

# World Journal of *Orthopedics*

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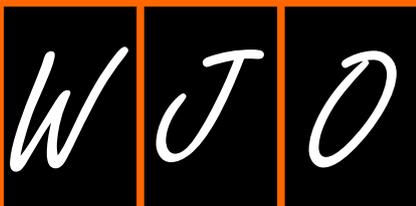
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*World Journal of Orthopedics*  
Room 903, Building D, Ocean International Center, No. 62 Dongsihuan Zhonglu, Chaoyang District, Beijing 100025, China  
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## Regulation of bone destruction in rheumatoid arthritis through RANKL-RANK pathways

Sakae Tanaka

Sakae Tanaka, Department of Orthopaedic Surgery, Faculty of Medicine, The University of Tokyo, Tokyo 113-0033, Japan  
Author contributions: Tanaka S wrote the paper.  
Correspondence to: Sakae Tanaka, MD, PhD, Department of Orthopaedic Surgery, Faculty of Medicine, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan. [tanakas-ort@h.u-tokyo.ac.jp](mailto:tanakas-ort@h.u-tokyo.ac.jp)  
Telephone: +81-3-38155411 Fax: +81-3-38184082  
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### Abstract

Recent studies have demonstrated that osteoclasts, the primary cells responsible for bone resorption, are mainly involved in bone and joint destruction in rheumatoid arthritis (RA) patients. Recent progress in bone cell biology has revealed the molecular mechanism of osteoclast differentiation and bone resorption by mature osteoclasts. We highlight here the potential role of the receptor activator of nuclear factor  $\kappa$ B ligand (RANKL)-RANK pathways in bone destruction in RA and review recent clinical trials treating RA by targeting RANKL.

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**Key words:** Rheumatoid arthritis; Osteoclast; Receptor activator of nuclear factor  $\kappa$ B ligand; Bisphosphonate; Denosumab

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### INTRODUCTION

Rheumatoid arthritis (RA) is a chronic inflammatory dis-

order characterized by remarkable synovial hyperplasia followed by the massive joint destruction<sup>[1,2]</sup>. Investigation into the pathogenesis of joint destruction in RA has revealed the transformed phenotype of rheumatoid synovial cells<sup>[3]</sup>. Proliferating inflammatory synovial cells lead to pannus formation that invades articular cartilage and bone<sup>[4]</sup>. Radiographic studies demonstrate that bone erosion in RA begins early in the disease, and progresses throughout its course<sup>[5,6]</sup>. Bone erosion results in severe deformity of the affected joints and impairs the normal activity of patients. Therefore, inhibiting bone destruction is one of the most challenging goals in the treatment of RA. Because the exact etiology of RA remains unknown, most treatments of RA have targeted symptoms of the disease. Non-steroidal anti-inflammatory drugs have been used to reduce the painful symptoms of the disease, but they have little effect on stopping the progression of joint destruction. Some disease-modifying anti-rheumatic drugs such as methotrexate are known to suppress joint destruction in RA<sup>[7,8]</sup>. In addition, recent clinical studies have demonstrated that various biological agents such as antibodies against inflammatory cytokines (e.g., infliximab, adalimumab and tocilizumab) or CTLA4-Ig (abatacept) not only suppress joint symptoms in RA patients but also markedly ameliorate joint destruction<sup>[9-12]</sup>. However, the bone-protective function of these drugs is still limited, and they are accompanied by severe side effects, such as infection, since they suppress a patient's immunological reaction<sup>[13]</sup>.

There is accumulating evidence that osteoclasts, primary cells responsible for bone resorption, are involved in bone destruction in RA, and recent progress in molecular biology and biochemistry has revealed the molecular mechanism of osteoclast differentiation and bone resorption. In this chapter, I would like to focus on the role of osteoclasts in bone and joint destruction in RA, the mechanism of osteoclast generation in inflammatory joint, and propose that osteoclasts can be potential targets in RA therapy.

## INVOLVEMENT OF OSTEOCLASTS IN BONE DESTRUCTION IN RA

RA is characterized by proliferative pannus formation leading to erosive bone destruction originating from the interface of cartilage and bone (the bare area). Synovial tissues of RA joints produce various inflammatory cytokines, such as interleukin-1 $\beta$  (IL-1 $\beta$ ) and tumor necrosis factor- $\alpha$  (TNF- $\alpha$ ), which are believed to play important roles in joint destruction. The cellular mechanism of bone and cartilage destruction in RA still remains unclear, but recent studies have revealed the essential role of osteoclasts (Figure 1). Bromley *et al*<sup>[14]</sup> observed a number of acid phosphatase-positive multinucleated cells (chondroclasts and osteoclasts) in the erosive areas of RA joints obtained at the time of joint replacements. In collagen-induced arthritis, multinucleated giant cells were observed at the bone-pannus junctions of arthritic joints, and cells isolated from the lesions were able to differentiate into mature osteoclasts. Gravallese *et al*<sup>[15]</sup> also found multinucleated cells present on subchondral bone surface and in the areas of direct invasion of pannus into subchondral bone. Their important discovery was that those multinucleated cells were positive for unique markers of osteoclasts such as tartrate-resistant acid phosphatase (TRAP), cathepsin K, and calcitonin receptors, satisfying the major criteria of mature osteoclasts. Interestingly, some multinucleated cells and mononuclear cells apart from the bone surface were TRAP-positive. These findings suggest the possible role of synovial tissues for osteoclastogenesis in RA. To reveal the osteoclastogenic potential of RA synovial tissues, synovial cells from RA synovia were cultured in the presence of osteotropic factors such as 1 $\beta$ ,25-dihydroxyvitamin D<sub>3</sub> [1,25(OH)<sub>2</sub>D<sub>3</sub>] and macrophage colony-stimulating factor (M-CSF)<sup>[16]</sup>. After 3 wk of culture, we observed many multinucleated giant cells, which were TRAP-positive, possessed abundant calcitonin receptors, and made resorption pits on dentine slices. We also demonstrated that peripheral monocytes can differentiate into osteoclast-like cells when co-cultured with synovial fibroblasts obtained from RA synovial tissues in the presence of 1,25(OH)<sub>2</sub>D<sub>3</sub> and M-CSF. Similar results were reported by Fujikawa *et al*<sup>[17]</sup>. They found that synovial macrophages isolated from RA synovial tissues can differentiate into osteoclast-like cells when co-cultured with UMR 106 rat osteoblast-like cells. These results suggest that RA synovial fibroblasts can support osteoclast differentiation from monocyte-macrophage lineage precursor cells under a suitable condition, at least *in vitro*.

## INVOLVEMENT OF RANKL/RANK PATHWAYS IN BONE DESTRUCTION IN RA

Remarkable progress has been made in recent years in the field of osteoclast research primarily due to the find-

ing of the receptor activator of nuclear factor  $\kappa$ B (NF- $\kappa$ B) ligand (RANKL)/RANK system<sup>[18]</sup>. RANKL is a member of the TNF superfamily of cytokines, which was originally identified as a membrane-bound survival factor for dendritic cells produced by activated T cells<sup>[19]</sup>. The expression of RANKL can be also induced in osteoblasts and bone marrow stromal cells by osteotropic hormones such as 1,25(OH)<sub>2</sub>D<sub>3</sub> and parathyroid hormone<sup>[20]</sup>. In the presence of M-CSF, RANKL can stimulate osteoclast differentiation from hematopoietic precursor cells *in vitro*<sup>[20]</sup>. RANKL also acts on mature osteoclasts and activates the bone-resorbing activity and survival of the cells. RANKL binds to its receptor RANK, a transmembrane receptor belonging to the TNF receptor superfamily, which is expressed in monocyte-macrophage lineage osteoclast precursor cells as well as in mature osteoclasts and dendritic cells. Binding of RANKL to RANK induces intracellular signals including NF- $\kappa$ B activation and c-Jun N-terminus kinase activation. The other important actor in this system is osteoprotegerin (OPG) a soluble receptor of RANKL, belonging to the TNF receptor superfamily<sup>[19]</sup>. OPG specifically binds to RANKL, and inhibits RANKL activity by preventing its binding to RANK.

The essential role of RANKL/RANK signaling pathways in osteoclast development *in vivo* has been established by a series of targeted gene disruption experiments<sup>[19]</sup> comprising, the targeted disruption of either RANKL or RANK induced osteopetrosis in mice, a pathological bone disease which is characterized by an increased bone mass due to a deficiency in osteoclast differentiation<sup>[21,22]</sup>. We and another group found that mice deficient in TRAF6, a signaling molecule involved in RANK signaling, also showed osteopetrotic phenotypes. In contrast, the targeted disruption of OPG induces reduced bone mass in mice, reminiscent of osteoporosis, due to the increased number and activity of osteoclasts<sup>[18,23,24]</sup>. These results clearly demonstrate the essential role of RANKL/RANK pathways in osteoclast development and activation *in vivo*. The next question is whether the RANKL/RANK system is also involved in pathological bone destruction, such as in RA. We and others have revealed by Northern blotting, immunocytochemistry and *in situ* hybridization (Figure 2) that RANKL is highly expressed in synovial fibroblasts<sup>[12,15,25,26]</sup>. 1,25(OH)<sub>2</sub>D<sub>3</sub> treatment increased the expression of RANKL in synovial fibroblasts and reduced the expression of OPG in the cells. RANKL expression was also detected in CD4<sup>+</sup> T lymphocytes in RA synovial tissues by *in situ* hybridization. Kong *et al*<sup>[27]</sup> demonstrated that activated CD4<sup>+</sup> T lymphocytes fixed with paraformaldehyde or culture supernatants from activated T cells can support osteoclast differentiation through the surface-bound and/or soluble RANKL they produce. They also showed that RANKL was expressed on the surface of activated T cells in synovial tissues of adjuvant arthritis rats<sup>[27]</sup>. These results suggest the important role of activated T lymphocytes in bone and joint destruction in RA. However, the role of T cells in osteoclast development is

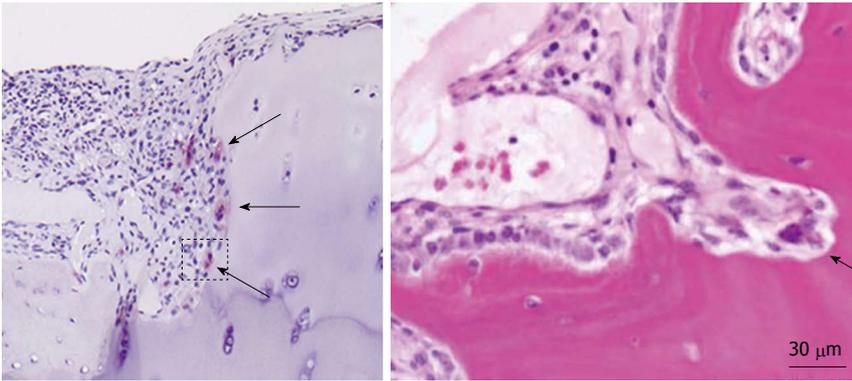


Figure 1 Inflammatory synovial proliferation and bone erosion (arrows) by osteoclasts in rheumatoid arthritis patients.

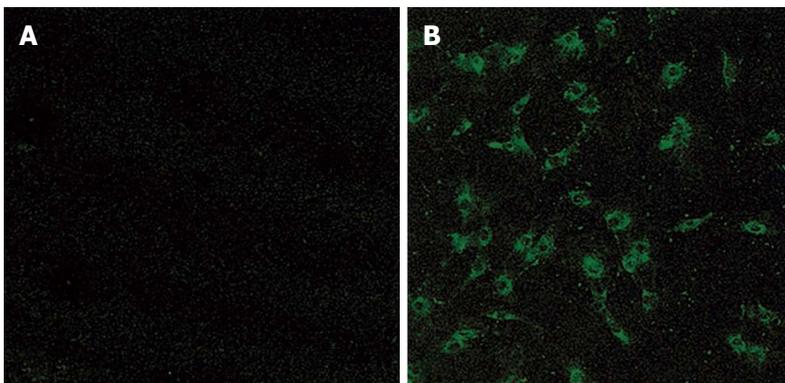


Figure 2 Immunostaining of synovial fibroblasts obtained from osteoarthritis (A) and rheumatoid arthritis (B) patients with anti-receptor activator of nuclear factor  $\kappa$ B ligand antibody.

still controversial because activated T cells also produce many cytokines which inhibit osteoclast differentiation, such as interferon- $\beta$  and IL-10. In any case, these studies indicate that RANKL produced by synovial fibroblasts and/or activated T lymphocytes in RA synovial tissues may play an essential role in osteoclast development and bone destruction in RA. Based on these findings, Kong *et al*<sup>[27]</sup> proposed that OPG can be a potent therapeutic agent against bone destruction in RA. Exogenous administration of recombinant OPG suppressed bone and joint destruction in rat adjuvant arthritis.

