The Mako Robotic System for Unicompartmental Knee Arthroplasty

Mustafa Citak, Andrew D. Pearle, Daniel O. Kendoff

12.1 Unicompartmental Knee Arthroplasty with Haptic Robotic Systems – 106

12.2 Preoperative Imaging and Planning – 106

12.3 Intraoperative Set-up and Surgical Technique – 107

12.4 Outcomes of Robotic-Assisted Unicompartmental Knee Arthroplasty – 108

12.5 Conclusion – 109

References – 110

R. Haaker, W. Konermann (Eds.), *Computer and Template Assisted Orthopedic Surgery*,
DOI 10.1007/978-3-642-29728-1_12,

Robotic systems have been used in surgery since 1980, while the integration of robotic systems in orthopedic surgery began with the use of RoboDoc (Curexo Technology Corporation, Fremont, CA, USA) for the planning and performing of robotic-assisted total hip arthroplasty (THA) in 1992. The use of robotic technology has facilitated minimally invasive surgery in some cases, which has gained popularity in patients (Banks 2009). Another advantage of robotic surgery is the higher precision and accuracy compared to conventional techniques, which is of enormous importance especially in spinal surgery (Devito et al. 2010). Current robotic systems can be classified as autonomous, haptic, surgeon-guided systems. Haptic or surgeon-guided robotic systems allow the surgeon to use the robot to perform the surgery. The permanent input of the surgeon is mandatory to perform the procedure. By contrast, in autonomous systems, the surgeon performs the approach and set-up of the system and then engages the robot to finish the surgery without the surgeon's help. A historical example of autonomous systems is RoboDoc (RoboDoc, Sacramento, CA, USA), which was especially popular in Germany in the 1990s. Statistically significant higher accuracy in implant positioning has been reported with the use of RoboDoc compared to conventional systems (Bargar 2007). However, nowadays, owing to the higher complication rate and safety concerns, the use of RoboDoc has sharply declined (Davies et al. 2007; Schulz et al. 2007). Nevertheless, the use of robotic systems has recently increased, especially the use of haptic or surgeon-guided systems.

12.1 Unicompartmental Knee Arthroplasty with Haptic Robotic Systems

Unicompartmental knee arthroplasty (UKA) was introduced in the early 1970s and today is commonly used for the treatment of isolated compartmental osteoarthritis of the knee (Berger et al. 1999; Suggs et al. 2006). UKA did not gain wide acceptance because of the high failure rate and poor outcome (Insall and Aglietti 1980). However, recent improvements in implant design, minimally invasive techniques, bone-sparing strategies, expanded indications, and early rehabilitation have all contributed to a renewed enthusiasm for UKA.

UKA has been shown to be a good and less-invasive alternative to total knee arthroplasty (TKA), especially for younger and active patients (Ohdera et al. 2001). Advantages of UKA include better postoperative range of motion, less soft tissue dissection, preservation of bone stock, minimal blood loss, faster recovery, lower complication rates, and more physiological function (Ohdera et al. 2001; Koskinen et al. 2009).

Nevertheless, early failures of femoral and tibial components have also been reported (Berend et al. 2005; Collier et al. 2006; Furnes et al. 2007; Mariani et al. 2007). Failures attributed to overcorrection and undercorrection have received the most attention (Hernigou and Deschamps 2004a, 2004b; Jeer et al. 2004; Ridgeway et al. 2002).

The use of computer-assisted surgery systems in UKA has resulted in improved postoperative alignment, reduction of outliers, and better postoperative clinical results (Buckup et al. 2007; Molfetta and Caldo 2008; Haaker et al. 2006). Cobb and colleagues (2006) reported that robot-assisted placement of UKA (Acrobot Sculptor; Acrobot Company, Ltd., London, UK) components was more accurate than traditional techniques and that, subsequently, clinical outcomes were improved. Cobb's method, however, employed rigid intraoperative stabilization of the bones in a stereotactic frame, which is impractical for routine clinical use.

