Angular Limb Deformities
Growth Retardation

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INTRODUCTION
Ideal musculoskeletal conformation, for reasons of both form and function, has long been a preoccupation of the equine enthusiast. The definition of perfect limb conformation remains elusive for several reasons, including 1–6:

- Differences in breed and discipline standards, with varying degrees of evidence to support those standards
- Challenges objectively and accurately measuring all aspects of the 3-D limb in clinical practice
- The presence of concurrent deformities further complicating subjective interpretation
- The range of expected normal deviations that correct spontaneously as the young horse grows
- The limited number of studies providing objective information on the precise effect of limb deformities on performance and the degree of severity associated with athletic injury

KEYWORDS
- Foal
- Angular limb deformity
- Transphyseal bridge
- Transphyseal screw

KEY POINTS
- Familiarity with normal growth of the young horse is critical for appropriate case selection of foals that require surgical retardation of physeal growth to correct an angular deformity that would not correct by other means.
- Preoperative radiographic evaluation is critical to confirm that the deformity has the potential to respond to physeal growth retardation.
- Growth retardation procedures are performed on the convex side of the physis of interest and may be combined with growth-promoting procedures on the concave side of the limb.
- The single transphyseal screw has become the preferred approach to surgical retardation in many cases; however, more knowledge on the use of this technique during the rapid growth phase and physitis is required to determine if significant complications will arise.
Therefore, arguably the most critical skill that contributes to successful management of angular limb deformities in foals is mastering the art of monitoring development of the young horse and knowing which treatments to use and when and, just as important, when not to treat.

Angular limb deformity, defined as a deviation of the limb in the sagittal plane, is a common developmental orthopedic disease in the horse. The deformity is named based on the direction of deviation of the distal limb and the joint that appears to be deviated. The location of the deformity, however, is most commonly at the level of the metaphysis (also the physis and occasionally the epiphysis) of the long bone proximal to the joint (Box 1). The distal radial physis and distal third metacarpal/metatarsal physis are most commonly affected, with the distal tibial physis requiring treatment less often. There are several options available for treatment of this disorder. This article focuses on surgical procedures that retard the growth of the physis on the convex (long) side of the affected long bone. The procedures discussed share the same fundamental principle, that is, static compression of the physis on the convex side to slow growth while allowing the opposite concave (short) side to continue to grow and straighten the limb. Appropriate case selection, surgical options, and complications are discussed.

PATIENT EVALUATION

**Foal Conformation Evaluation**

The details of orthopedic examination of the foal are covered elsewhere in this issue. Briefly, a foal should be observed standing squarely from the front and behind (Fig. 1). Observers should align themselves with the dorsal or caudal face of each limb to evaluate for angular limb deformity. The foal should also be walked toward and away from the clinician to allow observation of foot flight and tracking. Dynamic evaluation is important because the limb does not travel in a straight line if an angular deformity is present (ie, fetlock varus causes the toe to deviate medially during the flight phase). Careful attention should be paid to note concurrent deformities (ie, carpal valgus and fetlock varus).

Knowledge of normal conformation for the age of the foal, growth stages for the physes of interest, and age at physiologic growth plate closure is essential for correct interpretation of the conformation examination and the most appropriate treatment strategies, if any. Foals are typically born with carpal valgus (<10°) and fetlock valgus or fetlock varus. The entire forelimb often appears outwardly rotated due to the narrow

<table>
<thead>
<tr>
<th>Box 1</th>
<th>Angular limb deformity definitions</th>
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<tr>
<td>Valgus: lateral deviation of the limb distal to the origin of the deformity</td>
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<td>Varus: medial deviation of the limb distal to the origin of the deformity</td>
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<td>Fetlock angular limb deformity: common term referring to angular deformity originating from the distal third metacarpal/metatarsal physeal region</td>
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<td>Carpal angular limb deformity: common term referring to angular deformity originating from the distal radial physeal region</td>
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<td>Tarsal angular limb deformity: common term referring to angular deformity originating from the distal tibial physeal region</td>
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<td>Offset knee: common term referring to lateral displacement of the carpus and third metacarpal bone relative to the radius at the level of the radiocarpal joint. This is not a true angular deformity but can benefit from growth retardation procedures.</td>
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chest of the foal; however, the carpus and fetlock should still align in the axial plane. Foals should be examined every 2 weeks to monitor progression. The fetlock should improve to straight axial alignment from the metacarpus/metatarsus to the toe by 4 months of age, at which time the rapid linear growth phase of the limbs has ended and potential remaining growth in the distal metacarpal/metatarsal physes is minimal. Carpal valgus (5°–7°) is expected at this age, with further correction during accelerated growth of the distal radial physis at 8 months to 10 months of age. As the chest becomes broader, the forelimbs rotate inward (a normal outwardly rotated foal becomes straight; a straight foal develops inward rotation). Therapies are instituted when a foal is not developing as expected or when the initial deformity is severe (mild <5°, moderate 5°–10°, or severe >15°). Indications for growth retardation surgery are outlined in Box 2 (Fig. 2).

