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Preoperative templating in orthopaedic fracture surgery: The past, present and future[☆]

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ABSTRACT

Preoperative planning in orthopaedic fracture surgery corroborates with the goal of establishing the best possible surgical result and ensuring a functioning limb for the patient. From placing sketches on overhead projector paper and measuring lengths from anatomical landmarks, ways of preoperative planning have evolved rapidly over the last 100 years. Today, preoperative planning includes methods such as advanced 3-Dimensional (3D) printed models and software programs incorporating entire libraries of osteosynthesis materials that can be shaped and rotated to fit a patient's specific anatomy. Relevant literature was evaluated to review the development of preoperative templating from the past and present, in order to assess its impact on the future of osteosynthesis.We identified studies on 3D-imaging, computer-assisted systems, and 3D-printed fractured bones and drill guides. The use of some of these systems resulted in a reduction in operation time, blood loss, perioperative fluoroscopy and hospital stay, as well as better placement of osteosynthesis material. Only few studies have identified differences in patient morbidity and mortality. Future techniques of preoperative templating are on the rise and the potential is vast. The cost-effectiveness and usefulness of certain methods need to be evaluated further, but the benefit of preoperative templating has the potential of being revolutionary, with the possibility of radical advances within orthopaedic surgery.

Introduction

Preoperative planning has always been a matter of interest in orthopaedic fracture surgery [1]. Given the variety of surgical approaches and the importance of correct rotation, axis alignment and establishment of normal anatomy, the importance of preoperative planning in orthopaedic fracture surgery cannot be underestimated [2]. Advancements in preoperative planning have been rapid in recent years and templating technologies have evolved substantially [3]. The goal of preoperative planning is to achieve a greater understanding of the fracture, thereby increasing the chance of obtaining an effective reduction and optimising osteosynthesis.

The most common form of preoperative planning is templating, which has long been standard practice in most fields of arthroplasty surgery. Templating is also a key element of trauma surgery, although not as standardised as in arthroplasty surgery. Several forms of templating in trauma surgery have been examined in the literature, though most studies have been retrospective and observational, and randomised controlled trials are sparse and report varying results [4]. Despite this lack of evidence, the proverb *'If you fail to plan, you are planning to fail!'* applies well to fracture surgery.

The aim of this narrative review is to recount the past, present and future of preoperative templating in orthopaedic fracture surgery.

Relevant literature was identified from the PubMed and Embase databases using the keywords "Orthopaedic surgery", "Trauma", "Fracture", "Preoperative planning" and "Templating". In PubMed, MeSH search terms were used to narrow the search, and the reference lists of the included papers were checked for additional studies eligible for this review.

Past

The epitome of advancements in preoperative planning in fracture surgery was the invention of X-rays in 1895, which enabled the visualisation of the bones without breaking the skin. However, preoperative planning was possible without the use of X-rays; templating without X-rays consisted of taking preoperative measurements based on anatomical landmarks [5] or patient height

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[6,7]. These methods showed to be valuable templating options when more advanced options were not available. Pearson et al. conducted a retrospective review consisting of 245 patients with femur fractures treated with intramedullary nailing [6]. By comparing patient height with the length of the nail they found a correlation with the ability to predict nail length with an accuracy of 86% in antegrade nails and 88% in retrograde nails. Issac et al. compared even more ways of determining tibial nail length without the use of radiographic imaging, but compared to Pearson et al. they found a poor correlation with height [7]. Instead, the greatest correlation was found by adding a constant to the tibial tuberosity to ankle distance, with an accuracy of 81%

Following the invention of X-rays, preoperative templating was performed by making sketches and lines on transparent overhead projector paper that was placed over printed 2-Dimensional (2D) X-rays.

As the technology advanced, templating evolved to comprise perioperatively using sketches directly on fluoroscopy screens, for example after reduction [5,8]. Preoperative X-rays enabled sketches and overhead projector paper angles to be performed and entry points and osteosynthesis material sizes to be determined, both in primary fractures and in cases of malunion or nonunion correction [9,10]. But preoperative X-rays also come with difficulties. Noordeen et al. examined the geometrical challenges when combining the conical X-ray beam with a spherical object, as is the case in the femoral head where it results in a high risk of screw penetration [10]. They developed a template that could be applied to the perioperative X-ray. The template could predict whether screw placement was safe, or whether there was a risk of the screw penetrating the femoral head. They retrospectively reviewed 50 radiographic films and evaluated the risk of screw penetration.

