Perceptions of Minimally Invasive Osteosynthesis: A 2018 Survey of Orthopedic Surgeons

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Abstract

Objective: To report perspectives of minimally invasive osteosynthesis techniques in veterinary surgical practice in 2018

Study design: Electronic questionnaires

Sample population: Diplomates and residents of the American & European Colleges of Veterinary Surgery (ACVS & ECVS) and members of the Veterinary Orthopedic Society (VOS)

Methods: Survey questions pertaining to minimally invasive osteosynthesis (MIO) and minimally invasive plate osteosynthesis (MIPO) were sent electronically to the sample population. Questions assessed training, current caseload, benefits and limitations of MIO and MIPO.

Results: Two hundred and fifty-six veterinary surgeons completed questions pertaining to MIO and 238 veterinary surgeons completed questions pertaining to MIPO. When considering MIO, only 16% of respondents reported that they performed MIO techniques regularly or exclusively and 62% wanted to perform more MIO than they were currently undertaking. Tibial fractures were most commonly selected for MIO/MIPO stabilization techniques in both cats and dogs. Challenges in achieving adequate fracture reduction was identified as the biggest limitation of MIO/MIPO techniques. Forty three percent of respondents felt there weren't enough MIPO training opportunities.

Conclusions: Currently MIO/MIPO techniques are performed infrequently with a large proportion of respondents revealing that they would like to perform more in the future. There is also evidence that further training opportunities would be welcomed when considering MIPO.

Clinical significance: Despite evidence of the benefits of MIO and MIPO over more traditional fracture stabilization approaches our survey has highlighted that significant barriers remain before the techniques are likely to be more widely adopted.

Introduction:

In recent years there has been a trend in both human and veterinary medicine away from anatomical reconstruction and rigid internal fixation towards more biological approaches to fracture fixation.[1-3] Minimally invasive osteosynthesis (MIO) techniques, are becoming widely accepted as alternatives to open reduction and internal fixation (ORIF) for the stabilization of fractures. By definition MIO includes any fracture fixation technique that involves small skin incisions and avoidance of the deeper surgical/ fracture site. An intermediate surgical approach known as an 'open but do not touch' (OBDNT) can be utilized which lies somewhere between MIO and ORIF.[3,4] The authors are not aware of any study focusing on the benefits/ limitations of an OBDNT approach over other methods. Numerous MIO techniques are reported in the veterinary literature for the treatment of long bone fractures including external skeletal fixation,[5-8] minimally invasive plate osteosynthesis (MIPO)[9-20] and interlocking nails.[4,21-24] MIO techniques have also been applied to articular fractures,[25] sacroiliac joint luxation stabilization [26,27] and central tarsal bone luxation stabilization.[28] Reported advantages of MIO/MIPO techniques in human and veterinary patients include reduced postoperative pain,[29] preservation of the fracture hematoma,[1,30] improved vascularization of the fracture site,[31-33] more rapid healing,[4,11,15,17,29,34,35] less wound complications [12,17,36] and faster return to normal function compared with open approaches.[29,36] Disadvantages reported include the technical difficulty of the learning process, longer operating times, [37] prolonged healing, [38] fracture malreduction [34] and radiation safety issues associated with intraoperative fluoroscopy.[37,39] With the conflicting evidence Kulkarni et al [36] advocated an individual approach to each fracture based on a cost/ benefit analysis.

Minimally invasive plate osteosynthesis was first described by Brunner and Weber in the early eighties.[40] It involves the closed and indirect reduction of fractures followed by the

application of a bone plate without making an extensive surgical approach to the fracture site. Typically, small skin incisions are created at either end of the fractured long bone. A plate is then inserted through one of the incisions and passed through an epiperiosteal tunnel which spans the fracture site. Screws are then applied in the proximal and distal ends of the plate.[18] Advancements in implant technologies, in particular the introduction of locking plates, increased availability of intraoperative imaging and evolution of indirect fracture reduction techniques has resulted in MIPO gaining popularity in human orthopedic surgery.