Radiographs
Radiographic evaluation is always indicated when an abnormal angular deviation of the limb is severe, not improving as expected, or increasing in severity. The location...
and degree of angulation can be determined as well as complicating factors that may decrease prognosis or eliminate certain procedures as a viable option (Fig. 3). The presence of complete ulnas and fibulas in pony and miniature horse foals causing severe angular limb deformity has been reported.\textsuperscript{10,11} Due to the severity of the deformity, treatment is not commonly attempted and there is little information on treatment strategies. If treatment were attempted, segmental ulnar or fibular ostectomy would be a necessary surgical procedure to allow physeal manipulation.

The dorsopalmar view of the carpus and front fetlock and dorsoplantar view of the tarsus and hind fetlock should be evaluated. Angulation of the distal tibia is difficult to assess radiographically because of the tibia angles away from the cassette; however, physeal pathology can be assessed. The lateral-medial radiographic projection of the tarsus is also important to evaluate the cuboidal bones for evidence of crushing. Crushing of the carpal or small tarsal bones decreases prognosis for future soundness and cannot be corrected by physeal manipulation.\textsuperscript{8}

A study by Brauer and colleagues\textsuperscript{12} compared limb deformity of the carpal region using the pivot point method (angle and location of deformity determined based on the intersection of line drawn through the radius and metacarpus) and the individual angle method (angle of deformity measured at the level of the distal radial physis and each joint of the carpus and summed to produce the final deviation). Radiographs were evaluated before and after growth retardation in young horses with carpal valgus. The physis was the predominant contributor to the overall deformity in the carpal region (82% of cases) and there was a high degree of correlation between the pivot point and individual angle methods. There was improvement in the deviations at the level of the carpal joints after physeal growth retardation. These minor changes, however, cannot be expected to overcome the deformities that occur with significant carpal bone crushing due to incomplete ossification of the cuboidal bones.

\textbf{SURGICAL GROWTH RETARDATION PROCEDURES}

Reported surgical techniques for physeal growth retardation include the transphyseal staple, screw and wire transphyseal bridge, and the single transphyseal screw. Equine limbs undergo an initial rapid linear increase in length for the first 10 weeks of life, after which the rate of growth decreases dramatically.\textsuperscript{13} Several studies have evaluated

\begin{table}
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\textbf{Box 2: Indications for growth retardation procedures} \\
\hline
- Severe deformities that are unlikely to correct spontaneously before physiologic physeal closure \\
- Severe deformities that are either causing, or resulting in worsening of, concurrent angular deformities elsewhere in the limb \\
- Mild to moderate deformities that are increasing in severity over time or have remained static and no longer have sufficient time for physiologic correction before growth plate closure \\
- Deformity located at the level of the physeal region. Diaphyseal and intra-articular deformities do not benefit significantly from physeal manipulation. \\
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bone growth below the carpus and tarsus where cessation of growth is reported to occur between 140 days and 210 days (4.6–7 months); however, the earlier time point is more broadly accepted.\textsuperscript{4,14–16} Growth of the distal radius is effectively complete after approximately 60 weeks of age.\textsuperscript{13} Growth retardation procedures are typically performed after the rapid growth phase of the region of interest is complete, while leaving sufficient remaining time and growth to achieve correction (Table 1).

