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REGIONAL ANESTHESIA (P KUKREJA, SECTION EDITOR)

Upper Limb Blocks: Advances in Anesthesiology Research

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Abstract

Purpose of Review To summarize the recent literature regarding regional anesthesia of the upper extremity.

Recent Findings Brachial plexus anatomy is more variable than previously believed. Several novel techniques for upper extremity blockade have been recently described. The ability of local anesthetic adjuvants and liposomal bupivacaine to prolong block duration has been investigated with mixed results. Regional anesthesia has played an important role in the expansion of ambulatory upper extremity surgery, especially shoulder arthroscopy and arthroplasty. Knowledge about the management of local anesthetic systemic toxicity remains essential for the safe performance of upper extremity blocks.

Summary The widespread adoption of ultrasound guidance for nerve blocks and the increasing emphasis on value in healthcare have fostered numerous innovations in regional anesthesia of the upper extremity in recent years. Further research is needed to determine the best technique for diaphragm-sparing shoulder analgesia and the most appropriate role for liposomal bupivacaine.

Keywords Regional anesthesia · Peripheral nerve block · Upper extremity block · Upper limb block · Brachial plexus block · Interscalene block · Supraclavicular block · Infraclavicular block · Axillary block · Suprascapular block · Retroclavicular block · Costoclavicular block · Liposomal bupivacaine · Shoulder surgery

Introduction

Ultrasound-guided regional anesthesia of the upper extremity has grown in popularity and adoption throughout the country and the world over the last decade. Basic techniques of the most common brachial plexus blocks (i.e., interscalene, supraclavicular, infraclavicular, and axillary) are well known and well described. However, there is increasing awareness of the variations in anatomy from person to person along with a resurgence in interest in alternative approaches to the brachial plexus. The push to do more blocks in ambulatory surgery centers, extend block duration, and minimize the risk of complications has led to creative solutions to avoid phrenic nerve paralysis, increase block duration with adjuvants and catheters, and put an emphasis on safety during regional anesthesia. In this review, we will describe the anatomical variations of the brachial plexus described in recent literature, discuss some alternative approaches to the brachial plexus, evaluate the utility of adjuvants and liposomal bupivacaine to prolong and enhance nerve blocks, and highlight updates on local anesthetic systemic toxicity.

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Anatomical Variations of the Brachial Plexus

Vincent Chan described the ultrasonography of the brachial plexus in the early advancement of ultrasound guided regional anesthesia [1, 2]. These primary ultrasound descriptions of the interscalene (ISB), supraclavicular (SCB), infraclavicular (ICB), and axillary nerve (ANB) blocks have become the de facto standard anatomy for the levels of the trunks, divisions, cords, and nerves. However, with advancements in ultrasound technology and increased experience, these initial descriptions are now insufficient to account for the normal and pathologic variations in brachial plexus anatomy and important adjacent structures when performing regional anesthesia [3, 4]. Seven major variations of the brachial plexus have been described with none representing a significant majority and with over 60% of people having bilateral asymmetry [5]. One cadaveric anatomy evaluation series revealed that 47.7% of plexi varied from the "classic" anatomical description of the brachial plexus [6••, 7]. This significant degree of dissimilarity may represent a unique advantage of ultrasound imaging when used with anatomical variations in mind [7].

Stoplight

The classic "stoplight" cross-section image of the interscalene groove as seen on ultrasound during ISB block is typically assumed to represent C5, C6, and C7. However, frequently, the C5 nerve root can be quite small and underappreciated while the bottom two hypoechoic structures often represent branches of the C6 nerve root still coalescing and not separate C6 and C7 [8]. Alternatively, the superior trunk has been seen anterior to the anterior scalene or piercing the muscle itself instead of lying within the interscalene groove [6••]. The middle trunk has also been observed piercing the anterior scalene muscle. Interestingly, these variations can be unilateral on the same patient and do not require consistency in both arms [6••].

Phrenic Nerve

The phrenic nerve primarily arises from ventral rami of C4 with contributions from C3 and C5 nerve roots proximal to the formation of the brachial plexus trunks. Variations have been described including differences in origin, course, and distribution. One anatomical description shows a communicating branch between the phrenic nerve and the upper trunk of the brachial plexus. In 75% of cadavers, there is also the presence of an accessory phrenic nerve that can lie further lateral to the phrenic nerve and is thereby more susceptible to blockade with ISB and SCB. Unexpected hemi-diaphragmatic paralysis may occur despite caution with local anesthetic distribution and volume with ISB and SCB due to anatomical variations of the phrenic nerve [9•].