Whenever applicable, comparison X-rays of the contralateral side have been put to good use, primarily in radial, pelvic, tibial and ankle fractures [11].

One of the primary limitations of 2D X-rays is the magnification factor. In several studies, this factor has proven to cause difficulties in choosing the correct size of osteosynthesis materials, as 2D X-ray prints do not always have the same magnification factor as manufacturers apply to their osteosynthesis material. As a result, even thoughtful templating can result in a faulty choice in the size of osteosynthesis materials [12–14]. Iqbal et al. investigated the discrepancy between magnification factors deemed by manufacturers and magnification factor used by radiographers [12]. They reviewed 153 postoperative tibial radiographs by measuring the anticipated nail length on the radiograph and comparing it to the actual applied size. They concluded that proper preoperative templating based on radiographic imaging first would be valuable when magnification factors were standardized. A study by Krettek et al. of 200 randomly chosen radiographic images of femur and tibia came to the same conclusion [13].

Drynan et al. evaluated 513 post-operative radiographs with implants of known dimensions [14]. They found that hand, wrist, forearm, and ankle had the smallest magnification factor being 5% and shoulder and femur had the largest being 15%. They concluded that applying such a region-specific magnification factor would improve the accuracy of templating.

An additional limitation of 2D X-ray is its dependence on correct patient positioning when the X-ray is obtained, as malrotation of the extremities renders the X-ray useless for preoperative planning and templating [3].

The principles and use of templating by applying template sketches to X-ray prints have been employed both in surgery and in decision-making regarding which conservative treatment strategies the patient would most benefit from [15]. Kotnis et al. performed a 12-month review of all reduced radial fractures performed at a District General Hospital [15]. Out of 61 patients, 15 had not received the necessary reduction or had an unsatisfying reduction. They developed a template meant to be put on top of radiographs to help decide whether a fracture needed to be reduced or not. Use of this template showed a marked increase in correct decision-making about fracture reduction.

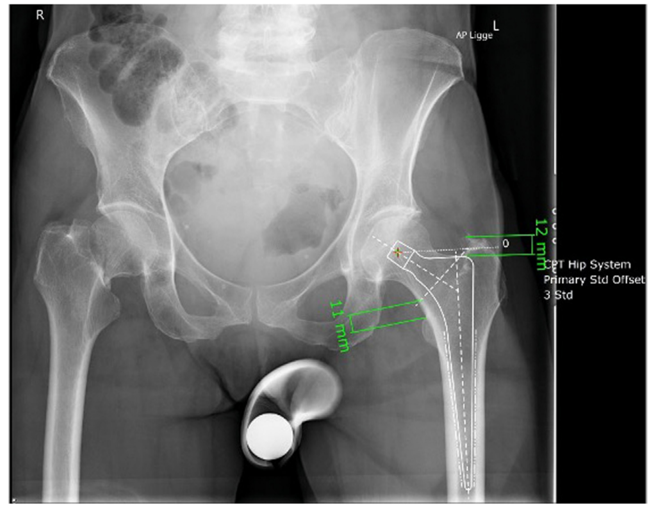

Fig. 1. Templating using digital planning software.

Present

Many functions of the current healthcare system have become digitalised. The principle of 2D imaging and overlying templates is still very much used, but hard-copy radiographic films have given way to digital programs in which the same concept is applied [16,17].

These digital programs enable surgeons to combine and shape different types of osteosynthesis components virtually to fit a patient's specific anatomy (Fig. 1).

Hip arthroplasty surgeons have used preoperative digitalised templating for years with good results in both elective total hip arthroplasty and hemiarthroplasty for femoral neck fractures [18,19]. Lakstein et al. compared the use of digital templating in a retrospective comparison of patients undergoing total hip arthroplasty for femoral neck fractures [18]. They included 23 patients, who had templating performed prior to surgery, and 48 controls with no templating. There was a significantly lower rate of limb length discrepancy in the cases compared to the controls.

In templating prior to hip surgery, the contralateral side is often used as the template, as studies have shown very little difference between the two hemipelvises [20]. Ead et al. included eight patients with unilateral fractured pelvises and constructed intact 3-Dimensional (3D) models of their pelvises by using the intact other half of the pelvis [20]. Afterwards, a 3D deviation analysis was conducted showing very little difference between the intact half and the newly reconstructed half.