Despite the presence of multiple studies advocating and reporting the use of MIO and MIPO techniques in both the veterinary and human literature there still remains conflicting evidence about the direct benefits of these approaches over more traditional rigid internal fixation techniques.[11,15,19,37,41] The veterinary literature to date has focused on objective benefits but has not identified whether these techniques are widely performed by the veterinary orthopedic community. A recent study demonstrated that minimally invasive surgical techniques were widely used by American College of Veterinary Surgeons (ACVS) Diplomates and residents but this study did not specifically investigate the application of MIO/MIPO techniques.[42] There is a paucity of data with regards to current application, training opportunities, perceived benefits and limitations of MIO/MIPO and motivating factors for performing these techniques. The objective of our study was to assess the current perceptions and applications of MIO/MIPO techniques amongst a population of veterinary orthopedic surgeons.

Materials & Methods:

Two electronic surveys were created using an Online Survey tool (www.onlinesurveys.co.uk). Ethical approval for the study was granted by the Ethical committee at the University of Bristol (Application 60043).

A link to the initial survey was provided by electronic mail to all small animal European College of Veterinary Surgery (ECVS) Diplomates and residents containing questions pertaining to minimally invasive osteosynthesis (MIO). This was then followed by another link to a second survey pertaining to MIPO which was also sent by electronic mail to all small animal ECVS Diplomates and residents. Finally, a link to the amalgamated survey (consisting of questions from the first and second survey) was circulated to members of the Veterinary Orthopedic Society (VOS) via electronic mail and posted on the American College of Veterinary Surgery (ACVS) small animal surgical forum.

Survey feedback and assistance was provided on an individual basis by email correspondence. Responses were only included if the questions were complete and returned within a 14-week period between February & May 2018. A survey response percentage was calculated where possible for the individual populations. The amalgamated survey sent to the VOS and ACVS can be found in the supplementary information online (Appendix 1).

Statistical analysis:

Descriptive statistical analysis was performed and presented as both counts and percentages of survey respondents. Groups were broadly defined based on age (over or under 50 years of

age) and Diplomate status (Diplomates vs non-Diplomates). Chi-squared tests were used to evaluate if there were any relationships between the age or Diplomate status of the respondents and relevant respondent's answers. An alpha of ≤ 0.05 was used for tests.

Results:

Survey response

In total 171 surgeons responded to the first survey, 153 responded to the second survey and 85 responded to the amalgamated survey. Both the first and second survey were sent to the 619 small animal members of the ECVS which equates to a 27.6% and 24.7% response rate, respectively. The total number of people exposed to the survey when it was circulated to the ACVS online forum and VOS is unknown and so response rates could not be calculated for these populations.

Minimally invasive osteosynthesis

Of the 256 veterinary surgeons who completed the questions pertaining to minimally invasive osteosynthesis, 73% were male (n=187) and 27% female (n=61). Seventy three percent (n=187) of respondents were 31-50 years of age. The Diplomate status for this group of respondents is presented separately (Figure 1). The majority of respondents (97%, n=248) reported that fractures consisted between 0-50% of their surgical caseload. Forty-one respondents (16%) stated that they performed MIO procedures regularly or exclusively. One hundred and fifty-seven respondents (62%) reported that they wanted to perform more MIO techniques than they currently did.

The three most common canine fractures addressed by the respondents using MIO techniques were tibial diaphyseal (82%, n=211), radial diaphyseal (45%, n=116) & femoral diaphyseal (45%, n=91) fractures.

The most frequent perceived advantages identified for MIO were faster healing time (64%, n=164), less post-operative pain (48%, n=123) and faster return to function (44%, n=113). The most commonly reported perceived limitations of MIO techniques were challenges to obtaining adequate fracture reduction (62%, n=158), technical difficulty (47%, n=120), increased surgical time (38%, n=97) and radiation safety issues (36%, n=92). When asked which of these was the most significant perceived limitation challenges to obtaining fracture reduction and the requirement for new equipment (Figure 2) were the two most frequently chosen options.

Minimally invasive plate osteosynthesis

Two hundred and thirty-eight veterinary surgeons completed questions pertaining to MIPO. Seventy four percent were male (n=177) and 26% were female (n=61). Seventy two percent (n=171) of respondents were between 31 & 50 years of age. Fifty nine percent (n=140) of respondents worked in private referral practice and 31% (n=73) in academic centers. Seventy one percent of respondents (n=169) performed MIPO for fracture fixation rarely or occasionally. Eighteen percent of respondents (n=42) reported that they have never performed MIPO before. Sixty three percent of respondents (n=151) wanted to apply MIPO more frequently than they were at the current time. Fractures most commonly stabilized with MIPO in dogs were tibial fractures (77%, n=184) followed by radial fractures (47%, n=112). Fractures most commonly stabilized with MIPO in cats where tibial fractures (55%, n=133) followed by femoral fractures (24%, n=57). A higher proportion of respondents had never performed MIPO in cats compared with dogs (39% vs 15% respectively).