Dorsal Scapular and Long Thoracic Nerves

Frequently missed during evaluation of the interscalene groove are the dorsal scapular nerve and long thoracic nerve that branch off the brachial plexus proximal and travel through the middle scalene muscle. There are multiple variations of branching of these nerves, requiring careful consideration during posterior approaches to the ISB [10].

Musculocutaneous Nerve

Typically, the musculocutaneous nerve (MCN) arises from the lateral cord as it separates from the lateral root of the median nerve distal to the clavicle. However, based on a pooled series of cadaveric dissections, approximately 20% of the time the MCN has some significant variation [11]. Variations included earlier branching of nerves to the coracobrachialis, no branching from the median nerve, and mixed communication after branching. These variations may lead to incomplete or unexpected block depending on the supraclavicular, infraclavicular, or axillary approach.

Supraclavicular

Although the entire bundle of anterior and posterior divisions are typically encased within a fascial sheath between the anterior and middle scalene muscles at the level of the supraclavicular block, it is not infrequent that branches of the plexus can exist outside this sheath, within one of the muscles, or completely on the other side of a scalene muscle [7]. Vascular branches, such as the transverse cervical artery or dorsal scapular artery, can often be seen crossing the brachial plexus sheath at this level thereby restricting flow of local anesthetic injected only in one location [12].

Lateral Cord

Variations of the distribution of the median nerve arising from the lateral cord can lead to unexpected block effects. Case reports have shown branches of the median nerve innervating the flexor muscles of the arm, as well as early and multiple branches of the lateral cord with multiple lateral pectoral nerves, abnormal course of the MCN, and atypical formation of the median nerve [13]. On ultrasound, classic appearance of the lateral cord may vary during an ICB block [14].

Infraclavicular

The separate locations around the axillary artery of the lateral, medial, and posterior cord as depicted in most illustrations of the infraclavicular block is not always observed. Depending on the rotation of the cords around the axillary artery, the level at which the ultrasound cross-section is visualized, the position of the arm, and the variations in plexus anatomy, the cords can be seen in any combination of clustering around the axillary artery or even fused as one nerve [7].

New Techniques for Upper Extremity Blocks

Retroclavicular Approach to Infraclavicular Block

Ultrasound-guided infraclavicular block has traditionally been performed with a needle insertion point caudal to the clavicle, just medial to the coracoid process. The ultrasound transducer is placed in the parasagittal plane just caudal to this point to visualize the axillary artery and cords of the brachial plexus in short axis. The relative depth of the brachial plexus at this point often necessitates a steep angle of approach that can make needle visualization difficult, particularly in obese or muscular patients. Furthermore, the lateral cord often lies in the needle trajectory to the desired injection point posterior to the axillary artery, where it is potentially at risk of needle trauma. First described in 2007 [15], the retroclavicular or posterior approach to infraclavicular block seeks to alleviate these two challenges by moving the needle insertion point cephalad to the clavicle, over the trapezius muscle. The needle passes posterior to the clavicle and approaches the brachial plexus at an angle perpendicular to the ultrasound beam, which improves needle visibility and allows for easier avoidance of the lateral cord.

Block success rate with the retroclavicular approach appears to be similar to that of the traditional paracoracoid approach [16, 17]. Recent studies comparing the two techniques found better needle visibility and shorter performance time with fewer needle passes with the retroclavicular approach [18•, 19]. The primary concern with the retroclavicular approach is the necessary blind passage of the needle through the acoustic shadow of the clavicle and the potential for injury of neurovascular structures therein. One cadaver study identified the suprascapular nerve and vein as structures at risk [20]. The authors suggest careful inquiry about paresthesia, concomitant use of nerve stimulation, and avoidance of this approach in coagulopathic patients as ways to mitigate risk. Although no cases of neurologic or vascular injury with retroclavicular block have been reported in the literature, no clinical studies to date have specifically addressed this issue.

