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TSS and traditional surgery in hip and knee replacement*

Received: 17 March 2007
Accepted: 20 May 2007
Published online: 17 September 2007

Abstract Surgery passes through a continuous evolution, thanks to the introduction of new technologies and techniques. Tissue-sparing surgery is a concept introduced in the last years to address prosthetic surgery to a more conservative fashion. We discuss the TSS decalogue with a critical eye, pointing out how traditional surgery is evolving in accordance with TSS statements.

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Key words Tissue-sparing surgery • Hip • Knee • Arthroplasty

Introduction

Medicine, and particularly surgery, has always been a science in continuous evolution, where every day new findings and new inventions give surgeons better, easier, safer (or, often, simply different) means to treat patients. The introduction of new technologies and techniques has always been difficult, and new technologies have always encountered skeptic adverse comments before gaining a good appreciation. In the nineteenth century, Louis Agassiz (geologist and naturalist, 1807–1873) said: “Every scientific truth goes through three states: first, people say it conflicts with the Bible; next, they say it has been discovered before; lastly, they say they always believed it.”

The history of medicine is full of examples of great inventors whose work was first pointed out as “immoral”, “insane” or “unuseful”, and was then adopted by everyone. Kurt Semm (1927–2003) was a pioneer in minimally invasive surgery who was initially ridiculed and attacked by many of his colleagues but was later praised for his early advances in a field that went on to become highly fashionable. He performed the world’s first laparoscopic appendectomy, wrote more than 1000 scientific papers and invented more than 80 surgical devices. Nevertheless, his first attempts to teach laparoscopic surgery to his colleagues were censored because they thought his surgery was unethical and, at the University of Kiel, his co-workers demanded that he undergo a brain scan because, they said, “only a person with brain damage would perform laparoscopic sur-

*Proceedings of the Consensus Conference “TSS in hip and knee replacement”, Rapallo, Italy, 22–24 June 2006

Table 1 The decalogue of tissue-sparing surgery (from [5])

1. Prosthesis integrates in the joint and does not substitute it
2. Maximum respect for anatomy
3. Maximum restoration of joint biomechanics
4. Dedicated surgical approach
5. Blood loss is minimized
6. Mini-protheses are used
7. Dedicated instrumentation
8. Computer-assisted applications
9. Bone-prosthesis integration promoted by regenerative medicine
10. Only diseased tissue is removed, healthy tissue is spared

gery". He is now considered the father of laparoscopic surgery.

As Everett M. Rogers describes in his work "The Diffusion of Innovation" (1962), the adoption of an innovation passes through the onset of new or different complications, and a process of modifications is required to overcome the new problems. This process allows the innovation to "melt" into the pre-existent knowledge and to be accepted by everyone.

One of the most fascinating innovations in hip and knee replacement in the last decades is minimally invasive surgery (MIS). This concept, firstly introduced in general surgery, aims to minimize surgical damage to the patient by using a faster and gentler approach for joint replacement. The rush for a smaller incision and less invasive technique has led to extreme solutions and showed few benefits with an unacceptable increase of some specific complications. The three major concerns about MIS have always been cosmetics, efficacy and complications, but in literature there is no scientific evidence for it [1–4]. As MIS appears today a bit less brilliant than it did years ago, a new path should be traced to drive conventional surgery to new horizons. An attempt has been made by Pipino, who introduced in recent years the acronym TSS for Tissue-Sparing Surgery and gave a decalogue of rules for performing tissue-sparing procedures (Table 1) [5].

1. The prosthesis integrates into the joint and does not substitute it

Virtually no prosthesis integrates into the joint without substituting it. All prostheses somehow substitute a biologically live structure with a foreign inert material. Therefore, we consider a prosthesis to be "TSS" when it is as small as possible, sacrifices as little tissue as possible and integrates with the surrounding articular structures in the best way.

Maybe, in future times, genetics and tissue engineering will introduce biological prostheses, i.e. prostheses made of live tissues that can be completely re-habitated by the host. That would be the most TSS prosthesis; until then, we can afford to use the prosthesis that best integrates into the joint. Some attempt has been made with allografts: knee and ankle joints from cadavers have been implanted in patients with joint arthritis [6]. Although these operations are absolutely fascinating, no long-term results have been reported yet.

In order to best integrate into the joint, a prosthesis should respect joint anatomy (e.g. a straight stem for cylindrical stovepipe femurs, an anatomic stem for "champagne fluted" ones), and have a good bone-prosthesis interaction (i.e. anallergic, non-cemented, porous coated, HA-coated). These aspects are discussed in the following sections.

