software; however, if multiple cameras are used, pictures need to be taken in sequence to avoid pattern overlapping due to the different viewpoints. This results in a prolonged data acquisition process, which in human subjects can be disadvantageous for data accuracy [27].

38.2.2 Stereophotogrammetry

Three forms of stereophotogrammetry can be distinguished: active, passive, and hybrid.

Active stereophotogrammetry combines natural texture correspondences with random unstructured light patterns projected on the surface of the desired object. In contrast to structured light, the camera is not previously calibrated with the characteristics of the projected light pattern. The latter simply works as an additional source for two-dimensional information that can be captured by the stereo triangulation process and converted into a more detailed three-dimensional image. Active stereophotogrammetry resists the otherwise confounding effects of ambient lighting.

Passive stereophotogrammetry relies heavily on sufficient texture correspondences (e.g., skin imperfections, freckles, wrinkles) on the surface of the target object. High-resolution cameras are needed to feed the associated imaging software with high-quality two-dimensional images, which are processed into a three-dimensional geometry model by using sophisticated stereo triangulation algorithms. After the surface has been calculated, color is added by the software. Passive stereophotogrammetry requires careful management of ambient light. In contrast to active stereophotogrammetry, with this method highly directional ambient light can cause glare effects on the surface of the subject, which affects the detail of the texture. Scattered light can produce undesired reflections, potentially disturbing data processing. The detailed mathematical and optical design principles of photogrammetry for the creation of three-dimensional surface images have already been described in detail in the literature [27, 28]. Compared with older surface-imaging modalities, the coverage of up to 360° and a fast acquisition speed are particularly noteworthy.

Hybrid stereophotogrammetry integrates both active and passive techniques, to provide higher quality and accuracy in creating a three-dimensional surface image.

For evaluation of follow-up data taken with 3D stereophotogrammetry, interobserver reliability was less than intraobserver reliability; it was therefore recommended that only one observer should assess 3D stereophotogrammetry data for follow-up measurements [29].

38.2.3 Analysis of Images

For analyzing the images, the patient will usually be photographed digitally or videotaped. To access images from videotaped data, video sequences are edited and saved to image files for analysis.

38.2.3.1 Landmark-Based Approaches

The most common approach to grading facial palsies from a single RGB image is to use facial landmarks. Facial movements are measured by calculating the distance and angle between facial landmarks.

Comaniciu et al. performed tracking of landmarks marked on the face using the software After Effects® CS 5 (Adobe Inc.). A special "mean-shift tracking algorithm" was implemented for this purpose [30] (Fig. 38.1). Accuracy of about 99% was achieved. Landmarks covered by skin creases (e.g., lower eyelid rim) were recalculated with additional software programs [24].

Gaber et al. [31, 32] implemented an automatic system based on Kinect v2 real-time facial recognition software, where there is no need to place markers on the face.

Similarly, Park et al. [33] proposed a landmark-based system using a smartphone video recording (iPhone 4S and iPhone 6) without marker placing, which can distinguish facial palsy from normal subjects by analyzing three states of facial expression—resting, smiling, raising eyebrows—without interference from the recording suroundings (Fig. 38.2).

Other methods, using facial landmark assessment and asymmetrical facial features for objective quantitative assessment of facial palsy, provide promising results, which can be implemented in clinical routines [34, 35].

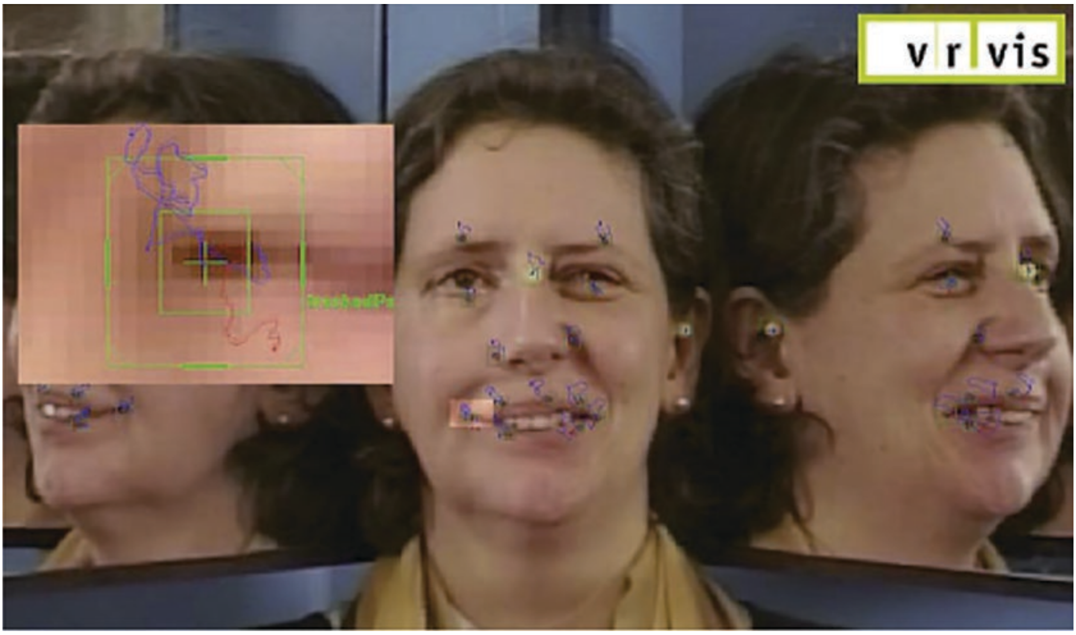


Fig. 38.1 This photograph demonstrates the function of the automatic tracking function of the software. The zoom window shows the tracking of right mouth corner during movement. The red trace visualizes the excursion already tracked, while the blue trace shows the excursion still to be tracked. (Reproduced with permission from Center for Virtual Reality and Visualization Research Ltd., Vienna, Austria, © 2010 VRVis Gmbh [24])

