



## An In-Depth Look:

INTERLOCKING  
NAIL FIXATION

# Intramedullary Interlocking Nail Fixation in Dogs and Cats: Biomechanics and Instrumentation\*

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## ABSTRACT:

To counter axial and rotational forces, intramedullary nails were developed with prefabricated holes to accommodate transcortical screws, which are inserted proximal and distal to the fracture line and securely locked the nail into position within the bone. Human orthopedic surgeons routinely use intraoperative fluoroscopy to facilitate fracture reduction, nail insertion, and accurate placement of locking screws; however, restricted access to fluoroscopy has delayed the application of interlocking nails in veterinary medicine. Intramedullary interlocking nail systems that circumvent the need for intraoperative fluoroscopy have recently been developed, allowing their use in veterinary surgery. Interlocking nails have several advantageous biomechanical characteristics compared with intramedullary pinning, external skeletal fixation, and bone plating. This article compares the biomechanics of interlocking nails with other commonly used fracture fixation modalities in veterinary medicine and describes the instrumentation and implants in the Dueland interlocking nail system.

\*A companion article on clinical applications appears on page 531.

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Interlocking nails are cylindrical implants designed for intramedullary stabilization of diaphyseal long bone fractures.<sup>1-3</sup> Interlocking nails have transverse cannulations that accommodate transcortical screws, allowing surgeons to firmly fix the rod within the medullary canal, thereby effectively neutralizing bending, rotational, and axial forces that act on fractures.<sup>1,4</sup> Interlocking nails have become increasingly

popular in veterinary orthopedics because they can be part of an economical technique for fracture fixation.<sup>1,5-13</sup>

Interlocking nails were initially developed to treat long bone fractures in humans.<sup>3,14-16</sup> In many instances, intramedullary interlocking nails have supplanted the use of plates and screws and external skeletal fixation to manage diaphyseal humeral, femoral, and tibial fractures in humans.<sup>17-21</sup> Human orthopedic surgeons routinely use intraoperative fluoroscopy to facilitate fracture reduction, nail insertion, and accurate placement of locking transcortical screws<sup>22,23</sup>; however, restricted access to fluoroscopy has delayed the application of this treatment modality in veterinary medicine. Recently, interlocking nail systems that circumvent the need for

positioned proximal and distal to the fracture, eliminating rotational and axial compressive forces.<sup>6</sup> The evolution of interlocking nails continued through the late 1960s and 1970s, with interest in the concept gaining momentum as the disadvantages and complications associated with rigid fixation of fractures using bone plates became apparent.<sup>21-27</sup> Over the past three decades, intramedullary interlocking nails have been used successfully, with union rates exceeding 90% in humans with diaphyseal femoral, tibial, and humeral fractures.<sup>15,16,28</sup>

The excellent clinical results obtained using interlocking nail fixation of fractures in humans prompted multiple independent investigations to explore the applicabil-

## ***The development of the Dueland interlocking nail system, which uses a drill jig, eliminated the need for intraoperative fluoroscopy and made intramedullary interlocking nail fixation a practical alternative for fracture stabilization in dogs and cats.***

intraoperative fluoroscopy have been developed, allowing their use in veterinary surgery.<sup>5,8</sup> This article discusses the evolution of interlocking nails for use in veterinary medicine, compares the biomechanics of interlocking nails with other commonly used fracture fixation modalities, and describes the instrumentation and implants of the Dueland interlocking nail system.

### **HISTORY**

Gerhard Kuntscher is credited with developing intramedullary fixation and first began using intramedullary nails in humans in the early 20<sup>th</sup> century.<sup>3</sup> Kuntscher used nails that were U-shaped (in cross-section) with a beveled point on one end to facilitate introduction of the nails into the medullary canal.<sup>24</sup> These nails did not have transverse cannulations and were not designed to accept interlocking screws. A single intramedullary nail or rod provides little resistance to rotational and axial compressive forces<sup>25,26</sup>; thus many modifications were made to the nails to improve their biomechanical properties.<sup>1,14</sup> In 1968, Kuntscher introduced the “detensor nail”—the forerunner of modern interlocking nails. The detensor nail had two threadless bolts that were inserted into prefabricated transverse holes in the nail that were

ity of this method in veterinary surgery. Jenny reported the first clinical nailing of a femoral fracture in a dog in 1943.<sup>29</sup> Although the use of intramedullary nail fixation in humans gained popularity during the 1950s and 1960s, Kuntscher nailing never became firmly established in veterinary medicine because of design limitations. Instead, smooth trocar-pointed Steinmann pins became the most popular implant used for fracture repair in dogs and cats.