The »Robotic Arm Interactive Orthopedic System« (RIO; MAKO Surgical Corp., Fort Lauderdale, FL, USA) (Fig. 12.1), is an example of a surgeon-guided robotic system that allows for dynamic bone tracking, which is of enormous intraoperative importance.

12.2 Preoperative Imaging and Planning

Preoperative computed tomography (CT) scans are obtained using specific scan protocols for all patients. The CT data are saved in DICOM (Digital Imaging and Communications in Medicine; Rosslyn, VA, USA) format and transferred to the software of the robotic system (MAKO Surgical Corp.).

Fig. 12.1 The »Robotic Arm Interactive Orthopedic System« (RIO) as an example of a surgeon-guided robotic system. (By courtesy of MAKO Surgical Corp.)

Fig. 12.2 The high-frequency burr is equipped at the distal end of the robot. (By courtesy of MAKO Surgical Corp.)

Fig. 12.3 Intraoperative set-up of the MAKO system during a robotic-assisted unicompartmental knee arthroplasty. (By courtesy of MAKO Surgical Corp.)

The bone surfaces are segmented in the software to create a patient-specific three-dimensional (3D) model of the knee.

CT-based planning is ideal for bony alignment including the assessment of osteophyte formations, cysts, or necrosis. However, CT-based planning also has its limitations. For example, soft tissues cannot be visualized with CT.

On the basis of the preoperative CT scan, the system allows for preoperative planning of the femoral and tibial implant position including the following aspects:

- Alignment parameters and intraoperative gap kinematics
- 3D virtual visualization of implant position

After planning and defining the optimal implant position, the data are saved in the system, while the system automatically defines the boundaries of bony resection.

12.3 Intraoperative Set-up and Surgical Technique

Positioning of the robotic system is performed before the patient's arrival in the operating room (OR). The positioning of the system is based on the affected knee and the surgeon's dominant hand. The haptic or surgeon-guided system (MAKO Surgical Corp.) consists of three components: robotic arm, optical camera, and operator computer cart (Fig. 12.1). The distal end of the robotic arm is equipped with a high-speed bone-resecting burr (Fig. 12.2). After sterile draping of the patient's leg and performing a tissue-sparing exposure, reference optical arrays are placed into the distal femur and proximal tibia using Steinman pins and also mounted on the robotic arm. After a routine registration process, the robotic arm-assisted resection process of the planned femoral and tibial surface can be performed (Fig. 12.3). The surgeon moves the robotic arm by guiding the force-controlled tip within the defined boundaries. While inside the volume of bone to be resected, the robotic arm operates without offering any resistance. As the

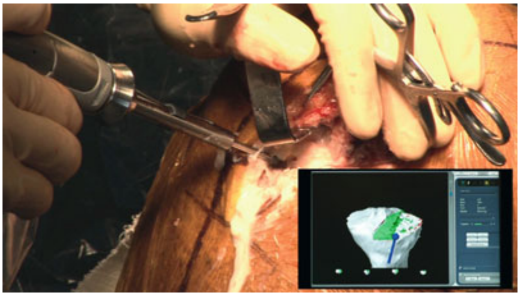

Fig. 12.4 Intraoperative image during a robotic-assisted unicompartmental knee arthroplasty. The *main image* shows the burring process of the femoral bone surface. The *inset* is a screenshot of the system showing the 3D visualization as a guide for the surgeon. (By courtesy of MAKO Surgical Corp.)

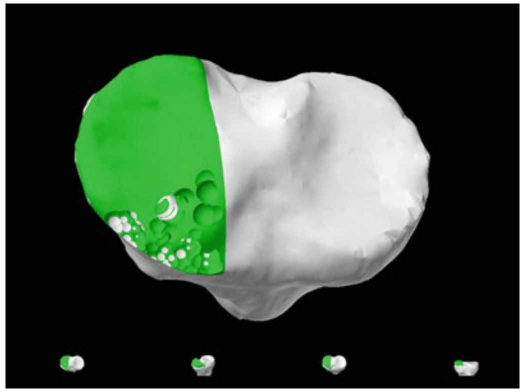

Fig. 12.5 Screenshot showing the 3D visualization of the planned tibial resection. The *green area* is a visual guide for the surgeon showing the area still to be resected. (By courtesy of MAKO Surgical Corp.)

