# Techniques in Shoulder and Elbow Surgery

## “Triple Window” Surgical Approach to the Elbow – A Hybrid Exposure

--Manuscript Draft--

| | |
|---|---|
| **Manuscript Number:** | |
| **Full Title:** | “Triple Window” Surgical Approach to the Elbow – A Hybrid Exposure |
| **Article Type:** | Technique |
| **Keywords:** | Triceps on approach; triple window |
| **Corresponding Author:** | Srinath Kamineni, MD<br>University of Kentucky<br>UNITED STATES |
| **Corresponding Author Secondary Information:** | |
| **Corresponding Author's Institution:** | University of Kentucky |
| **Corresponding Author's Secondary Institution:** | |
| **First Author:** | Srinath Kamineni, MD, MBBCh, BSc(Hons), FRCS-Orth |
| **First Author Secondary Information:** | |
| **Order of Authors:** | Srinath Kamineni, MD, MBBCh, BSc(Hons), FRCS-Orth |
| | Eric Abbenhaus, M.D. |
| | Ryan Snowden, MD |
| **Order of Authors Secondary Information:** | |
| **Manuscript Region of Origin:** | UNITED STATES |
| **Abstract:** | Triceps-off approaches of the elbow detach not only the central tendinous insertion but also the medial and lateral peripheral muscular extensions, which are often replaced by scar tissue instead of functioning contractile muscular tissue when re-attached firmly with suture. These muscular extensions have been shown to be important for terminal elbow extension and may explain why triceps-off approaches have a higher rate of triceps insufficiency in terminal, anti-gravity elbow extension. Triceps-on approaches encounter the difficulty of accessing the ulna for preparation and insertion of the ulna component of elbow replacements, with mal-positioning of the ulna component a commoner concern. We present an elbow “triple window” surgical approach that preserves the contractile medial and lateral footprints of the triceps, while affording a better in-line access than a pure ‘triceps on’ approach. This approach only violates 50% of the central tendinous insertion, with the remainder of the central tendon and the medial and lateral muscular extensions preserved. |

# “Triple Window” Surgical Approach to the Elbow – A Hybrid Exposure

Srinath Kamineni MD[1], MBBCh, BSc(Hons), FRCS-Orth, Eric Abbenhaus MD[1], Ryan Snowden MD[2]

[1] University of Kentucky, Department of Orthopaedic Surgery and Sports Medicine, Elbow Shoulder Research Center

[2] Tennessee Orthopaedic Alliance

Conflicts of Interest and Source of Funding: None

IRB: No IRB approval was needed for this technique guide

Corresponding Author: Srinath Kamineni MD, MBBCH, FRCS (Orth)

Department of Orthopaedic Surgery, Elbow Shoulder Research Centre,

University of Kentucky

740 South Limestone Street, K-412 Kentucky Clinic, Lexington, KY 40536-0284

Tel: 1-859-806-7703

Fax: 1-859-323-2412

E-mail: srinathkamineni@gmail.com

Srinath Kamineni MD,MBBCH, FRCS (Orth)
Department of Orthopaedic Surgery, Elbow Shoulder Research Centre,
University of Kentucky
740 South Limestone Street, Kentucky Clinic, Lexington, KY 40536-0284
1-859-806-7703
srinathkamineni@gmail.com

Edward V. Craig, MD and John W. Sperling, MD
Editors-in-Chief
*Techniques in Shoulder and Elbow Surgery*

August 12, 2019

Dear Dr. Edward V. Craig, MD and Dr. John W. Sperling, MD:

I am pleased to submit an original research article entitled ““Triple Window” Surgical Approach to the Elbow – A Hybrid Exposure“ by Srinath Kamineni MD, MBBCH, FRCS (Orth), Eric Abbenhaus MD, and Ryan Snowden MD, for consideration for publication in Techniques in Shoulder and Elbow Surgery. This represents a surgical approach that leaves the tricipital insertion intact while simultaneously allowing adequate exposure of the elbow. This surgical technique is even more relevant in the context of our anatomic study on the tricipital insertion footprint which we also recently submitted.

Our anatomic study demonstrates that the tricipital insertion has muscular medial and lateral extensions along the olecranon. This finding is consistent with our previous EMG data and also explains clinical outcomes, namely weakness in terminal extension, seen with triceps-off approaches. These findings suggest that our surgical approach presented here that does not violate these muscular medial or lateral extensions will not lead to terminal extension weakness, providing superior clinical results.

This manuscript has not been published and is not under consideration for publication elsewhere. All authors have read and approve this manuscript. All authors believe this represents honest work.

Thank you for your consideration!