Huckstep is credited with using the first interlocking implant in veterinary medicine: In 1981, he used a modified human interlocking nail to repair a fracture in a foal.<sup>29</sup> Johnson and Huckstep<sup>30</sup> later reported that experimentally created comminuted femoral diaphyseal fractures in dogs attained union within 8 to 12 weeks after stabilization with an 8.5-mm diameter interlocking nail. In 1993, Muir and coworkers<sup>9</sup> reported the successful repair of a tibial fracture in a dog using a custom-made intramedullary interlocking nail. Also in 1993, Durall and associates<sup>5</sup> developed an interlocking nail system and successfully treated 10 dogs with experimentally created femoral osteotomies.

There are currently several intramedullary interlocking nail systems designed for use in veterinary surgery. Interlocking nail systems have been developed specifically for

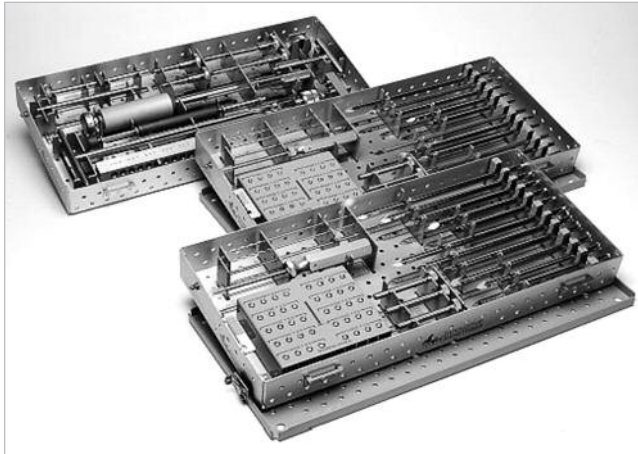
use in dogs by Huckstep in Australia,<sup>30</sup> Durall in Spain,<sup>5</sup> and Duhautois in France.<sup>31,32</sup> In the United States, the interlocking nail system developed by Dueland and associates<sup>8</sup> at the University of Wisconsin and produced commercially by Innovative Animal Products (Rochester, Minnesota) is used most frequently in dogs and cats (Figure 1). The nail design is a modified Steinmann intramedullary pin with a single trocar point. Nails were initially manufactured with six transverse cannulations equally spaced along their length to accept transcortical-locking screws. Nails are currently available in either three- or four-hole designs, with one or two holes positioned near each end of the nail (Figure 2). The keys to this system were the development of a drill jig that allows surgeons to accurately place the locking screws without fluoroscopic control as well as an extension device that allows the proximal end of the nail to be recessed below the surface of the bone (Figure 3). These developments have made the intramedullary interlocking nail a viable and practical alternative for fracture fixation in dogs and cats.

### BIOMECHANICS

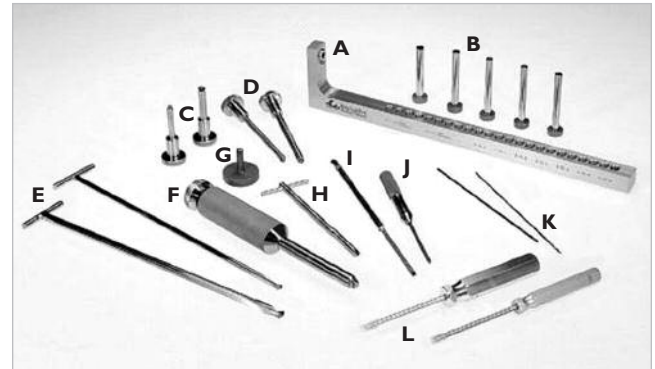
Interlocking nails have several advantageous biomechanical characteristics. Unlike an intramedullary Steinmann pin, which can only resist bending forces,<sup>25,26,33</sup> interlocking transcortical screws allow interlocking nails to resist axial and rotational forces as well.<sup>1,14</sup> Placing the interlocking nail within the medullary canal positions the implant along the neutral axis of the bone–nail construct.<sup>1,11,14</sup> The intramedullary position is superior to the eccentric position bone plates occupy when they are applied to the cortical surface. Placing the interlocking nail along the neutral axis of the bone–implant construct makes the nail less susceptible than plate fixation to failure from cyclic axial, torsional, and bending loading.<sup>1,5</sup> This effect is magnified when complete anatomic reconstruction of the fracture is not performed or is impossible.<sup>11,34,35</sup>