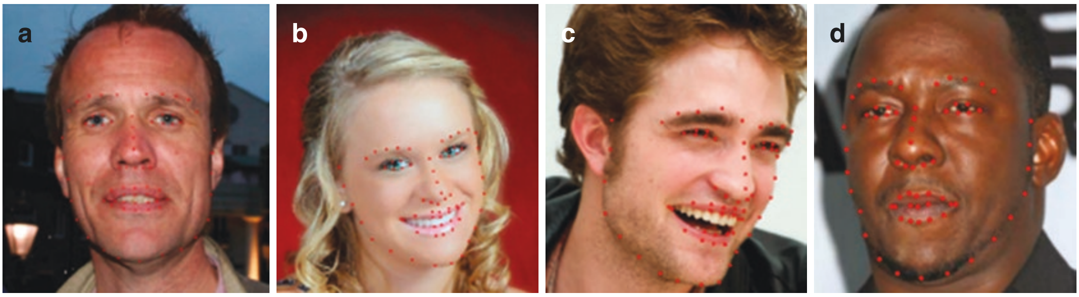


Fig. 38.2 Examples of images analyzed (**a–d**). The red dots represent 68 selected landmarks [33]. (© Figure distributed under the Creative Commons Attribution License)

38.2.3.2 Intensity-Based Approaches

Studies that recommend identifying facial motions using intensity-based features have been rare to date. In 2007, Monhar et al. proposed to use so-called optical flow-strain patterns as a simplified and appropriate method for visualizing and characterizing facial soft tissue [36] (Fig. 38.3). The proposed method has several unique characteristics. (a) Instead of using the image intensity, the strain pattern is used here for grading, as it is related to the biomechanical properties of the facial tissue that are unique to each individual. (b) The strain pattern is less sensitive to different illumination effects and face camouflage because it remains constant as long as the facial changes are reliably captured. (c) No special imaging equipment is required, as photos or videos of facial deformations can be captured with a regular video camera. In addition to generating an "identity signature," the generated facial strain pattern of an expression reveals the facial dynamics of a person [37]. Although this system was able to track almost all (99%) pixels, a 3D calculation of pixel excursion in millimeters was not yet feasible.

The optical flow-based method [38] and the multiresolution local binary pattern (MLBP) [39] showed promising results in automatic objective facial palsy grading. Guo et al. [40] proposed a Convolution Neural Network (CNN) based on GoogLeNet [41] by exploiting pattern recognition methods to perform objective facial palsy classification with a pretrained inception model. This system provided 91.25% accuracy for predicting the degree of facial palsy using the House-Brackmann scale based on a facial palsy image dataset.

Compared with landmark-based approaches by AAM technology [42], the application of a pretrained CNN [43], in combination with the Supervised Descent Method (SDM) [44], has the advantage of numerical stability during localization of landmarks, improved speed, and less sensitivity against slight nuances of facial expressions in the CNN training model (usually standard emotions using publicly available datasets) and the ability to analyze expression of facial palsy that differs from normal facial movements [45]. However, Zhuang suggested that a combination of landmarks-based and intensity-based approaches is essential to produce the most accurate results in facial palsy grading, when compared with either landmarks or intensity approaches separately [46].

38.3 Overview of 3D and 4D Surface-Imaging Software

Advances in optical systems and data processing software allowed ongoing improvements in the assessment of facial expressions. The 3D systems presented below are briefly explained in the following sections.

Fig. 38.3 Representation of facial expressions in the form of an "optical flow" (line 2) and as an "optical stretch" (line 3) in the example sequence. Different colors correspond to different directions of vectors; intensity of color correlates with strength of deformation. Whiter regions correspond to higher strain strength, while black regions contain no strain. (Reproduced with permission from the Department of Computer Science and Engineering, University of South Florida, Tampa, FL, © 2010 [24])

38.3.1 3D Video Analysis

The 3D video analysis system presented here consists of a system of specially arranged mirrors, a grid for calibration, and a commonly used digital video camera (Fig. 38.4). Eighteen facial anatomical landmarks were set, which are standardized and easy to reproduce. Three of

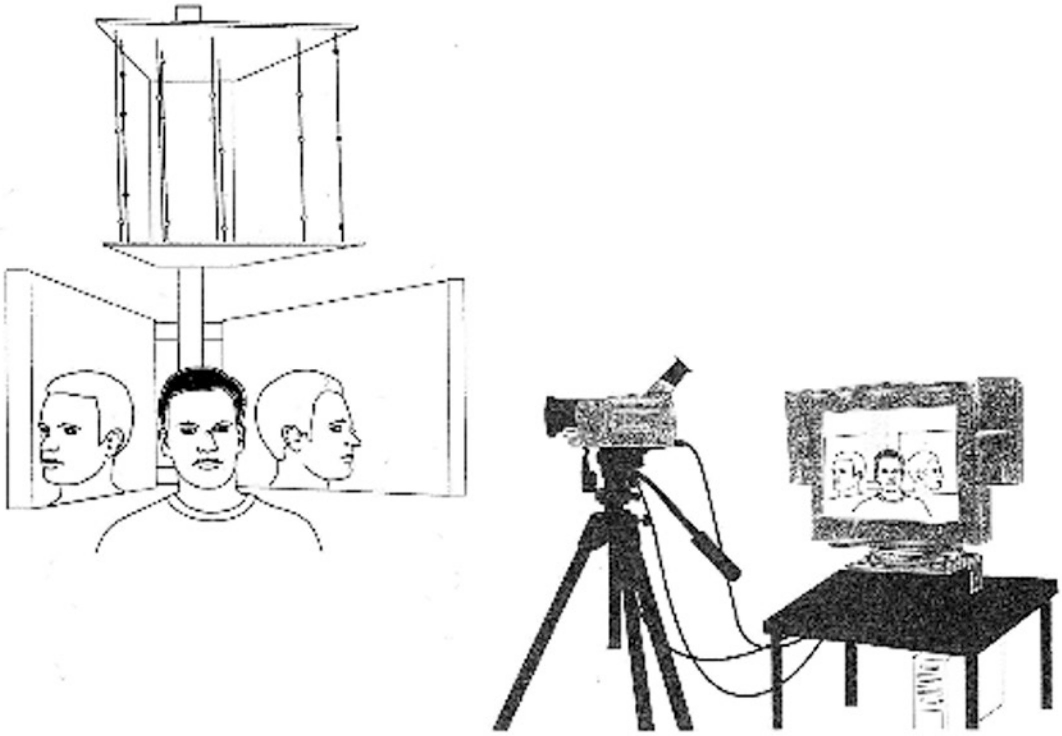


Fig. 38.4 Schematic drawing of the "3D video analysis system" setup. (Reproduced with the permission of Lippincott Williams & Wilkins [47])