Sincerely,

Srinath Kamineni MD,MBBCH, FRCS (Orth)
Department of Orthopaedic Surgery, Elbow Shoulder Research Centre,
University of Kentucky

**“Triple Window” Surgical Approach to the Elbow – A Hybrid Exposure**

**Kamineni S, Abbenhaus E, Snowden R**

**Abstract**

Triceps-off approaches of the elbow detach not only the central tendinous insertion but also the medial and lateral peripheral muscular extensions, which are often replaced by scar tissue instead of functioning contractile muscular tissue when re-attached firmly with suture. These muscular extensions have been shown to be important for terminal elbow extension and may explain why triceps-off approaches have a higher rate of triceps insufficiency in terminal, anti-gravity elbow extension. Triceps-on approaches encounter the difficulty of accessing the ulna for preparation and insertion of the ulna component of elbow replacements, with mal-positioning of the ulna component a commoner concern. We present an elbow “triple window” surgical approach that preserves the contractile medial and lateral footprints of the triceps, while affording a better in-line access than a pure ‘triceps on’ approach. This approach only violates 50% of the central tendinous insertion, with the remainder of the central tendon and the medial and lateral muscular extensions preserved.

Key words: Triceps on approach; triple window

**Introduction**

Improvements in the understanding of the elbow, with respect to biomechanics of the native joint as well as design of implants, have led to an increase in both indications and use of Total Elbow Arthroplasty (TEA) [1]. Originally used to address severe stages of inflammatory arthropathy, indications now include post traumatic osteoarthritis, acute distal humeral fractures, distal humeral nonunion, extreme intrinsic stiffness/ankylosis, large post-traumatic bone defects, primary osteoarthritis, hemophilic arthropathy, and reconstruction after tumor resection[2-11]. However, there are higher complication rates, compared to other joint arthroplasties, following TEA such as 10% readmission rate for short term complications and a 90-day re-operation rate of 8%[12]. In fact, the overall complication rate has been documented at over 44% with a reoperation rate of 27%[13].

One particular complication of interest is triceps insufficiency, which has the potential to occur following an approach that mobilizes the extensor mechanism from the olecranon process. When performing TEA, surgical techniques commonly involve a posterior skin incision and the triceps is generally dealt with in one of three manners: triceps splitting, reflecting, or sparing[14-16].

Triceps splitting approaches divide or split the triceps muscle and usually its olecranon insertion as well, although some techniques leave the insertion undisturbed[17]. Triceps reflecting approaches, the most widely used, keep the triceps in continuity with the anconeus as it is released medial to lateral, with the resultant muscular sleeve reflected laterally[14]. Finally, triceps sparing approaches mobilize the medial and lateral borders of the triceps as the epicondylar attachments are released while preserving the triceps insertion[18, 19]. Recently, “partial” triceps-on approaches have been described which similarly release epicondylar attachments while preserving the triceps insertion[20]. Difficulties with these approaches, as well complications such as triceps insufficiency, weakness, and risk of instability have all been documented[14-16, 21]. The advantage of the triceps splitting and reflecting approaches is that good exposure of the distal humeral articular surface is achieved[22-24]. On the other hand, “triceps on” approaches leave the tricipital insertion intact and decrease the risk of triceps insufficiency[25-27], at the expense of articular surface exposure[16, 21].

In patients undergoing TEA for rheumatoid arthritis, complications of triceps insufficiency have been reported in 1-5%[21]. Other reviews have noted an overall rate of triceps insufficiency in TEA of 2-3%[21, 28], with no significant difference in results according to various approaches. Resolving a triceps insufficiency can be a difficult endeavor.

The typical, commonly used, examination of the triceps function is imperfect. Many clinicians assess the range of motion in a gravity dependent manner and test strength in the mid-arc of sagittal plane motion. Both of these issues result in ‘objective’ assessments portraying a better function than the patient experiences. For the past 15 years, we have assessed motion in an anti-gravity plane and assessed strength both in the mid-arc of motion and in the terminal 30 degrees of extension, relevant when a patient wants to reach above head level. The complication of triceps insufficiency, if symptomatic, often requires revision operations with surgical reconstruction of the extensor mechanism.

The triceps insertion onto the olecranon process has a ‘Crescent-shaped’ footprint (Figures 1.1 and 1.2) , with the central part consistent of the central tendon and the peripheral limbs consistent of muscular extensions inserting almost directly onto bone[29, 30]. Triceps-on approaches encounter difficulty when accessing the ulna for preparation and insertion of the ulna component of elbow replacements[14-16]. The approach to the ulna is with the forearm/ulna rotated, and the reaming/broaching/implantation is from the side, and not in a direct parallel line to the long-axis. It is this non-parallel approach to ulna component implantation that is difficult and prone to seat the component in mal-rotation. Triceps-off approaches detach not only the central tendinous insertion but also the medial and lateral peripheral muscular extensions, which when re-attached firmly with suture, are often replaced by scar tissue, but not functioning contractile muscular tissue[2-4, 8, 14]. These muscular extensions have been shown to be important for terminal elbow extension[31]. The medial triceps has been shown to have significantly more electrical activity during the terminal 30° arc of supine motion and during pushing activity[31]. The medial and lateral triceps were also shown to have a higher EMG activation level than the central triceps in all functional tasks, clearly demonstrating their importance for elbow extension, particularly with terminal elbow extension against gravity[31]. By detaching and re-attaching these medial and lateral muscular elements of triceps, terminal extension is compromised and the muscular balance of the elbow may detrimentally change. We have developed a hybrid approach that only violates 50% of the central tendinous insertion, with the remainder of the central tendon and the medial and lateral muscular extensions preserved. We present an elbow “triple window” surgical approach, clinically utilized for 15 years, that preserves the contractile footprint of the triceps while affording a better in-line access than a ‘triceps on’ approach.