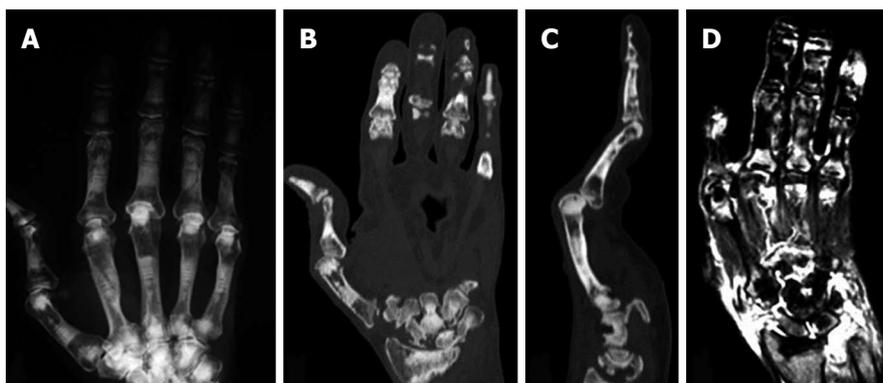
### Reduced bone destruction in a patient with osteopetrosis and RA

In addition to the animal studies described above, the importance of osteoclasts in bone destruction in RA was further confirmed by the clinical finding in a RA patient with osteopetrosis<sup>[28]</sup>. Osteopetrosis is an inherited disorder characterized by an increase in bone mass<sup>[29]</sup>. In humans, osteopetrosis comprises a heterogeneous group of diseases, which are classified into three major groups on the basis of inheritance, age of onset, severity, and secondary clinical features: autosomal recessive infantile malignant osteopetrosis, autosomal recessive intermediate mild osteopetrosis, and autosomal dominant adult onset benign osteopetrosis. The most frequent form of osteopetrosis, which has autosomal dominant (ADO)

inheritance (incidence 5:100000), is also called Albers-Schönberg disease or ADO type II. ADO type II is characterized by vertebral endplate thickening (rugger-jersey appearance), fragile bones with multiple fractures and delayed healing. Recent studies have shown that the *CLCN7* gene encoding type 7 chloride channel, which is essential for the acidification of the extracellular environment in resorption lacuna by osteoclasts, is a candidate gene for ADO type II. We recently reported a very rare case of RA associated with ADO type II. In spite of the severe inflammation and rapid progression of cartilage destruction in the patient, the progression of bone erosion was quite slow (Figure 3)<sup>[28]</sup>. These clinical findings further confirm the critical role of osteoclasts in bone destruction in RA but not in inflammation or cartilage destruction.

### The mechanisms of action of aminobisphosphonate

Since osteoclasts are critically involved in bone destruction in RA, therapeutics which target osteoclasts could be good candidates for the treatment of RA. One of the most promising group of reagents which inhibit osteoclast function is bisphosphonates. Bisphosphonates (BPs), stable analogs of pyrophosphate, strongly inhibit bone resorption and have been used to treat various diseases driven by increased bone resorption, such as postmenopausal osteoporosis. Although BPs are poorly absorbed



**Figure 3** Plain X ray (A), computed tomography scan (B and C) and magnetic resonance imaging (D) of the right hand of an autosomal dominant II patient with rheumatoid arthritis. Erosion of the carpal bones (B) and severe synovitis, as determined by the high intensity areas by T2-weighted magnetic resonance imaging images (D), were observed<sup>[14]</sup>.

from the intestine, they are quickly deposited on the bone surface once absorbed. BPs are divided into two groups according to the structure of the side chains, a nitrogen-containing type (N-BPs) and a non-nitrogen-containing type. Non-nitrogen-containing BPs are reported to act through the intracellular accumulation of non-hydrolyzable ATP analogs that exert cytotoxic effects on OCs, while N-BPs inhibit the mevalonate pathway and prevent the post-translational prenylation of small GTP-binding proteins such as Ras, Rho, Rac and Cdc42. We recently reported that risedronate, one of the N-BPs, induced osteoclast apoptosis by suppressing the Erk pathway and increasing the expression of a pro-apoptotic Bcl family protein, Bim, while it reduced bone-resorbing activity of the cells through suppression of the Akt pathway<sup>[30]</sup>.

Osteoporosis and osteoporosis-related fractures are common in RA patients<sup>[31-33]</sup> and several studies have demonstrated that bisphosphonates effectively increase bone mineral density and decrease fragile fractures in RA patients<sup>[34-36]</sup>. In spite of these strong and specific inhibitory effects of bisphosphonates on osteoclasts, only limited clinical data demonstrate the effectiveness of bisphosphonates in RA patients. Jarette *et al*<sup>[37]</sup> reported preliminary evidence that treatment with zoledronic acid plus methotrexate showed better results in reducing bone destruction than methotrexate alone. However, many other studies have failed to show positive effects of bisphosphonates against bone destruction in RA<sup>[38-40]</sup>. This may be because, in these studies, the treatment was initiated too late or the strength of the bisphosphonates used was not enough to treat the bone destruction in RA.

#### **Effects of anti-RANKL antibody on bone destruction in RA**

Denosumab is a fully human monoclonal antibody that specifically and avidly binds to RANKL. Previous clinical studies have demonstrated that administration 60 mg of denosumab subcutaneously every 6 mo to postmenopausal women with osteoporosis significantly reduced bone turnover markers, increased bone mineral density, and reduced osteoporosis-related fractures<sup>[41]</sup>. Because

of the critical role of the RANKL-RANK system in osteoclast development and bone destruction in RA, clinical studies were conducted to analyze the effect of denosumab on RA<sup>[42-44]</sup>. Sharp *et al*<sup>[42]</sup> demonstrated that twice-yearly subcutaneous injections of denosumab (60 mg or 180 mg) with ongoing methotrexate treatment significantly reduced cortical bone loss in RA patients for up to 12 mo. In a phase II clinical trial, subcutaneous administration of denosumab every 6 mo to patients with active RA suppressed the progression of subchondral bone erosions and systemic bone loss, although there was no an apparent reduction of joint inflammation or joint space narrowing. In addition, denosumab treatment over 12 mo increased mean lumbar spine and hip bone mineral density and reduced bone turnover markers such as sCTX-I and PINP compared with placebo, regardless of baseline bone mineral density or marker levels or concomitant bisphosphonate or glucocorticoid use<sup>[44]</sup>. The rate of adverse events and serious infections requiring hospitalization did not differ between patients treated with denosumab and with placebo. These clinical observations, in addition to the results of the basic studies, clearly suggest that denosumab is effective in preventing bone erosion but not cartilage destruction in RA.

## **CONCLUSION**

The ultimate goal of the treatment of RA is to prevent the bone and joint destruction and preserve the daily activity of patients. Recent studies have revealed that osteoclasts are involved in the pathogenesis of bone and joint destruction in RA and can be a potent therapeutic target of the disease<sup>[4,45]</sup>. Therapeutics targeting osteoclast formation or function can at least ameliorate the progression of these bone changes<sup>[27,43]</sup>. However, inhibition of osteoclast function by anti-resorptive agents alone do not completely prevent bone erosion in RA in spite of their preventive effects against systemic bone loss. Therefore, the combination of anti-resorption therapy and anti-inflammatory therapy could be an ideal therapy for RA. Thus, anti-RANKL therapy in combination with the

anti-inflammatory therapy is a promising strategy for RA treatment, and safe and effective therapies against RA may be expected in the near future.

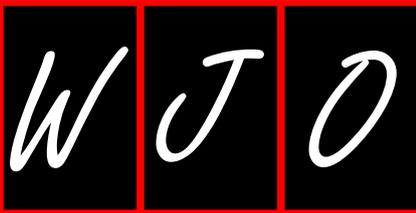
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Quanjun Cui, MD, Series Editor

## Femoral impaction grafting

John A Scanelli, Thomas E Brown

John A Scanelli, Thomas E Brown, Department of Orthopedic Surgery, University of Virginia School of Medicine, Charlottesville, VA 22908, United States

Author contributions: Scanelli JA contributed to background research, formulation of manuscript, revision of manuscript, procurement and management of images, final approval of manuscript; Brown TE contributed to background research, planning of manuscript, revision of manuscript, selecting of images, oversight/guidance, final approval of manuscript.

Correspondence to: Thomas E Brown, MD, Department of Orthopaedic Surgery, University of Virginia School of Medicine, PO Box 800159, Charlottesville, VA 22908,

United States. [tb4g@hscmail.mcc.virginia.edu](mailto:tb4g@hscmail.mcc.virginia.edu)

Telephone: +1-434-2430278 Fax: +1-434-2430242

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### INTRODUCTION

Managing bone loss is one of the most challenging aspects of revision total hip arthroplasty. Femoral impaction grafting is a technically demanding and time consuming procedure, but if performed well, is capable of restoring bone stock in the revision setting with high rates of graft incorporation<sup>[1]</sup>. The technique was developed in Europe in the 1980's and popularized by the Exeter, UK group in the early 90's. Long-term follow-up data is now available showing excellent survivorship beyond 10 years<sup>[2,3]</sup>. Advances in instrumentation, and the use of longer stems to bypass areas of weak cortical bone distally, have reduced the risk of stem subsidence and femoral fracture<sup>[4,5]</sup>. The performance time and technically demanding aspects of the operation currently limit its more widespread use compared to other types of revision stems that rely on biologic fixation. The long-term success of impaction grafting ultimately depends on incorporation of particulate allograft into host bone. This process is characterized by an initial inflammatory phase followed by revascularization. Allograft is eventually resorbed and replaced with new host bone by 6-12 mo after the operation.

### INDICATIONS

Femoral impaction grafting is an attractive option for restoring femoral bone stock, especially if patients are likely to require an additional reconstructive procedure in their lifetime. It can be used in revisions where the intramedullary canal is > 18 mm, as a fully porous coated stem in this situation is associated with an increased incidence of thigh pain. In femoral defects where there is not 4-6 cm of cortical bone distally to provide scratch fit of a porous coated stem, or the isthmus is non-supportive, femoral impaction grafting is a viable option. If there is minimal cancellous bone present after removal of a femoral stem,

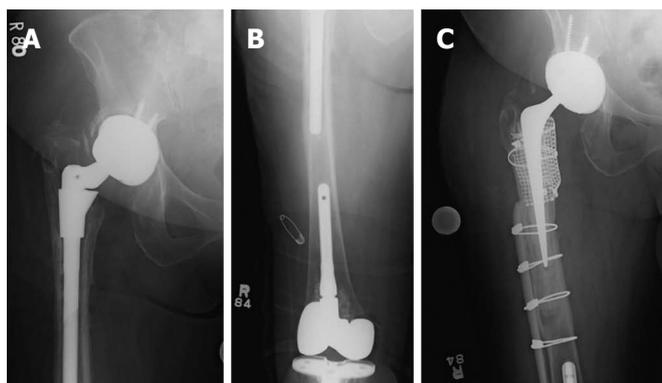
### Abstract

Femoral impaction grafting is a reconstruction option applicable to both simple and complex femoral component revisions. It is one of the preferred techniques for reconstructing large femoral defects when the isthmus is non-supportive. The available level of evidence is primarily derived from case series, which shows a mean survivorship of 90.5%, with revision or re-operation as the end-point, with an average follow-up of 11 years. The rate of femoral fracture requiring re-operation or revision of the component varies between several large case series, ranging from 2.5% to 9%, with an average of 5.4%.

