Preoperative Planning of Orthopedic Procedures using Digitalized Software Systems

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ABSTRACT: The progression from standard celluloid films to digitalized technology led to the development of new software programs to fulfill the needs of preoperative planning. We describe here preoperative digitalized programs and the variety of conditions for which those programs can be used to facilitate preparation for surgery. A PubMed search using the keywords "digitalized software programs," "preoperative planning" and "total joint arthroplasty" was performed for all studies regarding preoperative planning of orthopedic procedures that were published from 1989 to 2014 in English. Digitalized software programs are enabled to import and export all picture archiving communication system (PACS) files (i.e., X-rays, computerized tomograms, magnetic resonance images) from either the local working station or from any remote PACS. Two-dimension (2D) and 3D CT scans were found to be reliable tools with a high preoperative predicting accuracy for implants. The short learning curve, user-friendly features, accurate prediction of implant size, decreased implant stocks and low-cost maintenance makes digitalized software programs an attractive tool in preoperative planning of total joint replacement, fracture fixation, limb deformity repair and pediatric skeletal disorders.

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Preoperative planning and templating currently comprise standard stages for total joint replacement and fracture fixation [1-5]. Surgical planning had traditionally been performed by means of conventional radiography with a consistent radiographic magnification that allowed templating for the selected prosthesis with prepared component overlays [5]. Computerized tomographic (CT) scanning is another option for improving preoperative planning accuracy but at the cost of the patient's exposure to a relatively higher dose of ionized irradiation [6,7]. Questions have been raised about the accuracy of the standard templating system in terms of magnification mismatches between the radiograph and the templates [3]. A number of factors may affect this mismatch, among them the patient's body size, the tube-to-film distance, and the accuracy of the template's magnification. Digitalized radiography has become the standard modality in most orthopedic centers in industrialized countries over the past decade, creating the need for digitalized templating for the purposes of surgical planning.

Templating is the standard approach for preoperative planning in orthopedics today

Most of the digitalized software systems were developed for use by the orthopedic community in a filmless working environment. This software enables the import and export of all picture archiving communication system (PACS) files – namely X-rays, CTs, magnetic resonance images (MRIs) – from the local working station or from any remote PACS [8-11]. A designated marker is placed at the level of the bone so that it can be automatically detected in the image by the software for the purposes of scale calibration. The next step is positioning the template such that it mimics the intended procedure. These data are stored in each patient's file.

The TraumaCad™ software system (TraumaCad, Petah Tikva, Israel), for example, is used for preoperative planning in various fields of orthopedic surgery, such as joint replacement, fracture treatment, limb deformities in the pediatric and adult populations, spine surgery, and foot and ankle surgery. TraumaCad can be also used intraoperatively by incorporating the Digital Lightbox© (BarinLAB, Munich, Germany). The picture can be edited and refined directly on a large touch screen display. The TraumaCad™ template library contains more than 50,000 templates, each with anteroposterior (AP) and lateral views that were derived from leading companies worldwide.

In this review we present preoperative digitalized programs and the variety of conditions for which those programs can be used to facilitate preparation for surgery. Using the keywords "digitalized software programs," "preoperative planning" and "total joint arthroplasty" we searched for PubMed articles on preoperative planning of orthopedic procedures that were written in English during the period 1989–2014.

Figure 1. Anteroposterior pelvic view of an osteoarthritic hip, the preoperative planning and the postoperative result (from left to right)

PREOPERATIVE PLANNING FOR JOINT REPLACEMENT

Preoperative planning by means of a digitized software program for joint replacement in the hip, knee, shoulder, elbow and ankle has become an integral stage in surgical preparation. The program is an effective tool for training the surgeon how to decide on the type and size of the implant beforehand and thereby probably reduce the intraoperative complication rate. In the past, preoperative radiological planning was performed by applying a transparent template on standard celluloid film. Progression to digitalized technology led to the need for software that can perform digitalized templating. TraumaCad™, one of the more commonly used programs, is a system that combines importing properties from and exporting properties to all kinds of digitalized imaging technologies. This results in precise implant size, accurate measurements, and fewer mismatches between the transparent template and the digital reprint. The TraumaCad™ system [Figure 1] has the properties of digitalized radiography calibration and versatile templating software that can be adapted to accommodate various types and sizes of prostheses.

The earlier application of transparent templates on a standard non-digital film had a prediction accuracy of 62–99% for the acetabular cups and 78–99% within two sizes for the femoral stems [3,4,12]. Magnification differences were found to have affected the choice of the implant in 17% of cases [3]. Similar or even better results, i.e., a prediction accuracy of 86–92% for the acetabular cups and 95–96% within two sizes for the femoral stems, were achieved by shifting to the digitalized technology that uses digitalized radiographs and digitalized template software [1,13-16].

