Acta Orthop. Belg., 2009, **75**, 715-726

REVIEW ARTICLE

Treatment options in Kienböck's disease

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INTRODUCTION

Kienböck's disease or lunatomalacia is an aseptic osteonecrosis of the lunate bone initiating a progressive collapse of the lunate bone, followed by total carpal collapse. The first description was made one hundred years ago (*107*). Thus far, its exact cause and natural history remain unknown (*44*).

Several extrinsic and intrinsic factors have been investigated as to their role in the aetiology of the bone necrosis. Kienböck's disease is a slowly progressive disorder with well recognised stages leading to various treatment options. However, little is known about their effectiveness, mainly because Kienböck's disease is not very common and a long follow-up is needed to evaluate the ultimate outcome (*1,84*).

EVALUATION

Kienböck's disease is seen most often in young adults (between 20 and 45 years of age), but it is also diagnosed in children as well as in older age groups. It is somewhat more common in males. Kienböck's disease is usually unilateral and isolated. A history of trauma is often reported by the patients, often minor or repetitive trauma. The disease is slowly progressive with unspecific signs and symptoms. Patients complain of dorsal wrist pain, weakness and restricted motion. On physical examination, dorsal tenderness is obvious and is often well localized over the dorsal side of the lunate. More advanced cases may show swelling due to synovitis and a loss of wrist motion with decreased grip strength due to underlying degenerative arthritis. Early signs of synovitis include a restricted anteroposterior drawer test of the wrist and an obliteration of the anatomical snuffbox. The anteroposterior drawer test is done by the examiner grasping the forearm of the patient with one hand, just proximal to the wrist joint and with the other hand just distal to the wrist joint. The patient's hand is than moved in a dorsopalmar direction. Normally, some translation is possible, but not in the presence of synovitis (pseudo stability).

Occasionally, the patient has no symptoms at all and lunate collapse is detected on a routine radiograph of the wrist (*96*).

The diagnosis and staging of Kienböck's disease are based on the x-ray findings. In early stages, plain radiographs may be normal and the diagnosis is suspected on an abnormal bone scan or MRI. CT scan may reveal an occult lunate fracture. In a later stage, sclerosis of the lunate and collapse are observed. Lichtman *et al* (*56*) classified Kienböck's disease into four stages :

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No benefits or funds were received in support of this study

Stage I.	The radiographic appearance of the lunate is normal, bone scintigraphy is positive.
Stage II.	The lunate exhibits increased density but its size and shape are normal.
Stage III.	The lunate has collapsed, allowing the capitate to migrate proximally. In stage IIIA the scaphoid maintains a normal position relative to the rest of the carpus. In stage IIIB there is rotatory subluxation leading to a scaphoid "ring" sign.
Stage IV.	Secondary osteoarthritis of the radiocarpal joint.

The pathogenesis of the wrist pain in Kienböck's disease is not always apparent. The bone necrosis *stricto sensu* can be a source of dorsal wrist pain. Radial side wrist pain, in the presence of a positive Watson scaphoid shift test (*109*) may indicate rotatory subluxation of the scaphoid. Generalized wrist pain and swelling are signs of osteoarthritis.

Aetiology

The blood supply of the lunate is probably the key factor in the pathogenesis of the disorder (*44*). The extra-osseous and intra-osseous vascular anatomy has been well studied (*34*). The carpal bones with type 1 vascularity are "at risk". These are carpal bones which are mostly supplied by one single vessel without additional anastomoses, hence occlusion of this vessel will probably lead to necrosis. According to Gelberman *et al* (*34*), all scaphoids and capitates and 8 to 20% of the lunates have this vascular pattern. Besides arterial insufficiency, venous stasis has also been suggested as a possible cause of (carpal) bone necrosis. Extrinsic factors such as fractures or repetitive minor trauma can damage the intra-osseous blood supply leading to osteonecrosis. However, rather than causing the necrosis, the fracture may also be a consequence of the necrosis.

