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The Art of Fixation in ACL Surgery: A Comparative Review of Button, Screw, Pin, Staple, and Staple Anchor

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ABSTRACT

Anterior cruciate ligament (ACL) reconstruction is a common procedure in orthopedic surgery, and choosing the right graft fixation method is crucial for successful outcomes. This review compares the most commonly used fixation techniques—buttons, screws, cross-pins, staples, and staple anchors—based on their biomechanical performance, clinical results, and complications. Each method has its strengths and limitations. Cross-pins offer strong fixation but come with risks like joint damage. Screws are widely used but can cause graft slippage or tunnel problems. Buttons are flexible and provide high strength but may lead to tunnel motion. Staples and staple anchors are simple, affordable options, often used as supplementary fixation or in cases with graft-tunnel mismatch. Recently, bio-enhancement techniques such as platelet-rich plasma, biomaterials, and gene therapy have shown potential to improve graft healing and reduce complications. Overall, no single fixation method is best for all patients. The choice depends on the graft type, patient condition, and surgeon preference. Understanding the properties and limitations of each technique is key to optimizing ACL reconstruction results.

Keywords: *anterior cruciate ligament reconstruction; button; screw; pin; staple*

1. INTRODUCTION

Anterior Cruciate Ligament (ACL) reconstruction is a cornerstone procedure in orthopedic sports medicine, aiming to restore knee stability and function following ligamentous injury. While advancements in surgical technique and graft selection have evolved significantly over the decades, the method of graft fixation remains a critical determinant of postoperative success. Effective fixation not only ensures initial stability but also influences biological integration, rehabilitation protocols, and long-term clinical outcomes.

Among the diverse fixation methods available, implant choices such as suspensory devices (buttons), interference screws, transosseous pins, staples, and hybrid systems like staple anchors each offer unique biomechanical advantages and limitations. The choice of fixation technique is influenced by multiple factors, including graft type, tunnel orientation, surgeon preference, and patient-specific considerations.

This review aims to provide a comprehensive and comparative analysis of the most commonly used graft fixation techniques in ACL reconstruction. By exploring their biomechanical properties, clinical performance, complication profiles, and technical nuances, we seek to equip orthopedic surgeons with a nuanced understanding of the "art" of graft fixation balancing scientific evidence with surgical experience to optimize patient outcomes.

2. EPIDEMIOLOGY

ACL injury is one of the most common knee injuries. It can be caused by sports activities or accidents. ACL injuries can occur at any age, but are most common in children and young adults. This injury is most common in female athletes.[1,2] The incidence of ACL injuries in the world is estimated at 30-78 cases per 100,000 population each year. Based on ISP (Injury

Surveillance Program) data, the highest incidence of this injury is in women in the fields of gymnastics, soccer and basketball.[3,4] After ACL reconstruction, 61-89% of patients can return to sports within 8-18 months.[3] In Indonesia itself, the incidence rate of ACL injuries is still not clearly known because there is no database system for patients with ACL injuries.[2,5] The incidence of ACL injuries continues to increase over time.

3. SPECIFIC GRAFT SELECTION

Not only fixation on the graft affects mechanical stability, but the choice of graft type also affects stability. Based on the graft used in ACL reconstruction surgery, it is divided into autograft and allograft. Autograft uses donors from the patient himself, while allograft uses donors from other patients. Some grafts that are often used are BPTB (Bone - Patellar Tendon - Bone), hamstring, quadriceps and peroneus longus.[2,6] Each graft has its own advantages and disadvantages. Based on a meta-analysis, BPTB is the gold standard graft for ACL reconstruction because of its superior mechanical stability.[7,8]