2. Maximum respect for anatomy

New surgical approaches (or, most of the times, improved old surgical ones), using less invasive, less tissue-damaging instrumentations, protect anatomical structures better. New Hohmann retractors, angled reamers, specially designed retractors and smaller cutting devices allow for a shorter exposure and, therefore, for a reduced sacrifice of periarticular tissues. Whenever possible, surgical exposure of the hip can be performed with a posterior approach that spares the gluteus maximus and sometimes even the piriformis muscle. In knee surgery, the use of mid- or sub-vastus approach, or quad sparing, without everting the patella, better preserves the extensor mechanism. But respect for anatomy not only includes a careful approach: an aspect of paramount importance is also the correct reconstruction during wound closure of anatomical structures such as the joint capsule and fasciae, and the correct balance of forces (such as the restoration of the lever arm of the glutei muscles) and ligaments (soft tissue balancing in total knee arthroplasty).

Many newly introduced surgical techniques require closed or poorly visualised procedures (discussed later in the section "Dedicated surgical approaches"), in order to perform a shorter skin incision: in our opinion one can rather preserve anatomy by a wider exposure but a more careful, watchful dissection of soft tissues and bone cutting.

3. Maximum restoration of joint biomechanics

Can TSS approach guarantee good restoration of the original articular biomechanics? In comparison to traditional prostheses, neck-preserving arthroplasty considerably

respects the distribution of forces and the trabecular pattern of the meta-epiphyseal region of the proximal femur, with a biodynamically harmonic transfer of load through the bone.

Resurfacing arthroplasty substitutes only the articular surface. Therefore, it perfectly respects the original biomechanics of the articulation. The same concept applies to unicompartamental knee replacement, characterised by the preservation of structures fundamental for biomechanics and stability of the joint (ie: ACL, PCL, height of the joint), which in traditional total knee arthroplasty are sacrificed.

But respecting the original situation is not always favourable: in fact it is often an alteration of loads applied to the cartilage that produces cartilage wear. Therefore, the main goal is not to restore the pre-existing situation, but to correct the pathological situation that led to the cartilage damage. The more the prosthesis preserves the original anatomy, the less a correction is possible: almost nothing with resurfacing prostheses, limited in femoral neck-preserving hip arthroplasty and in unicompartamental knee replacement. Furthermore, if we do not correct the defect that produced the accelerated wear of articular cartilage, the prosthesis we implanted will be subjected to altered loads that will affect function and survival of the prosthesis. Total restoration of original articular biomechanics is not always favourable.

Regarding traditional prostheses and biomechanics restoration, in the last years, in order to meet the demands of orthopaedic surgeons for better adaptability to the various anatomical situations, many new modular prostheses have been designed. These prostheses are characterised by variable length, degree of anteversion and neck-shaft angle, and neck offset, and allowing not only perfect adaptability but also correction of defects, and therefore a better balance of forces. This high modularity nowadays allows traditional surgery to restore in a more than acceptable way almost every defect in joint biomechanics.

4. Dedicated surgical approaches

Total hip arthroplasty (THA) can be performed through a variety of different exposures. Sir John Charnley, who firstly introduced cemented THA more than 40 years ago, suggested the lateral approach and the transtrochanteric osteotomy. He believed this approach not only provided excellent exposure of the acetabulum, but also allowed the surgeon to optimally restore the abductor mechanism by trochanteric advancement. Unfortunately, complications such as trochanteric nonunion and heterotopic ossification were not uncommon. Therefore, from then on there has been a continuous quest for the perfect approach, which should allow for easy exposure of all structures, with the least dam-

age to soft tissues and bone, and with the lowest rate of complications. Nowadays, posterolateral and anterolateral approaches are the most frequently used techniques in THA.

In total knee arthroplasty (TKA), an anterior approach has always been used. Differences regarding patella exposure have been introduced by many authors: von Langenback described the medial parapatellar approach [7], Insall the midline approach [8] (in line with skin incision), and Kocher proposed the anterolateral approach [9] (often used for severe valgus deformities).

Recently, the introduction of MIS techniques has urged surgeons to decrease the size of the incision and to reduce tissue damage. Several techniques of MIS hip arthroplasty have been described and can be grouped into two main categories: minimal incision approaches and two-incision approaches. The minimal incision approaches are modifications of the standard posterolateral, anterolateral and anterior approaches that were already commonly used for hip arthroplasty, only performed through shorter wounds (10 cm or less). These mini-incision techniques are not radically new, but rather simply a modification of current well established techniques: therefore, anatomy of the exposure should be familiar [10–18]. The common principle underlying all these incisions is the creation of a mobile window that can be moved to different positions during different stages of the operation.