Hulten (*39*) noted an association between Kienböck's disease and an ulnar minus variance. The relevance of this finding in the aetiology of Kienböck's disease has however been questioned (*26,51*). Several authors have found a change in the ulnar variance with age, sex and position of the wrist as well as osteoarthritis secondary to Kienböck's disease (*71*).

Morphological factors may also play a role in the aetiology (*64,103*). In our series we found that a negative ulnar variance was not predisposing to Kienböck's disease (*99*). However, when we compared the contralateral wrist with an age - and sex matched control group, we found that in patients with Kienböck, the lunates were smaller and had more radial tilt than the controls and the radial slope of the distal radius was less. A recent biomechanical study with finite element modelling demonstrated that ulnar minus variance was important for further progression of the collapse of the lunate (*55,85*).

Management

A thorough evaluation of the involved wrist is necessary prior to instituting treatment. The stage of the disease must first be determined, followed by an evaluation of the biomechanical effects of the collapse of the lunate on the the carpus. The biological effects of the diseased bone, which may or may not be associated with synovitis and/or fibrosis resulting in wrist stiffness, and their effects on the patient's disability have important implications with regards to future management. Finally the presence or absence of osteoarthritis may help to choose between reconstructive versus salvage procedures.

Treatment options include both conservative and operative methods. As a rule (except in children) surgical treatment is preferred since it generally leads to a quicker improvement of the symptoms and a better outcome. Many operative treatment methods have been suggested for the various stages of Kienböck's disease and they can be grouped into three categories (fig 1a-s).

1) *Revascularisation.* This can be achieved either directly by vessel implantation or indirectly by a vascularised bone graft (VBG) in stage 1 and 2. The graft may be free or pedicled (fig 1l,m).

2) *Joint decompression*. This is done not only to relieve symptoms but also to allow spontaneous revascularisation of the lunate while diminishing the compressive forces acting on it to prevent further collapse in stages 1, 2 and 3A. This can be accomplished by levelling the distal radioulnar joint (DRUJ) by shortening of the radius, closing wedge osteotomy of the radius or lengthening of the ulna (fig 1i,j), intercarpal arthrodesis (fig 1b,c,e) or capitate shortening (fig 1d). Restoring the normal carpal height by either scaphotrapezialtrapezoidal (STT) or scaphocapitate arthrodesis is a key element in preventing osteoarthritis. Arthrodeses on the ulnar side of the carpus have also been proposed (hamatecapitate fusion). There exists a large amount of biomechanical evidence to demonstrate that all these procedures significantly reduce the pressure on the lunate (*4,14,38,112*).
3) *Salvage procedures for pain relief.* These include wrist denervation (fig 1,r), arthroplasty or arthrodesis (fig 1n,o,q) in stages 3B and 4. Arthroplasty can be done in different ways : resection of the lunate (fig 1a), replacement of the lunate by a tendon roll, the pisiform bone (fig 1k), a silicone spacer (fig 1g), the head of the capitate (Graner's procedure) (fig 1f) with or without associated intracarpal arthrodesis, and more aggressive arthroplasties such as partial of complete prosthetic replacement, or proximal row carpectomy (fig 1p).

Non-operative treatment

Non-operative treatment has its proponents. The rationale for this approach lies in the observation that spontaneous regression of the signs and symptoms has been observed in early Kienböck. Moreover, cases of asymptomatic patients with radiographic evidence of longstanding Kienböck's disease have been reported. Previous reports suggest that the pain can subside over several years. Kristensen *et al* (*52*) reported good results after short periods of immobilisation, whereas Mikkelsen and Gelineck (*61*) noted poor outcomes after nonoperative treatment. The debate continues, with some authors advocating a conservative approach (*9,25*) whereas others have observed progressive clinical and radiographic deterioration (*48*) or have demonstrated better outcomes with a surgical approach (*80*). In children, however, Kienböck's disease is uncommon and a non-operative approach is preferred (*23,37*). We and others have observed some adaptation of the carpus due to remodelling rather than collapse. A careful neglect policy or, in very painful wrists, temporary immobilization by cast or bracing, often results in an asymptomatic wrist.