## Materials and methods

For illustrative purposes, we utilized fresh frozen cadaveric elbows, for the depicted surgical approach, identical to the clinical situation, in a step by step fashion to allow easy reproducibility by the interested reader. The approach was replicated for Coonrad/Morrey (Zimmer), Nexel (Zimmer), and Latitude (Tornier) total elbow systems to ensure the approach could be replicated with multiple systems, although some systems are more amenable (Coonrad-Morrey) than the others. This approach was then employed in the senior author’s clinical practice for more than 10 years to ensure clinical reproducibility and ensure clinical outcome improvements.

### Procedure

When positioning to approach the elbow posteriorly, particularly for this approach, we prefer a supine patient, a tourniquet at 250mmHg, and a roll of towels acting as a bolster placed under the flexed elbow/forearm (Figure 2).

***Skin Incision* - ** A midline posterior 10cm skin incision, extending both 5cm proximal and distal to the tip of the olecranon process (Figure 3), which can be a straight incision or curved to avoid the olecranon tip.

***Step 1: Medial Para-Tricipital Window***

A medial full thickness skin flap is elevated over the flexor-pronator mass and the dissection is progressed medially allowing for the identification of the ulnar nerve. Following identification, the ulnar nerve is neurolyzed proximally 5 cm and distally to the first motor branch to the flexor carpi ulnaris. The nerve must be identified proximally after crossing the septum to ensure complete release of both the Arcade of Struthers and the cubital tunnel retinaculum. The ulnar nerve may now be mobilized as needed (medially and laterally) and protected with vessel loops (Figure 4.1). The interval between the triceps and the flexor-pronator mass is identified (Figure 4.2) and the triceps is released from the posterior surface of the humeral shaft with a curved elevator and the posterior capsule/fat pad is excised. The medial epicondyle is enucleated from the flexor-pronator mass origin and the brachialis and the anterior capsule are elevated from the anterior surface of the humerus (Figure 4.3). Following this medial dissection, one should have complete access to the medial epicondyle, medial aspect of the olecranon, and humerus, with the ulna nerve mobile and protected (Figure 4.4, 4.5). In acute fractures, the medial window is ideal for removing medial fracture fragments.

***Step 2: Lateral Para-Tricipital Window***

A lateral full thickness skin flap is now raised from the posterior incision. The fascia overlying the lateral margin of the triceps proximally and distally over the origin of the proximal extensor mass insertion provides a plane for the flap. A muscular interval is then created by incising the fascia along the most distal/lateral border of the triceps. This fascial incision is carried distally to coincide with the plane between Extensor Carpi Ulnaris and the Anconeus, similar to the Kocher approach (Figure 5.1, 5.2). Carrying this interval deep to underlying structures, the Lateral Collateral Ligament (LCL), Extensor mass origin, and the remainder of the anterior capsule are then sharply incised from their humeral origin and retracted laterally (Figure 5.3, 5.4, 5.5). Care must be taken to bring the origin off as a whole flap as this will need to be repaired at the end of the case.   The lateral epicondyle should, at this point, be enucleated. Finally, through the lateral window, blunt stripping of the most distal 5-7cm attachments of the brachialis fibers from the anterior humeral shaft and any remaining attachments of the triceps from the porterior shaft should be performed. At this point the distal humerus should be circumferentially free from ligamentous and muscular connections. The humerus then can be readily disarticulated and delivered through the lateral window to begin implant preparation (Figure 5.6, 5.7).

When humeral and ulnar preparation is complete, should a radial head excision or replacement be a part of the operative plan, the lateral window provides excellent access for either procedure. The annular ligament is transected obliquely, in line with the Anconeus, which allows subsequent repair as needed.

***Humeral Preparation***

This should be performed per implant specific guidelines, with the humerus accessed through the lateral window. The authors here generally rely on stemmed components requiring access to the humeral canal for reaming and broaching. The distal humerus is readily available through the lateral window to complete all portions of this preparation, including making distal humeral cuts (elective TEA, or removing fracture fragments in acute fractures), reaming, broaching and trail/final humeral stem implantation.