Respondents were asked to consider what surgical method they would elect to perform when stabilizing a non reconstructible, comminuted, mid diaphyseal fracture of the tibia, humerus, femur and radius in a 20 kg dog and 5 kg cat. The responses for preferred stabilization method for each scenario are shown separately (Figures 3 and 4). When considering MIPO training 40% (n=95) of respondents stated that they had taught themselves MIPO techniques and 40% (n=95) reported that they had received specific MIPO training during their residency. Forty three percent (n=104) of surgeons felt that there were not enough training opportunities available for MIPO techniques. Forty two percent (n=101) of respondents indicated that they had never used fluoroscopy when performing MIPO.

The four most common perceived limitations to performing MIPO were challenges to obtaining fracture reduction (25%, n=60), requirement for new equipment (16% n=38), lack of training opportunity (14% n=33) and lack of proven benefit and/or efficacy (12%, n=28).

Statistical analysis

An association ($\chi^2 = 9.573$, df = 3, $p = 0.02$) was found between Diplomate status and the response to how much MIO the respondent would like to perform when compared with their current level (Table 1), with non-Diplomates being more likely to want to perform more MIO techniques than their current level.

A similar relationship was found between Diplomate status and responses to the questions regarding how much MIPO the respondent would like to perform when compared with their current level ($\chi^2 = 16.255$, df = 3, $p \leq 0.001$) and whether they felt there were enough training

opportunities for MIPO ($\chi^2 = 19.157$, df = 3, $p \leq 0.001$) (Tables 2 & 3). Non-Diplomates were more likely to want to perform more MIPO than they currently did and they were more likely to report that there are inadequate MIPO training opportunities.

Relationships were found between age of the respondent and responses to the questions regarding how much MIPO the respondent would like to perform when compared to their current level ($\chi^2 = 9.205$, df = 3, $p = 0.023$) and whether they felt there were enough training opportunities for MIPO ($\chi^2 = 9.065$, df = 3, $p = 0.032$) (Table 4 and 5). Younger respondents were more likely to want to perform more MIPO than they currently did and stated that there are not enough MIPO training opportunities.

Discussion:

To the best of the authors' knowledge this is the first survey assessing the current perspectives of MIO and MIPO in the veterinary literature. A large proportion of respondents (62%) highlighted that they wanted to perform more MIO and MIPO techniques than they were currently doing. This suggests that a considerable proportion of respondents perceive significant benefits of MIO and MIPO over more traditional approaches but for undisclosed reasons were not currently performing these methods. The survey has however identified that there are barriers to performing MIO and MIPO in veterinary orthopedic practice. This appears to be in contrast to other minimally invasive surgeries such as laparoscopy or thoracoscopy which were reported to be more commonly performed than the MIO/MIPO techniques in our study.[42]

Results of the survey demonstrate that within the population of respondents MIPO was not being performed as commonly in feline patients when compared with dogs. The reason for this difference is currently unknown as respondents were not specifically asked to comment. Potential explanations would include a relatively lowercase load for feline fractures in practice, or the smaller patient size which may be associated with a greater number of technical difficulties when performing MIPO in these patients.

In both cats and dogs, tibial fractures were reported to be the most commonly chosen long-bone fracture to be stabilized with a MIPO approach. This is likely to be associated with the relative ease of reduction of fractures of the tibia and the absence of significant soft tissue when compared with other bones, but this was not specifically investigated in the survey. When asked how respondents would approach non-reconstructible, comminuted, mid

diaphyseal fractures in different bones in a 20kg dog and a 5kg cat, the most frequently chosen answer was an ‘open but do not touch approach with a plate and intramedullary (IM) pin’, with the exception of the radius where an IM pin cannot be safely placed without damaging the joints either side of the fracture. This suggests that many respondents recognize the benefits of a more biological approach to fracture stabilization, including minimising surgical trauma and preservation of the fracture haematoma over more traditional open approaches. That said, in the authors experience, there is a very wide margin of interpretation of exactly what pertains to an open but do not touch approach [3] and limited objectivity of this technique in the literature. Further studies are required to investigate if there are any significant differences between fracture healing and outcome when comparing an ‘open but do not approach’ and MIPO.