**Transphyseal Staples**

The transphyseal staple was the first technique developed to place an implant in the epiphysis and metaphysis to bridge the physis and thereby limit growth on the convex side of the limb.\textsuperscript{8} The most recent study reporting the outcome of the technique used 7/64-inch Steinmann pins to make staples.\textsuperscript{12} Horses between 1 week and 2 years of

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**Fig. 2.** (A) A 1-month-old foal with mild bilateral carpal varus. Although the deformity is mild, it is significant because a foal this age is expected to have mild carpal valgus and outward rotation of the limb. The deformity does not necessitate a growth retardation procedure but continued close monitoring and conservative measures and/or growth promoting procedures should be considered. (B) A 3-month-old foal with severe left carpal valgus and physeal inflammation of several physes. Given the degree of deformity, radiographic evaluation for bony abnormalities accompanying the physeal deformity should be performed before growth retardation surgery to determine prognosis. Note the large lateral flare on the left front foot and the medial to lateral imbalance of the foot. Management to balance the foot is essential after growth retardation surgery.
Fig. 3. (A) A 7-month-old zebra presented for severe left tarsal valgus. History of development was unknown. Based on clinical examination, a medial transphyseal screw is an appropriate treatment. Further radiographic projections (not shown here) revealed evidence of a healed, misaligned physeal fracture. (B) The medial aspect of the distal tibial physis has a bony bridge and is closed (arrow); therefore, no benefit would be gained by performing a growth retardation procedure. This case emphasizes the importance of radiographic evaluation when determining treatment options.

Table 1
End of the rapid growth phase, age at transphyseal screw and screw and wire transphyseal bridge placement, and the numbers of days postoperatively that implants were removed for the distal metacarpus/metatarsus III, distal tibia, and distal radius with angular limb deformities. Data presented as range alone (ie. 2–3 months) or mean (min – max) (ie. 3 [0.7–3.7])

<table>
<thead>
<tr>
<th>End of rapid growth (mo)</th>
<th>Distal Metacarpus/ Metatarsus III</th>
<th>Distal Tibia</th>
<th>Distal Radius</th>
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<tbody>
<tr>
<td>Rapid growth ends (mo)</td>
<td>2–3,24</td>
<td>4–6,24</td>
<td>6,7 8–10,24</td>
</tr>
<tr>
<td>Transphyseal screw</td>
<td>Age placed (mo)</td>
<td>3 (0.7–3.7),20 7.3 (3.9–12),19</td>
<td>12.6,21</td>
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<td></td>
<td>3.7 (3–4.8),18</td>
<td>13 (10.5–19),22</td>
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<td>Time to removal (d)</td>
<td>28–35,20</td>
<td>62 (39–89),19</td>
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<td></td>
<td>31.1 (9–65),18</td>
<td>38,21</td>
<td>39.5 (14–125),22</td>
</tr>
<tr>
<td>Screw and wire</td>
<td>Age placed (mo)</td>
<td>3 (1–5.8),18</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Time to removal (d)</td>
<td>42.8 (19–86),18</td>
<td>—</td>
</tr>
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* A second rapid growth phase occurs between 8 months to 10 months of age.
age with carpal valgus were included. Improvement in radiographic measurements at
the time of removal revealed improvement in only 76% of horses. The investigators
suggested that the older age of some cases may have contributed to the result.
Only 55% of staples, however, were intact with no distortion at the time of removal.
Complications included spreading of the legs of the staple (34%), broken staple,
and staple migration out of the bone. Other reported complications include difficulty
placing the staple correctly, poorer incisional cosmesis, and difficulty removing the
staple. Based on the inferior results, the procedure has been largely abandoned
in favor of the screw and wire or single transphyseal screw.

**Screw and Wire Transphyseal Bridge**

The screw and wire technique was developed next and was advantageous because it
was easier to place accurately, less prone to implant failure, could be placed through
stab incisions, and was easier to remove. The transphyseal screw has replaced the
screw and wire for many indications; however, for reasons discussed later, the screw
and wire technique can still be of value for correction of angular limb deformities in
foals. This technique is also used for physeal fracture repair in the distal physis of
metacarpal/metatarsal III, distal radial physis, and proximal tibial physis.