The two-incision approach constitutes a new approach for hip replacement, using intermuscular planes to gain access to the hip joint and minimizing the dissection of muscles and tendons. This approach was described by Berger [19] following on the work of Mears, who initially developed this technique. The principle of the approach is two incisions, one for the acetabulum and one for the femur, avoiding the division of muscle or tendons and aiming to achieve a faster recovery of normal function. This is in fact a combination of two traditional approaches: the proximal incision is the proximal part of the Smith-Petersen approach, while the distal incision is the middle part of the Hardinge approach.

In knee arthroplasty, new approaches have been introduced, with the purpose to reduce stress on the extensor mechanism. All these approaches are characterised by care for the vastus medialis muscle: the midvastus approach passes through it, the subvastus approach passes at its lower border, and the quad-sparing approach completely preserves the muscle.

All these new MIS approaches have the same defect: minimizing the wound leads to a more difficult visualization of anatomical structures (or, as in the two-incision THA, to a completely blind, fluoroscope-assisted surgery), rising the risk of damaging them. This discomfort can lead to great mistakes (first of all: malpositioning of prosthesis components) if one is not confident with the

approach. Length and invasiveness of the approach should therefore be carefully planned, and adapted to every single operation, considering all risk factors (e.g. obesity, muscularity, surgeon's skills). The aid of imaging and guiding devices (e.g. fluoroscopy and CAOS) is often mandatory to perform these approaches, but most of the times it is not sufficient to avoid mistakes.

5. Blood loss is minimized

MIS has been described as a blood-sparing procedure: some papers report a higher level of haemoglobin postoperatively in MIS patients than in patients who underwent traditional TKA or THA [20, 21]. But the majority of studies report no difference between the two techniques [2, 22–24].

There is no strong evidence supporting the theory of MIS either being a blood-sparing procedure or causing the same amount of blood loss as traditional surgery. We cannot therefore conclude that a different surgical technique leads to blood sparing.

In 2001, the Orthopaedic Surgery Transfusion Haemoglobin European Overview (OSTHEO) study [25] evaluated 2640 THA and 1305 TKA procedures performed across Europe. A total of 2762 patients received transfusions (69%; 35% autologous only and 25% allogeneic only), underlining the great discrepancy between estimates and calculations of surgical blood loss in knee and hip arthroplasties (estimates are about 40% of calculated blood loss). Estimation of blood loss should be performed at the time surgery is planned, not at the time of surgery itself. Only preoperative baseline haemoglobin levels are surely related to the probability of transfusion. The study offered sensitive predictive models that can be integrated into surgical practice. The proposed "blood management" in elective knee and hip arthroplasty should include: (1) a careful preoperative estimation of blood loss in order to choose between the different options for blood supply; (2) focus on haemoglobin levels to determine the probability needing of transfusion; and (3) good preoperative care, including haemoglobin monitoring and preoperative adjustment.

In summary, as the OSTHEO study confirmed, a comprehensive blood management program is required. Such programs should include procedures for selecting patients suitable for autologous blood donation, allow optimal collection and transfusion of appropriate amounts of autologous blood, assess operative procedures to limit and reduce blood loss, individualize blood management and transfusion practice, and optimize pre-, peri- and postoperative haemoglobin levels.

6. Miniprotheses are used

The theory that "miniprotheses are used to maximize the conservation of bone stock" is based on the belief that "the more we preserve bone, the less the prosthesis will damage the bone". In our opinion, a small prosthesis is not "the smallest available", but one that allows the surgeon to achieve good and safe results, and is small enough to sacrifice as little bone as possible.

With respect to the traditional straight cemented prosthesis, we can identify nowadays three kinds of "new design" prostheses:

- a. *Anatomical prostheses*. These prostheses require the same neck osteotomy as straight ones, but the load is transferred from the prosthesis to the bone in a more proximal part (metaphyseal) of the femur. These prostheses are therefore less invasive in the sense that the bone prosthesis interface is reduced only to the proximal part of the diaphysis.
- b. *Neck-preserving prostheses*. The osteotomy is carried out more proximally (in the mid-cervice region), and the bone-prosthesis interface is reduced to the cancellous bone of the neck and the proximal part of the diaphysis. This prosthesis is designed to best fit in the trabecular system of the proximal femur.
- c. *Resurfacing prostheses*. The prosthesis substitutes only the cartilage and subchondral bone, at the hip joint, while the neck and most of the cervical cancellous bone remain intact.

