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Risk factors and long-term surgical outcome of patellar luxation and concomitant cranial cruciate ligament rupture in small breed dogs

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Abstract: Concomitant cranial cruciate ligament rupture (CCLR) is a common complication in small breed dogs with patellar luxation (PL) with an elusive pathogenesis. Surgical treatment is available and commonly includes remodelling osteotomies. While these modern techniques have shown good functional results, access is limited due to the high costs for owners and the need for special surgical equipment. The objectives of the study were to evaluate the frequency and risk factors for concomitant CCLR in small breed dogs with PL. To study the outcome and complications of the combination of the Wedge recession osteotomy (WR) and Tibial tuberosity transposition (TT) with a Fascia over-the-top (OT) or a Capsular and fascial imbrication technique (CFI) for the simultaneous treatment of PL and concomitant CCLR. A retrospective study is presented here. The signalment, body weight, luxation grade and direction, affected side, bilateral or unilateral PL, CCLR and meniscal status were analysed. The surgical treatment for PL and concomitant CCLR, outcome and complications were investigated. Of 233 small breed dogs with PL, 52 (22.31%) had a concomitant CCLR. Maltese dogs were more likely to have concomitant CCLR. The mean age for the dogs with PL only was 5.32 years, which was significantly younger than the mean age of dogs with PL and concomitant CCLR (7.39 years). Overweight dogs with PL were prone to develop concomitant CCLR. Surgical stabilisation with a combination of WR, TT and OT or CFI had excellent or good results in 86.63% of the cases, while 16.67% of the cases developed complications. In conclusion, PL and concomitant CCL ruptures can be managed successfully by performing a combination of WR, TT and OT or CFI. The outcomes and complication rates are comparable to remodelling osteotomies. Moreover, these techniques are less expensive and can be performed with standard surgical equipment. These findings should be beneficial for clinical diagnosis, client education and treatment.

Keywords: knee surgery; stifle pathology; canine lameness

Patellar luxation (PL) and cranial cruciate ligament rupture (CCLR) are common pathologies affecting canine stifle joints (Jerram and Walker 2003; Di Dona et al. 2018). Prevalence reports on the combination of pathologies differ significantly. One study found that 15–20% of stifles in middle-aged and older dogs with PL had concomitant CCLR (Piermattei and Flo 1997). Other studies found concomitant CCLR in up to 41% of the PL cases in small and toy breed dogs (Campbell et al. 2010) and only 13% in large breed dogs (Gibbons et al. 2006).

Moreover, a significant correlation has been described between PL grade IV and concomitant CCLR in small-breed dogs (Campbell et al. 2010).

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Over the past decade, several modified remodelling osteotomies for the simultaneous treatment of PL and CCLR have been established (Leonard et al. 2006; Langenbach and Marcellin-Little 2010; Yeadon et al. 2011). Yet, the combination of the much more commonly used techniques like "Wedge recession osteotomy" (WR) or "Tibial tuberosity transposition" (TT) for PL and traditional treatment methods for concomitant CCLR, such as the intra-articular reconstruction ("Fascia over-the-top technique") (Brunnberg et al. 1992) or the extra-articular stabilisation ("Capsular and fascial imbrication technique") (Allgoewer et al. 2000), have not been studied to date.

This study reviews the frequency of CCLR in small-breed dogs with PL and investigates the long-term outcome of the patients treated for both pathologies with one of three combinations of the traditional surgical techniques.

MATERIAL AND METHODS

Inclusion criteria

The medical records of all dogs surgically treated for patellar luxation at the Small Animal Clinic of the Free University of Berlin (Berlin, Germany) between January 2004 and December 2016 were reviewed. Our sample included all patients classified as small breed dogs according to the American Kennel Club standards (American Kennel Club 1998) and was divided into two groups: one group consisted of cases of PL only (PL group), while the other group consisted of cases of PL and concomitant CCLR (PL+CCLR group).