**Surgical procedure**

Currently, the screw and wire transphyseal bridge is most commonly performed in
the distal radius (Fig. 4). The horse is positioned in dorsal recumbency with the
limb suspended. The hair is clipped and the skin prepared for aseptic surgery. The
limb is draped to isolate the surgical field. A 20G needle is inserted in the distal radial
physis. A needle may also be placed to mark the radiocarpal joint; however, this is
readily palpable. Stab incisions are made full thickness through the skin, subcutaneous
tissue, and periosteum in the center of the epiphysis and within the metaphysis
of the distal radius ensuring the screws are in the center of the bone. A tunnel con-
necting the 2 stab incisions is created using a curved hemostatic forceps. A 3.2-mm
drill bit is used to drill thread holes for 4.5-mm screws at the site of each stab incision
and the holes are tapped. The thread holes should be drilled so that the distal screw
is parallel to the radiocarpal joint and the screws are parallel to one another or slightly
converging. A prebent 18G wire is fed into the tunnel so that the loop is positioned
distally on the limb (the ends should exit the proximal incision). The top and bottom
screw are placed but not tightened. The wire is then pulled proximally so it sits snug
against the distal screw and the free ends are twisted (caution to avoid overtighten-
ing, which breaks the wire). The twisted end of the wire is held stable while the
screws are tightened. Only 1 wire is required. The excess wire ends are cut and
the twist is pressed into the bone to avoid soft tissue irritation. Intraoperative radi-
ographs confirm correct placement. The subcutaneous tissue and skin are closed and
the carpus is bandaged.

**Perioperative and postoperative care**

A single preoperative dose of broad spectrum systemic antimicrobials is sufficient.
Anti-inflammatories are administered for 5 days to 7 days postoperatively. The horse
is confined to a stall or small pen for 10 days until suture and bandage removal, after
which it may be turned out in a small paddock for an additional 2 weeks. Normal
turnout can resume if there have been no complications. Progress should be evalu-
ated every 2 weeks and implants removed as soon as correction is achieved but no
later. Implant removal can be performed standing or under general anesthesia. Com-
plications are discussed in comparison with the transphyseal screw.
Transphyseal Screw

The transphyseal screw differs from previous growth retardation techniques in that, rather than bridging the physis, the screw penetrates the physis. The technique for placing the transphyseal screw has been described for the distal physis of the tibia,\textsuperscript{19} distal physis of metacarpal/metatarsal III,\textsuperscript{18,20} and distal radial physis.\textsuperscript{21,22} The procedure in the carpus is predominantly performed on yearlings; therefore, only the procedures for fetlock and tarsal angular limb deformity correction are described.

Surgical procedure

For both the fetlock and tarsus, the foal is anesthetized and positioned in dorsal recumbency. The limb is suspended, clipped, and aseptically prepared. The surgical procedure involves:

1. Anesthetizing the foal and positioning it in dorsal recumbency.
2. Suspending the limb and preparing it for surgery.
3. Stab incisions are made subcutaneously.
4. Holes are drilled at each stab incision.
5. A wire is passed through the subcutaneous tunnel.
6. Screws are placed through proximal and distal drill holes and the wire is twisted to tighten.
7. The screws are tightened and incisions are closed.
8. Post-operative radiograph is taken.

Fig. 4. Surgical procedure and intraoperative radiograph: placing a screw and wire construct in the distal radial physis. (A) Kelly forceps are passed subcutaneously to connect stab incisions. (B) Holes are drilled at each stab incision. (C) The wire is passed through the subcutaneous tunnel. (D) Screws are place through proximal and distal drill holes and the wire is twisted to tighten. (E) The screws are tightened and incisions are closed. (F) Post-operative radiograph.
site is isolated using sterile drapes. A 20G needle is placed to identify the physis of interest.