Non-Diplomates were more likely to want to perform more MIPO and MIO when compared with their current level. This may reflect that MIO and specifically MIPO techniques are challenging and require a steeper learning curve which may be perceived to be too complex by inexperienced surgeons at the start of their career. Younger respondents were also more likely to want to perform more MIPO than their current level which again may support the theory that MIPO techniques are more technically challenging than open approaches, but the benefits are acknowledged. These differences may also be explained by the fact that there is more evidence supporting MIPO and MIO approaches in the recent literature which may encourage respondents who are currently training to perceive the benefits but due to the steep learning curve are reluctant to perform MIPO procedures.

Our study highlights that the most significant perceived limitations when performing MIPO were challenges when attempting fracture reduction, requirement for new equipment and a lack of proven benefit/ efficacy. The perceived limitations of MIO were similar to those for MIPO with challenges when attempting fracture reduction being the most commonly cited. Numerous techniques have been described to aid with fracture reduction including basic external skeletal fixators, distraction devices, plate fixation itself and other instruments such pointed reduction forceps.[11,14,43,44] A novel approach has recently been reported with the use of a 3D printed patient specific guide for repair of a comminuted humeral fracture in a cat [13] which is an area with considerable potential for use in these cases. In certain situations, expensive additional equipment is not always required. In a study by Schmokel et al [16] no specific additional equipment was required in seven dogs with tibial fractures stabilized with MIPO in which the application of a pre contoured plate was the sole device used in these cases. Further studies are required to ascertain whether the degree of fracture alignment is related with a detrimental outcome or not.

Interestingly, in our study, 50% of respondents either rarely or never used fluoroscopy when attempting MIPO techniques. This may be a potential explanation as to why challenges to adequate fracture reduction was listed as the most important perceived limitation to MIO & MIPO. Previous studies have recommended the use of intraoperative fluoroscopy to improve fracture alignment but suggest that the benefits should be weighed against the risks of performing fluoroscopy.[11,19,39,45] Currently, to the authors' knowledge, there are no specific studies evaluating whether there is a significant benefit of intraoperative fluoroscopy in fracture alignment when performing MIPO.

There are clear advantages and disadvantages for minimally invasive approaches to fracture stabilization when compared with open approaches. That said, the human and veterinary literature is not clear and often conflicting with regards to developing a cost benefit analysis for these cases. For example, there is some evidence that operating times were not statistically different when comparing MIPO and more traditional techniques in one metanalysis by Yu et al.[41] However, another metanalysis by Li et al [37] showed that minimally invasive approaches were associated with longer operating times. Nine percent of respondents of our survey perceived that longer operating times was the most significant perceived limitation to performing MIPO over a more traditional approach. One study in the human literature [36] did show that the operating time was largely dependent on surgeon skill and experience. The authors of this latter study concluded that an individual specific approach should be used in each case despite the benefits shown with a MIPO approach over an interlocking nail or open approach and rigid internal fixation.[36] Until clear evidence can be provided that one approach is significantly more effective than another the authors would suggest that a decision is based on a case by case basis. Further randomized controlled trials are required before further conclusions can be made.

Both younger respondents and non-Diplomates were more likely to respond negatively when asked if there were sufficient training opportunities for MIPO techniques. This mismatch suggests that there is feeling amongst younger surgeons that more training opportunities in MIPO would be beneficial. The ACVS have included a minimum number of minimally invasive surgeries in their residency training programs to try to increase the exposure of surgeons in training to these techniques.[42] There is scope for this to be adopted into other residency training programs to try to address this perceived lack of training opportunities as well as the development of MIPO specific training courses.

Interestingly, multiple respondents highlighted that there was confusion in the literature as to the exact definition of what techniques constituted MIO and MIPO. There is a danger as new techniques continue to be developed that this situation only becomes more confusing and highlights the potential need for a consensus to be developed.

