TEACHING TECHNIQUES

Prolotherapy Under C-Arm Fluoroscopy

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Interventional pain management traditionally has focused on the use of C-arm fluoroscopy to inject the spine. Fluoroscopy is a real time X-ray designed to allow the physician to guide a needle into a specific location. (*See Figure 1.*) While Prolotherapy has been performed without the use of imaging guidance, our training in pain management lent itself to using this technology for certain Prolotherapy techniques.

Like many physicians practicing regenerative medicine, our interest in Prolotherapy began because of our general dissatisfaction with the results of injecting steroids. In addition, we were also concerned about the body of literature that demonstrated that injecting high dose steroids (milligram range) could lead to problems in the joint.[1-5] This phenomenon, known as apoptosis, means that these medications can shut down all normal repair and maintenance functions in the joint for months, ultimately leading to a less swollen, but more degenerated joint.[3] In addition, high dose corticosteroids have also been shown to cause other issues such as systemic side effects and even catastrophic illnesses such as osteonecrosis.[6]

Osteonecrosis *– Loss of blood supply to bone leading to the death of bone tissue.*

One solution to this problem is simple, inject much less steroid. In lower concentrations (nanogram range), corticosteroids can have a net positive joint impact (by up regulating TGF-beta production and moving mesenchymal stem cells toward chondrogenic differentiation).[7] Despite this modification of the steroid injection, our practice began looking for better options. While Prolotherapy has been considered by some to be controversial, the data supporting the use of hyper-osmolar agents in injection therapy (the medication used in most Prolotherapy solutions) is as good as many of the techniques and procedures used every day in interventional pain management. This led our group to consider combining the use of proliferant injections with our core competency of interventional pain management (driving needles under X-ray).

Figure 1. C-arm fluoroscope that allows accurate guidance of a needle to a specific location.

C-arm fluoroscopy has been used for many years for needle guidance. Its advantage over fixed radiography (usual X-ray techniques performed in a hospital) is 360 degree coverage of any area to be injected and its ability to show live imaging. Its disadvantage is radiation exposure. However, the average radiation exposure during fluoroscopy is on the order of 5-10 cross country plane flights (where the high altitude exposes us to X-ray radiation from the sun).

The C-arm is commonly used with the image intensifier (I.I.) superior and the X-ray generator inferior or under the table. The standard lexicon of C-arm positioning uses many familiar terms from standard radiography with additional language to cover dynamic positioning of the beam. This includes AP, lateral, and oblique, but adds in C-arm motion terms which include orbital rotation (moving the C-arm around a fixed target, also called oblique), cephalad tilt (tilting the I.I. toward the head), caudal tilt (tilting the I.I. toward the feet), and the concept of "wig-wag" or moving the C-arm from a fixed point at the connection of the "C" to the machine in an angle cephalad to caudal (for a prone lying patient) or vice versa. (*See Figure 2.*)

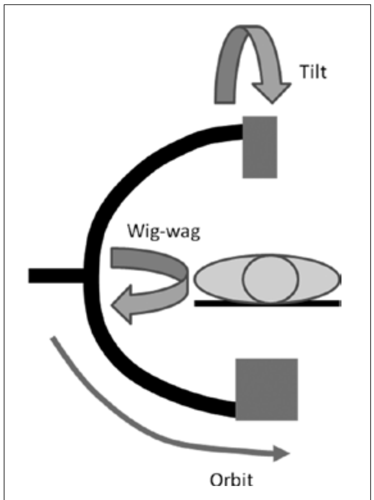

Figure 2. C-arm movements.

The needle is usually imaged "down the beam" (looking down the hub of the needle). The needle can also be imaged "off axis" (looking at the length of the needle at an angle). Two images are often used to confirm final needle placement, such as AP and lateral. This is known as "bi-planar" imaging. In addition, radiographic contrast agents are always used to confirm dye flow (these are substances that show up on X-ray as dark, so that the physician knows where the medication will flow). I have heard experienced radiographic technicians refer to this as "the dye doesn't lie", meaning that correct placement of the medication is always determined by dye flow in the target space, such as intraarticular. Thus, it's imperative to not only learn how to place the needle safely and accurately, but also to learn the correct dye flow pattern for each area injected.

ACCESSING INTRAARTICULAR LIGAMENTS WITH FLUOROSCOPY

Ligaments are the duct tape of the body. They help hold bones and joints together. Several joints in the body have important ligaments inside the joint. These include the C0-C1 facet joint (top neck joint just below the skull), the knee, and the sacro-iliac joint (joint between the back of the hip and tailbone). Many of these ligaments serve important stability functions like the cruciates in the knee or serve as "last resort" attachments to prevent catastrophic failure, like the interosseous ligaments inside the SI joint. The upper cervical ligaments are unique in that they seem to serve both functions.[8-11]

The C0-C1 facet is a joint about the size of a large finger joint. (*See Figure 3.*) There are actually 7 neck facet joints on each side. These can be commonly injured in a rear

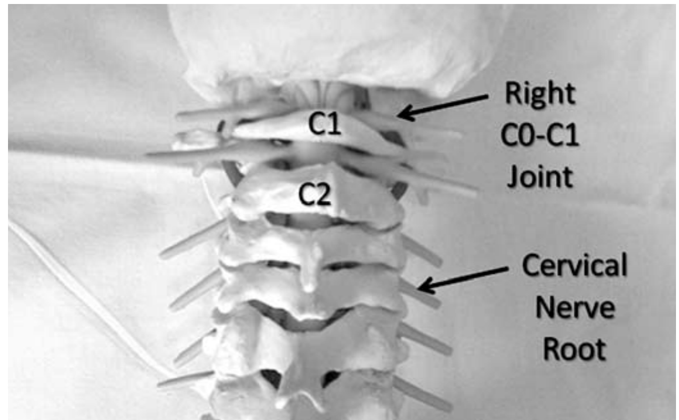

Figure 3. Diagram of C0-C1 joint location.