Following preparation of the trochlea, the humerus can be either be maintained in the lateral window or can be reduced. The forearm is then supinated, to allow visualization of the olecranon tip through the lateral window. Any remaining capsule is excised until full visualization of the triceps insertion is obtained. Approximately 5-7mm of olecranon tip, not including triceps insertion, is then removed to create a flat surface in the same plane as the prepared trochlea, flush with the greater sigmoid notch.

***Step 3: Central Triceps Tendon Window***

A 5-7cm split is made in the central triceps tendon (Figures 6.1, 6.2). This split is made in the mid to lateral third tendon and is progressed through the full thickness to the olecranon and posterior humeral cortex. The central 50% of the triceps tendinous footprint is elevated at its insertion from the olecranon, leaving the medial and lateral triceps extension footprints undisturbed. The elbow is then fully flexed (Figure 6.3) allowing an in-line view of the ulna, most importantly the whole of the coronoid and greater sigmoid notch. Through this posterior window the non-insertional tip of the olecranon can be excised, if not performed through the lateral window, and a burr is used to enter the ulna intramedullary canal (Figure 6.4).

***Ulnar Preparation***

The ulna is easily visible and accessible through both the lateral, central, and medial windows, but caution must be taken to protect the ulnar nerve. It more advantageous to use the lateral window when using recommended barrel reamers for the Latitude and Nexel Impants, to contour the surface of the trochlea while protecting the radial head. A hand held burr is a viable option through all three windows.

Preparation of the ulna canal can take place in its entirety through the central window for the Coonrad-Morrey impant, with final ulna canal preparation for the other two implants. Canal preparation through the central window allows an in-line axial preparation with lesser propensity for implant mal-rotation. For ulna preparation, the humerus is reduced, and the elbow hyperflexed to allow good visualization of the coronoid (Figure 6.3). This step essentially takes place through the arch of the prepared distal humerus (Figure 6.4). The ulna canal is then initially identified and accessed with a bone burr, which then allow access to reamers and broaches.

Once the humerus and ulna are prepared, and trail implants are confirmed, the canals are dried, cement restrictors placed appropriately, and the humerus is delivered through the lateral window. Cement is then injected into both canals, the humeral component is inserted, the humerus is reduced, and the ulna component is introduced, through the yolk of the humeral component, into the ulna canal. At this point the components are linked, (Figure 7.1 and 7.2), excess cement removed, and the elbow held in full extension, until the cement is fully cured.

After completion of prosthesis implantation, the collateral ligaments with extensor and flexor-pronator masses are repaired through bone tunnels back to their origin, using non-absorbable suture. The ulna nerve is allowed to be placed where it naturally lies, ensuring that this is tension free in all parts of the motion arc, and that there is a thick muscle/tendon sleeve intervening between nerve and implant. Hence a routine transposition is not performed. The central triceps window is closed with a running, locking non-absorbable suture, fixed distally through bone tunnels.

Typical post-operative management includes an anterior extension splint for two weeks if the triceps quality is questionable, or soft bulky dressing if the triceps is of good quality, with motion as tolerated, without weight-bearing. Load bearing is allowed for all patients at 6 weeks.

**Discussion**

Multiple approaches have been described in the literature for access to the elbow for elbow arthroplasty. Triceps splitting and reflecting approaches both provide good access to the joint surfaces of the elbow[32]. Triceps splitting approaches divide the triceps longitudinally over the ulna or split the proximal triceps muscle belly with a V-shaped turn down of the central tendon, typically splitting the olecranon insertion as well[32]. Triceps reflection approaches keep the triceps in continuity with the anconeus, as it is released medial to lateral[14]. Finally, triceps sparing approaches seek to prevent issues of triceps insufficiency or repair failure and mobilize the medial and lateral borders of the triceps as the epicondylar attachments[18].

Techniques describing triceps sparing approaches working through medial and lateral windows are described often in the setting of distal humeral trauma or substantial bony defects[33]. Other triceps sparing approaches that work from a single medial window, while sparing the triceps central tendon and lateral soft tissues, fail to easily access a portion of the articular surface in-line with the long axis of the ulna, compared to triceps splitting and olecranon osteotomy[22-24]. A more recent lateral para-olecranon approach described by Studer and King avoids central triceps detachment from the olecranon and also provides better articular surface exposure than the more classic “triceps on” approaches, but they violate the medial triceps muscular extension[20]. A similar approach, the lateral para-tricipital approach, also described by Studer and King likewise avoids central triceps detachment while providing adequate articular exposure, but violates the lateral triceps muscular extension. Studer and King reported that extension strength using either the medial para-olecranon or lateral para-tricipital approach was better compared to triceps splitting approach[20]. The authors suggest this finding is due to preservation of the triceps insertion, which is also achieved with our approach described here, while our approach does not violate either the medial or lateral triceps muscular extensions, and prepares and implants the ulna component, in-line with the ulna shaft, and not obliquely, as per other triceps-on approaches[20]. Based on EMG data, the medial and lateral triceps extensions are important for the terminal 30 degrees of elbow extension[31], and hence violating these components of the triceps may lead to dysfunction.