Limitations:

By nature of the design there are limitations to this survey. Whilst this study attempted to ascertain the perspectives of MIO and MIPO in veterinary practice the survey was only circulated amongst a specific subpopulation of veterinary surgeons, namely ECVS and ACVS Diplomates and residents and VOS members and only a proportion of these responded. The response rate was similar to a previous survey conducted on minimally invasive surgery perceptions. This potentially introduces an element of bias to the study. For example, individuals who may have a specific interest in the topic would probably be more likely to complete the survey compared to individuals who have no incentive, interest or requirement to complete the survey. As with all survey-based studies there is likely to exist bias between responders and non-responders, and between our target population and veterinary surgeons as a whole.

A further limitation of our study was in the design of the questionnaires. It would have been more prudent to simply create one survey that was circulated to every member of the study population.

Conclusion:

Despite evidence of the benefits of MIO and MIPO over more traditional fracture stabilization approaches, controversy still remains as to whether these techniques are superior to open reduction and rigid internal fixation. Further prospective studies are needed to clarify this position. Our survey has highlighted that significant barriers remain before the technique is likely to be more widely adopted. There is also evidence that further training opportunities would be welcomed when considering MIO and MIPO techniques. Currently MIO/MIPO techniques are performed infrequently with most respondents revealing that they would like to perform more in the future.

Disclosure:

The authors declare no conflict of interest to this report.

Table 1: Diplomate status vs responses to the question "How much MIO would you like to perform compared with your current level?"

		Less	The same	More	Exclusively	Total
Diplomate	Count	3	82	113	1	199
		2%	**41%**	**57%**	**1%**	
Non-Diplomate	Count	0	12	45	0	57
		0%	**21%**	**79%**	**0%**	

Table 2: Diplomate status vs responses to the question "How much MIPO would you like to perform when compared with your current level?"

		Less	The same	More	Exclusively	Total
Diplomate	Count	2	73	102	1	178
		1%	**41%**	**57%**	**1%**	
Non-Diplomate	Count	2	8	49	1	60
		3%	**13%**	**82%**	**2%**	

Table 3: Diplomate status vs responses to the question "Do you feel there are sufficient training opportunities for the technique of MIPO?"

		Yes	No	No opinion	Other	Total
Diplomate	Count	47	65	65	1	178
		26.4%	**36.5%**	**36.5%**	**0.6%**	
Non-Diplomate	Count	9	39	10	2	60
		15%	**65%**	**17%**	**3%**	

Table 4: Age vs responses to the question "How much MIPO would you like to perform when compared with your current level?"

		Less	The same	More	Exclusively	Total
21-50	Count	2	54	124	1	181
		1.1%	**29.8%**	**68.5%**	**0.6%**	
51-71+	Count	2	27	27	1	57
		4%	**47%**	**47%**	**2%**	

Table 5: Age vs responses to the question "Do you feel there are sufficient training opportunities for the technique of MIPO?"

		Yes	No	No opinion	Other	Total
21-50	Count	39	88	51	3	181
		21.5%	**48.6%**	**28.2%**	**1.7%**	
51-71+	Count	17	16	24	0	57
		30%	**28%**	**42%**	**0%**	

References:

1. Field JR, Tornkvist H: Biological fracture fixation: a perspective. Veterinary and Comparative Orthopaedics and Traumatology 14:169-178, 2001.
2. Perren SM: Evolution of the internal fixation of long bone fractures. The scientific basis of biological internal fixation: choosing a new balance between stability and biology. J Bone Joint Surg Br 84:1093-1110, 2002.
3. Palmer RH: Biological osteosynthesis. Vet Clin North Am Small Anim Pract 29:1171-1185, vii, 1999.
4. Horstman CL, Beale BS, Conzemius MG, et al: Biological osteosynthesis versus traditional anatomic reconstruction of 20 long-bone fractures using an interlocking nail: 1994-2001. Vet Surg 33:232-237, 2004.
5. Palmer RH: External fixators and minimally invasive osteosynthesis in small animal veterinary medicine. Vet Clin North Am Small Anim Pract 42:913-934, v-vi, 2012.
6. Yardimci C, Ozak A, Nisbet HO: Management of femoral fractures in dogs with unilateral semicircular external skeletal fixators. Vet Surg 40:379-387, 2011.
7. Guerin SR, Lewis DD, Lanz OI, et al: Comminuted supracondylar humeral fractures repaired with a modified type I external skeletal fixator construct. J Small Anim Pract 39:525-532, 1998.
8. Dudley M, Johnson AL, Olmstead M, et al: Open reduction and bone plate stabilization, compared with closed reduction and external fixation, for treatment of comminuted tibial fractures: 47 cases (1980-1995) in dogs. J Am Vet Med Assoc 211:1008-1012, 1997.
9. Beale BS, McCally R: Minimally invasive plate osteosynthesis: tibia and fibula. Vet Clin North Am Small Anim Pract 42:1023-1044, vii, 2012.