The same anatomic similarities have also been shown for the tibia, thus making the contralateral tibia a valuable and accurate template in tibial fracture surgeries [21] and prolonging the utilisation of traditional techniques [11].

As previously mentioned, conventional 2D X-ray imaging has its limitations, magnification factor being one of them, which apply to most forms of radiographic imaging. Moreover, it is difficult to comprehend the full aspect of the fracture and the effect of fracture reduction when an image is only shown in 2D. When it comes to solving the issue of magnification factor, it has become common practice to use a marker ball when requesting X-rays of the pelvis

(Fig. 1) [22]. As for the difficulties of comprehending fracture patterns in 2D imaging, this is where 3D imaging has gained momentum.

Preoperative 3D imaging has been shown to provide much more information regarding the fracture and placement of osteosynthesis materials [23] and is both time-efficient and reliable [24]. Carelsen et al. included 81 patients having intraarticular fractures of the foot, wrist, elbow, or shoulder [23]. In addition to conventional 2D radiographic imaging, a 3D-rotational X-ray was obtained. Comparison between the methods demonstrated a larger understanding of screw positioning and rotation of the fracture after 3D imaging was applied. When 3D imaging was applied there was, in general, larger satisfaction with results when it came to rotation of the fracture.

Better visualisation of complex intra-articular and comminuted fractures is facilitated by 3D imaging, which can prove helpful preoperatively and reduce planning time [25]. Thomas et al. retrospectively studied ten tibial plafond fractures and 3D puzzle solving methods was applied to them [25]. Images were obtained from the contralateral healthy tibia. The 3D puzzle program could virtually reduce comminuted fractures by using the healthy tibia as a baseline. The program could reduce planning time to less than 20 minutes.

In addition to better visualisation of fractures, more programs now offer surgeons the possibility of reducing the fracture virtually, thereby optimising their understanding of the fragments and the best way to reduce the fracture perioperatively [26,27].

The majority of studies on 3D imaging have shown a significant decrease in planning time, operation time, blood loss and duration of hospital stay [28–32], and one large study revealed a significant reduction in mortality and postoperative complications [33]. Chen et al. included 32 patients with distal femoral fractures [28]. Seventeen were handled with conventional planning and 15 were handled with virtual planning. They saw a significant lower level of blood loss, fewer fluoroscopic images, decreased operative time, and shorter hospital stay in the virtual planning group compared with the conventional planning group. There was no difference in patient-reported outcomes in the two groups.

A similar study was conducted by Wang et al. onlooking at intertrochanteric hip fractures [29]. They retrospectively analysed 125 patients treated with a Proximal Femoral Nail Antirotation (PFNA). Fifty-three patients underwent surgery with computer-assisted preoperative planning and 72 patients underwent conventional surgery. Again, a significant reduction in surgery time, radiation frequency and blood loss were shown in the computer-assisted group. Besides they showed a steeper learning curve amongst the surgeons using computer-assisted preoperative planning. They were not able to prove a reduction in hospital stay as Chen et al., and likewise could not show a difference in patient-reported outcomes and neither complication rates [28, 29].

Jia et al. also looked at intertrochanteric hip fractures [33]. They retrospectively collected data from 1221 patients receiving surgery for intertrochanteric hip fractures. 465 patients received computer-assisted virtual preoperative planning and 756 patients had conventional preoperative planning. They saw significant lower mortality in the virtual planning group as well as a lower reoperation rate. As seen in Wang et al. a steeper learning curve was seen among the surgeons [29, 33].

In addition to preoperative templating, perioperative templating has progressed. With the invention of 3D printing, templating both prior to and during surgery has expanded [34].

By preoperatively using contralateral anatomy as a template, it is now possible to reconstruct, and 3D print the fracture. With advancements in 3D printing have come the ability to preoperatively model osteosynthesis material directly to the fracture. By pre-contouring plates based on 3D-printed models of the injured extremity, patient-specific plates that are nearly 100% anatomically correct and fitted individually to each patient can be produced [35–38]. Studies examining the useability of these patient-specific plates are based on patients with pelvis fractures or other fractures with a healthy contralateral side as to compare with. FFA et al. applied virtual surgical planning to 10 patients with displaced acetabular fractures [38]. Mirroring of the contralateral healthy pelvis was used to verify the accuracy of the virtual fracture reduction. Drill guides to determine screw trajectories were 3D printed and patient-specific plates were designed. They utilized the known fact of pelvic symmetry, as mentioned earlier, and rendered successful reductions as a result.