## CONCLUSION

When the elbow joint is surgically approached posteriorly, the triceps is commonly elevated from its olecranon footprint, with subsequent reattachment with sutures. The medial and lateral triceps extensions are active contractile elements[31]; and when muscles are firmly sutured to bone, they lose their contractility and form static, non-contractile, scar[34,35]. This latter issue, the basis of post-operative triceps insufficiency, has spurred "triceps on" approaches. Triceps-on approaches face the difficulty of preparing and implanting the ulna component of an elbow arthroplasty from an "non-axial" plane, which has been documented to lead to component mal-positioning[15,32,36]. Modified triceps-on approaches which release either the medial triceps extension or the lateral triceps extension, can be considered to adversely influence the triceps function when suturing the elevated contractile element of the triceps[15,20,34,35].The "triple-window" approach addresses the short-comings of the "triceps-off" and traditional "triceps-on" approaches: 1) does not detach the medial and lateral contractile elements of the triceps insertion, and 2) allows the ulna to be prepared and implanted in-line with the ulna axis, through a direct, posterior, central window. This surgical approach can be utilized in cases with an intact joint, in-situ distal humeral implants, or distal humeral fractures. The primary goal of this approach is to prevent post-operative triceps insufficiency (Figures 8.1, 8.2), without the difficulty of a traditional triceps-on approach.

## References


1. Day JS, Lau E, Ong KL, et al. Prevalence and projections of total shoulder and elbow arthroplasty in the United States to 2015. *J Shoulder and Elbow Surg* 2010; 19(8): 1115-1120.
2. Morrey BF, Adams RA. Semiconstrained arthroplasty for the treatment of rheumatoid arthritis of the elbow. *J Bone Joint Surg Am* 1992; 74(4):479-490.
3. Cobb TK, Morrey BF. Elbow arthroplasty as primary treatment for distal humeral fractures in elderly patients. *J Bone Joint Surg Am* 1997; 79(6):826-832.
4. Schneeberger AG, Adams R, Morrey BF. Semi constrained total elbow replacement for the treatment of post-traumatic osteoarthrosis. *J Bone Joint Surg Am* 1997;79(8):1211-1222.
5. Frankle MA, Herscovici D Jr, Di-Pasquale TG, et al. A comparison of open reduction and internal fixation and primary total elbow arthroplasty in the treatment of intraarticular distal humerus fractures in women older than age 65. *J Orthop Trauma* 2003; 17(7):473-480.
6. Kamineni S, Morrey BF. Distal humeral fractures treated with noncustom total elbow replacement. *J Bone Joint Surg Am* 2004; 86(5):940-947.
7. Prasad N, Dent C. Outcome of total elbow replacement for distal humeral fractures in the elderly: A comparison of primary surgery and surgery after failed internal fixation or conservative treatment. *J Bone Joint Surg Br* 2008; 90(3):343-348.
8. Peden JP, Morrey BF. Total elbow replacement for the management of the ankylosed or fused elbow. *J Bone Joint Surg Br* 2008; 90(9):1198-1204.
9. Cil A, Veilette CJ, Snachez-Sotelo J, et al. Linked elbow replacement: A salvage procedure for distal humeral nonunion. *J Bone Joint Surg Am* 2008; 90(9):1939-1950.

10. McKee MD, Veillette CJ, Hall JA, et al: A multicenter, prospective, randomized, controlled trial of open reduction internal fixation versus total elbow arthroplasty for displaced intra-articular distal humeral fractures in elderly patients. *J Shoulder Elbow Surg* 2009; 18(1):3-12.

11. Gay DM, Lyman S, Do H, et al. Indications and reoperation rates for total elbow arthroplasty: An analysis of trends in New York State. *J Bone Joint Surg Am* 2012; 94(2):110-117.

12. Krenek L, Farng E, Zingmond D, et al. Complication and revision rates following total elbow arthroplasty. *J Hand Surg Am* 2011; 36(1): 68-73

13. Park SE, Kim JY, Cho SW, et al. Complications and revision rate compared by type of total elbow arthroplasty. *J Shoulder Elbow Surg* 2013; 22(8):1121-1127

14. Bryan RS, Morrey BF. Extensive posterior exposure of the elbow: a triceps-sparing approach. *Clin Orthop Relat Res* 1982; 166:188-192.

15. Prokopis PM, Weiland AJ. The triceps-preserving approach for semi constrained total elbow arthroplasty. *J Shoulder Elbow Surg* 2008; 17(3):454-458.