Digitalized software programs are enabled to import and export all picture archiving communication system files from either the local working station or from any remote PACS

A study conducted in our department using the TraumaCad™ software for total hip replacement found that the acetabular component measured within ±1 size was accurate in 89% of the patients (n=65 of 73), 2 sizes were accurate in only 11% (8 of 73), and that the femoral stem design component was accurate in 97% of the patients (n=70 of 73) [15]. TraumaCad™ successfully predicted the sizes of femoral and acetabular components and was easily integrated into all PACS files. A similar prediction accuracy was reported by Gamble et al. [17]. The same approach of preoperative planning with digitalized software can be applied for total knee replacement, which has a very high prediction accuracy for knee implants [13,18-22].

PREOPERATIVE PLANNING FOR FRACTURE TREATMENT

Understanding the fracture pattern is a crucial step in the surgeon's preoperative planning with regard to approach and the type of hardware needed for fracture fixation. In addition to understanding the mechanism of a given injury, appropriate imaging modalities are needed to correctly assess the fracture type. A view of the unaffected limb is recommended as a reference for the surgeon during both the preoperative planning process and the operation. An image is processed by the digitalized software to achieve the best possible fracture reposition and to determine the best placement of hardware type and size. After the outlines of the various broken components are marked separately, each one is shifted around to achieve a straight alignment of the bone. Preoperative estimation of hardware dimensions is critically important, especially in cases where the fracture is too close to the joint line, limiting the amount of hardware to be inserted [Figure 2].

Limb deformities are mainly congenital, developmental, or post-traumatic malunions. The first two etiologies will be discussed in the section on pediatric orthopedics below. Accurate estimations in the preoperative planning for the correction of a malunion deformity require AP and lateral views of the bone, CT scans or MRI studies, and three-dimension (3D) reconstruction in order to differentiate between a simple and a complex deformity. Specifically, a simple deformity is visible in only one plane, while a complex deformity (e.g., shortening, angular or rotational) occurs in at least two planes. Images of both the

Figure 2. Preoperative planning of a fracture of the distal tibia. The distal fragments were traced to the desired position and a nail with screws template was applied on the image

Figure 3. Pelvic view of developmental dysplasia of the right hip and an analysis and measurement table for the patient

Templates	Measurement tools	Report	Rt	Lt
Hilgenreiner Acetabular Index (*)			32	24
Central Edge Angle (*)			15	22
Reimer's Index (% migration)			38	19

☑	Show Hilgenreiner Angle
☑	Show Central Edge Angle
☑	Show Reimer's Index

normal and the deformed limb are needed to adjust the plan for performing the osteotomy and repositioning it as close as possible to the plan for the normal limb. The digitalized software integrates all the recorded images such that the preoperative planning is similar to the fracture repair itself. The deformity outline is drawn and the bone is split into two fragments at the level of the desired osteotomy. The two fragments are then lined up to obtain the desired corrected position. The software archive is used in the ensuing step for selecting the proper available fixation device. When these steps are completed to the surgeon's satisfaction, the planned program is saved to be used during the actual surgery.

PREOPERATIVE PLANNING FOR LOWER LIMB DEFORMITIES IN THE PEDIATRIC POPULATION

Conditions that may appear at birth, such as bone dysplasia, developmental dysplasia of hip (DDH) and scoliosis, or that develop later in life, such as Perthes' disease, slipped capital femoral epiphysis, limb deformities due to trauma, infection or metabolic condition and others, are classified according to radiographic parameters. The severity of these conditions, their natural history, indications for surgery, and the follow-up of surgical results are based on specific radiographic measurements between defined landmarks for assessing hip joint development, lower limb length differences and alignments, scoliosis curves and more.

The short learning curve and user-friendly features make digitalized software programs an attractive tool in preoperative planning

The key for performing all these measurements is defining the anatomic landmarks necessary for producing the line drawings [23]. Recent studies comparing inter- and intra-observer agreement for various measurements on conventional and digital radiographs showed that digital measurements were equal or more accurate than conventional ones [24-26]. The pediatric section of the TraumCad™ software (for example, TraumCad™ version 2.2, OrthoCrat™) was designed so that an illustration corresponding to various conventional measuring tools would appear at the bottom of the page when the anatomy of the hip, long leg, spine, foot or ankle was analyzed, thereby facilitating the locating and positioning of markers on specific anatomic sites. Some of the illustrations contain a short text giving a more exact definition of the anatomic landmarks.