Templating has also found its place in corrective osteotomies, where the importance of identifying correct angles is crucial (i.e., malunion of the tibia or radius), although the use of templating has not been found to improve patient outcomes [39]. Buijze et al. randomized 40 patients with malunited distal radial fractures to either receiving 3D computer-assisted planning or conventional 2D planning before receiving corrective osteotomy [39]. Radiographic outcomes like volar angulation and radial inclination showed significant better results in the 3D planning group. But there was no difference in regard to patient-reported outcomes, duration of planning of surgery, or complication rates.

Future

Software that assists surgeons in reducing complex fractures is evolving. While 3D images have made it possible to visualise more complicated and comminuted fractures preoperatively, reduction of the fracture is still most commonly performed manually by the surgeon perioperatively. New software advancements have introduced the potential of reducing the fracture virtually by distinguishing periosteal surfaces from each other and aligning matching fracture surfaces, enabling better alignment and thereby reducing the risk of posttraumatic arthrosis [40].

Most software programs that facilitate virtual fracture reduction do not consider the soft tissue surrounding the fracture. By incorporating ligaments, cartilage, tendon and muscle, a more realistic fracture reduction can be planned, and surgical approach performed. Newer programs incorporating these elements are in development and could help address the challenge of manoeuvring around soft tissue [30]. Boudissa et al. conducted a review of articles concerning computer-assisted surgery, especially regarding acetabular fractures [30]. Several software programs were mentioned, both when it came to virtual preoperative planning (SQ PELVIS, MIMICS etc.), but also custom-made plates and implants (3D Studio Max, MIMICS, Imageware 12.1 etc.).

The value of adding a haptic component to preoperative planning software programs for a more realistic experience is already well known in teaching settings. With the addition of tactile sensation, surgeons can improve their awareness of the tension of nearby ligaments and their placement in relation to the fracture. As an educational tool, this may prove extremely valuable, but the advantages of tactile sensation in preoperative planning are still unknown [41].

Newer software has been developed employing a library of 3D plates, which enhances preoperative templating by enabling the evaluation of multiple manufacturers' osteosynthesis materials to preoperatively determine the specific implant that fits the individual patient best. This technology already exists in arthroplasty surgery but is still in development in the domain of choosing plates and nails [42]. Huang et al. included 6 patients all with tibial plateau fractures treated with internal fixation [42]. They created a virtual 3D library of plates by acquiring CT scans of different plates from different manufacturers. 3D models of the fractured tibia were reconstructed by using the preoperative CT scans.

The fractures underwent virtual reduction and plates were picked out from the newly invented library.

Applying manufacturer-specific libraries to preoperative decision-making provides an opportunity to optimise internal fixations and streamlines the time spent on preoperative templating, as the size and placement of the osteosynthesis materials can be determined before surgery [28,29].

Planning that is performed perioperatively is only in its initial stages but will likely be used more extensively in the future as the systems evolve. Computer-assisted systems that can show guidewire trajectories and confirm correct entry points have already been developed, but their use at most hospitals is not standard practice. These systems can aid surgeons in placing the osteosynthesis material, reducing the need for fluoroscopy and minimising operation time [43,44]. Beerekamp et al. investigated the use of 3D Rotational X-ray [43]. They included 231 patients who have undergone open reduction and internal fixation of calcaneal fractures. Out of the 231 patients 107 had been operated on with the use of 3D imaging. Surgery time was significantly longer in the group where 3D imaging was used, but corrections in placement of osteosynthesis material were significantly less. There was no difference in patient outcome or complications.

Herman et al. also conducted a prospective case-control study investigating a computer-assisted system [44]. To test the system, called Surgix, they included 61 patients receiving dynamic hip screw. In 41 procedures Surgix was used. There was a significantly higher success rate regarding first-trial insertion of the guide wire and fewer insertion trials, but no difference in placement of osteosynthesis material was seen.

Further development of fracture reduction software could lead to the implementation of robot-assisted reduction as well as robot-assisted surgery [45].

The use of 3D-printed drill guides in open reduction and internal fixation has quickly evolved and is already widespread [32,46,47].