4. GRAFT HEALING AND INTEGRATION

The implant in graft fixation functions as temporary fixation, that is, this implant functions until graft-tunnel healing and ligamentization of the ACL graft occurs. The graft healing process following ACL reconstruction occurs in three distinct phases: the early healing phase, the proliferative phase, and the ligamentization phase.[9] The early healing phase spans the initial four weeks postoperatively and is characterized by hypocellularity and central graft necrosis, reflecting limited biological activity in the early period.[10] Around the fourth week, the proliferative phase begins, marked by the infiltration of cells originating from synovial fluid, residual native ACL tissue, and bone marrow-derived elements released during tunnel drilling. This phase typically lasts from week 4 to week 12 and is associated with increased cellular activity and extracellular matrix remodeling.[11] The final phase, ligamentization, commences approximately three months post-surgery and involves the gradual remodeling of the graft into tissue that mimics the structural and functional properties of the native ACL.[12] Restoration of normal cellular density and organization typically progresses until about six months postoperatively, signifying the transition toward biomechanical integration and functional recovery.[9]

5. BIOMECHANICAL PRINCIPLES & EVOLUTION

Biomechanical analysis of graft fixation is important, because the fixation must be strong enough to withstand daily workload and rehabilitation protocols. The forces acting on the ACL during activities vary between 20N-600N, walking (150N), standing on one leg (303N), jogging (450N).[13–15] So the fixation graft must have a failure load of >590N, which is required for early rehabilitation after surgery.[16] The optimal stiffness and prestrain of the graft fixation should be similar to the native ACL because it is necessary to restore joint motion and stability.[17,18]

In performing anterior cruciate tendon reconstruction, fixation is needed to maintain the graft. There are 2 types of fixation, namely mechanical and biological. In biological fixation, it can be done by connecting the graft directly to the ligament attachment site. While in mechanical fixation, it is done using other tools such as cross pins, interference screws, screw-washers, staples, and endobuttons.[2,19] Mechanical fixation itself is divided into two, namely aperture fixation and suspensory fixation.

The outcome of ACL reconstruction can be variable and is multifactorial. In addition to technical failure, there are many modifiable and nonmodifiable factors for ACL injuries that can affect the surgical outcome. Technical failures mainly include non-anatomical tibial and femoral tunnel positions. Compared to the transtibial drilling technique, the tibial tunnel-independent approach is preferred as it allows for a more anatomical placement of the femoral tunnel. Non-modifiable risk factors for ACL graft failure include genetic predisposition, female sex, young age, and ligamentous laxity, with young age at the time of the initial injury being the most significant. Modifiable factors include elevated body mass index (BMI), poor jump landing mechanics, and a steep posterior tibial slope.[20]

5.1. Suspensory fixation

This fixation suspends the graft within the tunnel, thus maximizing the amount of graft within the tunnel. Suspensory fixation methods are categorized into extracortical suspensory devices and transcondylar cross-pin systems.[16] Extracortical suspensory devices can be buttons, staples or staple anchors. Several studies have shown that suspensory fixation has a greater pull-out strength compared to aperture fixation.[21,22]

5.2. Aperture fixation

Aperture fixation refers to fixation methods placed within the bone tunnel, such as interference screws, which secure the graft by pressing it against the outer surface or wall of the tunnel. Aperture fixation has the risk of disrupting graft-bone healing and damaging the tunnel due to possible laceration and necrosis of the graft.[21,22] Additionally, aperture fixation carries the risk of graft slippage if there is inadequate mechanical interaction between the screw and the graft.[8] Therefore, suspensory fixation is more widely chosen today.