The recorded data included: the breed, age, sex, body weight, affected limb, grade and direction of the PL, concurrent CCLR and meniscal lesions (torn or not torn). For the dogs with a bilateral PL, the difference in the grade of the luxation was registered. The overweight dogs were assessed through the body condition scoring according to the American Kennel Club standards (American Kennel Club 1998). All the diagnoses and grading of the PL, CCLR and meniscal status were performed by the same experienced surgeon (LB). The PL grading was performed in accordance with Singleton's classification (Singleton 1969). The suspected diagnosis of CCLR was based on a physical examination (pain response on flexion and extension of the stifle, joint effusion, variable crepitus, medial buttress formation, positive cranial drawer test) as well as a radiological assessment according to Kowaleski et al. (2018) (lateral stifle joint view: effacement loss in the infrapatellar fat pad shadow through the soft tissue opacity; caudal displacement of the fat density, located caudal to the joint capsule and osteophyte formation) and was confirmed intra-operatively. The meniscal lesions were diagnosed through a direct visual examination of the medial and lateral meniscus during the arthrotomy.

PL group

The PL group was used as a control group to study the frequency and risk factors for concomitant CCLR in small breed dogs with PL. The surgical techniques and outcome for this group were not within the scope of this study.

PL+CCLR group

The PL+CCLR group was used as the study sample and included cases that were surgically treated for the combination of pathologies with one of three combinations of surgical techniques. All the patients were premedicated with midazolam (0.1 mg/kg *i.v.*, Midazolam®; B. Braun Melsungen AG, Germany), meloxicam (0.2 mg/kg *i.v.*, Metacam®; Boehringer Ingelheim Vetmedica GmbH, Germany) and levomethadone (0.2 mg/kg *i.v.*, L-Polamivet®; Intervet GmbH, Germany). General anaesthesia was induced with propofol (4 mg/kg *i.v.*, Narcofol®; CP-Pharma, Germany) and maintained with a mixture of isoflurane (Isofluran; Baxter, Germany) and oxygen. Amoxicillin clavulanate (12.5 mg/kg *i.v.*, AmoxClav®; Hexal AG, Germany) was given after the induction and lactated Ringer's solution (Sterofundin®; B. Braun Melsungen AG, Germany) was administered at a rate of 5–10 ml/kg/h through an intravenous catheter. The affected stifles were clipped, aseptically prepared with a povidone-iodine solution (Braunoderm®; B. Braun Melsungen AG, Germany) and covered with sterile field drapes.

The PL was treated with a "Trochlear wedge recession osteotomy" (WR) (Slocum and Slocum 1993b). The cases in which the patellar luxation persisted intraoperatively after performing the WR were ad-

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ditionally treated with a "Tibial tuberosity transposition" (TT) (Singleton 1969). Generally, the CCLR was corrected through a "Fascia over-the-top technique" (OT) (Brunnberg et al. 1992). In the cases where the intraoperative inspection revealed significant patellar ligament weakness, a "Capsular and fascial imbrication" (CFI) (Allgoewer et al. 2000) was conducted instead of an OT. Additionally, if a torn medial meniscus was evident, a caudal hemimeniscectomy (Flo and DeYoung 1978) of the medial meniscus was performed.

All the surgically treated stifle joints were protected by a modified Robert-Jones-Bandage for two days post-surgery. All the patients received standard pain treatment, which consisted of 0.1 mg/kg meloxicam (Metacam®; Boehringer Ingelheim Vetmedica GmbH, Germany) once daily. In addition, 12.5 mg/kg of amoxicillin clavulanic acid (Synulox®; Zoetis Deutschland GmbH, Germany) was administered orally twice daily for seven days.

The surgical outcomes were assessed by the treating surgeon or referring veterinarian, based on standardised questionnaires and classified as excellent, good, fair or poor. The criteria were based on a lameness score during walking (Monk et al. 2006), pain during flexion or extension of the stifle joint and the existence of patellar reluxation. An outcome was considered excellent, if there was no evidence of lameness (0/5), no pain at flexion or extension of the stifle joint and no patellar luxation. An outcome was considered good, if the lameness score was 1/5, and all the other criteria were excellent. An outcome was considered fair, if the lameness presented as 2/5, and all other criteria were excellent. If a lameness score of 2/5 or higher, pain at flexion or extension of the stifle joint or a patellar luxation were detected, the outcome was considered poor. Complications were classified as minor, if they did not require additional surgery, major, if they required additional surgery and catastrophic, if they lead to limb amputation, euthanasia or death of the patient. All the follow-ups were performed within six months post-surgery.