Sun et al. conducted a retrospective study including 54 patients undergoing minimal invasive percutaneous plate osteosynthesis for distal femoral fractures [47]. Thirty-four patients underwent conventional surgery, and 20 patients underwent template-guided surgery. They saw no difference in patient-reported outcomes but a smaller femoral length difference and rotational malalignment in the template group as well as femoral angle and anteversion difference.

However, further progress in the development of 3D-printed drill guides has the potential to facilitate the placement of percutaneous screws without soft tissue destruction, ensuring proper screw placement and drastically minimising surgical time. This has not been widely explored, but the possibilities cannot be disregarded [48].

Discussion

It is clear that preoperative templating in orthopaedic surgery is an area of interest and rapid development. For manufacturers of software as well as osteosynthesis material, this is a golden age. However, it is reasonable to ask questions regarding the cost-effectiveness of these new appliances, particularly given that only a few of these new systems have been able to prove any difference in patient outcomes compared to conventional methods, though the cost of these programs, tools and pre-ordered plates are often high [28,32,36].

One of the findings revealed in many studies is a reduction in time spent on preoperative planning, but one cannot disregard the possibility of extended preoperative planning time also occurring, particularly as a result of delivery times of custom-made plates and nails [4,38], which must be taken into account when considering the cost-effectiveness of some of these new initiatives.

Larger randomised controlled trials that compare newer preoperative templating tools with conventional methods are needed. Furthermore, in the excitement that follows these new programs and tools, it is important to remember that the implementation of new devices also increases the risk of improper use and often requires reorganisation of the entire department [22].

With its rapid development and significant potential, the possibilities for preoperative planning in orthopaedic trauma surgery are endless. Still, the essence of preoperative planning is the importance of planning itself when it comes to achieving good results. If you fail to plan, you are planning to fail – but some of these tools might help you make even better plans!

Declaration of Competing Interest

None.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.injury.2022.09.005.

References

[1] Wade RH, Kevu J, Doyle J. Pre-operative planning in orthopaedics: a study of surgeons' opinions. Injury 1998;29(10):785–6.
[2] Liu B, Luo X, Huang R, Wan C, Zhang B, Hu W, et al. Virtual plate pre-bending for the long bone fracture based on axis pre-alignment. Comput Med Imaging Graph 2014;38(4):233–44.
[3] Krakowski P, Karpiński R, Maciejewski M. Applications of modern imaging technology in orthopaedic trauma surgery. Appl Comput Sci 2018;14(3).
[4] Okike K. Preoperative Planning in Fracture Surgery: The End of Colored Pens and Tracing Paper: Commentary on an article by Yanxi Chen, MD, PhD: "Computer-assisted virtual surgical technology versus three-dimensional printing technology in preoperative planning for displaced three and four-part fractures of the proximal end of the humerus". J Bone Joint Surg Am 2018;100(22):e146.
[5] Colen RP, Prieskorn DW. Tibial tubercle-medial malleolar distance in determining tibial nail length. J Orthop Trauma 2000;14(5):345–8.
[6] Pearson J, Hess M, McGwin G, Quade J. Accurate prediction of antegrade and retrograde femoral intramedullary implant length from patient-reported Height. J Orthop Trauma 2019;33(10):503–5.
[7] Issac RT, Gopalan H, Abraham M, John C, Issac SM, Jacob D. Preoperative determination of tibial nail length: an anthropometric study. Chin J Traumatol 2016;19(3):151–5.
[8] Palial V. A novel way to template trochanteric hip fractures. Ann R Coll Surg Engl 2013;95(7):533.
[9] Mast JW. Preoperative planning in the surgical correction of tibial nonunions and malunions. Clin Orthop Relat Res 1983(178):26–30.
[10] Noordeen M, Lavy C, Briggs T, Roos M. Unrecognised joint penetration in treatment of femoral neck fractures. J Bone Joint Surg Br 1993;75(3):448–9.
[11] Burssens A, Vermue H, Barg A, Krähenbühl N, Victor J, Buedts K. Templating of syndesmotic ankle lesions by use of 3D analysis in Weightbearing and Non-weightbearing CT. Foot Ankle Int 2018;39(12):1487–96.
[12] Iqbal M, Saravanan R, Konchwala A, Sakellariou A. Preoperative templating of tibial nails - is it worthwhile? Injury 2000;31(6):449–50.
[13] Krettek C, Blauth M, Miclau T, Rudolf J, Könemann B, Schandelmaier P. Accuracy of intramedullary templates in femoral and tibial radiographs. J Bone Joint Surg Br 1996;78(6):963–4.
[14] Drynan D, McArthur M, Vohora A, Hinton D, Menegon G, Wilkinson MPR. Accuracy of digital radiography: regional scaling factors for trauma. ANZ J Surg 2018;88(4):341–5.
[15] Kotnis R, Waites MD, Fayomi O, Dega R. The use of a template to improve the management of distal radial fractures. Emerg Med J 2005;22(8):544–7.
[16] Kosashvili Y, Shasha N, Olschewski E, Safir O, White L, Gross A, et al. Digital versus conventional templating techniques in preoperative planning for total hip arthroplasty. Can J Surg 2009;52(1):6–11.
[17] Jamali AA. Digital templating and preoperative deformity analysis with standard imaging software. Clin Orthop Relat Res 2009;467(10):2695–704.
[18] Lakstein D, Bachar I, Debi R, Lubovsky O, Cohen O, Tan Z, et al. Radiographic templating of total hip arthroplasty for femoral neck fractures. Int Orthop 2017;41(4):831–6.
[19] Kwok IH, Pallett SJ, Massa E, Cundall-Curry D, Loeffler MD. Pre-operative digital templating in cemented hip hemiarthroplasty for neck of femur fractures. Injury 2016;47(3):733–6.
[20] Ead MS, Westover L, Polege S, McClelland S, Jaremko JL, Duke KK. Virtual reconstruction of unilateral pelvic fractures by using pelvic symmetry. Int J Comput Assist Radiol Surg 2020;15(8):1267–77.