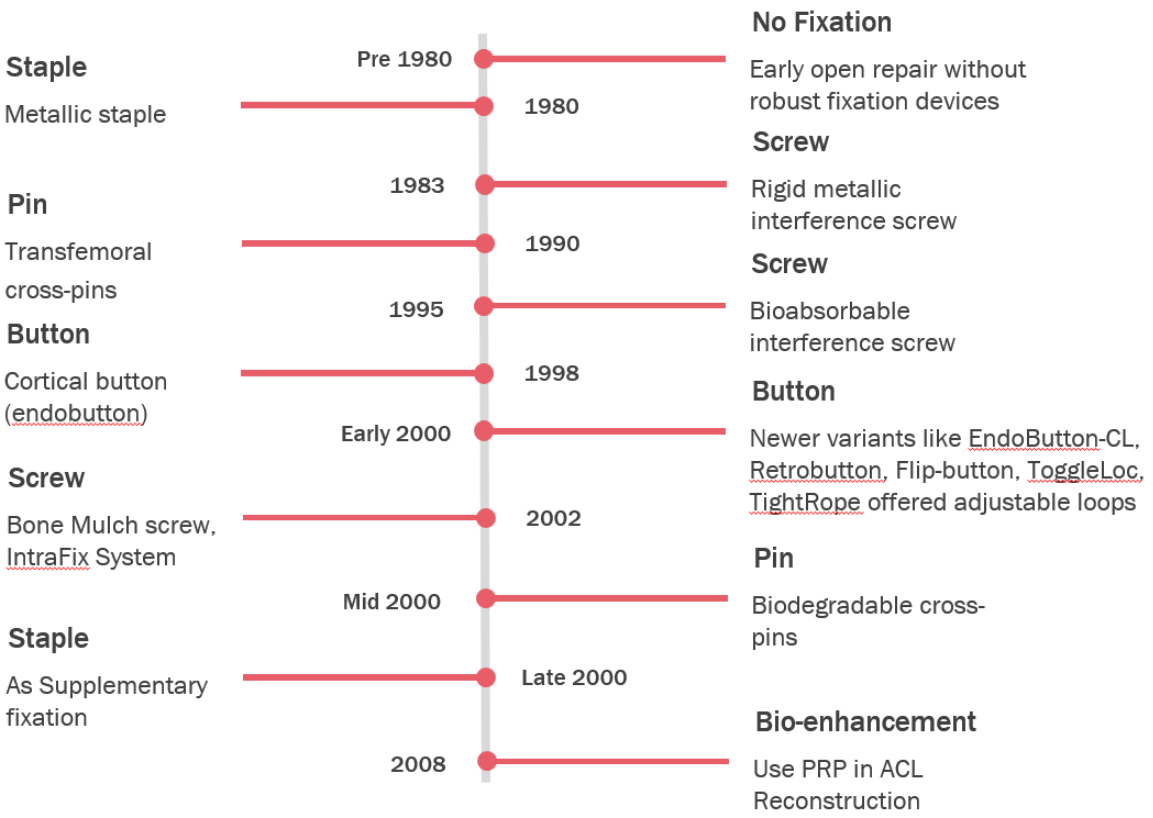

Figure 1. Timeline evolution of graft fixation ACL[23]

6. DISCUSSION

6.1. Button

Button or cortical button is included in suspensory fixation, where the button is located on the femoral cortex and the loop holds the graft until healing occurs. The loop on the button can be fixed (Endobutton CL, RetroButton, and ToggleLoc) or adjustable (Ziploop, TightRope RT I and TightRope RT II).[16] Biomechanical studies consistently show that buttons used for soft-tissue femoral fixation have a higher ultimate failure load compared to cross-pins and bioscrews.[24,25]

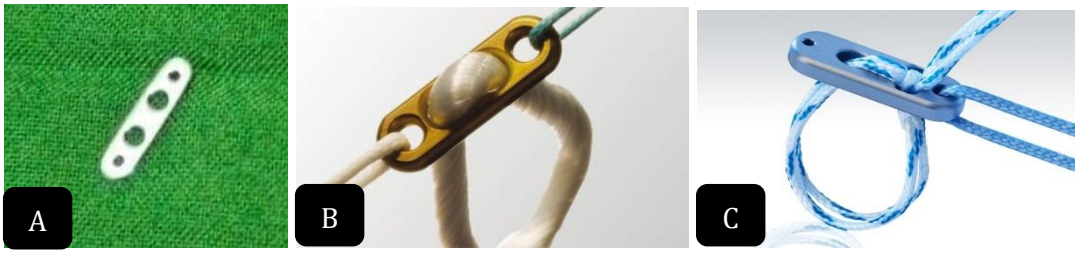

Figure 2. A. Button fixation; B. Button with fixed loop (Smith & Nephew EndoButton); C. Button with adjustable loop (GraftMax, ConMed)