**Fetlock** A stab incision through the skin, subcutaneous tissue, and periosteum is made approximately 1 cm to 1.5 cm proximal to the physis in the center of the bone (Fig. 5). The skin should be manipulated so that the incision is not directly

![Surgical procedure and intraoperative radiograph: placing a transphyseal screw in the distal metacarpal physis.](image)

**Fig. 5.** Surgical procedure and intraoperative radiograph: placing a transphyseal screw in the distal metacarpal physis. (A) A needle is placed in the physis and a drill is used to prepare the screw hole. (B) Final tightening of the screw with a screw driver. (C) The screw is placed until the screw head just contacts the bone. (D) The needle is removed, notice the skin incision slides over the screw head so the incision does not lie directly over the screw. (E) Intraoperative radiograph after screw placement.
over the screw head at the end of surgery. A 2.5-mm drill bit (if placing a 3.5-mm self-tapping screw) or 3.2-mm drill bit (if placing a 4.5-mm cortical screw) is initially seated in to the cortex and then directed distally maintaining alignment with the dorsal cortex of metacarpal/metatarsal III. Penetration of the physis can be detected by an increase and then sudden decrease in bone density when drilling. The thread hole is tapped if needed and the screw placed. The screw should not be tightened but should be advanced only until the screw head contacts the bone to avoid bending the screw or breaking the screw head. Intraoperative radiographs confirm correct placement. The screw should engage 60% to 75% of the epiphysis, should be as vertical as possible, and should not cross midline. The subcutaneous tissue and skin is closed and the limb is bandaged.

**Tarsus** A stab incision is made over the distal aspect of the medial malleolus. Radiographic guidance is used to confirm correct placement and angulation of a 3.2-mm drill bit prior to drilling the thread hole. The drill bit is advanced from distal to proximal to cross the physis and enter the metaphysis. The thread hole is tapped and a 4.5-mm cortical screw is placed. Again, the screw should not be tightened but advanced just until the screw head contacts bone. Intraoperative radiographs confirm correct placement, the incision is closed, and the limb bandaged.

Variations of the procedures have been described. The initial report in the distal tibial physis placed a 4.5-mm cortical screw in lag fashion; however, a later report stated that the technique had been modified to a position screw technique. One report described drilling the cortex of the distal metacarpus with a 5.5-mm bit to create a shelf to seat the screw head, elevation of periosteum, and suturing of periosteum over the screw head. As pointed out by another investigator, these steps are unnecessary and may create further trauma and complications.

Wall and colleagues described angular limb deformity correction in 6 foals with fetlock varus using a 4.5-mm absorbable transphyseal screw. Surgery was only performed when the investigators were confident overcorrection would not occur (mean age 137 days, range 106–156 days) since the implant is not removed. Although foals improved, only 2 foals achieved straight limb conformation. The principal advantage stated was that a second surgery was not needed for implant removal. Important questions need to be answered, however, prior to use in routine clinical practice. How long does the screw maintain sufficient mechanical strength to effect growth retardation? If the surgical site becomes infected, does the absorbable screw need to be removed to resolve the infection and can this be accomplished? How long does the screw persist in the bone? A clear radiolucent outline of the screw was still apparent on radiographs 9 months after surgery and the investigators stated that the material can last up to 3 years in people. Will the persistent radiographic appearance of the screw effect the value of young horse going to sale? How might persistence of the material have an impact on bone remodeling in horses that are started into heavy training?

**Perioperative and postoperative care**
Management is similar to that of the screw and wire procedure except that foals are not confined to a stall but allowed turnout in a small pen.

**Screw and Screw and Wire Removal**
Removal can be performed in the standing sedated foal with a subcutaneous local block or under general anesthesia (Fig. 6). Removal under general anesthesia should be performed in all cases with bony overgrowth of the screw head that may require removal of excess bone. Local anesthetic should not be injected directly over the
screw head because it makes palpation to identify the screw head more difficult; rather, the local anesthetic should be injected in an inverted “V” shape around the screw head or screw and wire construct. A 20G needle is inserted in the skin and used to probe for the metal screw head. Once identified, a stab incision is made down to the screw head (this step is performed for each screw in the screw and wire; recording the distance between the screws placed at surgery can make finding the second screw easier at the time of removal). A curved hemostatic forceps is introduced through the stab incision and used to find the center of the screw head. The forceps can also be used to remove soft tissue that may be filling the driver site. The screw driver is then firmly seated into the screw head. It is of utmost importance that attempts to remove the screw are not made until the screw driver is convincingly seated well into the screw head; otherwise, the screw head can be stripped. The smaller 3.5-mm screws are subjectively more prone to this problem. The screw is removed. In the case of the screw and wire, the first screw is back out until it is visible outside of the skin, and then the second screw is removed followed by the first. The wire may need to be elevated from the bone using a forceps. It is then grasped and tugged sharply to pull it from the distal stab incision. The stab incisions may be sutured or closed with adhesive tape, a sterile bandage is placed, and the foal is maintained in a bandage until 10 days postoperatively.