Statistical analysis

The data were analysed using SPSS (v22, IBM, USA). The significance was determined as $P < 0.05$. Nonparametric tests were used to calculate the significance. The Chi-Square Test, Fischer's Exact Test and Mann-Whitney *U*-test were used to determine any significant univariable associations between the breed, age, overweight, grade of the luxation and CCL deficiency, as well as for the overweight and castration status, torn meniscus and grade of the luxation, surgical technique and outcome.

RESULTS

Dogs

A total of 233 small and toy breed dogs were presented between the years 2004 and 2016 at the Small Animal Clinic of the Freie Universitaet Berlin (Berlin, Germany), for diagnosis and the consequent treatment of the PL. Of those patients, 52 (22.31%) suffered from both PL and CCLR.

From the whole sample, 81 dogs met the inclusion criteria and were divided into two groups. The PL group included 55 dogs (96 stifle joints), whereas the PL+CCLR group consisted of 26 dogs (30 stifle joints).

Breeds

The most common breeds in the PL group were Yorkshire Terrier ($n = 20$), Poodle ($n = 6$), Crossbreed ($n = 5$), West Highland White Terrier ($n = 5$) and Chihuahua ($n = 3$) among other small and toy breeds ($n = 16$). The breeds found with the PL and concomitant CCLR included Yorkshire Terrier ($n = 8$), Maltese ($n = 6$), Cairn Terrier ($n = 2$), Crossbreed ($n = 2$), Chihuahua ($n = 2$), Poodle ($n = 1$), West Highland White Terrier ($n = 1$), Jack Russel Terrier ($n = 1$), Shih Tzu ($n = 1$), Bolonka Zwetna ($n = 1$) and Biewer Terrier ($n = 1$). From those, only the Maltese dogs were significantly prone to develop concomitant CCLR ($P < 0.001$).

Sex

The PL group consisted of 27 female dogs (7 spayed) and 28 male dogs (8 neutered). In the PL+CCLR group, 15 female (10 spayed) and 11 male dogs (7 neutered) were found. No statistical correlation was detected between the sex and CCLR ($P = 0.182$).

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Age

In the PL group, a mean age of 5.32 ± 3.66 years was found, while the mean age in the PL+CCLR group was 7.39 ± 2.48 years. The animals with PL and concomitant CCLR were significantly older ($P < 0.05$) than the animals with PL only.

Weight/overweight

In the PL group, the mean weight was 5.07 ± 2.45 kg, while the mean weight in the PL+CCLR group was 5.61 ± 2.65 kg. In the PL+CCLR group, 57.69% of dogs were overweight, while only 18.18% were overweight in the PL group. A significant correlation occurred between the dogs that were overweight and had concomitant CCLR ($P < 0.001$).

Grade of patellar luxation and affected side

In the PL group, 23.96% of the stifles ($n = 23$) had the PL grade I. The PL grades II, III and IV were seen in 46.87% ($n = 45$), 21.87% ($n = 21$) and 7.30% ($n = 7$) of the stifles, respectively. In the PL+CCLR group, 16.66% ($n = 5$) of the stifle joints had a grade I PL, while grades II, III and IV represented 36.67% ($n = 11$), 36.67% ($n = 11$) and 10% ($n = 3$) of the cases, respectively. The mean grade of the luxation was 2.14 in the PL group and 2.40 in the PL+CCLR group. No significant correlation was detected between the grade of the luxation and the concomitant CCLR ($P = 0.130$).

In the PL group, 52.09% ($n = 50$) of the patellar luxations occurred in the left stifle joint, while 47.91% ($n = 46$) occurred in the right stifle. In the PL+CCLR group, 43.33% ($n = 13$) of the patellar luxations occurred in the left stifle joint, while 56.67% ($n = 17$) occurred in the right stifle joint. No correlation was detected between the affected limb side and concomitant CCLR ($P = 0.320$).