## ***Intramedullary interlocking nails are primarily indicated for stabilizing diaphyseal fractures of the humerus, femur, and tibia.***

In an ex vivo evaluation of femurs obtained from human cadavers, femurs (with subtrochanteric osteotomy gaps) stabilized with interlocking nails and subjected to combined bending and compressive loads had significantly greater loads to failure than femurs stabilized with plate fixation.<sup>35</sup> Likewise, in an in vitro study evaluating the structural properties and interfragmentary motion on osteotomized dog femurs stabilized with either an 8-mm interlocking nail or a 3.5-mm, 10-hole dynamic compression plate, much higher rigidity was noted with interlocking nail fixation.<sup>36</sup> Interlocking nails also provide superior fatigue resistance and bending stiffness compared with plate fixation.<sup>8,37–39</sup> Interlocking nails resist torsional forces better than plates and unlocked intramedullary nails. This is primarily because of the “spring

**Figure 1.** Interlocking nail instrumentation and implant sets.

Complete 6- and 8-mm interlocking nail instrumentation and implant sets.

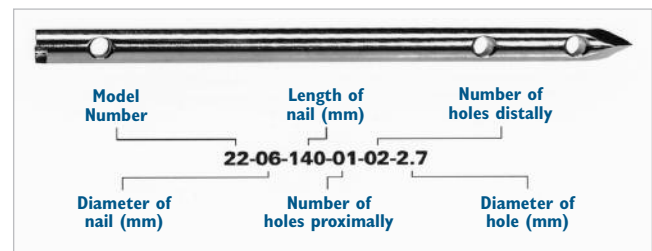


Individual instruments, including a drill jig (A), drill and tap sleeves (B), short femoral and humeral extensions (C), long tibial extensions (D), 6- and 8-mm reamers (E), a nail insertion tool (F), an attachment screw (G), a trocar (H), a depth gauge (I), a nail attachment hex driver (J), drill bits (K), and screwdrivers (L).

back” mechanism: An interlocking nail–bone construct subjected to torsional loading can undergo considerable elastic deformation and spring back (i.e., return) to its previous conformation when the load is released.<sup>1,14,40</sup>

Fracture configuration has a pronounced influence on the stability of repair. In humans, fracture classification schemes have been developed to help surgeons decide whether screws should be placed on one or both sides of a fracture.<sup>23</sup> When the interlocking screws are placed proximal and distal to the fracture, the fixation is considered to be a static interlock or load-bearing implant system. When interlocking screws are placed in either the proximal or distal bone segment, the fixation is considered to be a dynamic interlock or load-sharing implant system.<sup>7,22,33</sup> Rotational and axial forces are not opposed by implants when a dynamic interlock is used, and weight-bearing results in axial compression.<sup>2</sup> Most fractures in dogs and cats are stabilized using a static interlock.<sup>6,8,9</sup> In highly comminuted fractures, the interlocking nail may be responsible for virtually all of the load transfer across the fracture defect.<sup>1,41</sup> Decreased bending stiffness has been observed in ex vivo experimental studies evaluating the effects of segmental bone removal and was ascribed to an increase in radial clearance between the endosteal cortex and nail near the excised surface of bone segments.<sup>14</sup>

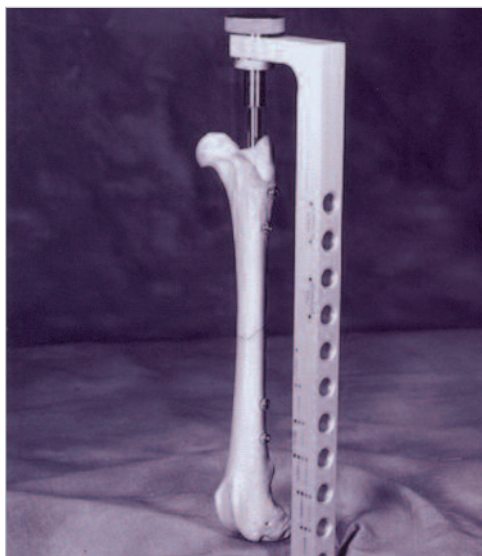
The area moment of inertia (a mathematical representation of the arrangement or distribution of mass around a defined axis through an object’s center) determines the resistance of an implant to bending.<sup>37</sup> Although the neutral axis can vary and is defined by the direction of bend-

**Figure 2.** Interlocking nail with an inscription indicating that it is a model 22 series, 6 mm in diameter, and 140 mm long, with one 2.7-mm hole proximally and two 2.7-mm holes distally. The model number (i.e., 22) denotes that proximal and distal holes are spaced 22 mm apart.