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**Key words:** Femoral impaction grafting; Femoral revision; Bone grafting; Revision total hip arthroplasty; Bone loss

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**Figure 1** 63 year-old female with an infected, loose right femoral component. A: A stem from an ipsilateral total knee arthroplasty prevented revision with a long extensively porous coated implant. A stage 1 revision was performed with retention of the pedestal to prevent cross-contamination followed by 6 wk of IV antibiotics with subsequent femoral impaction grafting; B: With subsequent femoral impaction grafting; C: 63 year-old female 3 mo after femoral impaction grafting. Allograft struts were applied to bypass a stress riser distally, and metal mesh was used to reconstruct the calcar.

impaction grafting is capable of creating a neomedullary canal that allows the use of a cemented stem with durable fixation. When a stem from an ipsilateral total knee arthroplasty prevents femoral component revision of a hip prosthesis with a long extensively porous coated implant, femoral impaction grafting is an option (Figure 1).

A continuous femoral tube must be confirmed intraoperatively before commencing with impaction of cancellous bone, otherwise another technique for revision should be considered. Segmental bone loss that can be converted to a contained defect with metal mesh, allograft struts or bulk allograft is amenable to impaction grafting. Although not commonly used for managing periprosthetic fracture, Tsiridis *et al*<sup>[6]</sup> reported a fracture union rate of 84% with 4 year follow-up when femoral impaction grafting was used to manage Vancouver B2 and B3 fractures.

Femoral impaction grafting requires the patient to be medically stable enough to tolerate a long operation. The technique becomes exceptionally challenging in reconstructions where there is near complete loss of the proximal 10 cm of the femur<sup>[7]</sup>. In these situations, an allograft prosthesis composite or megaprosthesis reconstruction is recommended. Although femoral impaction grafting can be used to manage infection, a two-stage operation is generally preferred over a single-stage revision.

## SURGICAL TECHNIQUE

The patient is positioned laterally on the operating table and secured between two hip positioners, ensuring enough space is available to dislocate the hip before prepping and draping. A posterior or posterolateral approach is preferred in all cases and can easily be extended. Previous scars in line with the planned incision are incorporated. The fascia lata is incised along the mid to posterior portion of the femoral shaft and the gluteus maximus bluntly dissected in line with its fibers to allow adequate exposure of the hip joint and proximal femur. The short external rotators and posterior hip capsule are then taken down as a single layer to the level of the lesser trochanter distally and repaired back to the greater trochanter with drill holes at the conclusion of the case. The anterior capsule is elevated off the femoral neck to help deliver the femur out of the wound. The iliopsoas and the femoral

insertion of the gluteus maximus tendon are usually taken down to ensure enough soft tissue tension is released to safely dislocate the femur without causing a fracture. A bone hook is placed underneath the femoral neck to lift the femoral head out of the socket instead of rotating through the leg to perform the dislocation.

Prior to removal of the femoral component, the surgeon should ensure enough space is cleared of soft tissue and bone laterally between the prosthesis and the greater trochanter to reduce the risk of femoral fracture during stem extraction. An extended trochanteric osteotomy is utilized if the stem cannot be removed easily. If a cemented stem is being revised, the cement is carefully removed with an osteotome, high-speed burr or ultrasonic device. If the cement plug is well fixed and is >2 cm from the tip of the planned revision stem, it need not be removed and can be left *in situ* to occlude the femoral canal distally.

Particulate allograft bone is the most common graft type utilized for impaction grafting. The structural support provided by the impacted graft depends on the size of the graft as well as how tightly the graft is packed at the time of revision surgery<sup>[8]</sup>. The optimal graft size and method of preparation is currently debated amongst surgeons. Commercially available bone mills typically produce graft sizes of 2 to 5 mm, however some published data suggests that larger sizes (7 to 10 mm) of graft material provide better stability<sup>[9]</sup>. Washing the graft prior to impaction removes fat and marrow contents, which theoretically improves the resistance to shear stresses and enhances frictional resistance providing a more mechanically stable environment to support the prosthesis and allow incorporation of the graft with host bone<sup>[10]</sup>. In general, smaller pieces of bone graft are impacted distally and larger ones used proximally at the time of reconstruction.

A continuous femoral tube must be confirmed intraoperatively before commencing with impaction of bone graft. This starts with assessing the size and location of femoral endosteal and cortical bone loss from preoperative radiographs. Areas of cortical bone destruction around the tip of the stem to be revised deserve close attention. These are frequently the site and cause of femoral fractures<sup>[4]</sup>, and the surgeon should attempt to bypass these defects by two cortical diameters at the time

of impaction grafting. Otherwise these areas should be reinforced with allograft struts or plate fixation. Fractures have occurred through these stress risers when reinforcement with only metal mesh or cerclage wires was performed<sup>[3]</sup>. Prophylactic cerclage wires should also be used liberally to reinforce weak areas of cortical bone.

A threaded distal intramedullary plug is placed 2 cm beyond the tip of the planned revision stem whose length and offset are determined from templating pre-operative radiographs. A central guidewire is screwed into the occlusion plug through which cannulated instruments are advanced to impact bone graft with a slotted mallet. The largest phantom (femoral stem shaped bone tamp) that passes through the canal without impinging distally with the appropriate offset is selected. Next, a series of distal impactors are chosen and marked according to the depth to which they should be advanced. Impaction of bone graft starts distally and advances proximally until the femur is backfilled to the mid-portion of the diaphysis. The phantom is then used to impact bone graft while being sure the desired amount of anteversion is reproduced with each sequential impaction. Graft impaction continues until there is enough axial and rotational stability of the phantom to allow a trail reduction. Metal mesh and cerclage wires are then used to reconstruct the proximal femur. The phantom is left in place and then larger bone graft pieces impacted around the phantom with proximal tamping instruments. The phantom should be difficult to remove at the conclusion of graft impaction and axial and rotational stability achieved.

The canal is then dried with a suction device that threads into the phantom and a collarless, polished, tapered femoral stem cemented in place. The distal aspect of the neomedullary tube takes the shape of a thin cone, which requires the cement to be inserted with a low enough viscosity to squeeze through a narrow tipped nozzle.

After the cementation is complete and the femoral head reduced, the wound is copiously irrigated and the short external rotators and hip capsule repaired back to the proximal femur through drill holes with a heavy non-absorbable braided suture.

Deep drains are utilized, and the incision is closed in layers in routine fashion.

## POST-OPERATIVE CARE

Total hip precautions are instituted after surgery and start with a hip abduction pillow placed between both lower extremities at the conclusion of the operation. Radiographs are taken shortly after surgery to assess whether there are any areas of cortical bone that may be deemed high risk for a post-operative fracture and to confirm there are no complications that would require early return to the operating room. Patients are frequently fitted for an abduction orthosis limiting hip flexion greater than 70 degrees to decrease torsional forces on the femoral stem and decrease the risk of implant loosening. The patient is

mobilized on the first post-operative day and is toe touch weight bearing for 6 wk followed by gradual advancement of weight bearing to tolerance.

If the indication for femoral impaction grafting is primarily to reconstitute cancellous bone loss and cortical bone is otherwise structurally intact, it is reasonable to allow weight bearing to tolerance in the acute peri-operative period. The hospital stay varies amongst different countries, but in the United States patients usually are discharged after 3 d. The patient returns for follow-up at 6 wk, 12 wk, 6 mo, 1 year and then every 2 years for clinical and radiographic surveillance.

## OUTCOMES

The long-term survivorship of the prosthesis depends on the success of graft incorporation. Ling *et al.*<sup>[11]</sup> performed histological analysis following post-mortem retrieval of revisions utilizing femoral impaction grafting. The authors described three zones of different cellular morphology and activity: A “deep zone” adjacent to the implant contained necrotic bone encased by cement, an “interface zone” consisted of osteoid in direct contact with methyl methacrylate and scattered giant cells. There was no evidence of viable mineralized bone in direct contact with cement in this zone. The “outer zone”, or regenerated cortical zone, was composed of normal cortical bone, fatty bone marrow and a few contained areas of dead bone.

Histology from biopsy specimens taken at multiple time points over a 4 year period from 19 patients who underwent revision surgery with femoral impaction grafting showed a cellular response characterized by infiltration of fibrous tissue into impacted bone graft with new peripherally located bone formation by one year. Reabsorption of bone graft however can take years to complete. Areas of necrotic bone were identified adjacent to well-fixed stems at 4 years from the time of revision surgery<sup>[12]</sup>.

Halliday *et al.*<sup>[4]</sup> reported 90.5% survivorship of 226 hips with re-operation as the end point with 10-11 year follow-up using the Universal Exeter stem in all cases. Femoral fracture was the most common indication for re-operation in this series. The authors reported 17 (7.5%) intra-operative femoral fractures. Eight of these were managed at the time of the initial procedure without requiring further surgery. The reported rate of revision for aseptic loosening for any cause after the initial procedure was 7%. The authors noted poor quality bone around the tip of the femoral stem probably predisposed some patients to femoral fractures. This led the group to modify their technique by using longer femoral stems for most revision cases and the development of instrumentation that permits impaction grafting along the entire length of the stem to bypass these inherently weak areas of femoral cortical bone.

Lamberton *et al.*<sup>[2]</sup> found a 84.2% 10 year survival rate in their cohort of 487 patients treated with femoral impaction grafting with revision for any reason as the

**Table 1** Summary of survivorship data and rates of complications for femoral impaction grafting

Ref.	No. of femoral impaction grafting cases	Average follow-up (yr)	Outcome measures	Survivorship	Rate of femoral fracture	Rate of infection
Lamberton <i>et al</i> <sup>[2]</sup>	540	10	Revision	84.2%	5.4%	3.9%
Schreurs <i>et al</i> <sup>[3]</sup>	33	10.4	Revision	100%	9%	0.0%
Halliday <i>et al</i> <sup>[4]</sup>	226	10	Re-operation	90.5%	7.5%	2.2%
Ornstein <i>et al</i> <sup>[13]</sup>	1305	15	Revision	94%	2.5%	1.4%
Wraighte <i>et al</i> <sup>[14]</sup>	75	10.5	Revision	92%	2.6%	1.3%
Sierra <i>et al</i> <sup>[15]</sup>	42	10	Re-operation	82%	4.7%	4.8%
Summary	2221	11	Re-operation (including revision)	90.5%	5.3%	2.3%

primary end-point. With aseptic loosening as the end-point, the 10-year survival rate was 98%. The most common intra-operative complication was perforation of the femoral shaft (8.5%). Other intra-operative complications included fracture of the greater trochanter (3.5%), calcar (5.9%) and femoral shaft (1.9%). The authors used supplemental fixation in the form of cerclage wires, cables, cortical strut allograft, metallic mesh or dynamic compression plating in 56% of the 540 revisions in their series of 487 patients. 36% of the 540 revisions required the use of 2 or more types of reinforcement to manage deficient bone stock to make impaction grafting feasible. The post-operative rate of femoral fracture was 5.4%.

A retrospective review of the Swedish National Joint Registry<sup>[13]</sup> revealed 1305 cases of femoral impaction grafting in 1188 patients with a mean age of 71 years at the time of revision surgery. Kaplan-Meier survivorship at 15 years was 94% considering all causes of failure. There was no difference in survivorship of the femoral component with respect to age or gender in the study group. The authors found centers where over 100 cases of femoral impaction grafting were performed had better outcomes. Interestingly, there was not difference in the rate of survivorship in revisions using a long stemmed femoral component over a shorter stem. The majority of complications requiring revision after the initial femoral impaction grafting procedure occurred within four years. Infection and femoral fracture were the most common complications (47.5%), while aseptic loosening (15.7%) and subsidence (18.6%) were also cited as causes of failure.

Wraighte *et al*<sup>[14]</sup> retrospectively reviewed 75 patients who were treated with femoral impaction grafting and reported a 92% survivorship with revision for any reason as the end-point with a mean follow-up of 10.5 years. Intra-operative fracture was associated with an increased risk of post-operative subsidence of the femoral component. The median subsidence of the femoral stem was 2 mm at 1 year and 10-year follow-up. Femurs with greater pre-operative bone loss were at higher risk of subsidence after impaction grafting. The data from the study group however showed no association between long-term clinical outcome and subsidence of the femoral component. Patients being re-revised for infection were more prone to complications than patients being managed for aseptic loosening with impaction grafting. The median Harris Hip score was 80.6 at the mean follow-up duration of 10.5 years and 88% of patients were either pain free or

reported only mild pain.