[21] Keltz E, Dreyfuss D, Ginesin E, Ghrayeb N, Hous N, Yavnai N, et al. Preoperative evaluation of intramedullary tibial nail measurements-a review of the literature and a new technique using contralateral radiographs and digital planning. J Am Acad Orthop Surg Glob Res Rev 2019;3(3):e015.
[22] Parwaiz H, Aliaga Crespo B, Filer J, Thorpe A, Seatter R, Faulkner DS, et al. Improving the accuracy of digital templating: achieving success through stakeholder management. BMJ Open Qual 2019;8(2):e000378.
[23] Carelsen B, Haverlag R, Ubbink DT, Luitse JS, Goslings JC. Does intraoperative fluoroscopic 3D imaging provide extra information for fracture surgery? Arch Orthop Trauma Surg 2008;128(12):1419–24.
[24] Chen Y, Zhang K, Qiang M, Li H, Dai H. Computer-assisted preoperative planning for proximal humeral fractures by minimally invasive plate osteosynthesis. Chin Med J 2014;127(18):3278–85.
[25] Thomas TP, Anderson DD, Willis AR, Liu P, Marsh JL, Brown TD. ASB Clinical Biomechanics Award Paper 2010 Virtual pre-operative reconstruction planning for comminuted articular fractures. Clin Biomech 2011;26(2):109–15.
[26] Fürnstahl P, Székely G, Gerber C, Hodler J, Snedeker JG, Harders M. Computer assisted reconstruction of complex proximal humerus fractures for preoperative planning. Med Image Anal 2012;16(3):704–20.
[27] Negrillo-Cárdenas J, Jiménez-Pérez JR, Feito FR. The role of virtual and augmented reality in orthopedic trauma surgery: from diagnosis to rehabilitation. Comput Methods Programs Biomed 2020;191:105407.
[28] Chen S, Zhang K, Jia X, Qiang M, Chen Y. Evaluation of the computer-assisted virtual surgical technology in preoperative planning for distal femoral fracture. Injury 2020;51(2):443–51.
[29] Wang D, Zhang K, Qiang M, Jia X, Chen Y. Computer-assisted preoperative planning improves the learning curve of PFNA-II in the treatment of intertrochanteric femoral fractures. BMC Musculoskelet Disord 2020;21(1):34.
[30] Boudissa M, Courvoisier A, Chabanas M, Tonetti J. Computer assisted surgery in preoperative planning of acetabular fracture surgery: state of the art. Expert Rev Medic Dev 2018;15(1):81–9.
[31] Chytas D, Malahias MA, Nikolaou VS. Augmented reality in orthopedics: current state and future directions. Front Surg 2019;6:38.
[32] Casari FA, Navab N, Hruby LA, Kriechling P, Nakamura R, Tori R, et al. Augmented reality in orthopedic surgery is emerging from proof of concept towards clinical studies: a literature review explaining the technology and current state of the art. Curr Rev Musculoskelet Med 2021;14(2):192–203.
[33] Jia X, Zhang K, Qiang M, Wu Y, Chen Y. Association of computer-assisted virtual preoperative planning with postoperative mortality and complications in older patients with intertrochanteric hip fracture. JAMA Netw Open 2020;3(8):e205830.
[34] Joskowicz L, Milgrom C, Simkin A, Tockus L, Yaniv Z. FRACAS: a system for computer-aided image-guided long bone fracture surgery. Comput Aided Surg 1998;3(6):271–88.