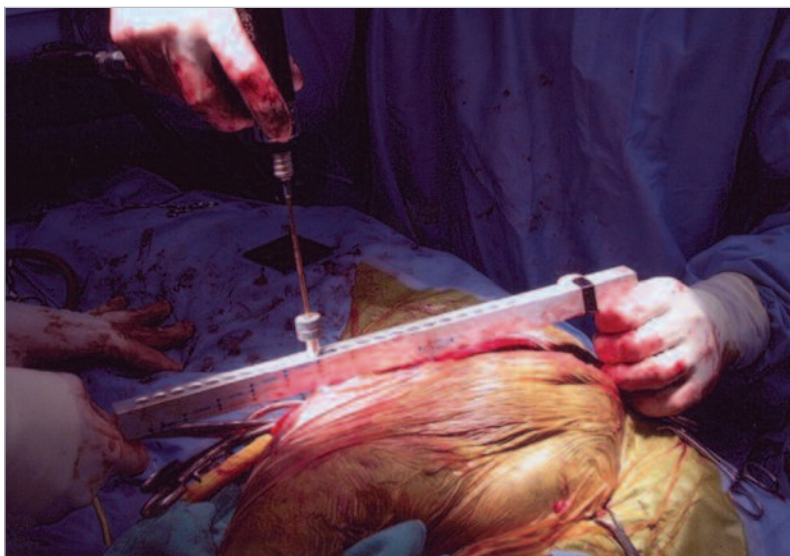
ing in a plate, the area moment of inertia is the same in the solid portion of a nail irrespective of the direction of applied load. The area moment of inertia is less at the screw holes in both bone plates and interlocking nails.<sup>37,38,42</sup> The area moment of inertia of 6- and 8-mm interlocking nails (Innovative Animal Products) is nearly four and 12 times, respectively, that of a 3.5-mm dynamic compression plate when the neutral axis is defined in the plane perpendicular to the holes in the nail.<sup>42</sup> If the neutral axis is defined in the plane parallel with the holes in the nail, the area moment of inertia of 6- and 8-mm interlocking nails is approximately 1.33 and 4.5 times, respectively, that of a 3.5-mm dynamic compression plate.<sup>42</sup>

The transverse cannulations, which accommodate the screws, weaken the interlocking nail and serve as a potential stress concentrator.<sup>38</sup> The area moment of inertia of a 6-mm interlocking nail at a 3.5-mm screw



**Figure 3.** Jig and clinical application.

Jig application and short extension used to stabilize femoral fractures.



Clinical application of an interlocking nail to stabilize a femoral fracture.

hole is 31% of the area moment of inertia of the solid portion of the nail.<sup>38</sup> When the transcortical screws are placed through the interlocking nail, the screws do not rigidly interact with the nail and thus do not reduce the stress concentrator effect of the screw holes.<sup>1</sup> Failure of 6-mm nails through screw holes positioned over a fracture site has been reported in some dogs.<sup>8,43</sup> In most of these cases, however, the diameter of the implanted interlocking nail was inappropriately small relative to

In the original design, the 6-mm interlocking nail accepted 3.5-mm screws and the 8-mm interlocking nail accommodated 4.5-mm screws. In the revised design, the 6-mm interlocking nail accommodates 2.7-mm screws and the 8-mm interlocking nail accommodates 3.5-mm screws. Reducing the diameter of the holes to accommodate 2.7-mm screws in 6-mm interlocking nails increases the estimated fatigue life by 52 times.<sup>38</sup> Reducing the diameter of the holes to accom-

***Intramedullary interlocking nails have several advantageous biomechanical characteristics that make them an excellent modality for stabilizing diaphyseal long bone fractures in dogs and cats.***

the size of the dog in which it was used (Figure 4). Concerns raised by these few cases have led Innovative Animal Products to revise its nail design as follows:

- Nails are now also manufactured with only three holes (i.e., one proximal and two distal or vice versa) to accommodate screws and avoid placing a screw hole at or near the fracture.
- A series of nails with decreased-diameter transverse cannulations was introduced.

modate 3.5-mm screws in 8-mm interlocking nails increases the estimated fatigue life by eight times.<sup>38</sup>

Although increased strength of the interlocking nail has been documented,<sup>1,38</sup> smaller diameter screws may break, resulting in implant failure.<sup>23</sup> Although generally less catastrophic than nail failure, screw failure is nonetheless problematic (Figure 5). Reducing screw diameters from 4.5 to 3.5 mm and 3.5 to 2.7 mm reduces the area moment of inertia of the corresponding

**Figure 4.** Radiographs of an undersized, 6-mm interlocking nail in the tibia of a rottweiler. The nail failed at a screw hole positioned adjacent to the fracture.