Sierra *et al*<sup>[15]</sup> retrospectively reviewed 567 cases of femoral impaction grafting from the Princess Elizabeth Orthopaedic Centre at Royal Devon and Exeter Hospital in Exeter, United Kingdom to determine the rate of post-operative periprosthetic fracture using a long stemmed (> 220 mm) femoral component. They established a cohort of 40 patients in whom 42 revisions were performed with a long stemmed femoral component and had a minimum follow-up of 5 years. The average age of their study group was 73.8 years. They found a substantial post-operative surgical complication rate of 33%, but only 2 of the 42 cases (4.7%) resulted in post-operative femoral fracture. The survival rate at 5 and 10 years with re-operation of the femur for any reason was 82%.

Schreurs *et al*<sup>[3]</sup> reported 100% survivorship of 33 femoral revisions managed with impaction grafting at a mean of 10.4 years with revision of the femoral component as the end-point. Three femoral fractures occurred post-operatively at three, six and twenty two months and successfully treated with open reduction and internal fixation. This decreased the survivorship to 85% at nine years with re-operation for any reason as the end-point. These fractures occurred at the tip of the stem where a segmental defect existed at the time of impaction grafting. In one case it was reinforced with metal mesh at the time of the initial procedure, and not reinforced in the other two. Two of the three post-operative fractures resulted from a fall and the other occurred unexpectedly. Three intra-operative complications resulted in femoral fracture that were not identified at the time of surgery, but successfully healed without an additional operation. Subsidence of the femoral stem within the cement mantle was common and averaged 3 mm over the case series. The largest change in stem position occurred within the first six months after impaction grafting. Interestingly, subsidence did not deleteriously affect Harris Hip scores. Seven patients with an average Harris Hip scores of 85 points, developed subsidence of the femoral stem within the cement mantle > 5 mm.

In conclusion, Femoral impaction grafting is primarily indicated for restoring bone stock in patients who require reconstruction of the femoral component, and for type IV femoral defects where the isthmus is not capable of supporting an implant that relies on biologic fixation. There are concerns about the risk of iatrogenic fracture both intra-operatively and post-operatively as well as

subsidence<sup>[16]</sup>. The procedure is technically challenging and time consuming. Femoral impaction grafting is not suitable for patients who are medically unable to tolerate a long procedure, or where an intact femoral tube cannot be restored. Despite the potential drawbacks of impaction grafting, this technique is associated with high survivorship rates at ten-year follow-up (Table 1), and represents a viable option when an extensively porous coated stem cannot be used.

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Quanjun Cui, MD, Series Editor

## Anterior muscle sparing approach for total hip arthroplasty

Joseph T Moskal, Susan G Capps, John A Scanelli

Joseph T Moskal, Virginia Tech Carilion School of Medicine, 3 Riverside Circle, Roanoke, WV 24016, United States

Susan G Capps, Bensol-Biologic Engineering Solutions, Warsaw, IN 46582, United States

John A Scanelli, Department of Orthopedic Surgery, University of Virginia School of Medicine, Charlottesville, VA 22908, United States

**Author contributions:** Moskal JT contributed to background research, formulation of manuscript, revision of manuscript, selecting of images, oversight/guidance, final approval of manuscript; Capps SG contributed to background research, formulation of manuscript, revision of manuscript, procurement and management of images, final approval of manuscript; Scanelli JA contributed to background research, formulation of manuscript, revision of manuscript, procurement and management of images, final approval of manuscript.

**Correspondence to:** Joseph T Moskal, MD, Virginia Tech Carilion School of Medicine, 3 Riverside Circle, Roanoke, VA 24016, United States. [jmoskal@carilionclinic.org](mailto:jmoskal@carilionclinic.org)

Telephone: +1-540-5261472 Fax: +1-540-9838211

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### Abstract

The purpose of this review is to examine the validity of positive claims regarding the direct anterior approach (DAA) with a fracture table for total hip arthroplasty. Recent literature regarding the DAA was searched and specific claims investigated including improved early outcomes, speed of recovery, component placement, dislocation rates, and complication rates. Recent literature is positive regarding the effects of total hip arthroplasty with the anterior approach. While the data is not definitive at present, patients receiving the anterior approach for total hip arthroplasty tend to recover more quickly and have improved early outcomes. Component placement with the anterior approach is more often in the "safe zone" than with other approaches. Dislocation rates tend to be less than 1% with the anterior approach. Complication rates vary widely in the published literature. A possible explanation is that the variance

is due to surgeon and institutional experience with the anterior approach procedure. Concerns remain regarding the "learning curve" for both surgeons and institutions. In conclusion, it is not a matter of should this approach be used, but how should it be implemented.

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**Key words:** Total hip arthroplasty; Anterior approach; Hip; Arthritis; Joint replacement

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### INTRODUCTION

The direct anterior approach (DAA) for total hip arthroplasty was first described by Judet<sup>[1]</sup> in 1947, and recently popularized in North America by Matta *et al*<sup>[2,3]</sup>. It is attractive to patients and surgeons because of its muscle sparing approach, which allows for a faster recovery<sup>[4,5]</sup>, less pain after surgery<sup>[6]</sup>, and post-operative hip precautions are not necessary<sup>[7]</sup>. It can be performed on a standard operating table or with the use of a specialized orthopedic table that facilitates femoral exposure. The patient is positioned supine, which allows for accurate assessment of leg lengths intra-operatively. Fluoroscopy and computer navigation can also be utilized to provide real time information about component position during surgery.

The surgeon's level of experience with the approach does directly correlate with complication rates until reaching a plateau after the first 40-100 cases<sup>[8-10]</sup>. The low rate of dislocation consistently reported using the DAA for total hip arthroplasty<sup>[2,11]</sup> is a testament to the accuracy of component placement, as well as the preservation of important soft tissue structures that confer hip stability.

### Advantages and disadvantages of the approach

The DAA is applicable for both primary<sup>[5]</sup> and revision total hip arthroplasty<sup>[12]</sup>. Bilateral hip replacement can easily be performed without re-positioning the patient. Achieving adequate femoral exposure is the most technically challenging aspect of the DAA for surgeons new to the technique.

There are some anatomic features of the native hip and pelvis that make the DAA more difficult, and all surgeons who desire to utilize this approach for total hip arthroplasty should be mindful of these morphologies. A wide or horizontal iliac wing can limit access to the femoral canal for broaching and placement of the femoral component. Acetabular protrusion brings the femoral canal closer to the center of the pelvis, which can obstruct access to the femur. A high neck shaft angle with decreased offset positions the femoral canal deeper in the thigh. Obese muscular males can limit the space available to place the components, and it takes considerable knowledge of how to position retractors as well as the leg in three-dimensional space to achieve enough exposure to do this accurately. A straight impactor that attaches to the acetabular component often impinges against the large muscular thigh distally, which can lead to more vertical and anteverted placement of the cup. An offset inserter is helpful in this situation. These are all technical aspects of the procedure that surgeons early in the learning curve are advised to consider in their patient selection process. Patients with a previous acetabular fracture associated with posterior heterotopic ossification, which requires excision, and when extensive exposure of the posterior acetabulum/column is necessary to address large posterior acetabular defects are relative contraindications<sup>[5]</sup>.

Mast *et al.*<sup>[12]</sup> described their operative experience in 51 patients with an average follow-up of 4.5 years using the DAA for revision total hip arthroplasty with an orthopedic table. When performing isolated acetabular liner exchange, cup revision or conversion of hip resurfacing to THA, the authors were able to perform these surgeries without proximal or distal extension of the standard approach.

### CONTRAINDICATIONS

Mast *et al.*<sup>[12]</sup> identify three scenarios that highlight the limitations of the anterior approach in revision surgery: (1) revision of long, extensively porous-coated femoral stems; (2) managing severe proximal bone loss or osteolysis; and (3) revision of a femoral stem with significant retroversion. It is worth pointing out that each of these three limitations involves the femoral exposure. Complications in this case series included loosening of the acetabular component (4%), heterotopic bone formation (2%), limb-length inequality (2%), trochanteric fracture (2%), with a reported complication rate of 9.8%. Interestingly, they reported no dislocations after revision surgery with a mean follow-up of 4.5 years.

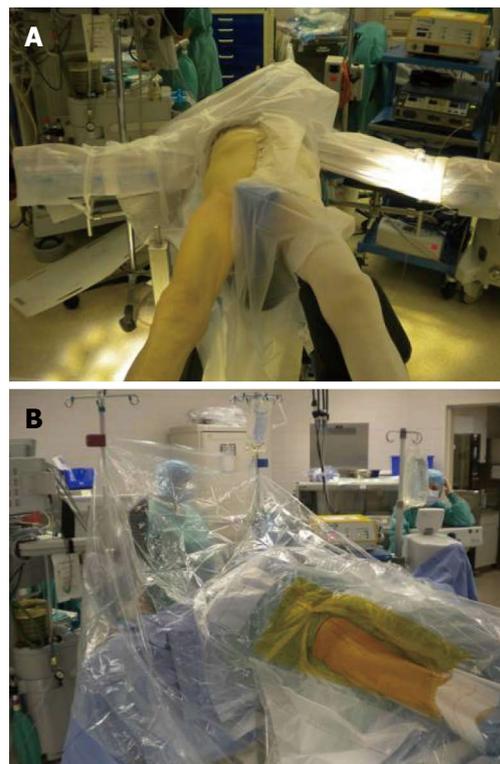


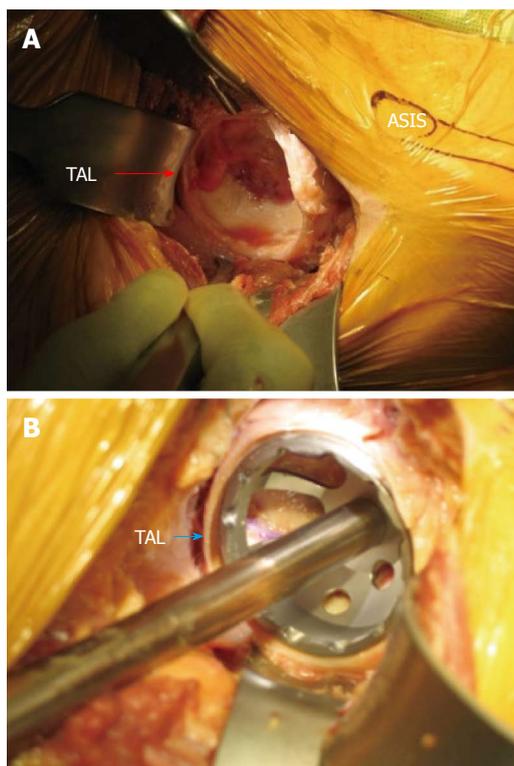
Figure 1 Patient positioned supine on a specialized orthopedic table (A) with the operative leg prepped and draped (B).

### SURGICAL TECHNIQUE

The surgeon can use a regular operating table or an orthopedic table designed to facilitate femoral exposure. The surgical technique described is with the use of an orthopedic table. The operative team consists of the surgeon, a single scrubbed assistant that stands on the opposite side of the table, a scrub nurse, a circulating nurse and the anesthesiologist. The patient is positioned supine on the operating table between a perineal post, which affords the benefit of being able to expeditiously utilize intra-operative fluoroscopy or computer navigation to assess leg lengths and ensure optimum placement of the components before leaving the operating room. Both feet are placed in boots that lock into a mobile spar that allows the leg to be positioned and rotated in any direction during the procedure. The original Judet orthopedic table has been modified to include a bracket that parallels the operative leg and supports a femoral hook, which holds the femur in an elevated position when broaching the canal. The operative extremity is draped from the iliac crest to the knee (Figure 1).

### ACETABULAR EXPOSURE

The proximal aspect of the incision is marked 2-3 cm posterior and 1-2 cm distal from the anterior superior iliac spine, and extends distally in line with and over the tensor fascia lata muscle belly. The incision is placed laterally to the interval between the tensor fascia muscle and



**Figure 2 Acetabular exposure.** A: Acetabular exposure with the direct anterior approach; B: Acetabular exposure using the direct anterior approach with trial component in place. The transverse acetabular ligament (TAL) is clearly identified by arrow. ASIS: Anterior superior iliac spine.

the sartorius to minimize the risk of lateral femoral cutaneous nerve injury. By developing the interval within the tensor fascia, the lateral femoral cutaneous nerve remains medial to the sartorial fascia and is avoided in the superficial dissection.