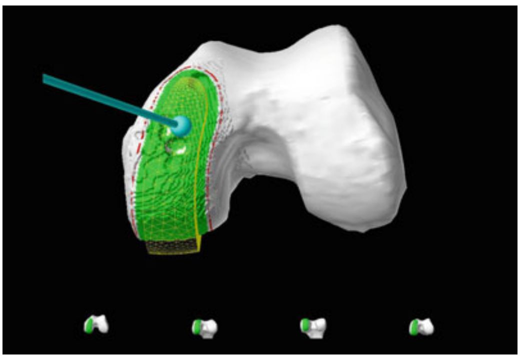

Fig. 12.6 The *green area* reveals the part of the femoral bone still to be resected. (By courtesy of MAKO Surgical Corp.)

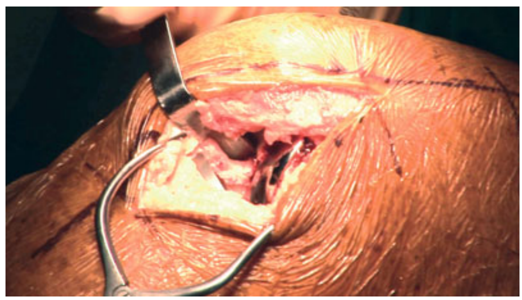

Fig. 12.7 Intraoperative situs showing the postoperative result after implantation of the prosthesis. (By courtesy of MAKO Surgical Corp.)

burr approaches the boundary, the robotic arm resists that motion and haptically keeps the burr within the accepted volume (Fig. 12.4).

It is recommended to perform first the tibial and then the femoral resection. However, the specific sequence can also be selected individually by the surgeon. Permanent visual feedback on the navigation screen shows the actually achieved versus the planned resection, which is based on the preoperative planning (Fig. 12.5 and Fig. 12.6).

Once both compartments have been prepared, femoral and tibial component trials are inserted and a full flexion – extension arc can be performed. Computerized simulation of the implants reveals the actual overlapping of the implant components, giving the surgeon feedback about the actual leg alignment and knee gap kinematics.

After acceptance of the implant positioning, both components are cemented and a final analysis of the implant kinematics and limb alignment is made (Fig. 12.7). The reference arrays and mini-checkpoints are then removed and a standard wound closure is performed.

12.4 Outcomes of Robotic-Assisted Unicompartmental Knee Arthroplasty

The Acrobot® (acronym for Active Constraint Robot) system, another tactile system with several similarities to the RIO system, was introduced in 2001 (Jakopec et al. 2001). In a prospective randomized double-blind (patient and assessor) study, Cobb et al. (2006) presented the results of robotic-assisted UKA using the Acrobot system compared to conventional UKA. A total of 27 patients were recruited in the study. In addition to the radiological differences in the planned and achieved tibiofemoral angles, the American Knee Society (AKS) score and Western Ontario and McMaster Universities osteoarthritis index (WOMAC) were evaluated in all patients. In the robotic group, all of the patients had tibiofemoral alignment in the coronal plane within 2° of the planned position. However, in only 40% of the conventional group was this level of accuracy achieved. There was also a significant difference in the AKS score between both groups, with a mean increase of the AKS score twice as large in the Acrobot system group. However, in the robotic-assisted group, an additional operative time of 16 min was required compared to the conventional technique. Another drawback of this system is the necessity of employing rigid intraoperative stabilization of the bones in a stereotactic frame. Robotic systems have now evolved to include dynamic bone-tracking technologies so that rigid fixation is no longer required.