Fixed-loop devices for graft fixation have stiffness levels similar to the native ACL, and they help reduce graft movement after surgery.[26] However, most failures with fixed loops occur due to suture loop breakage. One limitation is that they require precise tunnel length, which can affect bone preservation and graft healing.[25] Adjustable-loop devices offer flexibility by allowing surgeons to match different tunnel lengths and insert more graft into the tunnel. Failures in these devices are mostly due to tendon rupture, loop breakage, or slippage.[27] Overall, fixed-loop devices are considered biomechanically superior to adjustable-loop devices because they provide better initial stability and reduce graft slippage. In a systematic review comparing clinical outcomes between buttons and cross-pins, there was no significant difference assessed using the Lysholm score, IKDC (International Knee Documentation Committee) score and Tegner activity score parameters.[28]

In fixation with buttons, complications often occur in the form of early button flip and late button flip. In early button flip, the button flip occurs when the button is still in the femoral tunnel, causing the risk of graft failure. While in late button flip, the flip occurs in the soft tissue, causing soft tissue interpose between the button and the lateral femoral cortex. This can be prevented by performing graft tensioning with knee cycling.[29] Tunnel widening occurs more often when using buttons compared to cross-pins. Intratunnel graft movement can be classified into two types: longitudinal movement, known as the "bungee effect," and transverse movement, referred to as the "windshield wiper effect."[28] Fauno et al. observed that tunnel widening is more likely when the fixation point is located far from the joint. In addition to intratunnel graft motion, factors such as non-anatomical tunnel positioning and overly aggressive rehabilitation protocols can also contribute to tunnel enlargement.[30,31] Besides mechanical influences, biological factors also play a role in bone resorption, including osteoclast activation by mediators within the graft tunnel, non-specific inflammatory responses, and heat-induced necrosis caused by drilling.[32]

6.2. Screw

Screws are a fixation that is widely used in ACL surgery. Based on their material composition, screws are categorized as either metal (such as titanium or stainless steel) or biodegradable (including polylactic acid, poly-L-lactic acid, or polyglycolic acid). Biodegradable screws typically exhibit higher stiffness but lower ultimate failure load compared to metal screws.[33] Titanium screws tend to cause graft laceration from the screw threads, particularly on the femoral side compared to the tibial side. This suggests that biodegradable screws offer better biomechanical performance than titanium screws for fixing grafts.

Figure 3. Screw fixation. A. Metal screw (Arthrex); B. Bioabsorbable screw (LigaFix)

In terms of clinical outcomes, metal and biodegradable screws show comparable results based on IKDC scores, Lysholm scores, KT arthrometer measurements, and infection rates. However, patients with biodegradable screws experienced a higher incidence of knee effusion.[34] This is also in line with the meta-analysis by Xu et al., which showed no significant difference between metal and bioabsorbable screws on subjective knee function and knee laxity.[35] In a study comparing biodegradable screws and buttons, there was no significant difference in clinical outcomes at 24-40 month follow-up evaluation.[36] On the other hand, metal interference screws have a higher risk of ACL revision than other fixations within 2 years after surgery.[37]

In fixation using bioabsorable screws, the most common complications are screw breakage and screw malpositioned. To prevent this, when inserting the screw using a guide wire, if it feels hard, then try using a screw with a smaller diameter.[29] Meanwhile, with metal screws, complications can occur in the form of graft laceration, breakage of bone block, advancement of graft and incorrect screw placement.[38] The causes of screw migration are bone resorption, incorrect placement of the tunnel or screw, incomplete insertion of the screw, and secondary twisting injury.[16]

6.3. Pin

Cross-pins have been widely utilized for ACL graft fixation and are typically classified into corticocancellous suspensory devices (such as TransFix and Bio-TransFix) and cancellous suspensory devices (like RigidFix). While these devices offer superior failure loads and stiffness compared to other fixation methods, they are also associated with graft movement during cyclic loading, which can lead to tunnel widening due to intra-tunnel graft motion.[16] Graft slippage was found to be more pronounced with cancellous cross-pins and interference screws compared to button devices and corticocancellous cross-pins.[39,40]