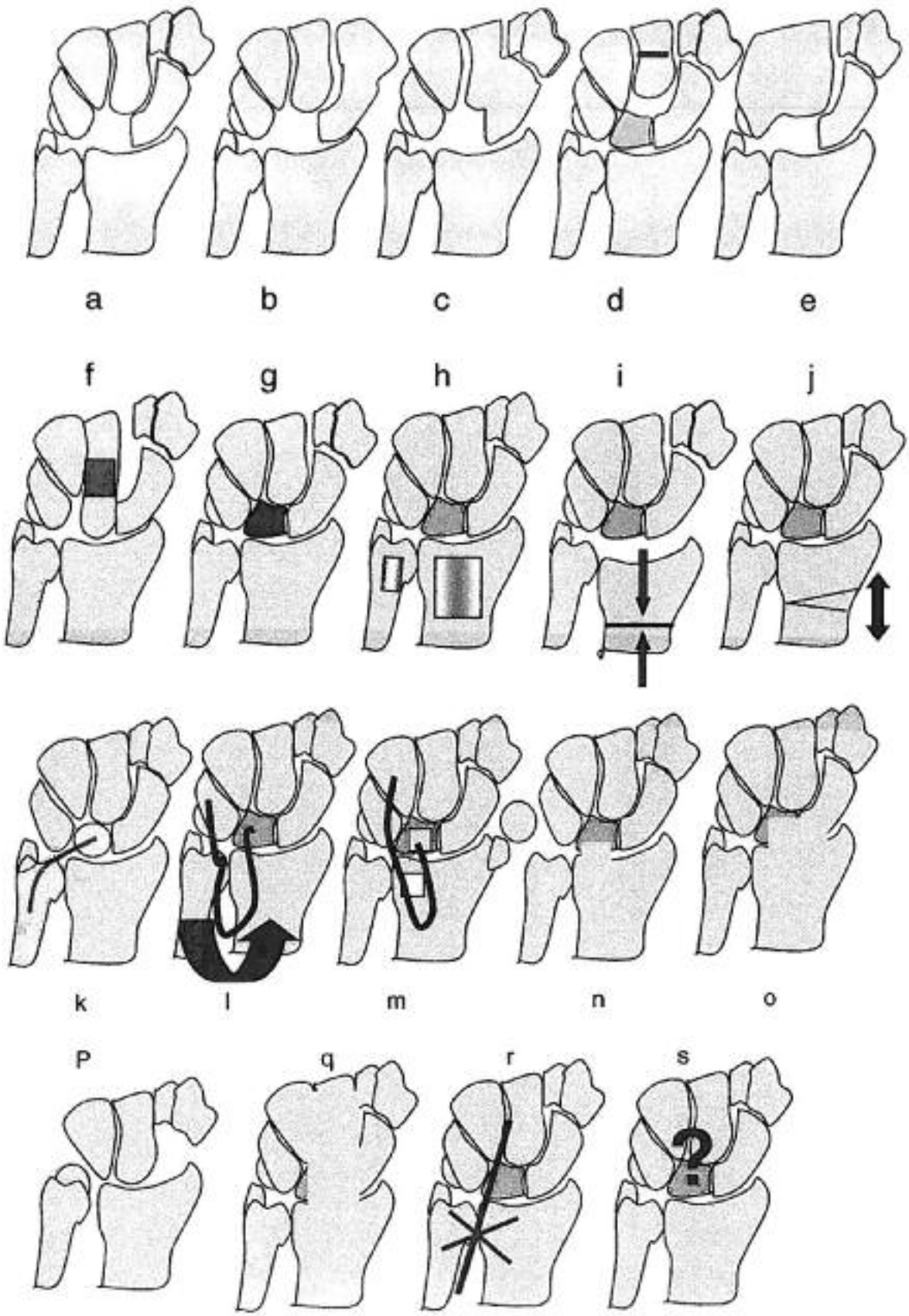
Revascularisation

The lunate is the keystone of the proximal carpal row. Simple resection leads to immediate and severe collapse of the carpus with subsequent osteoarthritis. The basic principles involve : removing the necrotic bone, replacing it with living bone and protecting the lunate during the revascularisation period (usually with temporary stabilization of the carpus). This is done either by direct revascularisation or indirectly by replacing the necrotic bone by vascularised bone.

Historically, the lunate has been replaced by the pisiform bone pedicled on the ulnar artery (*78*). This procedure is usually called Saffar's technique. Daecke *et al* (*16*) and Kuhlman *et al* (*53*) demonstrated favourable results in 14 and 23 patients respectively (fig 1k).

Some authors have removed the necrotic bone by curettage, followed by cancellous bone grafting and vessel implantation, such as the posterior interosseous artery (fig 1l) (*12*). There is clear evidence that the bone grafts were revascularised using this technique. We found only one paper by another group (*66*) reporting results with this technique in 11 wrists. They found a radiological stabilisation of the lunate with good pain relief in 9 patients. Recently, Jones *et al* (*45*) reported one case in which vessel implantation was combined with the introduction of Bone Morphogenetic Protein (BMP) into the lunate after scooping out the necrotic bone.

Vascularised bone grafts (VBG) (fig 1m) have the advantage of immediate implantation of viable bone which simplifies matters by substituting a healing fracture to a bone defect. This obviates the need to wait for secondary revascularisation of a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cancellous bone graft and it