The skin and subcutaneous tissues are dissected down to the translucent fascia over the tensor, where two or three perforating blood vessels are encountered. The fascia is then incised in line with the muscle just anterior to these perforating vessels. An Alice clamp is attached to the medial aspect of the fascial incision and provides counter traction as the surgeon uses his finger to bluntly sweep the tensor muscle off the sartorial fascia.

A blunt cobra retractor is placed over the superior lateral aspect of the femoral neck which enhances the interval exposure between the tensor muscle and gluteus medius laterally and the sartorial and rectus fascia medially. The lateral femoral circumflex vessels are found within this interval encased in a layer of fat in the middle of the wound. They are carefully dissected and cauterized, or tied off and transected, as bleeding from these vessels can be profuse and difficult to control if they retract. A Cobb elevator is then used to mobilize the indirect head of the rectus off the capsule at the base of the neck followed by placement of a second cobra retractor along the inferior medial portion of the femoral neck. A double bent homan retractor is then slid perpendicular to the inguinal ligament directly above the capsule and along



**Figure 3** The supine position of the patient on the operating table facilitates the use of fluoroscopy during surgery to assess component position and alignment.



**Figure 4** Exposure following femoral neck osteotomy with the direct anterior approach using a specialized orthopedic table.

the acetabulum (Figure 2).

The hip capsule is then incised as an inverted “T” parallel to the lateral aspect of the intertrochanteric line along the lateral portion of the femoral neck and extended medially along the inferior portion of the femoral neck. The capsule is tagged with non-absorbable suture and repaired at the conclusion of the case. This capsular closure provides an additional layer of soft tissue to theoretically minimize the risk of deep infection. Alternatively the capsule may also be excised.

A hip skid is then slid between the femoral head and the acetabulum to break up any adhesions to facilitate an atraumatic dislocation of the femoral head. The femoral neck cut is made in one of three ways: (1) with the hip reduced; (2) a “napkin ring” segment of bone is created and removed by making two parallel neck cuts which leaves a smaller segment of the femoral head; or (3) after dislocating the femoral head. After dislocation fixed bony landmarks such as the superior aspect of the femoral head or the lesser trochanter are used to determine the desired level of femoral neck resection. A corkscrew with a removable handle is placed in the femoral head prior to making the femoral neck cut. The corkscrew will allow the surgeon to remove the femoral head in a controlled fashion without damaging the tensor muscle with the

residual sharp spike of bone created by the distal end of the osteotomy. These steps allow expeditious removal of the femoral head after the neck cut. The femur is then externally rotated approximately 20 to 45 degrees, with slight adduction and flexion of the leg which enhances the exposure of the acetabulum for reaming and placement of the cup. Fluoroscopy and computer navigation can be used at this point to assess the placement of the socket, and adjustments made to component orientation if necessary (Figure 3).

## FEMORAL EXPOSURE

After the acetabular component is seated, any traction on the operative leg is released and the femur is rotated back to a neutral position. If a femoral hook is used to assist with femoral exposure, it should be placed just distal and posterior to the vastus ridge. It should slide in easily and without resistance superficial to the vastus lateralis. The leg is then externally rotated so the calcar is facing directly anterior and the greater trochanter posterior. The operative leg is then positioned so the hip is extended 25-30 degrees by bringing the foot to the floor, and then maximally adducted. The surgeon laterally displaces the proximal femur and manually lifts the femoral hook to elevate the femur and uses a foot pedal to bring the motorized bracket arm up to dock the hook. If the surgeon attempts to elevate the femur by only using the motorized bracket arm with the hook in place, the femur can easily fracture.

The key to obtaining femoral exposure is performing sequential capsular and soft tissue releases along the medial aspect of the greater trochanter and femoral neck under tension (Figure 4). This ultimately allows the greater trochanter to clear the posterior wall of the acetabulum. With the operative leg hyper-extended and adducted, a long curved homan retractor is placed behind the greater trochanter to sufficiently tension these soft tissue attachments. This allows the surgeon to see and feel the femur move with each structure that is released. The goal is to release the minimum amount of soft tissue attachments to translate the femur laterally and elevate it up and out of the wound. The capsule is the first structure taken down with electrocautery, followed by the piriformis, the gemelli and the obturator internus until sufficient exposure is achieved. Preserving the obturator externus is important for maintaining hip stability and should not be released unless necessary as this effects the most direct medial pull of the femur to the pelvis.

Offset broach handles and occasional use of flexible reamers facilitate preparation of the femur and placement of the final femoral component. Fluoroscopy and computer navigation are again optional (Figure 3). They allow the surgeon additional information to intra-operatively assess the center of rotation, offset, leg lengths, femoral stem alignment, and fit within the canal.

The hip is reduced and can be checked for stability and component impingement. If the approach is per-

formed with the utilization of a special table, lowering the foot to the floor and then adducting and externally rotating the operative leg can check anterior stability. Simply unhooking the boot from the mobile spar allows the surgeon to assess posterior stability and impingement.

The wound is copiously irrigated, the capsule re-approximated with heavy non-absorbable braided suture, and a deep drain drain is placed. The fascia of the tensor fascia lata muscle is closed with a running suture, and the subcutaneous and subcuticular layer closed with interrupted and a running 3-0 monocryl suture.

## POST-OPERATIVE CARE

Patients are mobilized the day of surgery and post-operative hip precautions are not necessary. Post-operative pain and narcotic use is often significantly less compared to other surgical approaches for total hip arthroplasty<sup>[6]</sup>. Patients are more frequently discharged to home instead of extended care facilities, thus further decreasing the time of exposure to harmful pathogens<sup>[13]</sup>. The length of time in the hospital after total hip arthroplasty is significantly less in some European countries with the DAA<sup>[6,13]</sup>.

If the patient has a pendulous abdomen that rests on the incision, precautionary steps are taken to minimize prolonged moisture on the incision. The senior author (Moskal JT) applies an abdominal binder at the conclusion of the case for patients with a pendulous abdomen to keep the pannus from resting on the incision until it has healed. Keeping the inguinal crease clean, dry and the incision covered with a sterile bandage also minimizes the risk of post-operative infection.

In a large prospective series, the average time to discontinuing the use of a cane or walker was 21 d, with 80% of patients discontinuing ambulatory assist devices by 7.6 d<sup>[11]</sup>. Gait analysis studies show quicker recovery of motor function for the DAA compared to other surgical exposures<sup>[14]</sup>. The patient returns for follow-up at 2 wk, 6 wk, 1 year, and then every 2 years for routine clinical and radiographic surveillance.

## OUTCOMES

The literature, in general, makes numerous positive claims regarding the DAA with a fracture table for total hip arthroplasty including quicker recovery and return to unassisted ambulation, and reduced soft tissue damage, surgery time, pain, and risk of dislocation with early elimination of hip precautions<sup>[4,5,8,11,15,16]</sup>.

In 2004, Sculco<sup>[15]</sup> wrote an early review of less extensive THA surgery. Sculco<sup>[15]</sup> stated in his review of minimally invasive total hip arthroplasty, "The rationale for performing hip arthroplasty through a less extensive exposure is to reduce hospital stay, speedy recovery, decrease surgical trauma. Certainly patients are happier with a smaller incision, and recovery is faster." As less invasive THA continues to evolve, it is important to consider patient satisfaction and the speed at which they recover is a

critical factor in their satisfaction and their return to normal activities of daily living.

The benefits of the anterior approach are mostly accrued from “muscle preservation” rather than the more traditional “muscle splitting” approaches<sup>[2,4,5,9,17-19]</sup>. Various authors have contributed to the literature focused on the mini-incision anterior approach, numerous aspects of this surgical technique are discussed: early outcomes and speed of recovery<sup>[4,5,9,14,17,20-22]</sup>, component placement<sup>[2,4]</sup>, dislocation rates<sup>[2,11,18,22-24]</sup>, complication rates<sup>[2,4,9,11,21-23]</sup>, and the impact of surgeon experience with this technique<sup>[2,4,9,11,22-25]</sup>.

### Early outcomes and speed of recovery

There are many ways to measure the early outcomes of THA and the speed of recovery from the surgery, such as time to full weight bearing, incidence of limping, biochemical muscle recovery, gait variables, range of motion, and traditional clinical measures<sup>[4,5,9,14,17,20-22]</sup>.

In 2004, Siguier *et al.*<sup>[22]</sup> reported that all patients were able to full weight bear within two days postoperatively and that most patients were able to discontinue walking aids within 8 d to 3 wk of surgery. There were no cases of limping secondary to gluteus medius insufficiency because the buttock muscles and greater trochanter were not affected by the surgical approach.

In an early investigational study, Pilot *et al.*<sup>[17]</sup> were concerned with specific indicators of muscle recovery following anterior approach THA. They found no significant difference in inflammation as measured by interleukin-6 levels, in muscle damage as measured by heart type fatty acid binding protein, or in hemoglobin levels when comparing the mini-incision anterior approach with the standard posterolateral approach for THA (10 subjects in each group). Although they speculate that the term minimally invasive surgery is “at least doubtful in terms of being less traumatic” that there were no significant negative outcomes in terms of muscle recovery with minimally invasive surgery using the anterior approach.

In a very recent study, Bergin *et al.*<sup>[19]</sup> reported the extent of muscle damage from the limited incision anterior approach ( $n = 29$ ) as compared to the standard incision posterior approach ( $n = 28$ ). The biochemical markers of inflammation, serum creatine kinase, C-reactive protein, interleukin-6, interleukin-1 beat, and tumor necrosis factor-alpha, were in general lower in the anterior approach group from post-surgery through post-operative day 2. The rise in creatine kinase was 5.5 times greater in the posterior approach group than in the anterior approach group post-surgery ( $P < 0.05$ ) and nearly twice as high over the measurement period ( $P < 0.05$ ). Serum creatine kinase levels indicated that the anterior approach causes significantly less muscle damage than the posterior approach<sup>[19]</sup>.

Roth *et al.*<sup>[21]</sup> looked at the early outcomes for 195 THA using the anterior approach in the supine position and found early restoration of full weight bearing and range of motion.

In a kinematic study comparing the DAA and the traditional anterolateral approach, Mayr *et al.*<sup>[14]</sup> found that both gait and total range of motion were better with the DAA. Gait was improved in more categories than with the traditional anterolateral approach, including: significant improvement in cadence, stride time, stride length, walking speed, hip flexion at foot contact, maximum hip flexion in swing.

Nakata *et al.*<sup>[4]</sup> compared the DAA and the mini-posterior approach in one of the few articles reporting on two different minimally invasive procedures. They found more rapid recovery of hip function and gait ability with the DAA. In the same year, Seng *et al.*<sup>[9]</sup> also reported an earlier recovery and return to activities of daily living with the anterior approach.

In a more recent study, Klausmeier *et al.*<sup>[20]</sup> compared the anterior approach with the anterolateral approach and a control group that did not have THA, their focus was the short term recovery of hip strength and motion. Hip abductor strength was lower in both of the THA groups when compared with the control group preoperatively, at six weeks, and at 16 wk. At 6 wk, the late stance peak abductor moment was not significantly different between the anterior approach and the control group; this measure was significantly lower for the anterolateral group. While the authors found no difference between the two approaches with regards to speed of recovery, or isometric strength and dynamic gait measures at six and sixteen weeks, the anterior approach was associated with improved gait velocity and peak flexor moment at 6 wk<sup>[20]</sup>.

Most studies do not evaluate the differences in standard clinical measures such as Harris Hip Scores, SF-36, WOMAC, and VAS energy, daily activities, or overall quality, however Restrepo *et al.*<sup>[5]</sup> did in 2010. In a study comparing the single-incision-modified Smith-Peterson anterior approach and the direct lateral approach, the outcomes using validated measures were found to be were significantly better for the anterior approach group at 6 wk, 6 mo, and 12 mo<sup>[5]</sup>.