end or other type of car crash.[12] The upper neck joints tend to be injured along with the ligaments that hold the head on.[13] These important ligaments include the alar, transverse, and accessory. Like other ligaments, when they are injured, they often fail to heal. The alar ligament courses through a part of the C0-C1 facet joint, so they are commonly injured together. Symptoms from this type of injury can include headaches, dizziness, disorientation, and pain at the base of the skull into the neck. Numbness and tingling in the extremities can also be present.

INJECTING THE C0-C1 JOINT

The C0-C1 joint is a good example of a joint that very difficult to access reliably without imaging guidance. (*See Figure 4.*) The vertebral artery runs close to the joint and its location anterior to the spinal cord makes injecting the joint blind a challenge. However, the medial joint also houses a portion of the alar ligament, which is an important ligament as discussed above.[13]

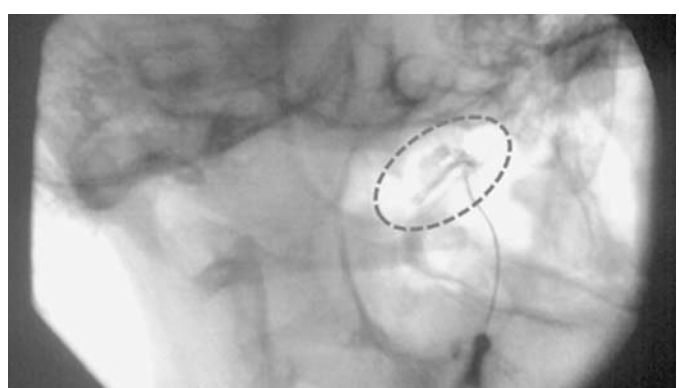

Figure 4. Contrast flow inside the C0-C1 joint. Note the needle entering the joint from below. Contrast flow is oblique along the joint line (dashed circle).

Why inject this joint to get to the alar ligament at all? Despite some minor risks, in the hands of an experienced interventionalist, complications are very rare. Our own practice has injected hundreds of C0-C1 joints without incident. In addition, my own clinical experience shows that patients with alar ligament stretch and sub failure injuries are miserable. Because the ligamentous checks to upper cervical stability are lost, the upper cervical muscles and trapezii go into overdrive, trying to act as stabilizers. This leads to significant neck, shoulder, and upper back pain. While surgical fusion is an option, the surgery has a high complication and mortality rate.[14] As a result, stiffening and initiating even a small repair response in the ligament can lead to dramatic benefits for the patient.

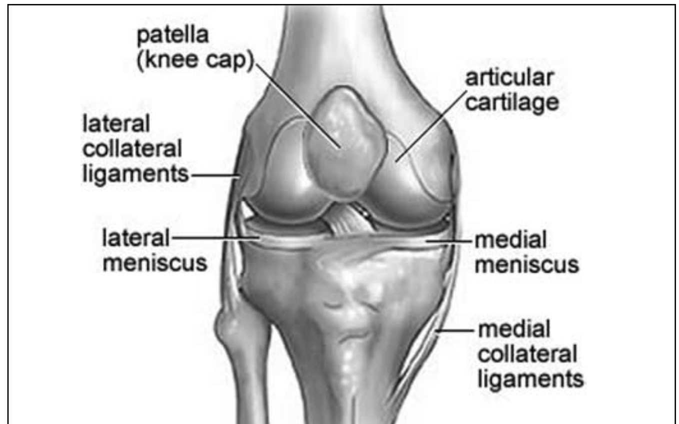

Figure 5. Right knee joint anatomy.

KNEE JOINT INJECTIONS

Traditional Prolotherapy injections for the knee usually involve injecting many tender sites around the knee including the collateral ligaments, pes anserine bursa area, or the knee cap. These parts of the knee anatomy can be injected without injecting inside the joint. However, if injection inside the joint is needed to treat a lax ACL as in the techniques described by Reeves, then being "in the joint" becomes important.[15,16] The knee would seem to be a simple joint to inject. However, when this assertion has been tested to see determine the accuracy of blind injections, different studies obtain different results. Lopes determined that blind injection of various peripheral joints of rheumatoid arthritis patients has an accuracy of 77-100%.[17] Toda further characterized accuracy as between 55-100% depending on the severity of the osteoarthritis.[18] Esenyel reported even lower accuracy, with only 56-85% of the injections getting the medicine in the joint, depending on the side of the anterior injection portal (medial or lateral).

Even if the practitioner can approach 100% accuracy, newer regenerative medicine techniques (more on this later) will require more accurate placement of cells or agents in specific parts of the joint (such as into the meniscal tissue, LCL, ACL, or medial chondral surface). In addition, even sclerosants have been determined to have much greater action at their initial injection site with declining effects as the distance from the site increases. We have developed many techniques depending on the structures being treated.