Costoclavicular Block

In the traditional approach to ultrasound-guided infraclavicular block, the cords of the brachial plexus are visualized as three distinct structures positioned around the axillary artery. As such, larger volumes of local anesthetic or multiple injection points may be required to adequately cover all three cords, and coverage of all three cords with a continuous catheter may be a challenge. The costoclavicular block has been described as an alternative technique to avoid these issues [21•, 22]. In the costoclavicular approach, the ultrasound transducer is placed in the transverse plane just caudal to the midpoint of the clavicle, allowing visualization of the axillary artery and cords in short axis. At this point in the plexus (proximal to the site of traditional infraclavicular block), the three cords are consistently clustered together just lateral to the artery [23]. The needle is advanced in plane from lateral to medial through the subclavius muscle. The target for local anesthetic injection or catheter tip position is a single point in the center of the three cords.

Recent studies comparing single-shot costoclavicular block with traditional paracoracoid infraclavicular block demonstrated similar rates of block success and low incidence of complications [24, 25]. Onset time may be shorter with costoclavicular block [25]. Costoclavicular block has also been examined as a diaphragm-sparing alternative to interscalene block for shoulder surgery as described elsewhere in this review [26].

Approaches to Blockade of the Intercostobrachial Nerve

The intercostobrachial nerve (ICBN) provides sensory innervation to the lateral chest wall, axilla, and the most proximal part of the medial upper arm. Because it originates from the lateral cutaneous branch of the T2 (and sometimes T3) thoracic spinal nerve, it is not covered by brachial plexus blocks. When anesthesia of this area is desired (e.g., surgery to establish hemodialysis access, proximal tourniquet placement), the ICBN must be blocked separately. Traditionally, this has been accomplished by subcutaneous infiltration of local anesthetic in a band across the medial upper arm. More recently, improvements in ultrasound imaging quality have allowed for visualization of the ICBN in the axillary fossa as a small, hyperechoic structure located in the subcutaneous tissue just superficial to the brachial fascia, lateral to the axillary artery and branches of the brachial plexus [27–29]. One study found that precise application of local anesthetic under ultrasound guidance allowed for more reliable blockade with lower volumes of local anesthetic, despite poor nerve visibility in half of the patients studied [29].

In its proximal course, the ICBN exits the intercostal space in the midaxillary line and passes between the interdigitations of the intercostal muscles and serratus anterior, emerging in the plane between serratus anterior and pectoralis minor. It travels laterally across the axilla, crossing the anterior aspect of the latissimus dorsi before arriving in the subcutaneous tissue of the medial upper arm [30]. This path makes the ICBN amenable to blockade by several of the ultrasound-guided chest wall fascial plane blocks described in recent years, including the Pecs II block and the serratus plane block [31, 32]. One study of patients undergoing superficialization of arteriovenous fistula found a higher rate of successful block and faster onset time with proximal blockade (in the plane between pectoralis minor and serratus anterior) compared to distal blockade by blind subcutaneous infiltration [33•]. The optimal plane of injection and volume of local anesthetic for proximal blockade of the ICBN is unclear. No studies have yet compared proximal blockade to ultrasound-guided distal blockade.

Upper Extremity Blocks for Ambulatory Surgery

Upper extremity surgery in general lends itself well to the outpatient setting, as it involves a limited area of the body, has minimal effect on ambulation, and in many cases can be performed under local or regional anesthesia. As health care policy and reimbursement structures have evolved to increasingly emphasize efficient, cost-effective delivery of quality medical care, there has been a trend toward performing more types of surgeries on an outpatient basis. Shoulder surgery in particular has seen significant expansion into the outpatient realm. Complex arthroscopic procedures such as rotator cuff repair are now routinely performed as same-day surgery, and outpatient total shoulder arthroplasty has been shown to be feasible and safe for selected patients [34]. This shift has been made possible in part by advances in opioid-sparing pain management strategies including regional blocks.