Type and direction of luxation

Overall, a unilateral PL was present in 23.45% ($n = 19$) of the dogs. Hence, a bilateral patellar luxation was found in 76.55% of the dogs ($n = 62$). In the PL group, 87.50% ($n = 84$) of the stifle joints were diagnosed with a medial patellar luxation (MPL), while 12.50% ($n = 12$) showed a lateral patellar luxation. In the PL+CCLR group, 100% of the stifle joints ($n = 30$) were diagnosed with an MPL. No statistical correlation occurred between the direction of the luxation and the concomitant CCLR ($P = 0.068$).

Cranial cruciate ligament rupture

In the PL+CCLR group, 30.76% ($n = 8$) of the patients were found with a bilateral CCLR, while 69.24% ($n = 17$) showed a unilateral CCLR. From these eight patients, three had a bilateral CCLR at the time of diagnosis. For those five patients that developed a second CCLR in the contralateral stifle, a mean time of 13 months was found. Of these 8 contralateral stifles with CCLR, a patellar luxation was found in 87.50% of the cases ($n = 7$). No significant correlation was found between the bilateral CCLR and the bilateral PL ($P = 0.375$).

Meniscal status

In the PL+CCLR group, meniscal lesions were found in 10% ($n = 3$) of the treated stifle joints during surgery, while no signs of meniscal disease were found in 90% ($n = 27$) of the cases. No significant correlation was found between the mean grade of the luxation and the meniscal disease ($P = 1.000$).

Surgical management of stifle joints with PL+CCLR

Of the surgically treated stifle joints, 46.67% ($n = 14$) were corrected with a combination of WR, TT and OT. Of these, 85.72% ($n = 12$) had an excellent outcome and 7.14% ($n = 1$) had a good outcome, while 7.14% ($n = 1$) showed a poor outcome. Furthermore, 46.67% ($n = 14$) of the stifle joints were corrected with a combination of WR, TT and CFI. Of those, 78.58% ($n = 11$) had an excellent outcome, while 7.14% ($n = 1$) showed a fair outcome and 14.28% ($n = 2$) had a poor outcome. A combination of WR and CFI was used to treat 6.66% ($n = 2$) of the stifle joints and of those, 100% ($n = 2$) had an excellent outcome. In sum, 83.33% ($n = 25$) of the surgically treated stifle joints had an excellent outcome. A good outcome was found in a further

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3.33% (n = 1) of the cases, while 3.33% (n = 1) showed a fair outcome and 10% (n = 3) had a poor outcome. The outcomes of the different surgical techniques were not significantly different (P = 1.000).

Complications

In 83.33% (n = 25) of the cases, the stifle joints healed without complications. While 3.33% (n = 1) showed minor complications (superficial wound infection), 6.67% (n = 2) developed major complications, of which both stifles showed a positive cranial drawer test within days after the surgery and needed an additional surgical correction. In addition, catastrophic complications occurred in one patient, diagnosed with a bilateral CCLR (n = 2; 6.67%), a bilateral PL of grade IV in the left stifle and grade II in the right stifle with a unilateral meniscal lesion and advanced osteoarthrosis prior to the surgery. Post-surgery, the patient showed no sign of patellar reluxation or instability in either stifle joint. However, an intermittent non-weight bearing lameness at walk persisted after surgery, which was unacceptable for the owner. Palliative measures were rejected, and the owner opted for euthanasia.

DISCUSSION

In this population study of small breed dogs with PL, 22.31% showed concomitant CCLR at a mean age of 7.39 years. Previous studies reported similar, but a slightly lower prevalence of CCLR, ranging from 15–20% in middle-aged and older dogs with PL (Piermattei and Flo 1997). Other studies have suggested that concomitant CCLR is more common in toy and small breed dogs compared to large dogs, with a prevalence of up to 41% in toy and small breed dogs (Campbell et al. 2010), compared to only 13% in large breed dogs (Gibbons et al. 2006).

The Maltese breed was significantly overrepresented in the PL+CCLR group (P < 0.001) compared to the other breeds included in this study, which, to the best of our knowledge, has not been previously described. This finding could simply be due regional differences in the breed popularity or suggest a true breed predisposition. Further studies are needed to assess breed affiliations considering the regional breed popularity.