Neck-preserving prostheses and resurfacing prostheses can be used only when the anatomy of the hip joint respect some parameters of "normality" (normal offset, neck-shaft angle and degree of anteversion of femoral neck, leg length discrepancy <1 cm, sufficient bone density); otherwise the prosthesis cannot correct these defects.

Beule et al. [26] introduced the Surface Arthroplasty Risk Index (SARI) that gives the right indication for resurfacing prostheses. SARI is a score from 0 to 6 points, giving points to 4 parameters:

- Femoral head cyst >1 cm: 2 points;
- Patient weight <82 kg: 2 points;
- Previous surgery: 1 point;
- UCLA activity level >6: 1 point.

If the score exceeds 3, surface arthroplasty is not indicated (Beule et al. [26] found that patients with SARI greater than 3 had a relative risk to have early problems 12-times greater than patients with SARI of 3 or less).

In clinical practice, most of the times surgeons deal with cases that are not fit for resurfacing or neck-preserving prostheses. We therefore suggest to rely in most cases on an anatomical stem and carefully select patients when a resurfacing or neck-preserving prosthesis is used.

7. Dedicated instrumentation

The introduction of minimally invasive surgery required specialized instrumentation. In fact, in order to implant prostheses through “mini” approaches, surgeons and implant manufacturers have developed new tools. Specifically designed retractors have been introduced, with long handles, angled at approximately 90° to the blade, so that the assistant’s hands are kept at a distance from the wound and do not obscure the surgeon’s view. In order to keep a minimum number of retractors inside the wound, flanged retractors are used: the flanges allow retraction of surrounding soft tissue when the handle is rotated about the axis of the retractor point, and they are therefore more efficient than standard retractors.

Several retractors also permit the attachment of an additional light source: the reduced length of incision inevitably leads to a reduction in the delivery of light to the surgical field, and these additional light sources (that provide light directly inside the wound) can be considerably useful in performing the procedure.

Preparation of the acetabular surface in MIS hip arthroplasty is difficult with straight reamers, particularly in the larger patient in whom soft tissue impingement may impede the surgeon. The use of a curved reamer shaft may avoid this problem and allow proper acetabular preparation. The use of an angled reamer shaft is an alternative: the handle is oriented vertically and the correct abduction angle is built into the shaft.

Repeated passage of standard reamers through small incisions may abrade the soft tissues; specialized reamers have a reduced area of cutting and allow the passage through the wound while minimizing soft tissue trauma. When introducing the acetabular component, the use of a straight impactor may suffer from the same drawbacks as the use of a straight reamer shaft during reaming, but these difficulties can be overcome through the use of angled instruments, many of which have built-in alignment guides to optimize cup position.

Special spreaders, with mechanical control of the distance but also with mechanical or electronic control of strength, are useful to provide a good balance in knee prosthetic surgery.

Many of these tools are now used successfully also in traditional surgery, in order to allow even more rapidity and less invasivity.

8. Computer-assisted applications

Various new computer-assisted surgical tools that aid in the planning and execution of surgical procedures are

becoming available to the orthopaedic surgeons. We can classify them according to the level of surgical independence given to devices in performing actions:

- *Active systems* are capable of performing individual tasks or entire procedures autonomously, while under the watchful eye of the surgeon.
- In *semi-active systems*, the surgical action is physically constrained to follow a predefined strategy. The action is guided or constrained, but final control still depends on the surgeon performing the action (e.g. virtual templates, telesurgery).
- *Passive systems* generally perform no action, but provide the surgeon with additional information prior to and during a procedure (called “surgical information technologies”).

Passive systems can be divided in 3 groups: the first, “preoperatively imaged”, requires pre-operative images (CT, MRI) that should be collected before operation and loaded onto the system’s computer. In the second category, “peroperatively imaged”, anatomical images are acquired in the operative room at the time of surgery, with a specially modified fluoroscopy unit. The third group is “image free”: an anatomical model is embedded in the software and is upgraded by the process of registration of landmarks in a pre-determined sequence. The accuracy of the registration process is of paramount importance: an error of a few millimetres can dramatically compromise the stability or the function of the prosthetic implant.

Computer-assisted orthopaedic surgery (CAOS) can be considered a useful help in traditional surgery, is very useful in TSS, and sometimes becomes a really essential tool (hip resurfacing arthroplasty, bi-unicompartamental knee prosthesis).