Interscalene block (ISB), long a mainstay of analgesia for shoulder surgery, has been shown to be safe and effective in the ambulatory setting [35, 36] and may shorten time to discharge when used instead of general anesthesia [37]. Portable infusion pump systems for peripheral nerve block catheters allow patients to benefit from prolonged regional anesthesia after discharge home, with a low incidence of complications [38–40]. Multiple studies have demonstrated superior analgesia after ambulatory shoulder arthroscopy with continuous interscalene block versus single shot [37, 41]. Other strategies for prolonging interscalene block after ambulatory surgery include local anesthetic adjuvants and liposomal bupivacaine, which are discussed elsewhere in this review. Subacromial and intraarticular infusion of local anesthetic have also been used as alternatives to ISB with the advantage of avoiding hemidiaphragm paralysis. ISB appears to provide superior analgesia however [42•], and concerns about chondrotoxicity with intraarticular and subacromial infusions has limited their use [43].

Several recent studies have examined regional blocks for ambulatory surgery on the distal upper extremity. Supraclavicular, infraclavicular, and axillary block are similarly effective for these procedures, and there is little evidence to recommend one approach over the other [44–46]. For hand surgery, more distal blockade of individual nerves can provide effective anesthesia and analgesia with less motor block than a brachial plexus block, which may be especially desirable for outpatient surgery [47].

Diaphragm-Sparing Blocks of the Shoulder

Interscalene nerve blocks provide excellent analgesia for shoulder surgery; however, with traditionally used doses of local anesthetic, there is almost a 100% chance of hemidiaphragm paralysis (HDP) due to phrenic nerve blockade. Patients with pulmonary insufficiency who cannot tolerate a reduction in ventilatory function stand to benefit significantly from the opioid- and anesthetic-sparing effects of regional anesthesia during shoulder surgery, making diaphragm-sparing alternatives to ISB an area of interest. Much has been published on this topic in recent years, as described in several excellent reviews [48•, 49••]. Techniques that have been recently investigated include modified ISB, low-volume supraclavicular block, costoclavicular block, and suprascapular and axillary nerve blocks.

ISB with a low volume of local anesthetic (5 cc versus the traditional volume of at least 20 cc) applied precisely under ultrasound guidance can result in effective blockade with an incidence of HDP as low as 27% [50]. Other modifications to ISB such as injection at the level of C7 [51], injection outside the fascial sheath of the brachial plexus [52, 53], and use of dilute local anesthetic can decrease the risk of HDP to as low as 13-20% [54, 55]. Unfortunately, for many patients, this is still a prohibitive level of risk.

More distal in the brachial plexus, low-volume supraclavicular block (SCB) appears to result in a further decreased incidence of HDP and similar analgesia to ISB for arthroscopic shoulder surgery. One recent study examined HDP after ISB with 20 cc of 0.5% ropivacaine versus SCB with 17 cc of 0.5% ropivacaine in patients undergoing arthroscopic shoulder surgery. 95% of the ISB group had HDP versus 9% of the SCB group. Pain scores and opioid consumption were equivalent across the groups [56]. As with modified ISB, this level of risk of HDP may still be unacceptable in certain patients.

Blocks targeting peripheral nerves remote from the phrenic nerve such as suprascapular nerve block (SSB) and axillary nerve block (ANB) can provide shoulder analgesia without HPD. However, there is mixed data on their relative analgesic benefit compared to ISB. Two recent trials comparing ISB, SCB, and SSB showed statistically similar pain scores and opioid use among groups and better preservation of pulmonary function with SSB [57, 58]. Another found noninferior analgesia, less motor block, and higher patient satisfaction with SSB versus ISB after outpatient shoulder arthroscopy [59]. A meta-analysis of 16 trials comparing SSB with ISB found no significant difference in pain scores or opioid use except for lower pain scores in PACU with ISB [60]. On the other hand, multiple studies have demonstrated nonequivalent or inferior analgesia and opioid consumption in the immediate postoperative period with the combination of SSB plus ANB compared to ISB [61, 62]. Although many of these studies do not address pulmonary function, the incidence of HDP with SSB and ANB is presumably zero given their anatomic location, making them a safer choice for patients with pulmonary insufficiency compared to modified ISB or SCB.

The combination of SSB with infraclavicular block has also been investigated as an alternative to ISB. One study found a 0% incidence of HDP with this combination. Patients receiving ISB used significantly less opioid and had significantly lower pain scores in the first 30 min after shoulder arthroscopy, but pain scores were comparable thereafter [56]. Another promising technique is the costoclavicular approach to infraclavicular block described earlier in this review [22]. One study found that costoclavicular block provided equivalent analgesia for shoulder arthroscopy with a 0% incidence of HDP, but with a longer onset time compared to ISB [26].