avoids the period of temporary weakening that occurs with nonvascularized bone grafts. The Mayo group studied the vascularity of the distal radius (*88*). Based on anatomic studies and animal experiments they developed the technique of the so-called 4,5 extensor compartment vascularized bone graft (*67*). In their clinical series of 26 patients they reported pain relief in 92%, a significant improvement in grip strength and maintenance of carpal height in 77%. We have applied this technique for the treatment of early Kienböck with a painful but still mobile wrist in eight patients (*36*). Postoperatively, patients had considerably less pain (45% pain reduction during activity and 74% at rest). Postoperative mean range of movement was 65% of the unaffected side. Three patients had an excellent result, three had good results, one had a fair result and one patient was unsatisfied. The mean postoperative disabilities of the arm, shoulder, and hand (DASH) score was 29.

The metacarpal head of the index ray is another donor site for VBG. It was used by Bengoechea *et al* (1 case) (*11*), Makino (1 case) (*59*), and Zafra (5 cases) (*115*). In all cases a satisfactory outcome was obtained, but an additional procedure on the radius (shortening or wedge osteotomy) was combined in all these cases.

Free VBGs from the ilac crest have also been used. Arora *et al* (*6*) and Gable *et al* (*31*) used this technique in 18 wrists each ; good bony integration was noted in 16 wrists in both studies. Good clinical results were obtained in 15 cases by Arora *et al* and in 16 cases by Gabl *et al*.

Stages I and II are good indications for a VBG, provided the lunate is not fractured. Smoking is considered a general contra-indication for all VBG's and this procedure is not suitable in older patients.