The sex ratios (male-to-female) in both the PL (1 : 1) and the PL+CCLR group (1 : 1.3) did not reveal a significant difference between the groups (P = 0.182). While studies on large breed dogs found male dogs to be at a significantly higher risk of PL compared to females (1.8 : 1) (Remedios et al. 1992; Gibbons et al. 2006), studies on small breed dogs did not find a correlation to either sex (Hayes et al. 1994; Vasseur 2003; Alam et al. 2007; Campbell et al. 2010) and reported similar sex ratios as found in our study sample.

Dogs with concomitant CCLR were identified (7.39 years) at a significantly higher age than dogs diagnosed with PL only (5.22 years) (P < 0.005). This matches previous reports that found middle-aged to older dogs with patellar luxation at an increased risk for concomitant CCLR (Hayes et al. 1994; Piermattei and Flo 1997; Campbell et al. 2010). Furthermore, a histopathologic study found signs of CCL degeneration in small breed dogs aged 7 years and older, which was significantly later than in large breed dogs (Vasseur et al. 1985). Considering the mean age of small breed dogs suffering from PL and concomitant CCLR in this study (7.39 years), as well as a previous study (7.8 years) (Campbell et al. 2010), CCL degeneration could be a risk factor for CCLR in patients with PL.

As seen in previous studies (Paatsama 1952; Doverspike et al. 1993; Duval et al. 1999), the overweight patients of this study sample were significantly prone to concomitant CCLR (P < 0.001). Being overweight is a known cause of mechanical joint stress, which can contribute to ligament degeneration and ultimately CCLR (Paatsama 1952; Doverspike et al. 1993; Duval et al. 1999).

Contrary to previous findings (Campbell et al. 2010), there was no significant difference between patients with grade I, II, III or IV and concomitant CCLR (P = 0.130). The mean grades of luxation were 2.14 and 2.40 for the PL and PL+CCLR groups, respectively. While the subjectiveness of the PL grading (Weber 1992) could limit results, this finding supports the hypothesis based on a study by Willauer and Vasseur (1987), which found CCLR in dogs with a surgically corrected PL, indicating that CCLR could be caused by factors other than PL.

On one hand, dogs with a high grade of luxation likely show acute lameness early on, in which case, they are more likely to be treated surgically. Consequently, they could be less likely to suffer from CCLR, since the risk factor was eliminated. On

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the other hand, dogs suffering from PL grades I-III could easily be overlooked by owners, which could result in delayed medical treatment. Preventing excessive internal rotation between the femur and tibia is an important function of the CCL (Arnoczky et al. 1977; Robins 1990). If the PL remains surgically untreated, the CCL could be subjected to increased stress, which could cause a functional weakness. In addition, anatomical abnormalities caused by an MPL, such as the internal torsion of the tibia, the varus angulation and the medial displacement of the tibial tuberosity, could lead to excessive forces and the rupture of the CCL.

There was no significant difference between the direction of the luxation and the CCLR ($P = 0.068$), as most patients in the PL group (87.50%) and all the patients in the PL+CCLR group were diagnosed with MPL. The modest sample size and selection of the patients could limit these findings. Further biomechanical studies are warranted to gain a better understanding of the effects of the anatomical changes of the medial and lateral patellar luxation cause to the CCL.

Eight patients were diagnosed with a bilateral CCLR (30.76%). Three of those presented with a bilateral CCLR upon first presentation, while the mean time between the initial and contralateral CCLR for the remaining five patients was 13 months. In 87.5% of the cases, a bilateral PL as well as a bilateral CCLR were diagnosed. These findings concur with previous studies, which found that 10–61.3% of patients with an initial CCLR diagnosis developed a contralateral CCLR within 12 to 16 months (Bennett et al. 1988; Doverspike et al. 1993; Johnson and Johnson 1993; Moore and Read 1995; Cabrera et al. 2008).

For a better aetiological understanding, future studies should explore the influence of the surgical PL correction on the CCLR. Findings from cases with CCLR without PL suggest a multifactorial aetiology (Brunnberg 1990), which, in turn, questions whether the surgical correction of the PL could delay or prevent the CCLR.