16. Pierce TD, Herndon JH. The triceps preserving approach to total elbow arthroplasty. *Clin Orthop Relat Res* 1998; 354:144-152.

17. Ziran BH, Smith WR, Balk ML, et al. A True Triceps-Splitting Approach for Treatment of Distal Humerus Fractures: A Preliminary Report. *J Trauma* 2005; 58(1):70-75

18. Choo A, Ramsey ML. Total Elbow Arthroplasty: Current Options. *J Am Acad Orthop Surg* 2013; 21(7):427-437

19. Ek ET, Goldwasser M, Bonomo AL. Functional outcome of complex intercondylar fractures of the distal humerus treated through a triceps-sparing approach. *J Shoulder Elbow Surg* 2008; 17(3):441-446.

20. Studer A, Athwal GS, MacDermid JC, et al. The lateral para-olecranon approach for total elbow arthroplasty. *J Hand Surg Am* 2013; 38(11):2219-2226

*21*. Voloshin I, Schippert DW, Kakar S, et al. Complication of total elbow arthroplasty: A systematic review. *J Shoulder Elbow Surg* 2011; 20(1):158-168

22. Dakouré PW, Ndiaye A, Ndoye JM, et al: Posterior surgical approaches to the elbow: a simple method of comparison of the articular exposure. *Surg Radiol Anat* 2007; 29(8):671-674

23. Wilkinson JM, Stanley D. Posterior surgical approaches to the elbow: a comparative anatomic study. *J Shoulder Elbow Surg* 2001; 10(4):380–382.

24. Amirfeyz R, Clark D, Quick T, et al. Newcastle approach to the elbow, a cadaveric study. *Arch Orthop Trauma Surg* 2011; 131:747–751.

25. Gschwend N, Scheier NH, Baehler AR. Long-term results of the GSB III elbow arthroplasty. *J Bone Joint Surg Br*. 1999; 81(6): 1005-1012.

26. Hildebrand KA, Patterson SD, Regan WD, et al. Functional outcome of semi constrained total elbow arthroplasty. *J Bone Joint Surg Am*. 2000; 82(10):1379-1386.

27. Inglis AE, Pellicci PM. Total elbow replacement. *J Bone Joint Surg Am*. 1980; 62(8):1252-1258.

28. Little CP, Graham AJ, Carr AJ. Total elbow arthroplasty: a systematic review of the literature in the English language until the end of 2003. *J Bone Joint Surg Br* 2005; 87(4):437-444.

29. Keener JD, Chafik D, Kim HM, et al: Insertional anatomy of the triceps brachii tendon. *J Shoulder Elbow Surg* 2009; 19(3):399-405.

30. Windisch G, Tesch NP, Grechenig W, et al. The triceps brachii muscle and its insertion on the olecranon. *Med Sci Monit* 2006; 12(8):290-294

31. Kamineni S, Gildea C, Nitz A, et al. Triceps Activation Amplitudes during Functional Activities. *MOJ Orthop Rheumatol* 2015; 2(5):00063

32. Booker SJ, Smith CD. Triceps on approach for total elbow arthroplasty: worth preserving? A review of approaches for total elbow arthroplasty. *Shoulder Elbow* 2017; 9(2):105–111.

33. Alonso-Llames M. Bilaterotricipital approach to the elbow: Its application in the osteosynthesis of supracondylar fractures of the humerus in children. *Acta Orthop Scand* 1972; 43(6):479-490.

34. Järvinen TA, Järvinen M, Kalimo H. Regeneration of Injured Skeletal Muscle after the Injury. *Muscles, Ligaments and Tendons J* 2013; 3(4): 337-345.

35. Danna N, Beutel B, Campbell K, et al. Therapeutic Approaches to Skeletal Muscle Repair and Healing. *Sports Health: A Multidisciplinary Approach* 2014;6(4): 348-355.

36. King A, Booker SJ, Thomas WJ, et al. Triceps on, alignment off? A comparison of total elbow arthroplasty component positioning with a triceps-on and a triceps-off approach. *Ann R Coll Surg Engl* 2018; 100(8): 635-640

389

390

## Appendix A: Figures

Figure 1:1 - 3D rendering of the triceps insertion, 1.2 – grey central tendon with brown medial and lateral muscular extensions

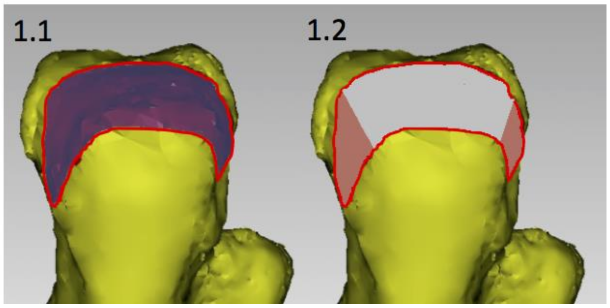


Figure 2: Elbow positioning with the patient supine, and the arm brought across the chest