In summary, modified ISB and low-volume SCB appear to offer equivalent analgesia to ISB with a lower, but still clinically significant risk of HDP. SSB alone or in combination with ANB or ICB likely succeeds in avoiding HDP, but perhaps at the expense of a degree of analgesia. Costoclavicular block shows promise, but further study is needed. More research examining the use of diaphragm-sparing blocks for analgesia in open procedures such as total shoulder arthroplasty and for surgical anesthesia is needed.

Adjuvants

Continuous catheters are commonly used to extend the duration of regional analgesia but may involve increased cost, procedural time, follow-up needs, and complications. Various adjuvants to local anesthetic have been studied over the years as a way to prolong analgesia without a catheter, including neostigmine, midazolam, morphine, fentanyl, tramadol, buprenorphine, nalbuphine, clonidine, dexmedetomidine, dexamethasone, epinephrine, verapamil, and magnesium. Of these, buprenorphine, clonidine, dexmedetomidine, and dexamethasone have the strongest evidence for efficacy. One systematic review reported an increase in block duration of > 6 h with buprenorphine, 3–6 h with clonidine, 1–8 h with dexmedetomidine, and 1–3 h with dexamethasone [63]. However, there are also studies of each of these that show no increase in block duration. Numerous studies have examined the effect of adjuvants on brachial plexus block specifically in recent years. Of note, the use of many of these agents as local anesthetic adjuvants is considered off-label.

Buprenorphine is a partial opioid agonist that may also block voltage-gated sodium channels [64]. Common dosing as an adjuvant is 0.15–0.3 mg. A few recent studies have shown an increase of up to 10 h in duration of brachial plexus analgesia with no increase in side effects [65, 66].

Clonidine and dexmedetomidine are alpha-2 adrenergic agonists that are thought to prolong peripheral nerve blockade by hyperpolarization of cation channels [67]. Typical adjuvant dosing is 100 mcg of clonidine or 20 mcg of dexmedetomidine. Side effects may include hypotension, bradycardia, and sedation. Several recent studies of clonidine in brachial plexus block suggest an increase in duration of analgesia of 1–4 h [68–70]. Dexmedetomidine has been extensively investigated as a brachial plexus block adjuvant in recent years. Four recent meta-analyses found that it prolongs analgesia by 4–5 h and speeds block onset time, but may increase the risk of bradycardia and hypotension [71–74]. Several studies suggest that dexmedetomidine may be superior to clonidine for enhancement of brachial plexus block [75–77].

Dexamethasone is thought to prolong neural blockade by anti-inflammatory and neuroinhibitory effects. A 2014 meta-analysis of its use in brachial plexus blocks found an increase in duration of analgesia of 3–9.5 h [78], and several more recent studies reported similar findings [79–84]. Evidence is mixed as to the relative benefit of perineural versus intravenous administration in brachial plexus blocks [85–89].

Liposomal Bupivacaine

Liposomal bupivacaine (LB) is supplied in a preservative-free aqueous suspension of multivesicular liposomes containing bupivacaine in a concentration of 13.3 mg/cc. Bupivacaine is released from these liposomes slowly over approximately 72 h, with the goal of prolonging analgesia. LB can be administered as a mixture with conventional bupivacaine HCl in a ratio of 2:1 (e.g., 133 mg LB to 75 mg bupivacaine HCl) to augment early analgesia. Use of additional local anesthetic should be avoided for 96 h after LB use for local infiltration and for 120 h after its use for interscalene block [90]. LB was approved by the FDA for surgical site infiltration in 2011 and for ISB in 2018. This approval was based on the results of a phase 3 multicenter trial comparing ISB with LB to placebo in 140 patients undergoing total shoulder arthroplasty or rotator cuff repair. This study found a 46% reduction in pain intensity and a 77% reduction in opioid consumption for 48 h postoperatively with LB ISB [91].