them are static and 15 are dynamic. The static points are marked with 5 mm plastic light balls. Black eyeliner is used to mark the dynamic landmarks as 2 mm black dots. All markings, except for the points of the philtrum and the center of the nose, were placed on each side of the face [11]. Frey et al. performed standardized video recordings of the subjects. After selecting the most suitable video sequences, these were edited and saved as video and image files on a storage medium. Subsequently, the 3D coordinates of landmarks in the face were generated using the specially programmed software Facialis®. Visualization of the generated data was done with the FaciShow® program. Both programs were specially developed by the Laboratory of Biomechanics of the Swiss Federal Institute of Technology, Zurich, Switzerland. This allows two- and three-dimensional trajectories of each set marker in motion to be evaluated [15, 24].

38.3.2 3dMD

3dMD (www.3dmd.com), since 1999 based in London, UK, and Atlanta, GA, USA, combines modular hardware architecture with an adaptable software environment. This interchangeability of components and the ability to upgrade existing systems allow for significant efficiency. These modular units consist of industry standard cameras that work with a set of scaffolding and mounting systems. The 3dMD technology utilizes hybrid stereophotogrammetry (active and passive) with software algorithms using the texture of the skin, as well as projected random patterns, to stereo-triangulate and generate a three-dimensional surface image. For the facial plastic surgeon, the following are the most suitable: *3dMDface* (Fig. 38.5), *3dMDhead,* and *3dMDdynamic 4D systems*. The *3dMDDynamic 4D system* enables 4D video analysis (3D over time).

Fig. 38.5 Mounted 3dMDface System. (Reproduced with permission from 3dMD, © 2020)

3dMD provides image fusion software called 3dMDvultus that combines a 3dMD surface image with computer tomography (CT), cone-beam computed tomography (CBCT), or digitalized training models. The program offers a variety of features to help assess patient condition, plan and simulate treatments and surgeries, and evaluate results. Other features include real-time 3D volume and cross-sectional visualization. There is the option to automatically load DICOM with stored orientation transformation. Patient images can be overlaid; surface measurement (distance/angle) and sophisticated 3D landmarking can be accomplished. Of particular interest are the superimposition and thus the comparison of pre- and postoperative conditions as well as the quantitative evaluation of surface and volume changes.

The 3dMDtempus software even allows the analysis of the skin dynamics of the subject in ultra-dense resolution. Furthermore, it allows dynamic analysis of posture, functional motion as well as a visualization of soft tissue deformations in sequence or in isolation.

Several studies confirmed the high precision and reproducibility of the 3dMD Systems. By comparing the data captured with 3dMD's system and Maxilim (Medicim NV, Mechelen, Belgium), for the evaluation of outcomes in oral and maxillofacial surgery, Maal et al. found the intra- and interobserver error of the reference-based registration to be 1.2 and 1.0 mm, respectively [48]. In a comparison with anthropometric landmark coordinate data in terms of precision, error, and repeatability, Aldridge et al. attest to the high repeatability and precision of the 3dMDface System [49].

Lubbers et al. recommend the 3dMD system for evaluating and documenting the facial surface. In a measurement on mannequins, they state the reliability with a mean global error of 0.2 mm (range, 0.1–0.5 mm) [50]. Hong et al. confirmed the accuracy of all landmarks and parameters analyzed in this study with the 3dMDface system by measurements on a mannequin. The mean total errors were below 1.00 mm for both linear and surface parameter measurements [51]. De Menezes found that the 3dMd method was repeatable, and random errors were always lower than 1 mm [52]. Concordance between craniofacial measurements using the 3dMDface system compared with manual anthropometry showed a significantly greater variability in manual compared with 3D assessments ($p < 0.02$) [53].

38.3.3 Artec3D

Artec3D (https://www.artec3d.com) is an international group of companies with their headquarters in Luxembourg, where it was founded in 2007, and subsidiaries in the USA and Russia. Its products and services are used in various industries, including mechanical engineering, healthcare, media and design, and entertainment. Its scanners are structured (white) light scanners. The three-dimensional coordinates obtained in this way are used to digitally reconstruct the real object. Artec3D offers a variety of different formats of 3D scanners, from portable solutions, like the Artec Eva (Fig. 38.6), to the Artec Ray for capturing large objects, like an airplane. For plastic surgery, only the formats Artec Leo, Artec Eva, Artec Eva Lite, and Artec Space Spider are of practical and reasonable size.

Artec Studio is 3D scanning and post-processing software. It guides the user through a series of questions regarding the properties of the scanned object and offers the ability to assist throughout the post-processing process. The autopilot mode automatically joins the scans within a parent coordinate system, selects post-processing algorithms, and cleans up captured data. Artec Scanning SDK is a freely distributed software development kit (SDK) that allows individual users or companies to modify existing software or develop new software to work with Artec handheld scanners. It comes with tools and libraries that allow users to develop their own scan app to control their Artec 3D scanner and edit the recorded data. It is possible to add support for the Artec scanners to existing software or create a C++ plug-in for any commercially available software.

Fig. 38.6 Scanning a subject with Artec Eva. (Reproduced with permission from Artec3D, © 2020)

Koban et al. compared the Artec3D scanner with a reference imaging system (Vectra XT from Canfield Scientific Inc) and demonstrated that three-dimensional surfaces captured for facial imaging by Artec Eva are similar in accuracy to those of Vectra XT reference images [54].