In addition, a dedicated wizard was developed to guide the marking of anatomic landmarks for carrying out the various measurements (length and angle) of the acetabulum, hip joint, lower limb, scoliosis and foot. This technique created a reproducible method for carrying out measurements on digital radiographs of various anatomic parameters [Figure 3].

Hip morphology analysis can be done for a non-ossified, partially ossified or fully ossified femoral head. The acetabular index, central edge angle, Reimer subluxation index and other more specific parameters can be measured for conditions such as DDH, cerebral palsy, Perthes' disease and other acquired hip pathologies [27]. The deformity wizard tool allows the surgeon to perform bone length and mechanical axis analysis, measure hip knee and ankle joints orientation in the frontal and sagittal planes, and trace the center of rotation angulation (CORA) for each bone segment. After the CORA has been defined, a simulated "osteotomy" for deformity correction and lengthening can be performed on the radiographs [28].

Scoliosis analysis by the TrumaCad™ software is done by placing the Cobb angle tool on the appropriate vertebrae, while other parameters, such as frontal and sagittal spinal balance and pelvic inclination, can be traced using special tools. The data and the final radiographs can be stored in the patients' PACS page or in any other file in the form of a report page for future reference [27].

CT FOR PREOPERATIVE PLANNING

CT scanning is another option for improving preoperative planning accuracy, but at the cost of the patient's exposure to a relatively higher dose of ionized irradiation [6,7]. Viceconti et al. [7] observed an increased accuracy from 83% to 89% for the stem and 69% to 93% for the socket using the CT-based surgical planning software (Hip-Op, Rizzoli, Italy) as compared to the standard templates. Similar prediction rates of 100% and 88–96% for stem and cup sizes were obtained using the Hip-Plan software (Symbios SA, Yverdon-Les-Bain, Switzerland) [26,29,30]. Inoue and co-authors [31] used a 3D CT scan and noted a 98% prediction of one stem size and 100% within one cup size. A 3D CT scan assessment optimizes the choice and position of implants, offering a range of motion simulation to prevent any type of impingement and anticipating difficulties encountered during surgery using ZipHip (LEXI, Tokyo, Japan) preoperative planning software [32]. Kobayashi et al., [8] however, did not find digital 3D CT scan preoperative planning to be superior to the conventional 2D templating for predicting implant size in total knee replacement. The advantage of a CT scan derives from the built-in calibration program not available in the 2D conventional templating. The latter requires a calibration tool to better approximate the accurate measured size. A combined CT scan and 3D reconstruction permit optimizing implant choice and positioning, thereby anticipating intraoperative difficulties. Offset measurements are better evaluated using a CT scan: they are not affected by body position or test conditions resulting from the frame having been placed in an improper position. Other benefits of using a CT scan for preoperative planning are seen in cases of severe hip deformities related to trauma or dysplastic conditions, such as femoral head displacement, acetabular fracture, and early osteoarthritis development. Finally, a 3D reconstruction CT scan was found to be more accurate than 2D preoperative planning with regard to internal rotation of the femoral component when using the 2D measurements [8,19]. All these advantages should be carefully weighed against the cost of the patient's exposure to a relatively higher dose of ionized irradiation.

OTHER APPLICATIONS OF THE DIGITALIZED PREOPERATIVE PLANNING SOFTWARE

Digitalized software can be used for various measurements of various spine deformities. It provides values required for foot and ankle surgery by using the foot osteotomy wizard for growth calculation, hallux valgus deformities correction, limb measurements and talar tilt after ankle injury. New applications include the incorporation of an implant template into a 3D configuration, e.g., using the TeraRecon's Aquarius iNtuition program (TeraRecon, Foster City, USA) and intraoperative assistance by software system integration with the BrainLAB navigation system (BrainLAB, Munich, Germany).

CONCLUSIONS

The transition from hard-copy radiographic films to the digital technique has brought with it increasing numbers of software programs. A considerable amount of time will be saved by using PACS compatible software: the various built-in tools have been constructed according to common orthopedic consensus and in collaboration with software developers, the PACS producers and the orthopedic community at large. The high prediction rate provides a financial benefit by significantly reducing implant stocks. The most accurate studies were found to be the 3D CT scan digitalized systems, but they expose the patients to a relatively high dose of radiation. The calibration software is already incorporated in the CT scan system without the need for an external calibration device. We recommend that only congenital or acquired deformed hips or knees be evaluated with the CT scan modality. The short learning curve, user-friendly features, accurate prediction of implant size, high versatility in various fields of orthopedic surgery, together with low cost maintenance, make digitalized software programs an attractive tool in the preoperative planning of total joint replacement, fracture fixation, limb deformity repair and pediatric skeletal disorders.

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