The knee has many parts. (*See Figure 5.*) The long bone of the thigh (femur) has its ends (the top part of the knee joint), covered with cartilage (called articular or chondral cartilage). This surface can commonly be injured and develop a "pot hole" in the cartilage which is also called an OCD (osteochondral defect). The meniscus acts as the shock absorber tissues between the femur and tibia bone. Finally, there are cruciate ligaments in the middle of the knee that hold the two bones together in a front back direction and collateral ligaments on the inside/outside of the knee that hold it together in the side to side direction.

The knee articular surfaces are easily injected with the knee flexed about 90 degrees. This position brings the weight bearing surface anterior. A lateral knee view is then developed on the C-arm, with both chrondral surfaces aligned by adjusting wig-wag. (*See Figure 6.*) The injection

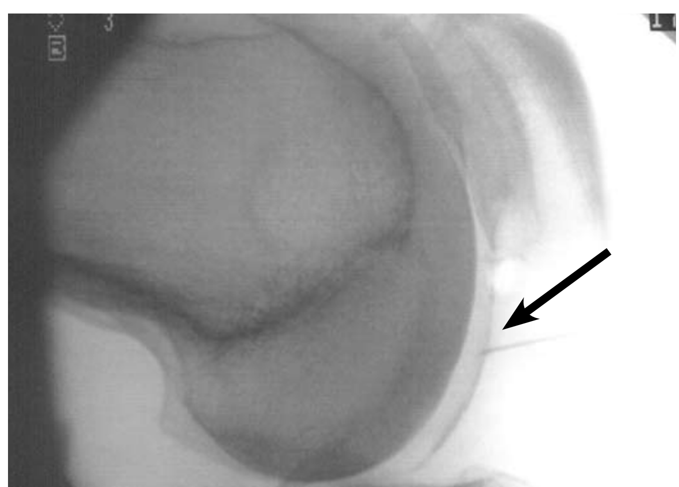

Figure 6. Anterior needle placement just lateral to the patella and directed perpendicular to the chondral surfaces. Note the contrast flow along the weight bearing chondral surface of the femur.

is begun just lateral or medial to the patella and directed toward the palpable chondral surface. Once the cartilage is lightly struck, the needle is pulled back slightly and a loss of resistance technique is used to ensure maximum chondral flow of contrast and injectate. This injection can be done in most patients with just a 27 gauge 1.5 inch or a 25 gauge 2 inch needle.

Injecting the knee through the usual anterior medial and lateral ports just inferior to the patella will usually result in more medial flow of contrast in the joint. (*See Figure 7.*) This approach is therefore preferred for access to the ACL and PCL. Fluoro also allows the ability to determine dye flow into the ACL or PCL once the sheath is penetrated.

In summary, depending on where the effect is desired, using C-arm guidance allows the physician to place the medication in the right spot. (*See Figure 8.*) As discussed, treating the "potholes" (OCD's) in the articular cartilage requires a different approach than treating the ligaments (ACL or PCL) in the middle of the knee.

Figure 7. Typical anterior medial or lateral injection ports more likely to produce mid-line flow of contrast and medication to treat ACL/PCL.

Figure 8. Sunrise view fluoroscopy for patella-femoral injection.

INTRAARTICULAR SI JOINT INJECTION

SI joint pain is present in between 18.5-30% of patients presenting with chronic low back pain.[19-24] Laxity in this joint has been also associated with back pain.[25-27] SI joint symptoms include pain in the back of the hip (PSIS area) often with pain in the groin and down the front of the thigh. Various SI joint ligaments can also mimic referred pain down the leg and into the foot. The "Fortin finger test" is usually present where the patient points to the PSIS area as the point of maximum pain.

The SI joint is another example of a joint with a strong ligament inside (interosseous). The joint is not perilous to access blindly, but very difficult to do so with any reliability. As an example, as an experienced interventionalist, the number of physicians able to access the joint and obtain good intraarticular flow even with fluoroscopic guidance is small.[28] While many believe they can access the joint without imaging, in cadaver courses where we have tested this ability, a large number of attempts fail to establish convincing flow of contrast within the confines of the joint.

The starting point on the skin for injecting the SI joint is usually the bottom of the sacrum. The needle is inserted under fluoroscopy guidance. From this point, our technique for SI joint injection under fluoroscopy differs from those usually described. We enter the lower part of the SI joint similar to other techniques, but recognize that the SI joint is a potential space. As a result, a 22 gauge needle 3.5 inch quinke is used (over a 25 gauge needle) to dilate the lower portion of the joint. The fluoroscope beam is tilted cephald so that the lower portion of the joint can be imaged with the beam "looking down" the lower joint. As with any other technique, more time is spent with image prep than injection. The C-arm is orbited back and forth such that both sides of the lower joint are crisp. This injection technique relies on the idea that small changes in the depth of the injection can lead to dramatic improvement in contrast flow. (*See Figure 9.*) As a result, the needle is inserted into the joint lucency until "articular slide" is appreciated. This is a tactile feel whereby the needle starts to slide or glide as

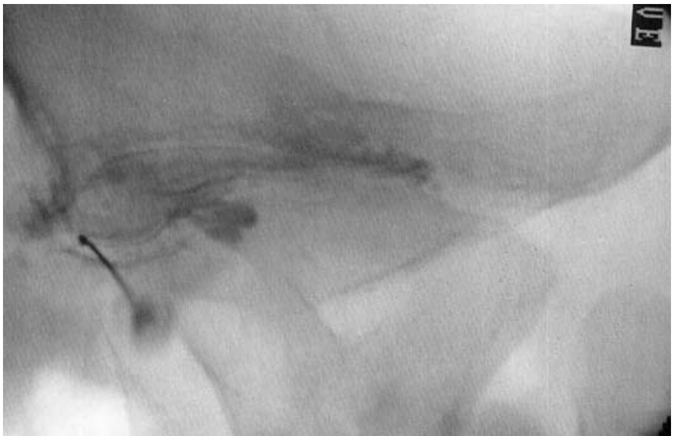

Figure 9. Contrast flow within the left SI joint. Note the medial and lateral visible joint lines.