Pearle et al. reported the first clinical series of ten implanted UKAs using a robotic system with dynamic bone-tracking technology (Pearle et al. 2010). No outliers or complications were noted in the study. The difference between the planned and the intraoperative tibiofemoral angle was less than 1° (Pearle et al. 2010).

Roche et al. (unpublished data) analyzed the first 43 robotic-assisted UKAs using radiographic measurements performed by an independent reviewer. Of the 344 radiographic measurements, only three femoral components were considered to be outliers. Hence, less than 1% of the measurements were found to be outliers (Sinha 2009).

Sinha and colleagues (2009) reported on their first 20 cases of robotic arm-assisted UKA. They concluded that robotically assisted UKA has extremely accurate bone preparation relative to the preoperative plan and is a reliably accurate tool.

In a recent study, Lonner et al. (2010) compared the postoperative radiographic alignment of the tibial component with the preoperatively planned position with and without the use of robotics and found a higher root mean square (RMS) error of the posterior tibial slope and a higher varus/valgus RMS error with the conventional technique.

Coon (2009) found that the RMS error of the posterior tibial slope was 2.5 times better, the variance was 2.8 times lower, and varus alignment 3.2° better in the robotic group compared to the conventional technique.

Based on an analysis of 223 robotic-assisted cases using the MAKO platform contributed from three centers, the complication rates and patient outcomes were also analyzed (Sinha 2009). In total, six revision surgeries (2.7%) were required because of infection (n=2), femoral shaft fracture (n=1), arthrofibrotic band release (n=1), arthrotomy dehiscence (n=1), and unexplained pain (n=1). Implant loosening, as a cause for revision surgery, was not reported in these series. Moreover, a postoperative statistically significant improvement in range of motion (ROM), Knee Society Score (KSS), WOMAC scores, pain and stiffness was shown in these patients.

Despite the described advantages of robotic systems, there are also disadvantages. These mainly include the high costs and longer surgery time. The required preoperative CT scan and preoperative planning increase the overall time, effort, and cost (Swank et al. 2009). Learning curve issues associated with new techniques should also be considered. However, the surgery time decreased after 20 cases from 80–120 min to 40 min after integration of the MAKO system into the operating room, as reported by Coon (2009).

12.5 Conclusion

The use of robotic technology offers promising short-term results compared to traditional conventional orthopedic procedures. The technological innovations and advances help the surgeon perform a more precise surgery with preoperative planning and robotic-assisted resection. However, financial barriers and the lack of long-term prospective studies are still limiting factors to the widespread use of robotic technology. Although the improved short-term results of lower blood loss and faster rehabilitation support the use of robotic technology, further studies are required to identify whether robotic technology truly improves the long-term outcome.

References

Banks SA (2009) Haptic robotics enable a systems approach to design of a minimally invasive modular knee arthroplasty. Am J Orthop (Belle Mead NJ) 38:23–27

Bargar WL (2007) Robots in orthopaedic surgery: past, present, and future. Clinl Orthop Relat Res 463:31–36

Berend KR, Lombardi AV Jr, Mallory TH, Adams JB, Groseth KL (2005) Early failure of minimally invasive unicompartmental knee arthroplasty is associated with obesity. Clin Orthop Relat Res 440:60–66

Berger RA, Nedeff DD, Barden RM et al (1999) Unicompartmental knee arthroplasty. Clinical experience at 6- to 10-year follow-up. Clin Orthop Relat Res 36750–60

Buckup K, Linke LC, Hahne V (2007) Minimally invasive implantation and computer navigation for a unicondylar knee system. Orthopedics 30:66–69

Cobb J, Henckel J, Gomes P et al (2006) Hands-on robotic unicompartmental knee replacement: a prospective, randomised controlled study of the acrobot system. J Bone Joint Surg Br 88:188–197

Collier MB, Eickmann TH, Sukezaki F, McAuley JP, Engh GA (2006) Patient, implant, and alignment factors associated with revision of medial compartment unicondylar arthroplasty. J Arthroplasty 21:108–115