[35] Shen F, Chen B, Guo Q, Qi Y, Shen Y. Augmented reality patient-specific reconstruction plate design for pelvic and acetabular fracture surgery. Int J Comput Assist Radiol Surg 2013;8(2):169–79.
[36] Chen X, Chen X, Zhang G, Lin H, Yu Z, Wu C, et al. Accurate fixation of plates and screws for the treatment of acetabular fractures using 3D-printed guiding templates: An experimental study. Injury 2017;48(6):1147–54.
[37] Mishra A, Verma T, Vaish A, Vaish R, Vaishya R, Maini L. Virtual preoperative planning and 3D printing are valuable for the management of complex orthopaedic trauma. Chin J Traumatol 2019;22(6):350–5.
[38] FFA IJ, Meesters AML, Merema BBJ, Ten Duis K, de Vries JPM, Banierink H, et al. Feasibility of imaging-based 3-dimensional models to design patient-specific osteosynthesis plates and drilling guides. JAMA Netw Open 2021;4(2):e2037519.
[39] Buijze GA, Leong NL, Stockmans F, Axelsson P, Moreno R, Ibsen Sörensen A, et al. Three-dimensional compared with two-dimensional preoperative planning of corrective osteotomy for extra-articular distal radial malunion: a multicenter randomized controlled trial. J Bone Joint Surg Am 2018;100(14):1191–202.
[40] Thomas TP, Anderson DD, Willis AR, Liu P, Frank MC, Marsh JL, et al. A computational/experimental platform for investigating three-dimensional puzzle solving of comminuted articular fractures. Comput Methods Biomech Biomed Eng 2011;14(3):263–70.
[41] Kovler I, Joskowicz L, Weil YA, Khoury A, Kronman A, Mosheiff R, et al. Haptic computer-assisted patient-specific preoperative planning for orthopedic fractures surgery. Int J Comput Assist Radiol Surg 2015;10(10):1535–46.
[42] Huang H, Hsieh MF, Zhang G, Ouyang H, Zeng C, Yan B, et al. Improved accuracy of 3D-printed navigational template during complicated tibial plateau fracture surgery. Australas Phys Eng Sci Med 2015;38(1):109–17.
[43] Beerekamp MSH, Backes M, Schep NWL, Ubbink DT, Luitse JS, Schepers T, et al. Effects of intra-operative fluoroscopic 3D-imaging on peri-operative imaging strategy in calcaneal fracture surgery. Arch Orthop Trauma Surg 2017;137(12):1667–75.
[44] Herman A, Dekel A, Botser IB, Steinberg EL. Computer-assisted surgery for dynamic hip screw, using Surgix, a novel intraoperative guiding system. Int J Med Robot 2009;5(1):45–50.
[45] Jiménez-Delgado JJ, Paulano-Godino F, PulidoRam-Ramírez R, Jiménez-Pérez JR. Computer assisted preoperative planning of bone fracture reduction: Simulation techniques and new trends. Med Image Anal 2016;30:30–45.
[46] Nie W, Gu F, Wang Z, Wu R, Yue Y, Shao A. Preliminary application of three--dimension printing technology in surgical management of bicondylar tibial plateau fractures. Injury 2019;50(2):476–83.
[47] Sun L, Liu H, Xu C, Yan B, Yue H, Wang P. 3D printed navigation template-guided minimally invasive percutaneous plate osteosynthesis for distal femoral fracture: a retrospective cohort study. Injury 2020;51(2):436–42.
[48] Yin HW, Xu J, Xu WD. 3-Dimensional printing-assisted percutaneous fixation for acute scaphoid fracture: 1-shot procedure. J Hand Surg Am 2017;42(4):301 e1-e5.