Other studies that reported on these factors consistently found that the anterior approach provided for faster recovery and improved early outcomes when employing the anterior approach<sup>[4,5,9,14,17,21,22]</sup>.

### Component placement

Component placement is an important factor in the success of THA, two sources reported on this outcome using the anterior approach<sup>[2,4]</sup>. Matta *et al.*<sup>[2]</sup> had “safe zone” placement rates for the acetabular component; 96.07% (440 of 458 THA) in safe zone abduction angle and 93.01% (426 of 458 THA) in safe zone anteversion angle. Nakata *et al.*<sup>[4]</sup> stated that significantly more acetabular components were placed in “safe zones” with DAA (98 of 99 THA, 98.99%) as compared to the mini-posterior approach (87 of 96 THA, 90.63%) ( $P = 0.008$ ).

### Dislocation rates

Dislocation rates are a common and useful metric when

discussing THA, 8 studies discuss the dislocation rate using the anterior approach<sup>[2,4,9,11,21-23,25]</sup>. Of the 5801 THA reported in these studies, there were 55 dislocations (0.95%). Dislocation risk tends to be less than 1.0%, excepting for the rate reported by Sariali *et al*<sup>[18]</sup> (1.53%).

### Complication rates

Various complications were reported: total complications, nerve related complications, and fractures (dislocation reported above)<sup>[2,4,9,11,21-23,25]</sup>. The overall complication rates ranged from 2.03% to 15.79%<sup>[22,24]</sup>. The two highest rates of overall complications, 15.79% and 15.63%, were in studies focused on complication rates with anterior THA using fracture tables<sup>[23,24]</sup>. The overall complication rate from aggregated data was 7.74% (320 of 4136 THA)<sup>[2,4,9,11,22,24]</sup>.

The rate of nerve related complications was reported to range from 0.00% to 14.81%<sup>[21,25]</sup>. Most rates of nerve related complications were less than 2%; the rate reported by Bhargava *et al*<sup>[25]</sup> was clearly much higher than the others, possibly due to this study being focused on nerve related complications<sup>[2,4,11,19,21,22,24]</sup>.

The rate of fracture complications ranged from 0.10% to 7.29%<sup>[22,24]</sup>. Most complication rates were less than 3%; the rate reported by Woolson *et al*<sup>[24]</sup> came from a study of complications in a community hospital and may have been influenced by the setting and surgeon experience<sup>[2,4,11,19,21-23]</sup>.

### Impact of surgeon experience with this technique

The level of experience that an orthopaedic surgeon has with any new technique clearly impacts the successful execution of that technique; various authors have reiterated this with regards to the DAA using a fracture table<sup>[4,9,11,23-25]</sup>. Jewett *et al*<sup>[23]</sup> and Woolson *et al*<sup>[24]</sup> found disturbingly high rates of complications with this technique when performed by surgeons still in the “learning curve.” When Woolson *et al*<sup>[24]</sup> examined outcomes associated with the early experience of four community surgeons; the series was only of the early cases. Jewett *et al*<sup>[23]</sup> examined the complication rates for the first 800 cases performed using this technique and found that after the first 400 cases, intraoperative complications such as fracture no longer occurred. Bhargava *et al*<sup>[25]</sup> noted that the incidence of nerve impairment decreases as surgeon experience increases.

Two studies attempted to quantify the “learning curve” for the DAA using a fracture table<sup>[9,11]</sup>. Bhandari *et al*<sup>[11]</sup> found a clear decline in complications after the first 100 cases were performed by creating subgroups for analysis, one group contained surgeons with less than 100 cases and the other group contained surgeons with over 100 cases. Surgeons who had performed less than 100 cases had complication rates double that of more experienced surgeons<sup>[11]</sup>. Seng *et al*<sup>[9]</sup> sought to define the learning curve for joint arthroplasty surgeons in high volume practices. After six months and 57 cases, over 50% of DAA THA were performed comfortably and surgical time and intraoperative blood loss decreased<sup>[9]</sup>.

## CONCLUSION

What are the benefits of the anterior approach? In contrast to muscle-splitting approaches such as the direct lateral approach, the anterolateral approach, or the posterior approaches, the anterior approach is a muscle-sparing procedure thus no muscles are cut or detached. Muscle-splitting approaches require the cutting and detachment of soft tissues. This in turn disturbs the natural dynamic stabilization of the hip and makes it impossible for the hip to function normally until those structures have healed. Therefore, with muscle-splitting approaches, patients require at least six weeks of muscle healing plus additional time and rehabilitation effort to recover lost muscle strength. In short, patients must recover from both the surgical approach and the hip arthroplasty. Additionally, restrictions are required regarding patient movement and weightbearing to allow the soft tissues adequate time to heal.

In contrast to muscle-splitting approaches, with a muscle-sparing procedure, such as the DAA, no muscles are cut or detached. The patient must recover/heal from the surgical procedure only, not the approach. Recovery requires no additional time for healing of the muscle sleeve or its attachment, thus patients recover more quickly and may rehabilitate without restrictions. Experience suggests that patients benefit from a quicker recovery and elimination of postoperative restrictions, particularly younger and/or more active patients who need to return to work or return to other activities without restriction.

As more studies regarding the anterior approach for total hip arthroplasty are published, it becomes clearer that this approach does present distinct benefits for patient focused outcomes. However, there are concerns when incorporating new techniques into surgical practice; these often create a “learning curve” and unforeseen technical complications.

In conclusion, the DAA is a muscle-sparing approach with a quicker rehabilitation because the recovery is faster since the patients need only to recover from the procedure and not the approach. The question is not whether the orthopaedic community will embrace this technique but rather how should it be introduced into routine practice.

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## Access related complications during anterior exposure of the lumbar spine

Gary A Fantini, Abhijit Y Pawar

Gary A Fantini, Abhijit Y Pawar, Spinal Surgical Service, Department of Orthopaedic Surgery, Hospital for Special Surgery and Weill Cornell Medical College, New York, NY 10021, United States

**Author contributions:** Both authors contributed to conception and design of review material, drafting and/or critically revising the article, and final approval of the version to be published.

**Correspondence to:** Gary A Fantini, MD, Spinal Surgical Service, Department of Orthopaedic Surgery, Hospital for Special Surgery and Weill Cornell Medical College, New York, NY 10021, United States. [gaf@newyorkphysicians.com](mailto:gaf@newyorkphysicians.com)

Telephone: +1-212-3174550 Fax: +1-212-7522454

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### Abstract

The new millennium has witnessed the emergence of minimally invasive, non-posterior based surgery of the lumbar spine, in particular *via* lateral based methodologies to discectomy and fusion. In contrast, and perhaps for a variety of reasons, anterior motion preservation (non-fusion) technologies are playing a comparatively lesser, though incompletely defined, role at present. Lateral based motion preservation technologies await definition of their eventual role in the armamentarium of minimally invasive surgical therapies of the lumbar spine. While injury to the major vascular structures remains the most serious and feared complication of the anterior approach, this occurrence has been nearly eliminated by the use of lateral based approaches for discectomy and fusion cephalad to L5-S1. Whether anterior or lateral based, non-posterior approaches to the lumbar spine share certain access related pitfalls and complications, including damage to the urologic and neurologic structures, as well as gastrointestinal and abdominal wall issues. This review will focus on the recognition, management and prevention of these anterior and lateral access related complications.

### INTRODUCTION

Anterior spinal access is often required for the treatment of spinal deformity, bony and/or discogenic infection, trauma, tumor and degenerative disease. Advantages of this approach include performance of a thorough discectomy and release, capability to implant high profile interbody fusion and non-fusion devices, debridement and excision of necrotic tissue, removal of migrated/misplaced devices, and a favorable milieu for interbody fusion with rich blood supply and graft/device placement under compression. The most common associated complications include damage to the vascular, urologic and neurologic structures, as well as gastrointestinal and abdominal wall issues.

### VASCULAR INJURY

Anterior exposure of the spine at the L4-L5 and L5-S1 levels requires mobilization of the left common iliac vessels, as they course obliquely across the anterior aspect of the L5 body, traversing variable portions of the L4-L5 and L5-S1 disc spaces in the process. The most dorsally located, the left common iliac vein is the most likely vascular structure to be injured during anterior lumbar spinal surgery. Apart from intraoperative hemorrhage and the challenge associated with vascular control and repair,

**Table 1** Reported incidence of major vascular injury during anterior spinal surgery *n* (%)

Ref.	Year	<i>n</i>	Arterial injury	Venous injury
Fantini <i>et al</i> <sup>[1]</sup>	2007	345	1 (0.3)	9 (2.6)
Brau <i>et al</i> <sup>[2]</sup>	2004	1315	6 (0.5)	19 (1.4)
Kulkarni <i>et al</i> <sup>[3]</sup>	2003	336	8 (2.4)	NA
Gumbs <i>et al</i> <sup>[4]</sup>	2005	64	0	2 (3.1)
Fritzell <i>et al</i> <sup>[5]</sup>	2003	72	0	2 (3.7)
Holt <i>et al</i> <sup>[6]</sup>	2003	450	0	7 (1.6)
Kaiser <i>et al</i> <sup>[7]</sup>	2002	98	0	3 (3.1)
Oskouian <i>et al</i> <sup>[8]</sup>	2002	207	2 (0.9)	7 (3.4)
Kuslich <i>et al</i> <sup>[9]</sup>	1998	591	0	10 (1.7)

NA: Not available.

thrombotic occlusion may occur in the postoperative period following seemingly uncomplicated iliac venorrhaphy, or simply as a result of prolonged retraction of the iliac vein or inferior vena cava. The ascending iliolumbar vein acts as an important dorsolateral tether to the left common iliac vein, therefore routine ligation and division will facilitate anterior exposure of the L4-L5 disc space<sup>[1]</sup>. Similarly, ligation and division of the L4 segmental vessels will release the aortic terminus and the terminal inferior vena cava (IVC), thus permitting retraction to the right side of the spine, further facilitating anterior exposure of the L4-L5 disc space. Previous osteomyelitis/discogenic infection, previous anterior spinal surgery, spondylolisthesis, osteophyte formation, transitional lumbosacral vertebra and anterior migration of interbody device have been identified as risk factors for injury to the major vascular structures during anterior spinal surgery<sup>[1]</sup>. With the sole exception of transitional anatomy, the identified conditions share the underlying pathogenesis of inflammation of the annular and pre-vertebral soft tissues, as well as of the periosteum, thereby limiting mobility of the overlying vascular structures. The vast majority of major vascular injuries to the great vessels of the abdomen occur during attempts at anterior exposure of L4-L5 and L5-S1.

The reported incidence of significant venous injury is in the 2%-4% range (Table 1). Arterial thrombosis occurs in less than 1% of cases, and is typically associated with fixed retraction of the large vessels, either *via* a table mounted mechanical system<sup>[2]</sup> or through Steinman pins placed directly into the vertebral body<sup>[3]</sup>. Although we do use a table mounted mechanical retractor system, the major vascular structures are manipulated only through the use of hand held retractors, with release of traction at regular intervals of no longer than fifteen minutes. In addition, attempts to mobilize heavily calcified vessels should be tempered, as loss of normal elasticity and recoil will predispose to plaque fracture and arterial thrombosis.

The use of lateral based approaches for discectomy and fusion of the lumbar spine cephalad to L5-S1 has nearly eliminated the occurrence of great vessel injury. That said, it is not uncommon to encounter the aforementioned ascending iliolumbar vein during performance

of a lateral based approach to the L4-L5 disc from the left. In this setting, ligation and division of the ascending iliolumbar vein in controlled fashion is the preferred approach.