SCREW AND WIRE VERSUS TRANPHYSEAL SCREW: ADVANTAGES, DISADVANTAGES, AND COMPLICATIONS

Potential complications associated with all growth retardation surgeries include surgical site infection, overcorrection, bony overgrowth, and cosmetic defects.
Complications specific to the screw and wire include wound dehiscence (if a long incision is used rather than 2 stab incisions), wire breakage, soft tissue thickening, and seroma.\textsuperscript{18} Surgical complications during transphyseal screw placement or removal include breaking the screw, stripping the screw, and difficulty locating the screw head.\textsuperscript{20} Witte and colleagues\textsuperscript{19} reported no surgical or postoperative complications for transphyseal screws placed in the distal tibial physis. Superficial surgical site infections after surgery to place a transphyseal screw were attributed by several investigators to postoperative bandaging problems.\textsuperscript{18,20,24} This may be related to exposure of the incisions before wound healing was complete or bandaging too tightly, which can lead to pressure necrosis of the thin skin overlying the screw head. Advantages of the transphyseal screw in the distal metacarpus/metatarsus and distal tibia include faster surgery time, faster rate of correction, and improved cosmesis.\textsuperscript{18–20} Concerns have been raised regarding the potential for spot welding of the physis at the site where the transphyseal screw penetrates the physis resulting in overcorrection after the screw is removed; however, specific examples have not been reported to date.\textsuperscript{18}

A study comparing the complication rate after treatment of angular deformities of the carpus in yearlings with a screw and wire transphyseal bridge ($n = 253$) or a transphyseal screw ($n = 315$) was performed.\textsuperscript{21} Although the focus of this article is on foals, the study highlights some important findings. There was no difference in any preoperative parameter including age, severity of deformity, gender, age at the time of surgery, and so forth. Correction of the deformity was significantly faster (16 days) in yearlings treated with a transphyseal screw compared with those treated with a screw and wire (see Table 1). There was no difference between groups for the incidence of incisional infections, seromas, or overcorrection. Significantly more yearlings treated with the transphyseal screw, however, developed physitis (17.1\%) compared with the screw and wire (7.5\%), and 4.4\% of yearlings treated with a transphyseal screw developed a particular group of signs termed metaphyseal collapse, whereas no horses treated with a screw and wire developed this complication.\textsuperscript{21} Metaphyseal collapse was defined by acute change in limb angulation associated with pain and lameness with no evidence of a bony bridge crossing the physis and occurring 2 months to 5 months after screw removal. Of the 14 affected horses, 4 required growth retardation on the opposite side of the limb to correct the acute deformity; 6 of 14 horses went on to race.\textsuperscript{21} There are no large studies evaluating the use of the transphyseal screw in the distal radial physis when physitis is already present nor in foals with significant remaining growth potential. Growth retardation procedures are only performed in foals with severe angular deformities at the level of the distal radial physis that are not responsive to other therapies. The principal advantages of the transphyseal screw (faster correction and improved cosmesis) may be less critical in a foal with ample time for correction to occur and for swelling associated with the more bulky screw and wire construct to resolve. Therefore, until there is more evidence supporting the safe use of the transphyseal screw in foals and cases of physitis, it is advisable to continue to use the screw and wire transphyseal bridge.

**SUMMARY**

Growth retardation procedures are reserved for foals with angular limb deformities that are severe or not responsive to more conservative therapies or when insufficient time for physiologic correction remains for the degree of the deformity. Knowledge of normal growth patterns and appropriate timing for intervention is critical to successful
treatment. The 2 principal surgical procedures used currently are the transphyseal screw and the screw and wire transphyseal bridge. The transphyseal screw is the preferred technique in the fetlock and tarsus because of the improved cosmesis and more rapid correction, which is of particular importance in the fetlock. The majority of distal radial growth plate manipulation is performed at 1 year of age; however, in young foals with severe deformity of the carpus necessitating growth retardation surgery, the screw and wire may be the preferred procedure.

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