9. Bone-prosthesis integration promoted by regenerative medicine

The bone-prosthesis interface, where prosthesis integration takes place, requires interdigitation of bone into the surface of the prosthetic component, thanks to the combined action of osteoblasts and osteoclasts [27].

The chronologic course of healing follows three overlapping phases: (1) an initial phase with destruction and necrosis of bone, which creates a gap between bone and prosthesis, and demineralizes periprosthetic bone, where the new bone formation takes place; (2) a phase of repair with integration of the implant into the bone, through a cycle of activation, resorption and formation (ARF) of osteoblasts and osteoclasts activated by cytokines; and (3) a phase of stabilization of the permanent implant bed with

adaptation to load transfer and possible reactions to different stimuli (infection, instability, corrosion, degradation of implant materials) [28].

Although prosthesis fixation used to be provided by bone cement, nowadays the use of bone cement has been dropped, or at least reduced to only special cases, and non-cemented prostheses are used. Many means of osseointegration have been proposed: porous vs. non-porous surfaces; different metal alloys (Cr-Co-Mo, Ti₆Al₄V); coating of prosthesis with osseoinductive materials (mostly hydroxyapatite); local application of various substances such as concentrated thrombocytes (platelet enriched plasma) and growth factors (e.g. bone morphogenetic proteins; TGF- β , interleukins); and external physical therapy (e.g. electromagnetic stimulation, ultrasound). Although a large number of studies has evaluated the results of the different means of osseointegration, there is no definitive evidence on which alloy, coating, substance or form of physical therapy has a significant advantage over the others [29–31].

In clinical practice, some means like growth factors cannot be used, because these would raise the cost of the operation and have not been approved by health authorities for this application.

In our opinion, the best osseointegration is given by the use of a microporous, hydroxyapatite-coated prosthesis. Hydroxyapatite not only creates an interlocking mechanical bond, but also a chemical bone bond. This allows for the building of a bridge between bone and prosthesis of up to 2 mm, whereas other materials do not reach more than 0.3 mm.

10. Only diseased tissue is removed, healthy tissue is spared

The concept of sparing healthy tissue has always been applied to all surgical procedures, particularly to oncologic surgery. The question in prosthetic surgery is: which tissues can be considered diseased, and which are sound? On one hand, all tissues, being alive and not affected by any specific pathology (neoplastic or degenerative) should be spared, except the articular cartilage, damaged by arthritis. On the other hand, we must consider that some

anatomical features induce arthritis (e.g. axial deformities of joints), and that every surgical approach and every prosthetic implant somehow damages some tissues.

“Tissue sparing” means, therefore, removal of all tissues that are frankly diseased, i.e. articular cartilage, and of all tissues affected by arthritis-related diseases (subchondral sclerotic bone, bone cysts, synovial tissue). It also means correction of all deformities that led to arthritis or that derived from arthritis: i.e. use of osteotomies or modification of cutting angles for varus/valgus deformities both in hip and knees, and soft tissue releases in severe deformities, particularly at the knee level. Finally, it means use of surgical approaches that respect as much as possible all anatomic structures, and use of small prostheses, as discussed earlier.

TSS appears not to be a list of “do’s and don’t’s”, but as a philosophical approach to hip and knee prosthetic surgery. MIS has been introduced as a “new era” in orthopaedic surgery, but has proven to be affected by many defects. The concept of a “reduced invasiveness” has therefore evolved into the idea of “tissue sparing”, focusing the attention not only on surgical approaches, but also on restoration of anatomy and biomechanics, and the use of every aid that technology offers to the surgeon (e.g. new materials, bio-engineering, computers).

As Rosenberg said at the Current Concepts in Joint Replacement winter meeting held in Orlando, Florida in December 2004 [32], “The vast majority of surgeons who perform total hip arthroplasty on a regular basis have already modified their operative approaches to incorporate less invasive techniques”. This means that every surgeon during his or her career tends to perform an always more tissue-sparing surgery. The acronym TSS can then be interpreted as tissue sparing “spontaneous”.

As in all fields of knowledge, experience and wisdom should guide the surgeon to choose the right decision for every single case. As Rosenberg said: “an open mind, along with a critical eye, is required”. In our opinion, TSS is the natural evolution of traditional surgery, as it progressively absorbed new findings and new technologies. All surgeons that perform hip and knee arthroplasty should be aware of the TSS decalogue and try to be as tissue-sparing as possible, according to their own experience and to the single case being treated.

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