if between two lubricated joint surfaces. Once the needle has been inserted approximated 1-2 cm into the joint, the injectionist attempts to inject contrast under only light to moderate pressure. Usually no immediate contrast flow will be detected in the joint (in my experience less than 10-20% of the time) and the plunger of the needle will fail to budge. To reduce fluoroscope exposure, the needle is then very slowly extracted while the injectionist turns his or her attention from the fluoroscope screen to the syringe. Without any imaging, while the needle is very slowly extracted, the physician continues to apply light to moderate pressure to the plunger. Once a significant loss of resistance is seen in the syringe, the physician injects ¼ cc of contrast and checks the fluoroscope image. If an arthrogram is not detected, the needle continues to be slowly withdrawn until one is detected or the needle needs to be reinserted for a second pass. Please realize that the needle extraction occurs millimeter by millimeter as often flow will be obtained at a very specific point (for instance at 6 mm of extraction but not until this exact point has been reached). As a result, think of this technique as similar to other loss of resistance techniques.

Why does this technique work? The SI joint is a very tortuous joint that is different in most patients.[4] As a result, the needle often ends up against cartilage or bone and is unable to transmit contrast into the joint. In addition, as the needle is extracted, it can be freed of local impediments to flow yet remains in the joint capsule. Our group has also had great success with the same technique applied to cervical facet injections. Again, here as with the SI technique, the needle often remains in the capsule but actually leaves the space between joint surfaces.

We have found that many patients, who fail to respond to injecting the SI joint ligaments using the traditional Prolotherapy techniques described by Hackett, often get relief with this X-ray guided technique. These are usually patients with more severe instability that involves damage to the interosseous ligaments.

CONFIRMING TENDON ORIGINS/INSERTIONS BY IMAGING THEIR BONY LANDMARKS

Muscles move our joints. To do that, they need a place on the bone to anchor (origin) and a place to attach (insertion). Many of the original Hackett points for Prolotherapy involved injecting tendon origins or insertions (enthesis). While many of these are easily accessible, I have found fluoroscopy very helpful for imaging deeper landmarks where incorrect needle position could cause unintended injury. While many of these areas can be easily accessed in thin patients, obese or heavily muscled subjects can be difficult to accurately inject. I have outlined three areas where I have seen fluoroscopy improve clinical outcomes:

1. Adductor origin at the ischial tuberosity
2. Rib origin/insertions of paraspinal muscles
3. Superior labral attachment of the biceps tendon

ADDUCTOR ORIGIN AT THE ISCHIAL TUBEROSITY

Enthesopathy of the adductor origin is a common problem in athletes. Enthesopathy means that the area where a muscle or tendon attaches to bone is being overloaded (which leads to chronic swelling at that attachment site). Our own clinical experience shows it's also common in patients with chronic SI instability and those with upper lumbar radiculitis. Early clinical data has shown Prolotherapy to be effective for this condition.[29] Patients with this problem often have significant groin pain that may extend to the inside of the knee.

The adductor muscle is illustrated in *Figure 10*. Note how the muscle originates from the groin area and travels down toward the inside of the upper thigh and knee. In *Figure 11*, the areas of attachment of the various muscles of the adductor complex are illustrated. The adductor group origin including the magnus, longus, and brevis as well as the garcilis can be injected at the tuberosity of the ishium. However, a stray needle in a heavy patient could also end up injuring many structures in the perineum or bladder. As a result, we utilize a contralateral oblique

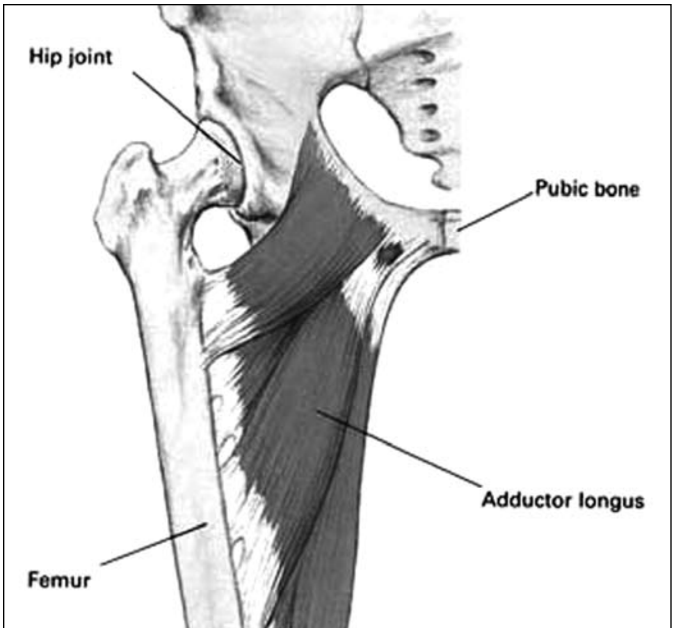

Figure 10. Adductor muscle complex.