### Principles of venous repair

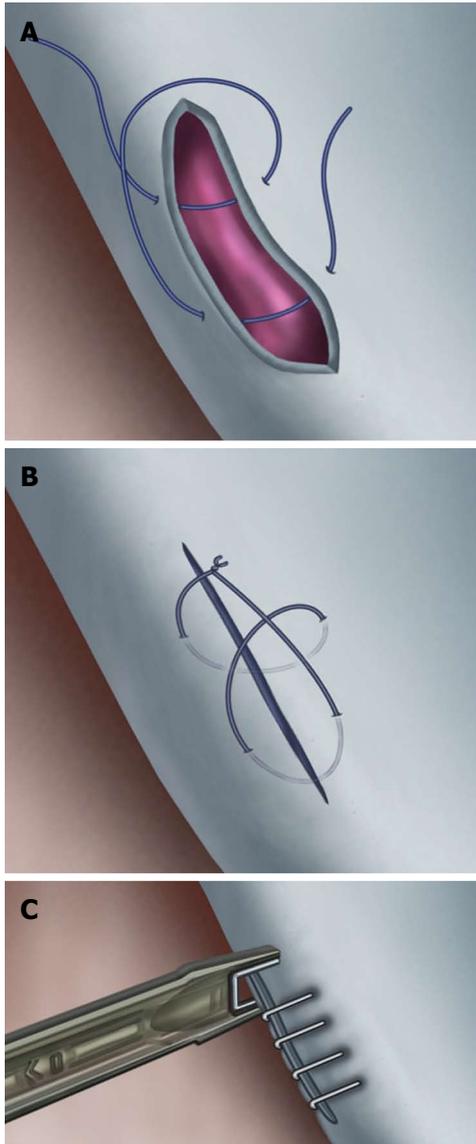
Initial maneuvers following recognition of injury to a major venous structure (e.g., iliac vein or vena cava) are of critical importance and may very well determine outcome. Aggressive use of suction and/or traction at the venotomy site, prior to gaining control, can cause further damage to the injured vessel and must be avoided. Trendelenburg's position should be utilized. Control of hemorrhage should be obtained with compression proximal and distal to venotomy, typically through the use of Kitner peanut dissectors and/or sponge-sticks. Wylie renal vein retractors may also prove useful in this regard. No attempt to encircle the iliac vein or to apply vascular clamps should be made, as this will generally result in further venous disruption and increased bleeding. Once adequate visualization of the venotomy has been obtained, primary repair with 5-0 prolene suture on a cardiovascular needle may be carried out (Figure 1). Should a minimal access incision not permit formal suturing and tying, vascular clips may be placed at right angles to the long axis of the vessel in "railroad track" fashion (Figure 1C). Recent experience with endovascular repair of the left common iliac vein with a covered stent suggests that this will be a viable methodology as this technology becomes more widely available<sup>[10]</sup>. Topical hemostatic agents including Gelfoam® (Pfizer, New York, NY), Surgicel® Fibrillar™ and Surgiflo® (Ethicon, Somerville, NJ), and Tisseel (Baxter, Deerfield, IL) are important adjuncts to direct repair, and in many instances can be effective as the sole method of hemostasis.

### Postoperative surveillance for iliac vein thrombosis

Successful repair of seemingly minor injuries of the iliac vein can result in thrombosis in the postoperative period. Remarkably, manifestations of leg swelling may not be readily apparent in the setting of bed rest and limited ambulation. Venous duplex scanning is notoriously unreliable in detecting thrombosis cephalad to the inguinal ligament. For this reason, iliac venous imaging by computed tomographic angiography (CTA) or magnetic resonance venography is performed routinely following iliac venous repair<sup>[1]</sup>. Detection of iliac vein thrombosis in the early postoperative period typically mandates placement of a vena caval filter, as anticoagulation is generally not an option.

### Management of arterial injury

As noted above, arterial complications can be minimized by avoiding the use of fixed retraction systems on the large vessels, and by limiting the degree of arterial mobilization in the setting of heavy vessel calcification. Arterial hemorrhage can be managed with traditional lateral suture repair, applying vascular clamps above and below



**Figure 1** Lateral repair of iliac vein with 5-0 prolene suture placed in figure-of-eight fashion (A, B) and vascular clips placed in "railroad track" fashion (C).

the arteriotomy if necessary. Arterial thrombosis can be a more difficult problem in the patient with atherosclerotic disease. Continuous pulse oximetry of the lower extremity ipsilateral to the site of arterial retraction, typically the left, is a useful monitor to employ routinely. Management by catheter thrombectomy and repair of the culprit lesion, sometimes requiring adjunct methods of endarterectomy or bypass, will be required. Consideration to leg fasciotomy should be given, depending upon the degree and duration of extremity ischemia.

## UROLOGIC INJURY

Blood supply to the ureter is segmental in nature, and as such, no attempt to skeletonize the ureter should be made. Rather, the ureter should be rotated medially along with the visceral sac. Incidence of ureteral injury dur-

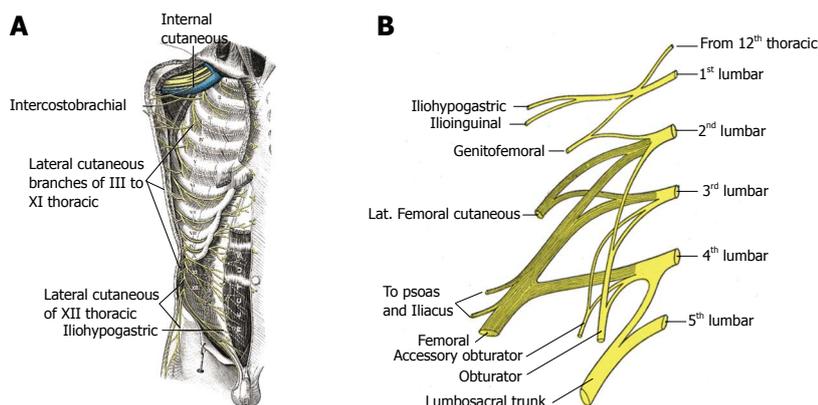
ing primary retroperitoneal exposure is exceedingly low, though has been reported<sup>[4]</sup>. In contrast, the ureter is at significant risk of injury during revision anterior spinal surgery. This is especially true in the setting of removal of anterior instrumentation, as the ureter may be encased in scar tissue immediately overlying the instrumentation. In this instance, delayed images taken during preoperative CTA will delineate the course of the ureters, and typically signal the need for ipsilateral ureteral stent placement. In addition, methylene blue is administered intravenously on a routine basis at the start of the revision anterior procedure.

## Retrograde ejaculation

The sympathetic fibers of the hypogastric plexus are adherent to the posterior surface of the peritoneum at the level of L5-S1, thus further emphasizing the importance of *en bloc* mobilization of the visceral sac. Avoidance of electrical and/or thermal injury to the hypogastric plexus can be achieved by using a scalpel for the annulotomy and by using bipolar electrocautery sparingly and only as absolutely necessary. Modern series have reported low incidences of retrograde ejaculation. The ProDisc<sup>®</sup> (Synthes, West Chester, PA) lumbar total disc replacement (TDR) trial reported an incidence of 1.2% (1/82) in males undergoing TDR<sup>[11]</sup>, while the Charité<sup>™</sup> (DePuy, Raynham, MA) artificial disc trial reported an incidence of 4% (6/147) in males undergoing either TDR or anterior fusion<sup>[12]</sup>. A recent retrospective consecutive cohort study implicates the inflammatory reaction associated with recombinant human bone morphogenetic protein-2 (rhBMP-2) use as an adjunct to anterior lumbar interbody fusion (ALIF) at L5-S1 in generating an increased incidence of retrograde ejaculation<sup>[13]</sup>. A 6.3% incidence (15/239) of retrograde ejaculation was identified in male patients receiving rhBMP-2 as an adjunct to one (L5-S1) or two (L4-5/L5-S1) level ALIF, as compared to an incidence of 0.9% (2/233) absent rhBMP-2 use in the control arm. Noteworthy is that of 12 patients with retrograde ejaculation followed for at least 2 years postoperatively, six (50%) reported resolution.

## GASTROINTESTINAL COMPLICATIONS

The most common gastrointestinal issue complicating the postoperative course of the patient undergoing anterior lumbar spinal surgery is ileus. Routine measures taken to reduce the incidence of ileus include preoperative mechanical bowel preparation, use of an orogastric tube intraoperatively, and avoidance of nitrous oxide as an anesthetic agent. Use of preoperative mechanical bowel preparation is especially worthwhile in the setting of a significant preoperative narcotic requirement, as gastrointestinal transit time may be dramatically prolonged. Methylnaltrexone bromide (Relistor<sup>®</sup>, Salix Pharmaceuticals, Raleigh, NC) injection is particularly useful in treating opiate induced constipation postoperatively. In cases of refractory ileus, as well as colonic pseudo-obstruction



**Figure 2** Anatomy of thoraco-abdominal nerves (A) and iliohypogastric and ilioinguinal nerves (B).

(Ogilvie's syndrome), neostigmine administered intravenously is frequently effective, although a monitored setting is required as bradycardia is a recognized side effect of this parasympathomimetic agent<sup>[14]</sup>.

## ABDOMINAL WALL COMPLICATIONS

Sometimes referred to as abdominal asymmetry, a change in contour of the abdominal wall is a recognized outcome following oblique flank incisions during the course of aortic, renal and/or anterior spinal surgery. The resulting prominence or bulge is not a true hernia, as there is no accompanying fascial defect, and consequently no risk of incarceration exists. Generally thought to occur as a result of denervation of the oblique musculature of the flank, an increased incidence has been noted with incisions extending into the eleventh intercostal space<sup>[15]</sup>, suggesting an important role for the eleventh intercostal nerve in preserving normal muscular function of the abdominal wall. Innervation of the oblique and rectus abdominis musculature is by the anterior divisions of intercostal nerves VII-XII, referred to as thoraco-abdominal nerves (Figure 2A). Coursing between the internal oblique and transversus abdominal muscles, the thoraco-abdominal nerves perforate the rectus sheath and terminate as anterior cutaneous branches of the abdomen. Further innervation of the internal oblique and transversus abdominal muscles is by the iliohypogastric (superior branch) and ilioinguinal nerves (inferior branch), arising together from the anterior rami at T12 and L1 (Figure 2B). Preservation of the thoraco-abdominal neurovascular bundle in the interval between the internal oblique and transversus abdominal muscles is felt to be an important element in maintaining integrity of muscular function of the abdominal wall during performance of lateral transposiotic interbody fusion.

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## Finger movement at birth in brachial plexus birth palsy

Rahul K Nath, Mohamed Benyahia, Chandra Somasundaram

Rahul K Nath, Mohamed Benyahia, Chandra Somasundaram, Research Division, Texas Nerve and Paralysis Institute, Houston, TX 77030, United States

**Author contributions:** Nath RK designed the study, and performed the surgeries; Benyahia M and Somasundaram C analyzed the data, and wrote the paper; all the authors revised and approved the manuscript.

**Correspondence to:** Rahul K Nath, Institute Director, Research Division, Texas Nerve and Paralysis Institute, 6400 W Fannin Street, Suite 2420, Houston, TX 77030, United States. [drnath@drnathmedical.com](mailto:drnath@drnathmedical.com)

Telephone: +1-713-5929900 Fax: +1-713-5929921

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### Abstract

**AIM:** To investigate whether the finger movement at birth is a better predictor of the brachial plexus birth injury.

**METHODS:** We conducted a retrospective study reviewing pre-surgical records of 87 patients with residual obstetric brachial plexus palsy in study 1. Posterior subluxation of the humeral head (PHHA), and glenoid retroversion were measured from computed tomography or Magnetic resonance imaging, and correlated with the finger movement at birth. The study 2 consisted of 141 obstetric brachial plexus injury patients, who underwent primary surgeries and/or secondary surgery at the Texas Nerve and Paralysis Institute. Information regarding finger movement was obtained from the patient's parent or guardian during the initial evaluation.

**RESULTS:** Among 87 patients, 9 (10.3%) patients who lacked finger movement at birth had a PHHA > 40%, and glenoid retroversion < -12°, whereas only 1 patient (1.1%) with finger movement had a PHHA > 40%, and retroversion < -8° in study 1. The improvement in glenohumeral deformity (PHHA, 31.8% ± 14.3%; and

glenoid retroversion 22.0° ± 15.0°) was significantly higher in patients, who have not had any primary surgeries and had finger movement at birth (group 1), when compared to those patients, who had primary surgeries (nerve and muscle surgeries), and lacked finger movement at birth (group 2), (PHHA 10.7% ± 15.8%; Version -8.0° ± 8.4°,  $P = 0.005$  and  $P = 0.030$ , respectively) in study 2. No finger movement at birth was observed in 55% of the patients in this study group.