The possibility of prolonged brachial plexus analgesia without a catheter is intriguing, but as many have pointed out, the true clinical utility of LB must be determined though comparison to current standard interventions rather than placebo, especially given the high cost of LB (currently approximately $300 per vial at our institution). Several studies comparing local infiltration (not ISB) with LB to ISB with conventional bupivacaine found similar analgesia after total shoulder arthroplasty [92–95], while another found that pain scores were higher with LB in the first 8 h postoperatively but lower at 24 h [96]. Another found no additional benefit with the addition of LB local infiltration to conventional ISB [97]. Three recent studies have compared LB local infiltration with continuous ISB (CISB) for shoulder arthroplasty with mixed results [98–100].

We identified only one study examining the efficacy of ISB with LB versus conventional regional techniques. One randomized controlled trial comparing ISB with conventional bupivacaine versus LB-bupivacaine mixture in 52 patients having major shoulder surgery found modestly improved analgesia and patient satisfaction with the addition of LB during the first postoperative week, with no difference in opioid consumption, sleep duration, or complications [101•]. Further research examining the relative efficacy, safety, and cost of LB compared to conventional ISB, ISB with adjuvants, and CISB will be critical to define the best role for LB in pain management after shoulder surgery.

Local Anesthetic Systemic Toxicity

The incidence of local anesthetic systemic toxicity (LAST) is very rare and trending downward, ranging anywhere from 1/500 to 1/10,000 depending on the definition [102, 103], but it remains a significant concern for clinicians performing regional anesthesia. Local anesthetics are increasingly being used throughout the hospital due to advances in block techniques and a desire to reduce opioid consumption [104•]. LAST has been reported to occur with single-injection peripheral nerve blocks and continuous blocks, immediately after a block is performed or after delayed injection, and with lower doses of local anesthetic as well as greater than maximally recommended doses [103, 104•, 105••]. Presentation of LAST can range from neurologic symptoms such as perioral numbness, tinnitus, and metallic taste and evolve to depressed consciousness or seizure or cardiovascular collapse and cardiac arrest [104•, 105••].

Avoidance of LAST is the most important aspect of management. Monitoring for intravascular injection with frequent aspiration and small aliquots of injection, consideration of a vascular marker such as epinephrine, using the least amount of local anesthetic necessary to achieve the desired block, awareness of highly vascular injection sites with rapid absorption, and evaluation of patient factors such as liver and cardiac dysfunction that may make a patient more susceptible to LAST are all key aspects of safe regional anesthesia [102, 104•, 105••].

Treatment of LAST is a modified version of the Advanced Cardiac Life Support algorithm with key differences related to the etiology of the event, extended duration of support due to the pharmacokinetics of local anesthetics, and the utilization of 20% lipid emulsion as a unique antidote for LAST [104•, 105••]. In 2018, the American Society of Regional Anesthesia and Pain Medicine (ASRA) released their third Practice Advisory on the management of LAST [105••]. In this updated advisory, ASRA simplified the management of LAST with an emphasis on earlier lipid emulsion 20% therapy. The new recommendations advise using lipid emulsion at any sign of LAST and not just cardiovascular symptoms. Dosing for adult patients was also simplified with the new recommendation to give 100 mL IV bolus for any patient over 70 kg followed by an infusion of 200–250 mL over 15–20 min. This simplified dosing strategy was intended to reduce the time to therapy and based on the established safety profile of lipid emulsion. For patients < 70 kg, weight-based dosing is still recommended (see Checklist) [105••]. The other key clarification in the 2018 advisory is to minimize epinephrine boluses to < 1 mcg/kg, avoid vasopressin, beta-blockers, calcium channel blockers, and other local anesthetics. Lastly, earlier consideration of cardiopulmonary bypass support is recommended [104•, 105••].

Conclusion

Regional anesthesia, and particularly ultrasound-guided regional anesthesia, is growing rapidly throughout the world. The community as a whole is now evolving from the originally described basic brachial plexus blocks to new blocks with new pharmaceutical combinations to expand the value, increase the safety, and solve unique problems related to upper extremity surgery and acute pain control. We recommend that clinicians become aware of these considerations as they advance their regional anesthesia skills and develop their regional anesthesia programs.

Compliance with Ethical Standards

Conflict of Interest Lane Crawford declares that she has no conflict of interest. Jason Zatkoff declares that he has no conflict of interest. Rajnish K. Gupta has received research funding from the National Institutes of Health (NIH).

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- • Of importance
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