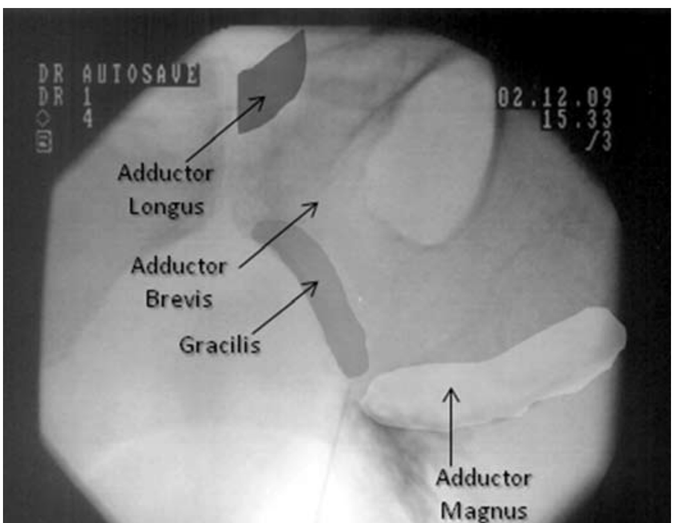

Figure 11. The attachments of the adductor group of muscles on the left ischial tuberosity with a needle shown injecting contrast and medication into the adductor magnus attachment.

angle on the C-arm and use manual pressure to find the bony prominence of the tuberosity in the A-P plane. The patient is positioned supine on a fluoroscopy table with the hip to be injected slightly abducted. By flipping between a contralateral oblique and an AP view, we obtain easy bi-planar imaging to guide the needle to its bony target without posterior overshoot. *Figure 11* also shows an AP demonstrating dye flow in the origin of the adductor magnus and gracilis. Note that the pubic symphysis is easy visible on an AP view and can be injected as well. *Figure 12* shows a contralateral oblique of the same injection site, where the C-arm is approximately at 35 degrees of rotation opposite to the side injected. Note the fact that the ischial tuberosity is seen "on end" in this projection.

RIB TENDON ORIGIN/INSERTION INJECTION

We see many patients with rib related pain after car crashes, as a result of surgeries where the ribs have been manipulated, or due to scoliosis. The pain is usually along the rib and can travel along its course. While many of these pain syndromes are due to enthesopathy, many are misdiagnosed as costochondritis. *Figure 13* shows just a few of the attachment points of the muscles to the rib cage.

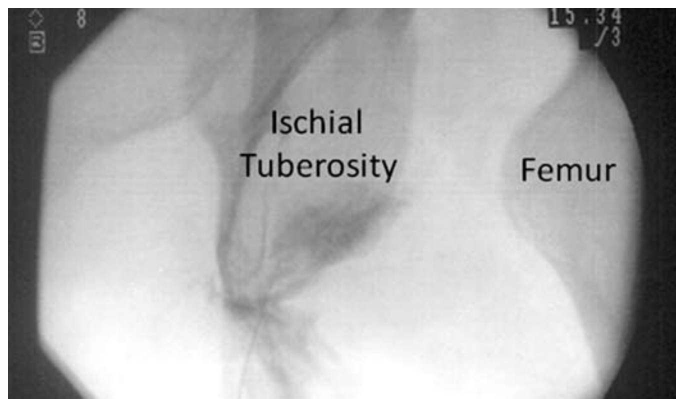

Figure 12. A left contralateral oblique of the right ischial tuberosity showing it "on end" with a needle touching bone at the inferior end of the tuberosity.

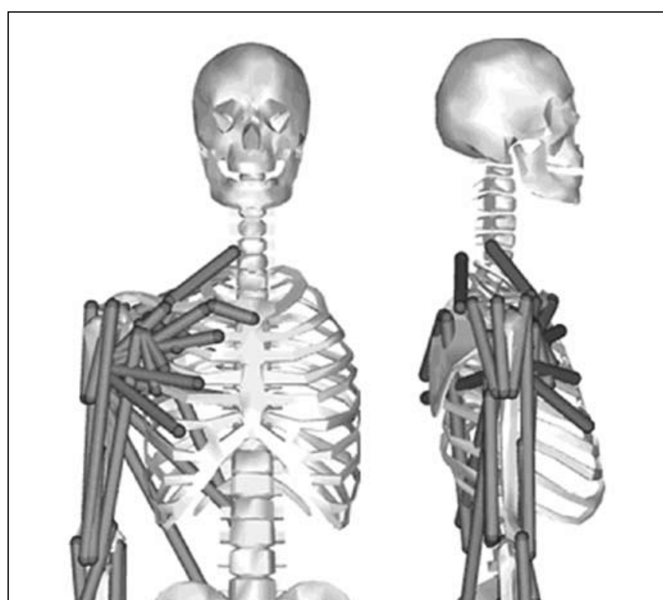
Figure 13. Attachment sites of muscles to the rib cage.

Injecting painful areas of enthesopathy from paraspinal muscles that insert on the ribs can be a very successful treatment for many patients with chronic upper back and rib pain. However, in patients who are obese, the fear of lung puncture with resultant pneumothorax has driven me to utilize AP fluoroscopy. *Figure 14* shows that in AP view, the ribs are easily visible. As the injection site moves more lateral along the rib, I usually add ipsilateral oblique to ensure that the target rib is easily visible so that the needle direction is horizontal to the direction of the beam. Points along the anterior chest can be similarly imaged if needed. In addition, points along the mid-axillary line require the patient to be side lying and the beam to be positioned AP. Finally, with AP fluoroscopy, the ligaments attaching the rib to the transverse process can be easily and safely injected.