Meniscal lesions did not significantly differ between the patients with the different luxation grades ($P = 1.000$). Unlike previous reports of meniscal lesions in 36.6–74% of CCLR patients of all sizes and breeds (Flo 1975; Flo and DeYoung 1978; Gambardella 1981; Hayes et al. 2010), only 10% of the cases in the PL+CCLR group showed meniscal lesions. The low prevalence found in this study could be due to the small sample size and selective inclusion criteria or suggest that they are a less common complication in small breed dogs.

Three different surgical combinations were used to treat the PL and CCLR in 30 stifle joints. Although the surgical techniques used in this population study are commonly used to treat PL and CCLR, additional information on the frequency, range of complications and outcome was needed. Moreover, this is the first detailed study of long-term outcomes in patients treated with the combination of techniques for both pathologies. The mean follow-up time in this study was 24 weeks, which is similar or exceeds that of other studies (Leonard et al. 2006; Langenbach and Marcellin-Little 2010; Yeadon et al. 2011; Flesher et al. 2019).

There was no significant difference between the post-surgical outcome and the surgical technique ($P = 1.000$). Overall, 86.63% of all the surgically treated patients had excellent (83.3%) or good (3.3%) outcomes, which closely matches previous reports of functional outcomes (82–98% good or excellent) for the individual techniques for CCLR treatments (Brunnberg 1990; Slocum and Slocum 1993a; Allgoewer et al. 2000; Lafaver et al. 2007). The outcomes for the MPL treatment in small breed dogs differ according to the PL grade. One study found that patients suffering from PL grade II were successfully treated in 100% of the cases, while 11% of the dogs with a grade III luxation had recurrent patellar luxation post-surgery (Wangdee et al. 2013). For patients with a grade IV luxation, the success rates vary between 64–93%, and were negatively influenced by skeletal deformities, the necessity of corrective osteotomies and higher rates of complications (Wangdee et al. 2013; Dunlap et al. 2016).

The overall complication rate in this study was 16.67%, which is comparable to or lower than those reported for other PL and CCLR treatment techniques (Leonard et al. 2006; Langenbach and Marcellin-Little 2010; Yeadon et al. 2011). Studies on PL and concomitant CCLR patients have reported complication rates of 28.40% for the "Tibial tuberosity transposition advancement" (TTTA) technique (Yeadon et al. 2011) and 18.40% for the "modified TPLO" one (Flesher et al. 2019). In large breed dogs, a complication rate of only 15.38% was reported for the "modified TPLO" technique, although the sample size was rather small (Langenbach and Marcellin-Little 2010). One study

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found that a combination of the "TPLO and Tibial tuberosity transposition" techniques was an effective surgical treatment with 0% complications (Leonard et al. 2006). However, the study is limited by the very small sample size and short follow-up time (10 weeks), as well as its retrospective nature.

Limitations

This study is limited by its retrospective design. The analysed data was subject to the accuracy of the medical records, which was limited by the subjectiveness of the PL grading and owner's compliance throughout the treatment. The breed distribution in the present study could be impacted by the regional breed popularity and specific features of the clinic, therefore, it may not be representative of the general patient population. Moreover, the significance of the findings could be affected by the modest sample size.

In conclusion, concomitant CCLR in small breed dogs with PL appears to have a multifactorial pathogenesis. Our findings indicate that patellar luxation might not be the main risk factor for CCLR. The lack of difference between the grade of the luxation and the CCLR found in this study questions whether a high-grade PL could be a singular cause of CCLR. Moreover, associations of CCLR with being overweight and older age, as well as potential breed predispositions and natural age degeneration likely contribute to the CCLR in the PL patients.

Over the past decades, a variety of remodelling osteotomies for the simultaneous management of PL and concomitant CCLR have been described. These modern techniques have shown a disparity of results and so far, a technique with a superior outcome has not been singled out (Leonard et al. 2006; Langenbach and Marcellin-Little 2010; Yeadon et al. 2011; Flesher et al. 2019). The surgical treatment combinations of WR, TT, OT and CFI are equally able to achieve excellent results (83.3%) and show low complication rates (16.67%). Furthermore, they are inexpensive, and unlike remodelling osteotomies, do not require special surgical equipment. Although insufficient evidence is available to recommend the combination of the surgical techniques used in this study, the excellent clinical outcomes and low complication rates should be considered in treatment recommendations.

Conflict of interest

The authors declare no conflict of interest.

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