**CONCLUSION:** Posterior subluxation and glenoid retroversion measurements indicated significantly severe shoulder deformities in children with finger movement at birth, in comparison with those lacked finger movement. However, the improvement after triangle tilt surgery was higher in patients who had finger movement at birth.

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**Key words:** Finger movement; Triangle tilt surgery; Brachial plexus birth palsy; Glenohumeral dysplasia; Pejo-rative sign

Nath RK, Benyahia M, Somasundaram C. Finger movement at birth in brachial plexus birth palsy. *World J Orthop* 2013; 4(1): 24-28 Available from: URL: <http://www.wjgnet.com/2218-5836/full/v4/i1/24.htm> DOI: <http://dx.doi.org/10.5312/wjo.v4.i1.24>

### INTRODUCTION

Normal shoulder development requires balanced dynamic muscle environment between the humeral head and the glenoid. Initial damage during birth to the brachial plexus, and its incomplete recovery results in full or partial paralysis of shoulder muscles during the child's development. The most common muscle imbalances after partial recovery occur between the internal and

the external rotators, and the abductors and adductors of the shoulder. The chronic evolution of the muscle imbalance causes changes to the developing bony structures, and formation of scapular and glenohumeral joint deformities.

Lack of finger movement at birth in obstetric brachial plexus injury (OBPI) represents a pejorative sign of prognosis. In these patients, the shoulder muscles are all weakened, and there is no muscle balance, indicating a severe initial injury that mostly affects the entire brachial plexus. However, the presence of finger movement at birth in asymmetrical brachial plexus injury (initial damage to C5-C6 or C5-C7) also predicts the development of severe bony deformities caused by severe muscle imbalance on the growing bony structures of the infant shoulder<sup>[1,2]</sup>. This progress to a posterior subluxation or complete dislocation of the humeral head. These secondary deformities, including internal rotator and adductor contractures, glenohumeral dysplasia, cause major long-term morbidity requiring surgical correction to improve limb function.

The severity of glenohumeral dysplasia and shoulder function associated with nerve repair in OBPI patients has been recently demonstrated<sup>[3]</sup>. In this report, we further evaluated the severity of glenohumeral dysplasia in OBPI patients with and without finger movement at birth, and correlated the outcome of primary and secondary surgeries in this patient population.

## MATERIALS AND METHODS

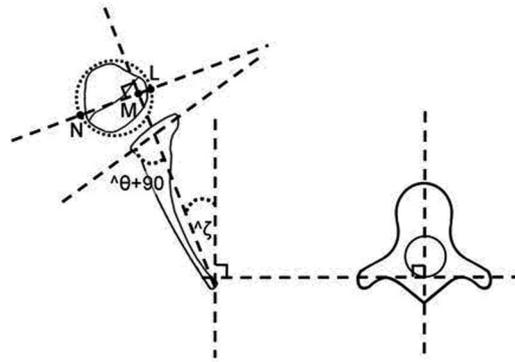
### Study 1

We conducted a retrospective study reviewing pre-surgical records of 87 patients with residual obstetric brachial plexus palsy. Their ages at the time of computed tomography (CT) or magnetic resonance imaging (MRI) scan were between 4 mo and 16 years (average 4.6 years). All the patients in this study have a CT/MRI of bilateral shoulders prior to any surgical procedure. We compared and correlated the pre-surgical results of posterior subluxation of the humeral head (PHHA), and glenoscapsular version angle to the finger movement at birth. In studies that quantify obstetric brachial plexus deformities, the most common measurements are PHHA and glenoid retroversion.

Radiological measurements were taken using patients CT or MRI on the transverse sections at the level of the scapular spine as follows: (1) PHHA<sup>[4]</sup> calculated as percent humeral head anterior to the scapular line (Figure 1); and (2) Glenoscapsular version angle ( $\theta$ -angle difference between the glenoid and a line 90° to scapular line), was measured from either CT or MRI scans<sup>[5]</sup> as previously described<sup>[6,7]</sup>, and in the figure legend (Figure 1).

### Study 2

This study consisted of 141 OBPI patients, who underwent primary surgeries and/or secondary surgery at



**Figure 1** Schematic drawing showing the method of calculating glenoid version and percentage of humeral head anterior to scapular line. Measuring the glenoid version angle ( $\theta$ ): The scapular line is drawn between the medial margin of the scapula to the midpoint of the glenoid. Another line is drawn through the anterior and posterior aspects of the glenoid labrum. The angle between these two lines is measured, and 90° is subtracted. A negative value indicates a retroverted glenoid. A line perpendicular to the scapular line is drawn and the percentage of humeral head anterior to scapular line is defined as the ratio of the distance from the scapular line to the anterior portion of the head to the diameter of the humeral head ( $LM/LN \times 100$ ). Reproduced from Nath RK *et al*<sup>[7]</sup>.

the Texas Nerve and Paralysis Institute. All the patients in this study were injured severely enough to develop shoulder deformities that required surgical reconstruction. All surgeries were performed by the same surgeon (Nath RK), whose practice has focused on reconstructive surgery in this population for the past 15 years. The age of these patients ranges from 5 mo to 20 years at the time of visit. One group included 50 patients who underwent nerve reconstruction and secondary surgeries (muscle and bony), the second group included 82 patients, who underwent only secondary surgeries (no nerve surgery), and the third group included 9 patients, who have had only bony (triangle tilt) surgery.

Nerve repair, modified Quad, and triangle tilt surgeries were performed on these patients by the senior author and the surgeon (Nath RK) as described previously<sup>[8-11]</sup>. Information regarding finger movement was obtained from the patient's parent or guardian during the initial evaluation.

### Statistical analysis

Statistical analysis was performed using Analyse-It plugin (Leeds, United Kingdom) for Microsoft Excel 2003 software. A *P*-value of < 0.05 was considered as statistically significant.

## RESULTS

### Study 1

No finger movement at birth was observed in 56% of the patients. Among 87 patients, 9 (10.3%) patients who lacked finger movement at birth had a PHHA > 40%, and glenoid retroversion < -12°, whereas only 1 patient (1.1%) with finger movement had a PHHA > 40%, and

retroversion < -8°.

## Study 2

The improvement in glenohumeral deformity (PHHA, 31.8% ± 14.3%; and glenoid retroversion 22.0% ± 15.0%) was significantly higher in patients, who have not had any primary surgeries and had finger movement at birth (group 1), when compared to those patients, who had primary surgeries (nerve and muscle surgeries) and lacked finger movement at birth (group 2), (PHHA, 10.7% ± 15.8%; Version -8.0% ± 8.4%,  $P = 0.005$  and  $P = 0.030$ , respectively).

The change in radiological measurements was not statistically significantly different in patients who have had primary surgeries (data not shown) with reference to finger movement at birth. No finger movement at birth was observed in 55% of the patients in this study group.

## DISCUSSION

The integrity of the motor cortex and the corticospinal tract is critical for the movements of the extremities, and for the control of finger movements<sup>[12-17]</sup>. Finger movement at birth is an important indication of the functional and anatomical integrity of the brachial plexus.

There are numerous reports in the literature relating finger movements to brain region and brain damage<sup>[18-22]</sup>, stroke<sup>[23-25]</sup>, cerebral palsy<sup>[26-28]</sup>, Parkinson's disease<sup>[29,30]</sup>, carpal tunnel syndrome<sup>[31,32]</sup>, traumatic injury<sup>[21,33-37]</sup>. However, there are only few reports correlating finger movements and obstetric brachial plexus injury<sup>[2,38]</sup> and hand injuries, despite the hands are important in performing daily activities<sup>[36]</sup>.

Finger movement at birth was evaluated as one of the potential risk factors for permanent injury and predictors of future osseous shoulder deformity<sup>[2]</sup>. Glenoid retroversion was significantly more severe in patients with finger movement at birth, and thus associated with the development of a worse glenohumeral deformity. Posterior subluxation was also more severe in these patients, however not significantly.

Although, the mean radiological scores show that lack of finger movement at birth is actually protective against bony deformities of the shoulder, yet, some patients in this group faced severe bony deformities (up to PHHA-31, and version-16, data not shown). Therefore, these patients also suffer extensive functional impairment that necessitated for surgical treatment.

Permanently injured patients with finger movement at birth develop more severe bony deformities of the shoulder than patients without finger movement at birth due, in part, to asymmetrical muscle action on growing bony elements, also underwent surgical treatment at the Texas Nerve and Paralysis Institute.

The outcome of triangle tilt surgery in terms of radiological scores (PHHA and version) was significantly higher in patients who have not had any primary surger-

ies and had finger movement at birth (group 1), when compared to patients who had primary surgeries (nerve, nerve and muscle surgeries) and lacked finger movement at birth (group 2). Other investigators have reported that some OBPI patients achieved voluntary finger movement with double free-muscle transfer<sup>[38]</sup>.

Our present study is unique in that it evaluates the relationship between finger movement at birth, and the outcome of the primary and secondary surgeries in OBPI patients. Finger movement at birth, may be used as a simple and rapid clinical test, as a predictor of the outcome. The finger movement data in this study is based on retrospective information which was obtained from patient families. The limitation of this study is that a population of transiently injured patients was not available for comparison. In addition, there are not many reports in the literature to compare the finger movement at birth and the surgical outcome in OBPI patients.

## COMMENTS

### Background

The severity of glenohumeral dysplasia and shoulder function associated with nerve repair in obstetric brachial plexus injury (OBPI) patients has been recently demonstrated. In this report, authors further evaluated the severity of glenohumeral dysplasia in OBPI patients with and without finger movement at birth, and correlated the outcome of primary and secondary surgeries in this patient population.

### Research frontiers

Finger movement at birth has been evaluated as one of the potential risk factors for permanent brachial plexus injury, and predictors of future osseous shoulder deformity.

### Innovations and breakthroughs

Although, there are numerous reports in the literature relating finger movements to brain region and brain damage, stroke, cerebral palsy, Parkinson's disease, carpal tunnel syndrome, traumatic injury, this is the first report proposing that finger movement may be used as a simple and rapid clinical test, and as a predictor of the surgical outcome in obstetric brachial plexus injury.

### Applications

Finger movement at birth, may be used as a simple and rapid clinical test, as a predictor of the surgical outcome.

### Terminology

Triangle tilt surgery: This operative technique includes osteotomies of the clavicle, neck of the acromion and scapula in order to release the distal acromioclavicular triangle and allow it to reorient itself in a more neutral position into the glenoid. The modified Quad procedure: Transfer of the latissimus dorsi and teres major muscles, release of contractures of subscapularis pectoralis major and minor and axillary nerve decompression and neurolysis.

### Peer review

The limitation of this study is that a population of transiently injured patients was not available for comparison. In addition, there are not many reports in the literature to compare the finger movement at birth and the surgical outcome in OBPI patients.

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## Instructions to authors

Road, Beijing 100039, China

### Editorial office

Jian-Xia Cheng, Director

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*World Journal of Orthopedics*

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Beijing 100025, China

Telephone: +86-10-85381892

Fax: +86-10-85381893

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In press

- 3 **Tian D**, Araki H, Stahl E, Bergelson J, Kreitman M. Signature

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### Statistical data

Write as mean  $\pm$  SD or mean  $\pm$  SE.

**Statistical expression**

Express *t* test as *t* (in italics), *F* test as *F* (in italics), chi square test as  $\chi^2$  (in Greek), related coefficient as *r* (in italics), degree of freedom as  $\nu$  (in Greek), sample number as *n* (in italics), and probability as *P* (in italics).

**Units**

Use SI units. For example: body mass, *m* (B) = 78 kg; blood pressure, *p* (B) = 16.2/12.3 kPa; incubation time, *t* (incubation) = 96 h, blood glucose concentration, *c* (glucose)  $6.4 \pm 2.1$  mmol/L; blood CEA mass concentration, *p* (CEA) = 8.6 24.5  $\mu\text{g/L}$ ;  $\text{CO}_2$  volume fraction, 50 mL/L  $\text{CO}_2$ , not 5%  $\text{CO}_2$ ; likewise for 40 g/L formaldehyde, not 10% formalin; and mass fraction, 8 ng/g, etc. Arabic numerals such as 23, 243, 641 should be read 23 243 641.

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Quantities: *t* time or temperature, *c* concentration, *A* area, *l* length, *m* mass, *V* volume.

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