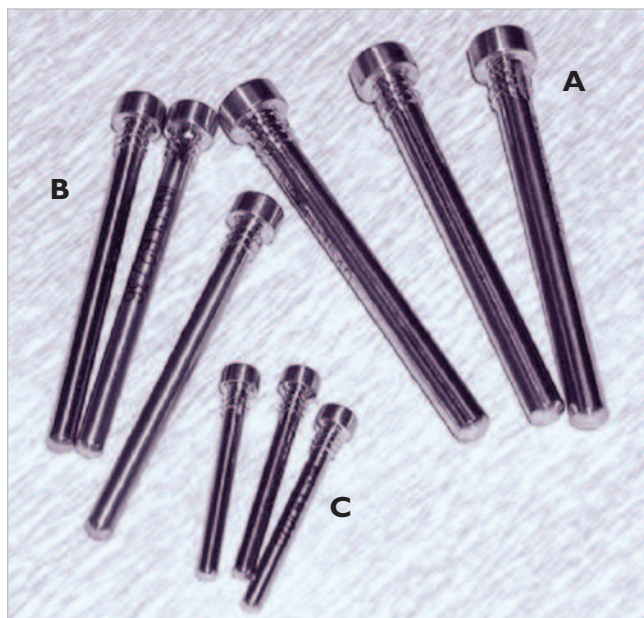
**Figure 5.** Craniocaudal view radiograph of a tibial fracture repair using a 6-mm nail, with failure of the two distal 2.7-mm interlocking screws.

screws by approximately 40%, and the yield strength in cantilever bending is reduced 34% and 44%, respectively.<sup>38</sup> Fatigue life of screws, however, is not dependent on screw size alone. In a study comparing the fatigue life of 2.7-mm cortical bone screws used in 6-mm interlocking nails, the effects of bone diameter and eccentric loading of a single interlocking screw were examined. Increases in bone diameter from 19 to 31.8 mm significantly decrease the number of cycles to failure. Within a constant bone diameter, the number of eccentrically loaded screws was significantly greater than that of centrally loaded screws.<sup>44</sup> In response to concerns over screw failure, Innovative Animal Products has developed 2-, 2.7-, and 3.5-mm bolts to replace the corresponding screws. The bolts consist of a solid shaft that completely fills the transverse hole of the corresponding interlocking nail. Complete contact between the bolt and nail may increase implant load sharing, resulting in more stable fixation. Threads are located adjacent to the head

of the bolt and engage the *cis*-cortex, preventing bolt migration. Bolts are currently manufactured only in sizes 3.5 × 40, 2.7 × 36, and 2 × 20 mm (Figure 6), but they can easily be cut to the appropriate length with a bolt cutter.

## INSTRUMENTATION AND IMPLANTS

Innovative Animal Products initially produced 6- and 8-mm diameter interlocking nails for use in dogs. This limited use to large dogs and excluded application of nails in many smaller dogs and cats. Since then, a smaller 4.7- and 4-mm system that uses 2-mm screws has been introduced. Innovative Animal Products has developed two basic interlocking intramedullary nail sets for the 6- and 8-mm and 4- and 4.7-mm nails. Each set contains the appropriate drill jig, extensions, and drill sleeves, along with other necessary instrumentation to effectively place intramedullary interlocking nails (Figure 1). The drill jig is an aiming guide that is



**Figure 6.** Interlocking bolts: 3.5 (A), 2.7 (B), and 2 (C) mm.

screwed to the proximal end of the intramedullary interlocking nail via an extension. Extensions are temporarily attached to the nail with a setscrew. Extensions come in two lengths: Short extensions should be used when repairing femoral and humeral fractures. Long extensions should be used when repairing tibial fractures because the longer length prevents the drill jig from interfering with the stifle during application. The extensions allow the proximal end of the nail to be recessed so that the nail does not protrude from the bone following implantation. The drill jig, when attached with an

Each diameter nail is available in a variety of lengths with various hole configurations. Six- and 8-mm nails are available in 120, 140, 160, 185, 205, and 230 mm. The initial nail design was the model 22 series, in which screw holes are placed 22 mm apart. Now there is also a model 11 series, in which screw holes are 11 mm apart. Six- and 8-mm nails are available in both the model 11 and 22 series. Four- and 4.7-mm nails are available in 68, 79, 91, 101, 112, 123, and 134 mm. Four- and 4.7-mm nails are available only in the model 11 series.