Coon TM (2009) Integrating robotic technology into the operating room. Am J Orthop (Belle Mead NJ) 38:7–9

Davies BL, Rodriguez y Baena FM, Barrett AR et al (2007) Robotic control in knee joint replacement surgery. Proceedings of the Institution of Mechanical Engineers Part H. J Eng Med 221:71–80

Devito DP, Kaplan L, Dietl R et al (2010) Clinical acceptance and accuracy assessment of spinal implants guided with SpineAssist surgical robot: retrospective study. Spine 35:2109–2115

Furnes O, Espehaug B, Lie SA, et al (2007) Failure mechanisms after unicompartmental and tricompartmental primary knee replacement with cement. J Bone Joint Surg Am 89:519–525

Haaker RG, Wojciechowski M, Patzer P, Willburger RE, Senkal M, Engelhardt M (2006) Minimally invasive unicondylar knee placement with computer navigation. Orthopaede 34:1073–1079

Hernigou P, Deschamps G (2004a) Alignment influences wear in the knee after medial unicompartmental arthroplasty. Clin Orthop Relat Res 423:161–165

Hernigou P, Deschamps G (2004b) Posterior slope of the tibial implant and the outcome of unicompartmental knee arthroplasty. J Bone Joint Surg Am 86:506-511

Insall J, Aglietti P (1980) A five to seven-year follow-up of unicondylar arthroplasty. J Bone Joint Surg 62:1329–1337

Jakopec M, Harris SJ, Rodriguez y Baena F et al (2001) The first clinical application of a »hands-on« robotic knee surgery system. Comput Aided Surg 6:329–339

Jeer PJ, Keene GC, Gill P (2004) Unicompartmental knee arthroplasty: an intermediate report of survivorship after the introduction of a new system with analysis of failures. Knee 11:369–374

Koskinen E, Paavolainen P, Eskelinen A et al (2009) Medial unicompartmental knee arthroplasty with Miller-Galante II prosthesis: mid-term clinical and radiographic results. Arch Orthop Trauma Surg 2009;129:617–624

Lonner JH, John TK, Conditt MA (2010) Robotic arm-assisted UKA improves tibial component alignment: a pilot study. Clin Orthop Relat Res 468:141–146

Mariani EM, Bourne MH, Jackson RT, Jackson ST, Jones P (2007) Early failure of unicompartmental knee arthroplasty. J Arthroplasty 22:81–84

Molfetta L, Caldo D (2008) Computer navigation versus conventional implantation for varus knee total arthroplasty: a case-control study at 5 years follow-up. Knee 15:75–79

Ohdera T, Tokunaga J, Kobayashi A (2001) Unicompartmental knee arthroplasty for lateral gonarthrosis: midterm results. J Arthroplasty 16:196–200

Pearle AD, O'Loughlin PF, Kendoff DO (2010) Robot-assisted unicompartmental knee arthroplasty. J Arthroplasty 25:230–237

Ridgeway SR, McAuley JP, Ammeen DJ, Engh GA (2002) The effect of alignment of the knee on the outcome of unicompartmental knee replacement. J Bone Joint Surg 84:351–355

Schulz AP, Seide K, Queitsch C, et al (2007) Results of total hip replacement using the Robodoc surgical assistant system: clinical outcome and evaluation of complications for 97 procedures. MRCAS 3:301–306

Sinha RK (2009) Outcomes of robotic arm-assisted unicompartmental knee arthroplasty. Am J Orthop (Belle Mead NJ) 38:20–22

Suggs JF, Li G, Park SE et al (2006) Knee biomechanics after UKA and its relation to the ACL – a robotic investigation. J Orthop Res 24:588–594

Swank ML, Alkire M, Conditt M, Lonner JH (2009) Technology and cost-effectiveness in knee arthroplasty: computer navigation and robotics. Am J Orthop (Belle Mead NJ) 38:32–36