Figure 14. An AP of the thorax showing easily visible ribs and a needle "touching down" on the medial aspect of the right 4th rib.

SUPERIOR ATTACHMENT OF THE BICEPS TENDON TO THE LABRUM-SLAP TEARS

The biceps muscle attaches itself to the top of the shoulder joint (superior labrum), where it can become torn. Most patients have pain with lifting the shoulder forward, made worse by a palm up maneuver where the biceps tendon is stressed. *Figure 15* shows the glenoid fossa (the socket part of the ball and socket joint of the shoulder) looking into the joint. The SLAP tear is shown at the superior (top) part of the labrum. The best way to visualize the labrum is that it's the lip around the socket where the ball of the shoulder joints fits. A sudden shift of the ball in this socket joint can injure this fibro-cartilage lip (labrum).

Many different types of tears to this attachment have been described.[30] Type 1 is by far the most prevalent,

Figure 15. Tear of the superior labrum.

which involves a non-displaced fraying or injury to the biceps attachment and is often associated with rotator cuff tears. While our surgical colleagues commonly debride these under arthroscopy, we have had good success with Prolotherapy injections at the attachment using fluoroscopy to identify the target area. While types 2-4 which involve more detachment may be more difficult to treat, we have also seen some success with these cases as well.

Setting up this injection involves knowledge that the glenoid fossa faces anterior. As such, an ipsilateral oblique will show the labrum as a clock face. (*See Figure 16.*) The needle is then directed toward the outer rim of the

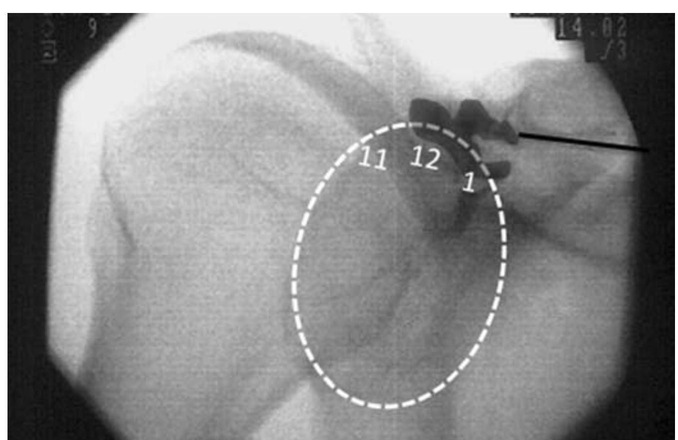

Figure 16. An ipsilateral oblique of the left shoulder showing the glenoid fossa as a clock face (outlined in the dashed circle). The injection targets for most SLAP tears are the 11am-1pm positions. This is an off-axis view.

glenoid labrum from the 11-1 o'clock positions. This area can be injected with contrast to confirm flow along the more proximal biceps tendon origin. Flow can also be demonstrated along the more distal biceps tendon as seen in *Figure 17*.

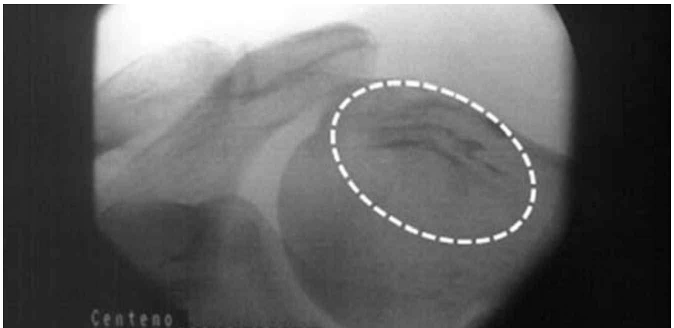

Figure 17. A right shoulder AP showing the dye flow along the right biceps tendon as it traverses just lateral to the greater tuberosity in the biceps groove of the humerus.

THE CERVICAL SPINE-MAKING YOUR LIFE EASIER

Cervical ligament injuries are common in car crash victims who have been diagnosed with "whiplash."[10,13, 31-37] While this catch all, pejorative term doesn't allow for this more specific diagnosis, we have seen dramatic results from patients who have been treated with cervical Prolotherapy. These patients commonly have instability symptoms like popping and cracking in the neck. Often times these sounds cause pain.

I remember the first time an experienced Prolotherapist showed me her injection technique for the cervical spine. She flexed the neck over a chest pillow and had the patient bring the chin to the chest to bring the spinous processes (SP's) more superficial. She then proceeded to use what I called the "hunt and peck" technique, trying to find the cervical SP's. This worked for this experienced practitioner, but the first time I attempted this in the office, I was likely injecting far too superficial to make a difference (out of fear of placing the needle into the epidural space or worse). After attending a scientific conference where an experienced interventional pain physician described a cervical cord injury and resultant quadriplegia from a blind trigger point injection with a 1.5 inch needle, I became even more concerned. While I have safely injected the supraspinous and interspinous ligaments in this area without fluoro, I have recently adopted a technique for use in larger patients that has improved the coverage of these ligaments.