10. Hudson CC, Lewis DD, Pozzi A: Minimally invasive plate osteosynthesis in small animals: radius and ulna fractures. Vet Clin North Am Small Anim Pract 42:983-996, vii, 2012.
11. Boero Baroncelli A, Peirone B, Winter MD, et al: Retrospective comparison between minimally invasive plate osteosynthesis and open plating for tibial fractures in dogs. Vet Comp Orthop Traumatol 25:410-417, 2012.
12. Craig A, Witte PG, Moody T, et al: Management of feline tibial diaphyseal fractures using orthogonal plates performed via minimally invasive plate osteosynthesis. J Feline Med Surg 20:6-14, 2018.
13. Oxley B: A 3-dimensional-printed patient-specific guide system for minimally invasive plate osteosynthesis of a comminuted mid-diaphyseal humeral fracture in a cat. Vet Surg 47:445-453, 2018.
14. Peirone B, Rovesti GL, Baroncelli AB, et al: Minimally invasive plate osteosynthesis fracture reduction techniques in small animals. Vet Clin North Am Small Anim Pract 42:873-895, v, 2012.
15. Pozzi A, Hudson CC, Gauthier CM, et al: Retrospective comparison of minimally invasive plate osteosynthesis and open reduction and internal fixation of radius-ulna fractures in dogs. Vet Surg 42:19-27, 2013.
16. Schmokel HG, Stein S, Radke H, et al: Treatment of tibial fractures with plates using minimally invasive percutaneous osteosynthesis in dogs and cats. J Small Anim Pract 48:157-160, 2007.
17. Guiot LP, Dejardin LM: Prospective evaluation of minimally invasive plate osteosynthesis in 36 nonarticular tibial fractures in dogs and cats. Vet Surg 40:171-182, 2011.

18. Pozzi A, Lewis D: Surgical approaches for minimally invasive plate osteosynthesis in dogs. Vet Comp Orthop Traumatol 22:316-320, 2009.
19. Hudson CC, Pozzi A, Lewis DD: Minimally invasive plate osteosynthesis: applications and techniques in dogs and cats. Vet Comp Orthop Traumatol 22:175-182, 2009.
20. Johnson AL: Current concepts in fracture reduction. Veterinary and Comparative Orthopaedics and Traumatology 16:59-66, 2003.
21. Dejardin LM, Guiot LP, von Pfeil DJ: Interlocking nails and minimally invasive osteosynthesis. Vet Clin North Am Small Anim Pract 42:935-962, vi, 2012.
22. Moses PA, Lewis DD, Lanz OI, et al: Intramedullary interlocking nail stabilisation of 21 humeral fractures in 19 dogs and one cat. Aust Vet J 80:336-343, 2002.
23. Endo K, Nakamura K, Maeda H, et al: Interlocking intramedullary nail method for the treatment of femoral and tibial fractures in cats and small dogs. J Vet Med Sci 60:119-122, 1998.
24. Dueland RT, Johnson KA, Roe SC, et al: Interlocking nail treatment of diaphyseal long-bone fractures in dogs. J Am Vet Med Assoc 214:59-66, 1999.
25. Beale BS, Cole G: Minimally invasive osteosynthesis technique for articular fractures. Vet Clin North Am Small Anim Pract 42:1051-1068, viii, 2012.
26. Tomlinson J: Minimally invasive repair of sacroiliac luxation in small animals. Vet Clin North Am Small Anim Pract 42:1069-1077, viii, 2012.
27. Dejardin LM, Marturello DM, Guiot LP, et al: Comparison of open reduction versus minimally invasive surgical approaches on screw position in canine sacroiliac lag-screw fixation. Vet Comp Orthop Traumatol 29:290-297, 2016.
28. Hudson CC, Pozzi A: Minimally invasive repair of central tarsal bone luxation in a dog. Vet Comp Orthop Traumatol 25:79-82, 2012.