38.3.4 Di4D

Dimensional Imaging (Di4D, formerly Di3D, https://www.di4d.com) was founded in 2003 and is based in Glasgow, Scotland (UK), with a subsidiary in Los Angeles, California (USA). The Oscar-winning company provides systems, solutions, and services for high-resolution 3D and 4D visual field acquisition. Its systems, based on passive stereophotogrammetry, with nine synchronized 12-megapixel machine vision cameras create ultrahigh-resolution three-dimensional surface images able to cover 180° of the face using standard digital still cameras and allow the capture of fine nuances of the unique nature of facial expressions.

Di4D also offers the world's first commercial head-mounted camera system (Fig. 38.7) using passive stereophotogrammetry, remote control, and live recording at up to 60 frames per second. The data video sequence can be evaluated with DI4D optical flow tracking software.

Winder et al. analyzed the geometric accuracy and found a mean error of 0.057 mm, a repeatability error (variance) of 0.0016 mm, and a mean

Fig. 38.7 Di4D's portable head-mounted camera. (Reproduced with permission from Dimensional Imaging Limited, © 2020)

error of 0.6 mm for linear measurements compared to manual measurements [55]. Khambay et al. evaluated the accuracy and reproducibility compared to a coordinate measuring machine and found an average system error of 0.21 mm (range 0.14–0.32 mm) [56]. Fourie et al. compared 3D stereophotogrammetry (Di3D system), laser surface scanning (Minolta Vivid 900), and CBCT (3dMD) and concluded that all are precise and reliable for use in research and clinical applications [57]. Wong et al. demonstrated that their digital measurements with the 3dMD system were reliable, precise (with a mean absolute difference across all measures lesser than 1 mm), accurate, and unbiased relative to direct anthropometry [58].

38.3.5 Canfield

Canfield Scientific Inc. (www.canfieldsci.com), located in Fairfield, NJ, USA, was founded in 1988. Canfield's 3D surface imaging systems are based on passive stereophotogrammetry. VECTRA® H1 and H2 are handheld stand-alone units that use precision optics to produce high-resolution 3D images for facial aesthetics, breast and body aesthetics, and clinical documentation. The VECTRA® XT (Fig. 38.8) creates 3D images of the face, breast, and body as 360° images and circumferential measurements.

Fig. 38.8 Canfield Vectra XT system. (Courtesy of Canfield, Fairfield, New Jersey. Reproduced with permission from Canfield, © 2020)

Canfield's Mirror® imaging software is a fully integrated solution for medical image management, visual communication, and aesthetic simulation. After defining the area of interest, the software automatically calculates the root mean square (RMS) distance values between the facial halves separately for each facial third, thus providing a set of symmetry values. Biomechanical 3D analyses are possible by precisely superimposed image information. This software includes an automated quantitative approach for assessing soft tissue changes, which characterizes the degree of stretching, compression, lifting, and volumization (Fig. 38.9).

Canfield's surface registration procedure has already been applied to facial palsy patients and has been found to be highly repeatable [59]. Sawyer et al. found in their research that intra-rater reliability for measurements of facial landmark motion and angle was very accurate (intra-class correlation coefficients >0.93 for both raters; intra-class correlation coefficients >0.92 for inter-rater reliability) [9]. Oliveira-Santos et al. evaluated the accuracy of the 3D-FACE-Simulator by comparing synthetic and

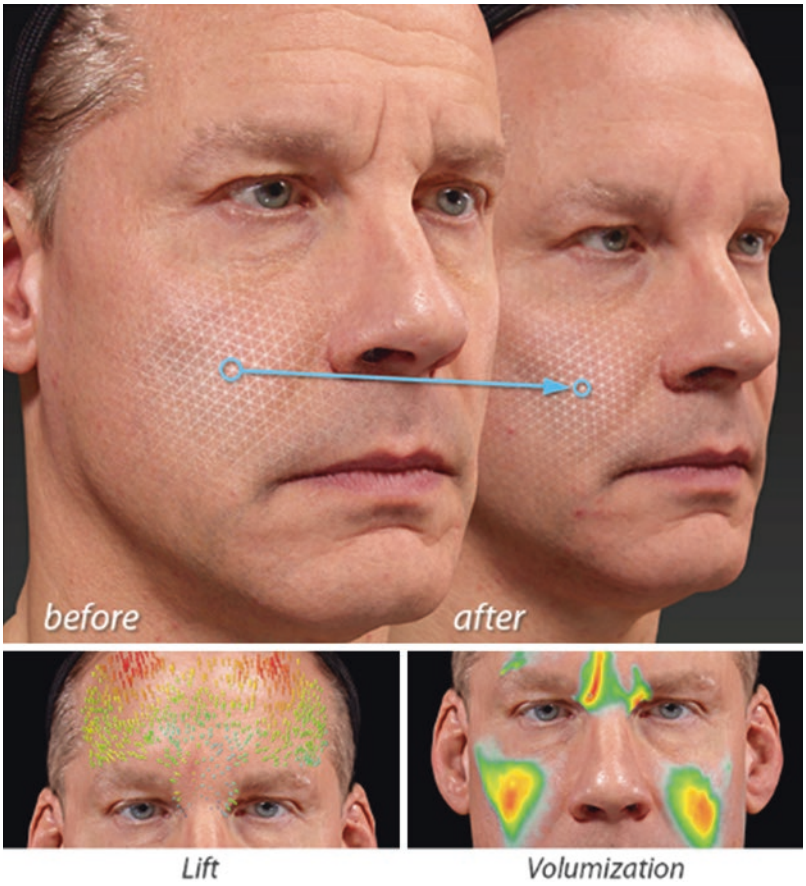


Fig. 38.9 Canfield's software assesses the degree of extension, compression, elevation, and volumization. (Reproduced with permission from Canfield, © 2020)

real faces. Their investigations revealed an average reconstruction error over the entire data set (338 faces) of less than 2 mm [60]. They conclude from their results that the simulation is sufficient for use in consulting. De Menezes et al. showed that Canfield's 3D stereophotogrammetric imaging system can assess the coordinates of facial landmarks with good precision and reproducibility and confirm that Canfield's method is fast and can obtain facial measurements with few errors [52]. In a study by Spanholtz et al., the Vectra technology reliably recorded even volume differences of less than 3 cm^3 and the values measured manually on the body and those measured by the Vectra system showed a mean deviation of only 0.55 mm [61]. Vectra H1 showed high repeatability and is suggested to be accurate and reliable enough for clinical and research applications [62].