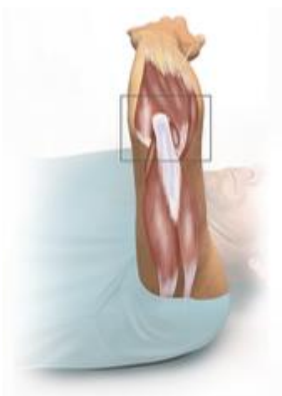

Figure 3a.  Midline posterior 10cm skin incision, extending both 5cm proximal and distal to the tip of the olecranon process; LE-lateral epicondyle, UN- ulnar nerve location, ME- medial epicondyle. Inset for picture orientation with arm proximal and forearm distal. Figure 3b. The skin is incised and the musculotendinous layer is exposed

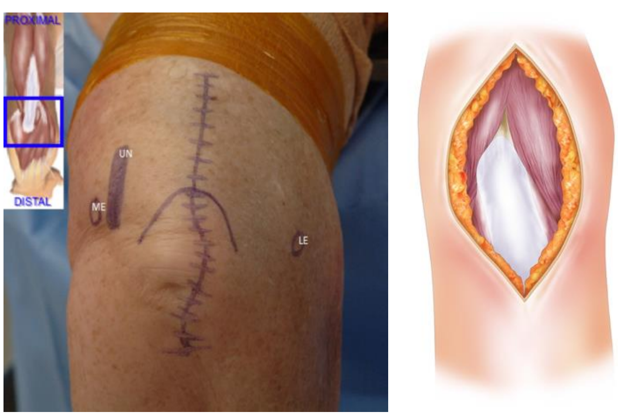

Figure 4.1, 4.2 **Step 1 - Medial Window**: The ulnar nerve mobilized and protected. Interval between the triceps and the flexor-pronator mass is identified prior to triceps being released from the posterior surface of the humerus with posterior capsule excision.

Figure 4.3, 4.4, 4.5  Medial epicondyle is enucleated from the flexor-pronator mass origin. Anterior surface of the humerus is dissected with an elevator mobilize the brachialis and the anterior capsule, with complete access to the medial epicondyle, olecranon and humerus, with the ulna nerve mobile and protected.

Figure 5.1, 5.2. **Step 2 - Lateral Window**: The fascia overlying the lateral margin of the triceps has been divided proximally and distally over the origin of the proximal extensor mass insertion. A muscular interval is then created by incising the fascia along the most distal/lateral border of the triceps, shown by dotted line. Incision is carried distally to the plane of the Extensor Carpi Ulnaris and the Anconeus. T-triceps, O-Olecranon, LE-lateral Epicondyle

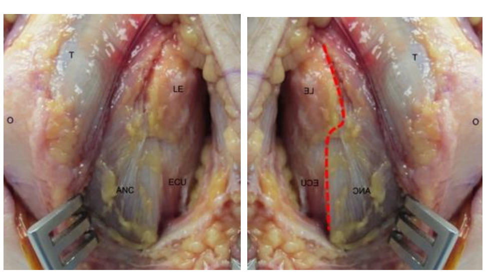

Figure 5.3, 5.4, 5.5: Lateral Collateral Ligament(LCL) and Extensor mass origin are identified. The LCL, Extensor mass origin along with the remainder of the anterior capsule are then sharply released from their origin and retracted. T-triceps, O-Olecranon, LE-lateral Epicondyle, ANC-anconeus, LCL-lateral collateral ligament

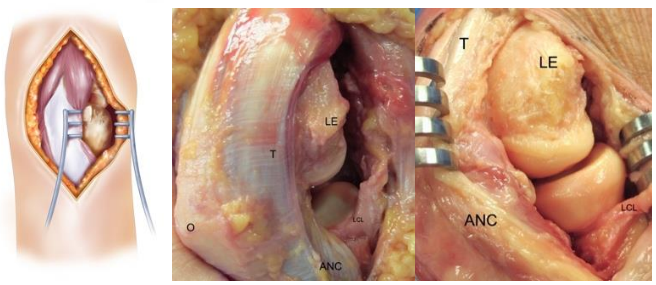


Figure 5.6, 5.7: Humerus is disarticulated and delivered through lateral window, (4.7) and prepared for implantation (either in acute fractures or elective arthroplasty)

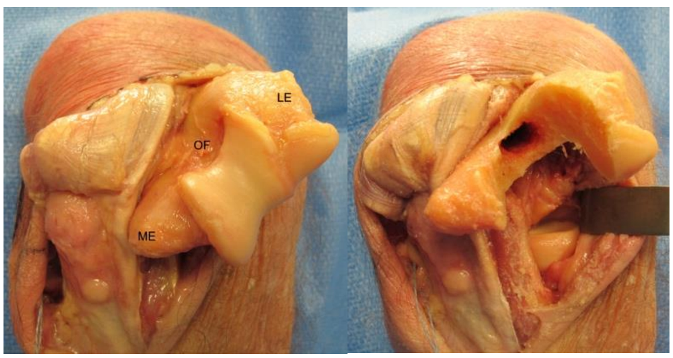


Figure 6.1, 6.2: **Step 3 - Central Window**: A split is made in the central triceps tendon and carried down to olecranon, without detaching the medial and lateral extensions.