29. Zhao W, Zhang Y, Johansson D, et al: Comparison of Minimally Invasive Percutaneous Plate Osteosynthesis and Open Reduction Internal Fixation on Proximal Humeral Fracture in Elder Patients: A Systematic Review and Meta-Analysis. Biomed Res Int 2017:3431609, 2017.
30. Grundnes O, Reikeras O: The importance of the hematoma for fracture healing in rats. Acta Orthop Scand 64:340-342, 1993.
31. Farouk O, Krettek C, Miclau T, et al: Minimally invasive plate osteosynthesis and vascularity: preliminary results of a cadaver injection study. Injury 28 Suppl 1:A7-12, 1997.
32. Farouk O, Krettek C, Miclau T, et al: Minimally invasive plate osteosynthesis: does percutaneous plating disrupt femoral blood supply less than the traditional technique? J Orthop Trauma 13:401-406, 1999.
33. Borrelli J, Jr., Prickett W, Song E, et al: Extraosseous blood supply of the tibia and the effects of different plating techniques: a human cadaveric study. J Orthop Trauma 16:691-695, 2002.
34. Zou J, Zhang W, Zhang CQ: Comparison of minimally invasive percutaneous plate osteosynthesis with open reduction and internal fixation for treatment of extra-articular distal tibia fractures. Injury 44:1102-1106, 2013.
35. Pozzi A, Risselada M, Winter MD: Assessment of fracture healing after minimally invasive plate osteosynthesis or open reduction and internal fixation of coexisting radius and ulna fractures in dogs via ultrasonography and radiography. J Am Vet Med Assoc 241:744-753, 2012.
36. Kulkarni VS, Kulkarni MS, Kulkarni GS, et al: Comparison between antegrade intramedullary nailing (IMN), open reduction plate osteosynthesis (ORPO) and

555 minimally invasive plate osteosynthesis (MIPO) in treatment of humerus diaphyseal
556 fractures. Injury 48 Suppl 2:S8-S13, 2017.
557 37. Li A, Wei Z, Ding H, et al: Minimally invasive percutaneous plates versus conventional
558 fixation techniques for distal tibial fractures: A meta-analysis. Int J Surg 38:52-60,
559 2017.
560 38. Hasenboehler E, Rikli D, Babst R: Locking compression plate with minimally invasive
561 plate osteosynthesis in diaphyseal and distal tibial fracture: a retrospective study of 32
562 patients. Injury 38:365-370, 2007.
563 39. Kaplan DJ, Patel JN, Liporace FA, et al: Intraoperative radiation safety in orthopaedics: a
564 review of the ALARA (As low as reasonably achievable) principle. Patient Saf Surg
565 10:27, 2016.
566 40. Brunner CF, Weber BG: Besondere Osteosynthesetechniken, Springer-Verlag, 1981.
567 41. Yu BF, Liu LL, Yang GJ, et al: Comparison of minimally invasive plate osteosynthesis
568 and conventional plate osteosynthesis for humeral shaft fracture: A meta-analysis.
569 Medicine (Baltimore) 95:e4955, 2016.
570 42. Bleedorn JA, Dykema JL, Hardie RJ: Minimally invasive surgery in veterinary practice:
571 a 2010 survey of diplomates and residents of the American College of Veterinary
572 Surgeons. Vet Surg 42:635-642, 2013.
573 43. Leunig M, Hertel R, Siebenrock KA, et al: The evolution of indirect reduction techniques
574 for the treatment of fractures. Clinical Orthopaedics and Related Research:7-14, 2000.
575 44. Gilbert ED, Lewis DD, Townsend S, et al: Comparison of two external fixator systems
576 for fracture reduction during minimally invasive plate osteosynthesis in simulated
577 antebrachial fractures. Vet Surg 46:971-980, 2017.
578 45. Guiot LP, Dejardin LM: Perioperative imaging in minimally invasive osteosynthesis in
579 small animals. Vet Clin North Am Small Anim Pract 42:897-911, v, 2012.

580