38.3.6 Crisalix

Crisalix (http://www.crisalix.com), founded in 2009 and based in Bern, Switzerland, is a leading tech company in the field of 3D aesthetic simulation. In contrast to the other companies presented, Crisalix does not offer any hardware but is purely a web-based 3D simulator for plastic surgery and aesthetic procedures. The patient can be imaged in 3D by either uploading three standard digital photographs of the patient (front view and both profiles) or by using a portable 3D sensor ("Structure Sensor" from Occipital Inc.) connected to an iPad (Fig. 38.10). Crisalix software simulates plastic surgery procedures such as breast augmentation, nose correction, body contouring, and real-time 3D simulations via the Crisalix software. Crisalix software simulation can be

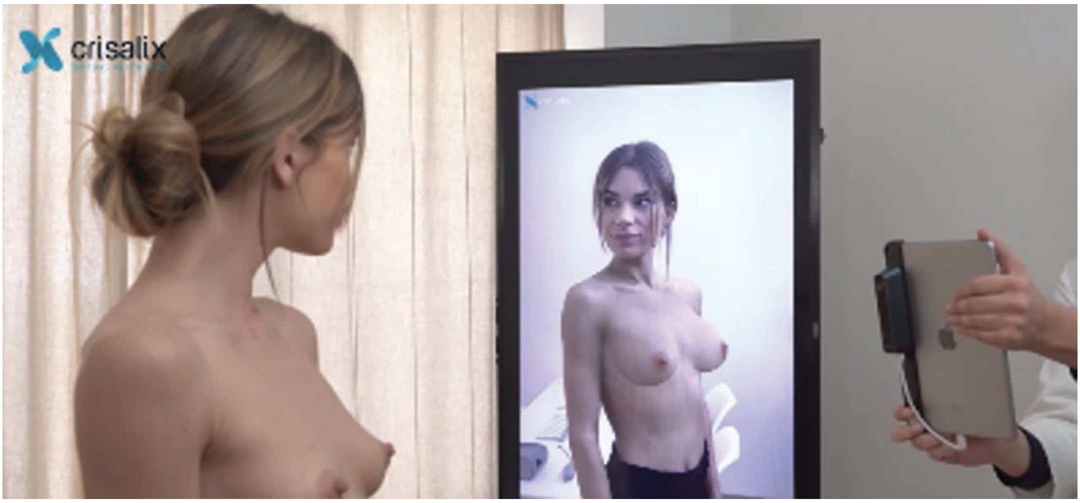


Fig. 38.10 Crisalix live simulation with 3D scanner plugged into iPad and streaming the simulation on a special mirror. (Reproduced with permission. © 2020 Crisalix S.A.)

Fig. 38.11 With VR glasses, patients can access the Crisalix virtual showroom, where surgery simulations can be shown in real time. (Reproduced with permission. © 2020 Crisalix S.A.)

viewed with virtual reality goggles: Oculus (Samsung) and Google Cardboard (Google) (Fig. 38.11).

There are only limited data available for validating the Crisalix system. Oliveira-Santos et al. evaluated the accuracy of the 3D-FACE-Simulator by comparing artificial and real faces. The average reconstruction error was below 2 mm [60]. They conclude that the simulations provide sufficient precision for communication between the doctor and the patient to visualize facial treatment options.

38.3.7 Facegramm

Facegramm was first presented in 2016 by researchers in Porto, Portugal. This system is capable of quantitatively and objectively evaluating complicated three-dimensional facial move-

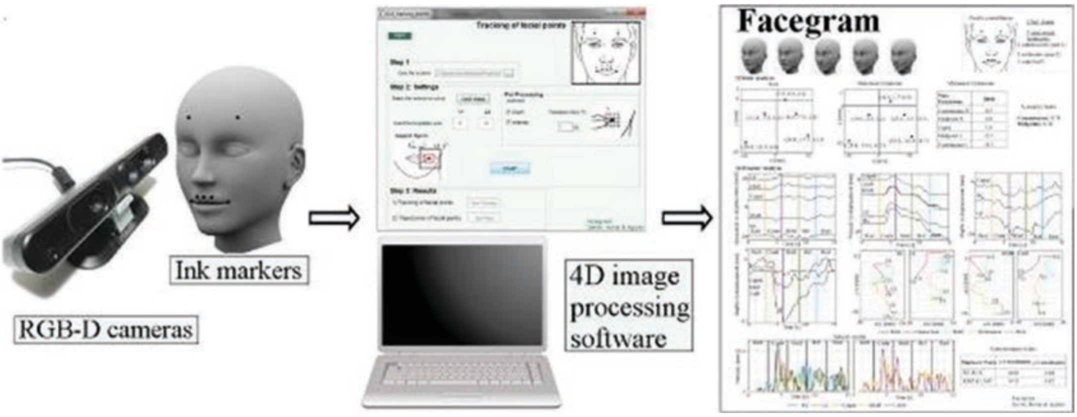


Fig. 38.12 Graphical abstract of Facegramm system [25]

ments by taking a series of static, dynamic, and morphological measurements. Color and depth images can be acquired using specific RGB-D cameras. An algorithm then tracks the location of anatomical landmarks of interest (Fig. 38.12). The system provides useful and detailed quantitative information, both static and dynamic. These characteristics make this system a suitable solution for objective quantitative evaluation of facial movements in a clinical setting [25].