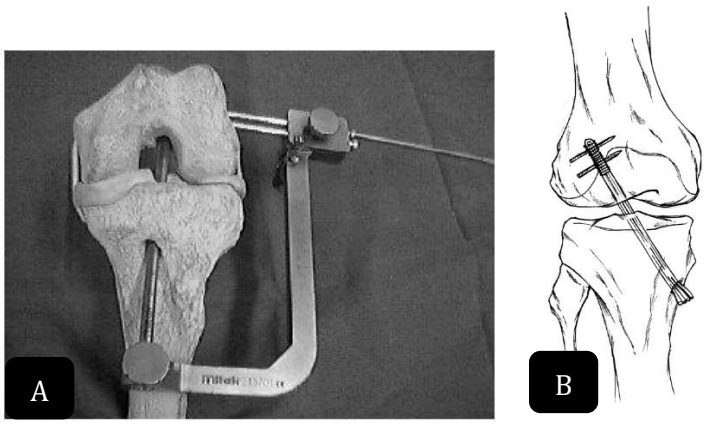

Figure 4. Cancellous cross-pin. A. RigidFix system[41]; B. Schematic vie of cross-pin in femoral tunnel[42]

In a study comparing cross-pin and biodegradable screw fixation, it was shown that there were no significant differences in the parameters of knee laxity, IKDC score, Tegner activity score and Lysholm score.[43] Cross-pins have a lower risk of early ACL revision compared to other fixations.[37] In a meta-analysis study comparing buttons and cross-pins, there was no significant difference in clinical outcome and postoperative knee laxity.[44] In another study, cortical suspensory fixation was found to have a significantly increased risk of revision, while intratunnel transfixation demonstrated a lower risk of revision.[45]

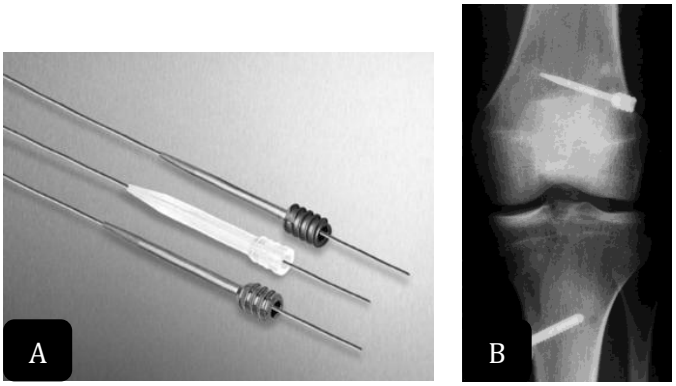

Figure 5. Corticocancellous cross-pin. A. TransFix and Bio-TransFix; B. Xray showing corticocancellous cross-pin fixation in femoral tunnel[46]

A common complication of fixation using cross pins is inaccurate cross-pin positioning.[16] This can cause less fixation of the graft, which will result in graft failure. To prevent this, direct vision verification can be performed, or by using 2 wires inserted from the cross pin site and from the femoral tunnel, resulting in metal to metal feeling.[29] Cross-pins have been linked to several complications, including pin migration, supracondylar fractures, and iliotibial band (ITB) friction syndrome. Due to these risks, many surgeons now favor using button-based fixation methods instead.[47,48]

6.4. Staple

Staple is the first fixation used in ACL surgery.[23] Staple can act as aperture fixation or suspensory fixation. As aperture fixation, staple is placed on the tunnel to make the graft fixated with the tunnel. While as suspensory fixation, staple is placed on the cortex, the outer side of the tunnel, so that the graft is fixed on the outer side of the tunnel. One of indication of using staple is graft tunnel length mismatch.[49] This staple can also be used as a supplementary fixation in ACL surgery, usually combined with interference screws. However, the study stated that the use of staples as supplementary fixation is not routinely done and does not provide significant benefits, instead there is a risk of symptomatic hardware problems.[50] In another study, it was shown that the use of staples would increase the pain scale in patients and there was no significant difference in clinical and functional outcomes between the staple group and non-staple groups.[51,52]

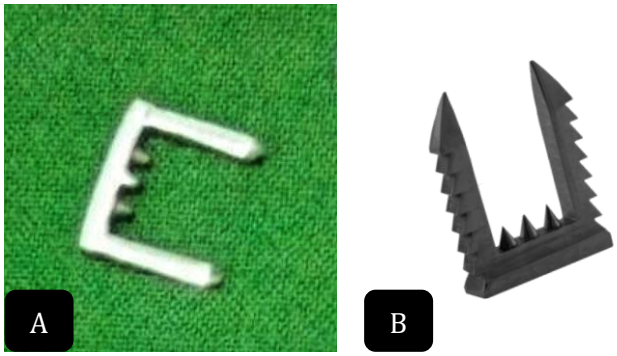

Figure 6. Staple fixation. A. Stainless steel staple; B. Titanium staple (Hardik)