Within each nail length and model, nails are available with either three or four holes to accommodate screws (Figure 2). Four-hole nails allow placement of two screws on each side of a fracture. Three-hole nails allow placement of one screw proximally and two screws distally or vice versa. Three-hole nails are designed for use in fractures with short proximal or distal fracture segments so that a screw hole is not positioned at or near the fracture.

## CONCLUSION

The use of intramedullary interlocking nails is increasing in popularity in veterinary medicine. Interlocking nails have many advantageous biomechanical properties compared with other forms of internal fixation, and development of an efficient drill jig has increased the applicability of this treatment modality to veterinary surgery.

Tips on using interlocking nails and radiographs of actual case studies are available at [VetLearn.com/compendiumdownloads.html](http://VetLearn.com/compendiumdownloads.html).

***Intramedullary interlocking nails resist bending, rotational, and axial forces that act on fracture sites.***

extension to the nail, should be positioned parallel to the nail and has holes corresponding to those of the nail, allowing accurate placement of the transcortical screws. A series of drill sleeves, which fit through the drill jig holes, accept the appropriately sized drill bit and tap for the intramedullary interlocking nail being implanted. The sleeves hold the drill bit, tap, and screwdriver perpendicular to the nail to accurately drill, tap, and place screws through the cannulations in the nail (Figure 3).

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### 1. Intramedullary interlocking nails are primarily indicated for internal fixation of \_\_\_\_\_ fractures.

- |                   |                              |
|-------------------|------------------------------|
| a. Salter Harris  | c. diaphyseal long bone      |
| b. axial skeleton | d. metatarsal and metacarpal |

### 2. Intramedullary interlocking nails effectively resist \_\_\_\_\_ forces that act on fractures.

- |               |                     |
|---------------|---------------------|
| a. rotational | c. compressive      |
| b. bending    | d. all of the above |

### 3. Intramedullary interlocking nails are less susceptible to failure from cyclic axial, torsional, and bending loading than plate fixation because

- a. the nails are placed along the neutral axis of the bone–implant construct.
- b. locking screws provide rigid intramedullary fixation.
- c. the nails have fewer holes to accept implant screws than do bone plates.
- d. less soft tissue dissection is needed during nail application than for bone plates.

### 4. Which development made intramedullary interlocking nails applicable for use in veterinary surgery?

- a. increased availability of fluoroscopy in veterinary surgery
- b. development of a drill jig that negated the need for fluoroscopy to place locking screws
- c. the ability of interlocking nails to effectively treat any type of fracture
- d. increased complication rates associated with external skeletal fixation

### 5. Transcortical locking screws, when placed through an interlocking nail, do not reduce the stress concentrator effect of the screw holes because the screws

- a. prevent compressive forces from acting on the fracture.
- b. prevent rotational forces from acting on the fracture.
- c. do not rigidly interact with the nail.
- d. have a higher area moment of inertia than the nail.

### 6. The first true interlocking nail was developed by

- a. Dueland.
- b. Steinmann.
- c. Huckstep.
- d. Kuntscher.

### 7. Screw holes in 4- and 4.7-mm nails are placed \_\_\_\_\_ mm apart.

- a. 10
- b. 11
- c. 15
- d. 22

**8. In humans, union rates when using intramedullary interlocking nails have exceeded \_\_\_\_%.**

- a. 25
- b. 30
- c. 50
- d. 90

**9. Intramedullary interlocking nails currently have**

- a. six transverse cannulations equally spaced along the nail.
- b. four transverse cannulations equally spaced along the nail.
- c. one transverse cannulation placed at each end of the nail.
- d. a three- or four-hole design, with one or two holes positioned near each end of the nail.

**10. Intramedullary interlocking nails provide superior resistance to torsional forces compared with plate fixation because**

- a. the “spring back” mechanism allows the system to return to its previous conformation.
- b. nails are placed eccentrically on the cortical surface of the bone.
- c. plates have minimal torsional resistance.
- d. plates are placed concentrically within the marrow cavity.