This system has been used in various clinical applications to evaluate facial functions, as in postoperative radiotherapy [63], and in long-term follow-up of facial palsy patients, whose paralytic lower eyelid retraction was improved with midcheek lifts [64]. Validation of this system was performed using a 3D print in an orthogonal three-dimensional coordinate system and resulted in 100 μm accuracy in all three directions [25].

38.3.8 FACE System

Facial Assessment by Computer Evaluation (FACE) software was announced in 2012 by ENT surgeons in Boston, USA [65], designed for 2D facial analysis. This system was built on the "Scaled Measure of Improvement in Lip Excursion" (SMILE) program [66], which used a MATLAB-based image analysis software tool from Mathworks Inc. for quantifying oral commissure excursions.

It evaluates the static positions of the anatomical landmarks in the face as well as the dynamic facial movements. Photoshop (Adobe Inc) is used to scale the images to be analyzed to the iris diameter (11.8 mm) for normalization [67] before assessment. To facilitate measurements with the built-in measurement tool for the areas of interest, a horizontal line is set through the pupils and a vertical line is set to bisect the interpupillary line.

38.3.9 Kinect

Kinect (Version I and II, Microsoft, Albuquerque, United States) is based on structured light technology and time-of-flight measurement. The RMS accuracy of 3D images generated with Kinect I and Kinect II ranges between 0.84 and 2.0 mm [68]. Kinect II was used to assess facial palsy and offers assessment scores according to three widely used traditional grading systems [32, 69]. Various studies have applied Kinect system for automated classification of facial palsy [70–73], interactive oral rehabilitation system [74], and systems that can grade facial palsy to set up a suitable rehabilitation program [75].

38.3.10 RealSense

Studies were carried out in Nijmegen, The Netherlands, in 2017 and 2020 [76, 77], validating the 3D geometric (depth) accuracy of facial palsy patients analysis with RealSense Depth Systems (Intel® RealSense™ Depth Camera D415 and

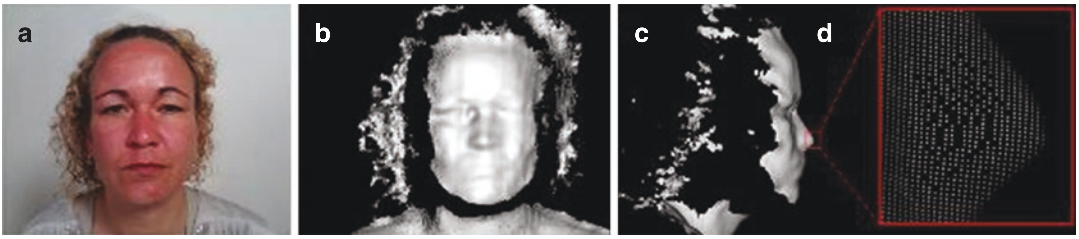


Fig. 38.13 A single frame from a RealSense data set is shown, which at the same time captures the color image (**a**) and the depth image (**b**), by the color sensor and the IR sensor, respectively. The depth data can be also shown from different angles, e.g., from a lateral view (**c**). When zooming in, the individual points of the cloud become visible (**d**) (ten Harkel et al., 2017). (© Figure distributed under the Creative Commons Attribution License)

RealSense™ Camera F200, Santa Clara, USA) by comparing these systems with a clinically validated 3dMD system. RealSense simultaneously captures both the color image and the depth image through the respective sensors (Fig. 38.13). Its measurements and 3dMD measurements expressed on average the agreement of −0.90 mm (−4.04 to 2.24) and −0.89 mm (−4.65 to 2.86) for intra- and inter-rater agreement, respectively [76]. Based on the reported reliability and agreement of the RealSense measurements, RealSense can be considered as a viable option to perform objective 3D facial palsy measurements. These studies were intended to be a foundation for implementing RealSense in a clinical or telemedicine setting, to assess facial palsy patients.

38.3.11 Smart Facial System

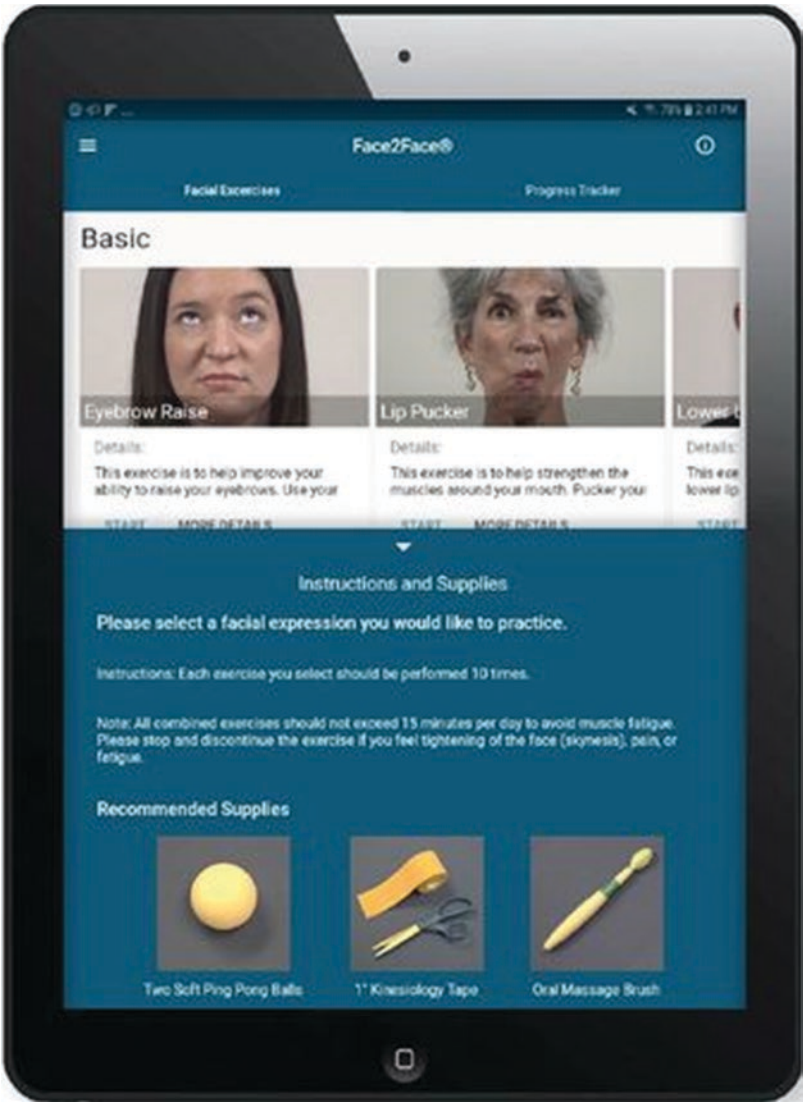
Scientist from Rome, Italy, proposed a video system that captures patients' facial movement with gray, circular retroreflective self-adhesive markers. The video was recorded using a commercial smartphone, within a weakly illuminated room, with the smartphone light switched on. Virtual Instrument (VI) software developed in LabVIEW (Laboratory Virtual Instrument Engineering Workbench) was used to grade the patients' facial palsy. Video recordings of patients were assessed by three blinded examiners using the House-Brackmann and Sunnybrook facial scoring systems; the third investigator, an independent technician, performed the assessment using the SMART FACIAL system. Consistency of rating between scores obtained using all three assessment methods was observed in 87% ($n = 41$ patients). Statistical analysis found a significant correlation between these three grading systems ($p < 0.0001$) [78, 79].