The patient is positioned prone on a fluoroscopy table. The C-arm beam is lateral so that the SP's are easily visible. Manual palpation is then used (as in the original Hackett technique) and the needle position remains midline, but the lateral X-ray image is used to guide the needle to the posterior aspect of spinous process. (*See Figure 18*.) I find that while my blind technique might have me injecting 3-4 of the 7 SP's available to treat, with this fluoroscopy procedure I can now safely inject all of his SP's. I can also specifically target the SP's associated with laxity in flexion on flexion-extension views or Digital Motion X-ray (DMX). In addition, note that in *Figure 19*, the dashed line represents the ligamentum flavum which should not be penetrated. This also allows the Prolotherapist to get deeper coverage of the interspinous ligament, without fear of an epidural or intra-dural injection.

Figure 18. The injection technique for injecting cervical interspinous and supraspinous ligaments under fluoroscopy. The patient is shown prone and the needle is inserted posterior in the midline with the fluoroscopy unit in lateral view.

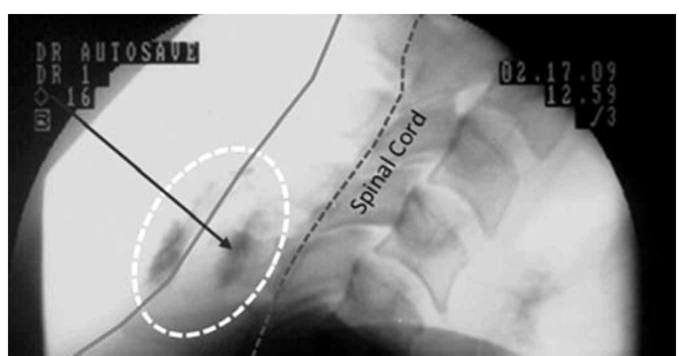

Figure 19. A lateral view c-spine showing the needle position enhanced by the black arrow and the level of the supraspinous ligament denoted by the gray line. The dashed line represents the level of the ligamentum flavum, which should not be penetrated by the advancing needle.

Does the traditional Hackett technique of injecting the supraspinous and interspinous ligaments help cervical instability? Several years ago we tested this theory by measuring cervical translational instability as in *Figure 20*. We used cervical flexion-extension views where the film reader was blinded to which films were pre or post Prolotherapy. Our study showed significant decreases in cervical flexion translation after treatment, but not for translation in extension.[38] This made sense, as only the checks to flexion were treated (supraspinous and interspinous ligaments) and not the checks to extension (anterior longitudinal ligament).

The patient is set up identically as above, and palpation is still used to confirm mid-line and start needle placement. An AP with a cephalic tilt can also be used to confirm that the needle is midline. Contrast can also be used to identify the location of the posterior atlanto-occipital membrane (PAOM) without injecting intra-dural or epidural. If contrast is detected anterior to the line of the PAOM in the epidural space, no injection of proliferant is undertaken (anterior to the dashed line in *Figure 20*). Since the rectus capitus posterior minor may be an important muscle in headache generation due to its attachment to the dura, injecting these sub occipital muscle attachments is clinically important.[39-42] This same injection technique can also be used to inject deeper sub occipital and cervical muscles (rectus capitus posterior major and minor) that attach at the skull base while confirming that the needle placement is not near the foramen magnum.

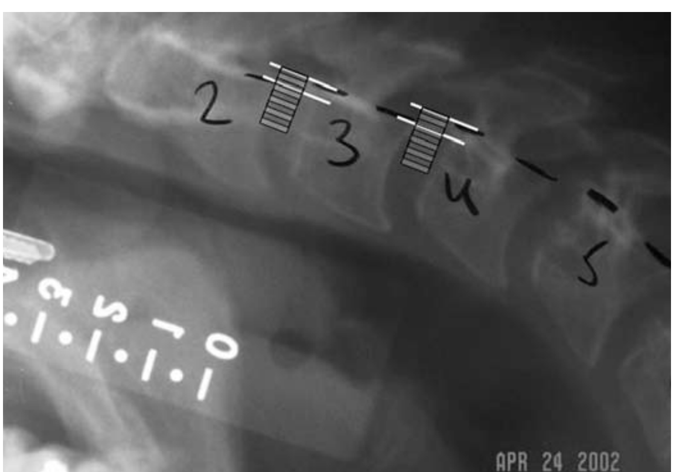

Figure 20. Cervical translation measured in mm (shown as vertical marks). Note the radiographic ruler in the field (lower left) which is used to benchmark the 1 cm distance at this magnification. There is 2-3 mm of anterolisthesis of C2 on C3 and 3-4 mm at C3 on C4.

This lateral fluoroscopy technique has also opened up a new area of injection. The posterior aspect of C2 is easily injected blind in thin patients, but heavier patients rarely have this area injected. This site is not only the attachment of the nuchal ligament, but also of many smaller sub occipital muscles prone to enthesopathy. The posterior aspect of C1 is another example of a bony landmark tied into this rich area of ligamentous stability for the upper neck, being attached to the posterior atlanto-occipital membrane (an extension of the ligamentum flavum that reaches into the posterior aspect of the foramen magnum) as well as the ligamentum nuchae. (*See Figure 21.*) Again, because of the risk of injury to the patient, rarely is the posterior aspect of C1 injected. However, a lateral fluoroscopy view makes these areas safely accessible.