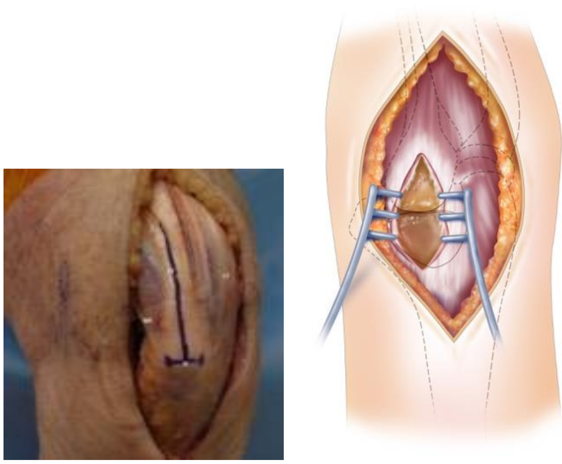

Figure 6.3: With the medial and lateral footprint intact the elbow should be fully flexed. The triceps footprint is elevated at its central 50% footprint (red line), thereby leaving the medial

(25% - green line) and lateral (25% - green line) central tendon attached. Through the posterior window the ulna is readily visible and accessible. Figure 6.4: The ulna is now prepared, in line with the shaft for easier orientation of the component implantation. H-humerus, O-olecranon, M-medial, L-lateral, UC-ulna intramedullary canal, UN-ulna nerve, CT-central tendon

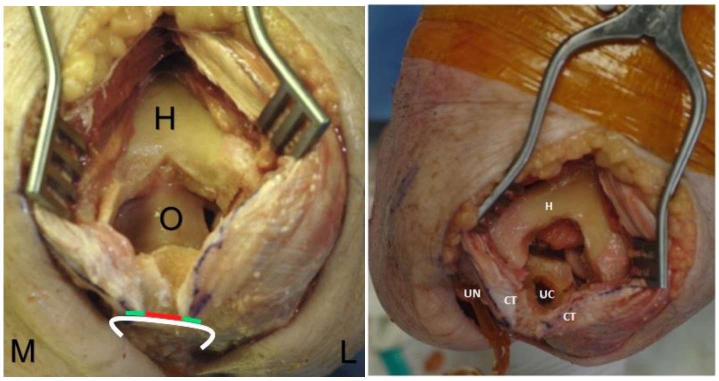


Figure 7.1: Implanted Coonrad-Morrey TEA viewed through central window, 7.2: Implanted Nexel TEA

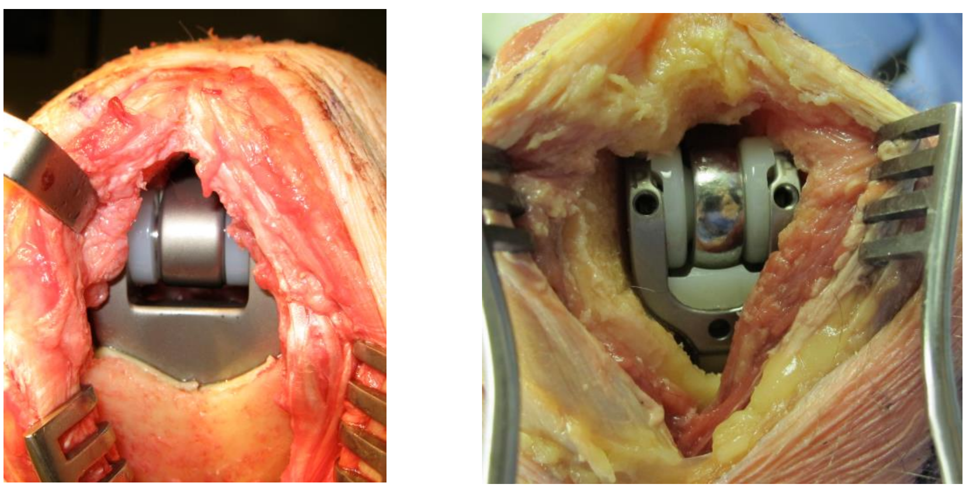

Figure 8.1, 8.2 : Typical overhead active range of motion using Triceps Triple Window approach