38.4 Mobile Apps

Mobile apps for smartphones or tablets are an emerging trend. From playful apps that allow users to apply "beauty filters" to their photos to complex programs that simulate plastic surgery operations on the face, there is a wide variety of apps for smartphones. There is even an app to support and guide patients during rehabilitation after facial paresis. A few interesting and helpful apps for the plastic facial surgeon are briefly described below. It can be assumed that the market for apps for both physicians and patients will continue to grow. VR apps can help not only during the counseling process, but also in incorporating the patient's expectations.

38.4.1 FACE2FACE® App

The Face2Face Facial-Palsy-App (Kapios Health, Toledo, USA) supports the treatment and rehabilitation of patients with facial paralysis (Fig. 38.14). The application uses the prin-



Details:
This exercise is to help improve your ability to raise your eyebrows. Use your

Details:
This exercise is to help strengthen the muscles around your mouth. Pucker your

Details:
This exe
lower lip

Please select a facial expression you would like to practice.

Instructions: Each exercise you select should be performed 10 times.

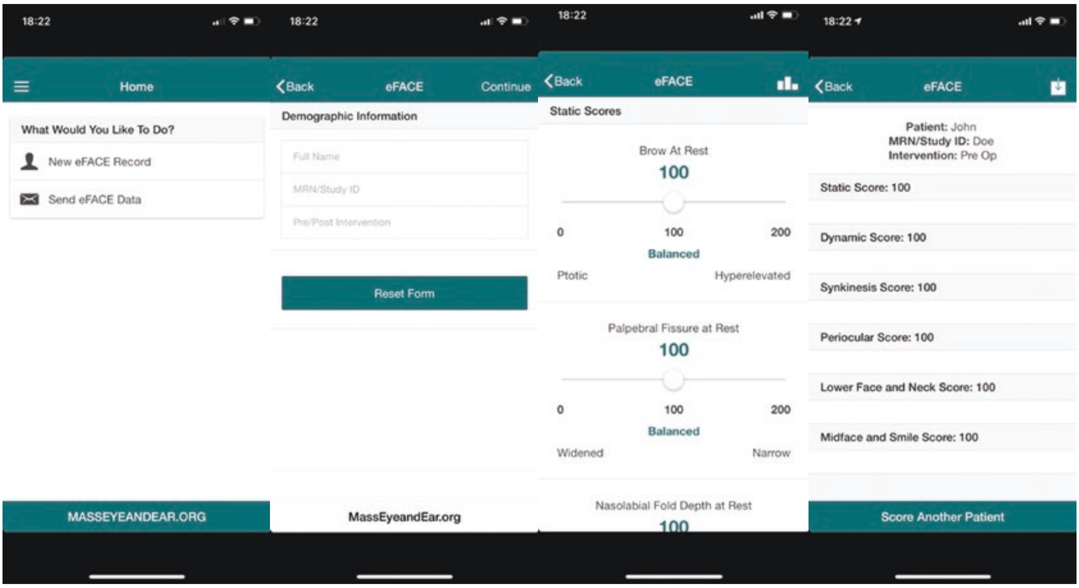
Note: All combined exercises should not exceed 15 minutes per day to avoid muscle fatigue. Please stop and discontinue the exercise if you feel tightening of the face (skynesis), pain, or fatigue.

Fig. 38.14 Face2Face Facial-Palsy-App on the iPad. (Reproduced with permission from Kapioshealth.com, © 2020)

ciple of mirror biofeedback therapy, which has been associated with positive results in treating idiopathic facial paralysis [80, 81]. The program works like a double-mirrored slit mirror and projects the unaffected side onto the affected side, creating the illusion of a complete, symmetrical face. This is intended to put the patient in a positive and motivating environment while performing the exercises with sufficient repetition to bring about long-term synaptic changes [82].

38.4.2 eFace App

The eFace App is a Clinician-Graded Electronic Facial Paralysis Assessment (eFACE) by Massachusetts Eye and Ear Infirmary (Boston, USA) (Fig. 38.15). The app is available through the Apple Appstore for iOS devices. This application can be used for rapid quantitative and graphical representation of various facial function values in patients with unilateral facial paralysis using visual analog scales [83]. It evaluates resting



Patient: John
MRN/Study ID: Doe
Intervention: Pre Op
Static Score: 100
Dynamic Score: 100
Synkinesis Score: 100
Periocular Score: 100
Lower Face and Neck Score: 100
Midface and Smile Score: 100

Fig. 38.15 The eFace App for mobile devices. (© Massachusetts Eye and Ear)

(static), dynamic motion, and synkinesis movements in facial palsy patients. It has a high test-retest correlation [84], validity and reliability [85].