NEEDLE DRIVING SKILLS

Driving long needles under fluoroscopy is harder than it looks. The first several dozen times it will prove more difficult than blind injections and anatomical orientation as well as recognition of bony landmarks will prove difficult. However, once learned, the skills developed are

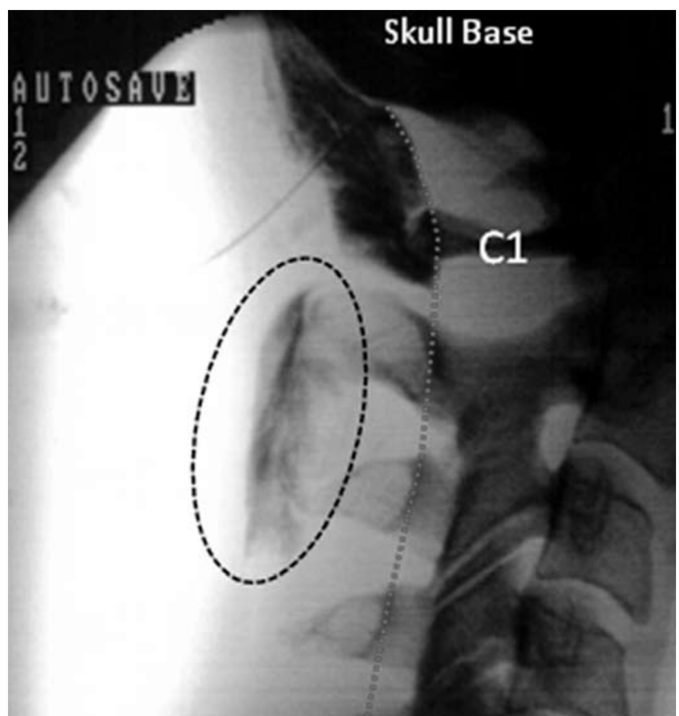

Figure 21. Cervical lateral view showing contrast in the area of the nuchal ligament (posterior to C1). Note the contrast also in the supraspinous ligament of the C2-C3 vertebra (dashed black circle). The dashed line represents the level of the ligamentum flavum and then the posterior atlanto-occipital membrane from C1-C0.

invaluable. Our group believes that medicine is on the verge of a great renaissance in regenerative injection therapy that will require the accurate placement of growth factors, stem cells, and other agents. In our practice, we have demonstrated MRI evidence of repair of various musculoskeletal tissues with accurate placement of mesenchymal stem cells (MSC) into peripheral joints.[43,44] We have also observed regeneration of the posterior disc annulus with reduction in disc bulge size as well as the healing of chronic fracture non-union using highly accurate placement of MSC's under C-arm guidance. (*See Figures 22 & 23.*) These new autologous cell based procedures have allowed us to add a state of the art cell biology facility to our practice. This is important to note as it represents what I call "Prolotherapy 2.0 and 3.0". Regardless of the injectate, whether it be autologous cells, off the shelf cells, autologous or recombinant growth factors, or biologic scaffolding, the need for accurate placement of these substances will be more important. While fluoroscopy will eventually be replaced by newer high-frequency, low-intensity computer enhanced radiography, "needle driving" skills to make these regenerative medicine techniques successful will be in high demand. As a result, I would encourage all Prolotherapists who are early in their careers and amenable to learning a new skill set to consider interventional pain training. While ultrasonography has some advantages over C-arm including the ability to better visualize soft tissues and avoiding ionizing radiation exposure, as discussed above, the next generation of high frequency X-ray technology will solve these issues, making this high frequency fluoroscopy the future needle guidance tool of choice for most deep injection applications. Groups such as The International Spinal Injection Society (www.spinalinjection.com) and the American Society of Interventional Pain Physicians (www.asipp.org) offer excellent course work and certification programs. We are also happy to help in educating Prolotherapists who have taken this formal training, further hone their needle driving skills. ■

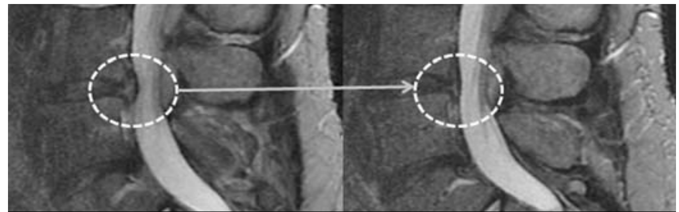

Figure 22. L4-L5 sub-ligamentous disc extrusion before and 3 months after placement of autologous MSC's in the disc via fluoroscopy.

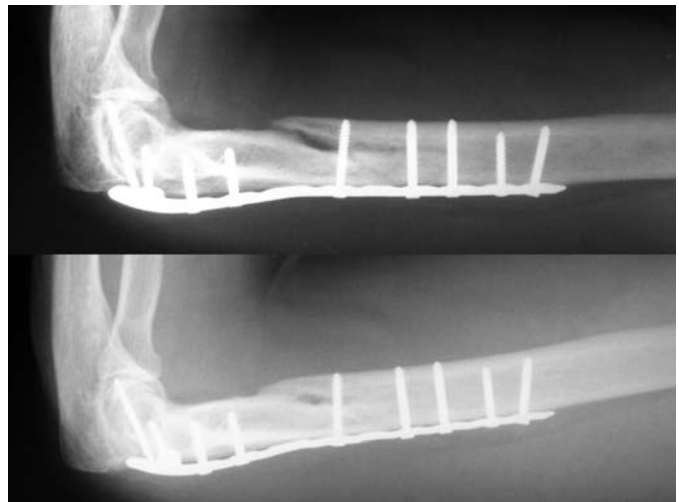

Figure 23. 38 yo white female smoker s/p ORIF for distal humerus fracture who failed a bone stimulator and was treated with percutaneously implanted MSC's into the fracture line. Five week post-op film on bottom showing healed fracture.

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