Staple fixation has fixation strength comparable to interference screw and failure load is sufficient to withstand graft load during rehabilitation period.[53] Using a single staple to fix a semitendinosus tendon graft provides limited strength and stiffness. However, the use of a second staple to create a "belt-buckle" configuration significantly enhances fixation, as demonstrated in a porcine model, with a reported failure load of 705 N and stiffness of 174 N/mm. Despite this improved biomechanical performance, staples are often associated with postoperative pain at the implantation site and may require removal.[49]

6.5. Staple Anchor

Staple anchor is a modified fixation using staples plus compression from screws, thereby strengthening the pull-off strength of the graft. This fixation is made of stainless steel (SS316L), so in terms of cost it is superior to other fixations. However, there is still little research data on this type of fixation.

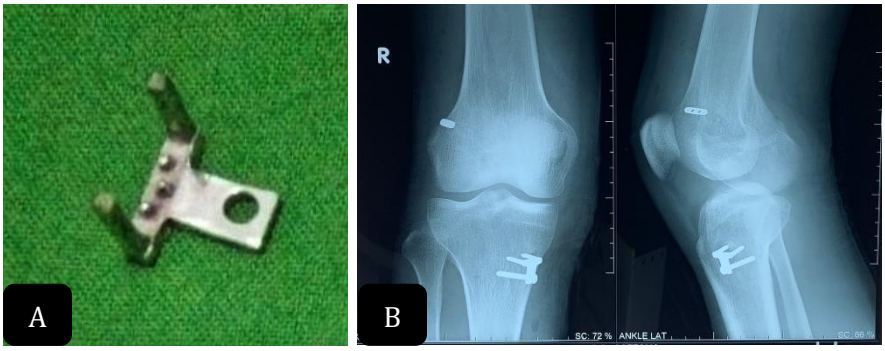

Figure 7. Staple anchor fixation. A. Staple anchor device; B. Xray showing button fixation for femoral tunnel and staple anchor fixation for tibial tunnel

Complications that can occur are prominent implant, implant breakage or migration, infection, complex regional pain syndrome and arthrofibrosis. For prominent implants, it usually occurs in fixation with screws, staples or staple anchors, while other complications can occur in all types of fixation.[29]

7. FUTURE TRENDS

Emerging bio-enhancement techniques are poised to revolutionize ACL fixation by promoting graft–bone integration, accelerating ligamentization, and strengthening early-phase mechanical resilience. Bio-enhancement yang dapat digunakan berupa growth factors, gene therapy (BMP-2 gene), biomaterials (collagen matrix, hyaluronic acid, bioglass) dan multi or pluripotent cells.[54] Platelet-rich plasma (PRP), rich in growth factors like PDGF, VEGF, and TGF-β, has shown promising results in preclinical and small clinical studies by enhancing vascularization and graft maturation at the graft–bone interface.[55] Additionally, calcium-phosphate or hydroxyapatite hybridization of grafts has demonstrated reduced tunnel widening and improved knee laxity with stronger radiographic incorporation in RCTs. A sophisticated future direction lies in multiphasic scaffolds and nanomaterial coatings, which can support zonal differentiation and enhance osseointegration and mechanical continuity at the tendon–bone interface.[56] Collectively, these innovations informed by biomaterials and tissue engineering may bridge the gap between early mechanical fixation and long-term biological healing in ACL reconstruction.

8. CONCLUSION

No single graft fixation method reigns supreme for all ACL reconstruction scenarios. Cross-pins rank highest overall on objective metrics, with interference screws and suspensory devices also delivering strong results depending on surgeon preference, graft type, and contextual variables. Hybrid techniques incorporating staple anchors or combination hardware further optimize graft stability, especially in anatomically or biomechanically.

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