38.5 Virtual, Augmented, and Mix Reality in Plastic Surgery

Virtual reality (VR) is the representation and simultaneous perception of reality in a real-time computer-generated interactive virtual environment. In other words, it is a fully immersive experience, where a user leaves the real-world environment behind to enter a fully digital environment via a VR headset. In contrast to this, a user in augmented reality (AR) experiences virtual objects superimposed onto the real-world environment via smartphones, tablets, and heads-up displays via AR glasses or displays. Mixed reality works with digital overlay displays that project interactive holograms into the user's field of view.

The user sees the real world while being able to modify the digital content generated by the device. Control over the imaged content is often possible through verbal commands and hand gestures [86].

These technologies provide physicians with hands-free, real-time access to internet resources, prebuilt content environments, or even electronic medical records. VR is a powerful tool, which is increasingly being used in surgical training for laparoscopic procedures [87, 88]. With AR glasses, surgeons can project details of ultrasound, X-ray, or MRI images directly in the operating area [89]. This feature benefits trainees in technically sensitive procedures by overlaying the surgical field with patient-specific clinical information (e.g., flap perfusion or depth and location of vessels) [90]—which was proven to have positive effects on the learning curve and the improvement of basic psychomotor skills in the operating room [91–95]. Radiological anatomy 3D VR trainings can be achieved by transforming 2D images into a 3D model by using thresholding and segmentation [96].

For highly specialized and complex surgery, it would be beneficial for doctors and patients to train for each specific facial palsy surgery. Region modules for each specific facial palsy surgery can be created with inputs to control the rotational and translational movement of 3D models in the virtual space. 3D models can be rendered to allow users to explore 3D models by using head tilt and controller input, visualizing essential steps and structures during each surgical procedure. These modular VR trainings will increase educational interactivity (www.facialpalsy.eu). VR provides a rich, interactive, and engaging educational context, which supports learning-by-doing and intuitive understanding of anatomic structures in 3D space. With the enhanced learning curve, it raises interest and motivation and effectively supports knowledge retention and skills acquisition [97].

The benefits of microsurgery VR simulators are endless repetitions of surgery, a safe environment for trainee and patients, a return to the training program wherever the user has left it, possible stress-free conditions for best learning, and reduced costs associated with maintaining animal-based and cadaver-based surgical training [98].

In today's society, interest in safer patient and medical staff workplaces is growing. The need for cost-effective training of personnel and the use of live data as training modules to model certain surgical scenarios are increasing. Surgical situations may involve a multiprofessional team of surgeons, anesthesians, nurses, and medical specialists, all working on one patient at the same time. However, existing simulations are focused on monoprofessional training, omitting the crucial communications and interactive collaboration between the teams. Models for multiprofessional medical team training can be developed from following emergency management education that addresses the combination of activity theory and naturalistic decision-making and recognition-primed decision models, implemented to build a basis for a pedagogical model for multiprofessional emergency management training [99].

Virtual Surgical Planning (VSP) is an evolving technology that updates reconstructive surgery with increased reconstructive accuracy, faster surgical procedures, and improved outcomes [100, 101]. AR has already been successfully used in the preoperative planning and execution of various plastic surgery procedures [101–104].

38.6 Telemedicine

Telemedicine is an upcoming technology, which facilitates the exchange of medical information to assist medical staff to diagnose and treat at a distance. Because the numbers of plastic surgery specialists are limited and because plastic surgery diagnoses are based on visual examination, this technology can extend our expertise to remote sites, beyond major medical centers [105]. Telemedical assessment of facial palsy patients with the House-Brackmann and Sunnybrook grading systems was tested and found to be as reliable as face-to-face assessment, but insufficient when synkineses needed to be evaluated [106]. Moreover, telemedicine has the potential to increase the efficiency of postoperative care for microsurgical procedures, improve care coordination and management of burn wounds, and facilitate interprofessional collaboration, thus eliminating unnecessary referrals and connecting patients located far from major medical centers with plastic surgery specialist "without impinging on—and in some cases improving—the quality or accuracy of care provided" [107]. During the COVID-19 crises, telemedicine served as an essential tool, to provide continuous personal medical service to high-risk patients and patients unable to travel long distances [108]. Furthermore, a study in the United Kingdom reported that telemedicine could improve access to the delivery of facial palsy therapy via telerehabilitation, and that "one legacy of the pandemic may be lower organizational barriers to telemedicine, especially if cost effectiveness can be demonstrated" [109]. Telemedicine potentially has far-reaching effects on healthcare delivery—locally, nationally, and internationally [110]. Since telemedicine has been used and expanded by a variety of healthcare professionals, its legal implications need to be thoroughly considered to safely integrate privacy and medico-legal issues of electronic communications into daily practice. Further research is needed to conclusively demonstrate its benefit in routine clinical care.

38.7 Conclusion

Although a lot of research has been conducted over the decades to analyze facial movements, no objective method for facial grading has yet become universally accepted. Surgical therapy results are therefore difficult or impossible to compare [12, 111]. Subjective methods for facial palsy classifications, such as the House-Brackmann scale [3] and the Sunnybrook facial grading system [1], are reliable and easy to apply. However these systems are observer-dependent subjective assessments [112] and have a pronounced intersubject and interobserver variability [21], restricting the clinical use of such subjective analysis instruments, particularly planning treatments or evaluating interventions [13, 113].

Technologies have evolved rapidly over the past few decades, leading surgeons into a new era of opportunity that will transform working as a surgeon, training, preoperative planning, comparing outcomes, and communicating with patients. Technologies used in 3D and 4D imaging systems and in virtual, augmented, and mixed reality are emerging and beginning to be applied clinically; however, more trials and evidence will be needed to define the practicability of these systems in routine work.

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