Decompression of the lunate

1. Levelling procedures of the DRUJ : radial shortening or ulnar lengthening ?

Levelling the ulna to the radius by shortening the radius or lengthening the ulna (fig 1i) is based on Hulten's finding (*39*) that Kienböck's disease was more frequent in ulna minus variant wrists. Despite the fact that several authors have questioned this finding, good clinical results were reported with these levelling procedures (*2,3,5,7,13,18,22,27,28,32,35, 50,70,74-77,83,88,92,98,100,102,111,114*) (table I). The basic mechanism appears to be unloading of the lunate preventing further collapse. These procedures have been used for several decades and they

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Fig. 1. — Overview of the most popular procedures to treat Kienböck's disease
a. Resection of the lunate
b. STT arthrodesis with or without lunate resection
c. Scaphocapitate arthrodesis with or without lunate resection
d. Capitate shortening
e. Lunate resection with ulnar column arthrodesis
f. Lunate resection and capitate lengthening
g. Lunate prosthesis
h. Metaphyseal osteotomy (Core decompression)
i. Ulna lengthening and/or radial shortening
j. Wedge (opening or closing) osteotomy
k. Lunate resection and substitution with the vascularised pisiform
l. Direct vessel implantation
m. VBG
n. Radius-lunate (Chamay) arthrodesis
o. Radius-lunate-scaphoid arthrodesis
p. Proximal row resection
q. Full wrist arthrodesis
r. Denervation
s. Non classified - combinations

Table I. — Radial shortening

Author	Year	N	% good
Calandriello	1966	10	90
Axelson	1973	19	100
Rosemeyer	1976	19	69
Eiken	0980	8	87
Oversen	1981	8	87
Almquist	1982	12	91
Schattenkerk	1987	20	70
Nakamuro	1990	23	83
Weiss	1991	29	87
Gomis	1994	28	85
Garbuio	1996	13	84
Siala	2000	31	80

Ulnar lengthening

Author	Year	N	% good
Tillberg	1968	10	100
Armistead	1982	20	90
Sundberg	1983	19	95
Schattenkerk	1987	15	70
Quenzer	1993	64	90
Ducarmois	1999	9	100

probably have the best documented series in the treatment of Kienböck's disease. Good outcome is reported in 69 to 100% of cases.

Proponents of more sophisticated procedures including lateral closing, lateral opening wedge osteotomies and medial closing wedge osteotomies of the radius (fig 1j), claim that the osteotomy changes the morphology of the distal radius (*33,47, 54,65,90,97,106*). In general the results are good. Radial opening osteotomies produce a better decompression than closing wedge osteotomies (*108*). However the clinical outcome was not significantly different in one comparative series (*43*).

Some authors believe that the biological decompression effect of the osteotomy is responsible for the pain relief. Based on this, Illarramendi *et al* proposed a pure fenestration of the distal radius and ulna rather than changing their length or orientation (*40*) (fig 1h). In their series of 22 patients, 16 were pain free and 4 had only moderate pain. Schultz *et al* (*86*) confirmed these findings in their series of 10 patients.

Most papers and handbooks still recommend an osteotomy for stages I and II, some authors even for stage III, provided there is an ulna minus variance. The morphology of the sigmoid notch and the ulnar head must be evaluated prior to any joint leveling procedure. In morphological studies of the DRUJ (*19,30,79*) three different types of sigmoid notch of the radius were distinguished ; in some cases, there may be a risk of creating DRUJ incongruity or impingement following a change in the length of one of the forearm bones. In these cases, some other type of decompressive procedure should be considered.

Although adequate pain relief has been obtained with levelling procedures (radial shortening and ulnar lengthening), the fate of the lunate following these procedures is not clear. Weiss *et al* (*111*) found no progression but Wada *et al* (*106*) saw further progression of the disease as we did in a previous study (*22*). The outcome was also determined by the occurrence of a revascularisation process (*64*).

Based on our personal experience with this technique (*22*) and the fact that intracarpal procedures can produce a similar unloading on the lunate (*38,112*) with similar clinical outcomes (*69*), we only have limited indications for these procedures, i.e. stage II and sometimes IIIa in wrists of non-smokers with a marked ulna minus and a parallel DRUJ (type 2).

2. Intercarpal procedures

One of the important consequences of lunate necrosis and the subsequent collapse is the disturbance of the carpal architecture, in particular rotational subluxation of the scaphoid. Based on the work of Watson *et al* (*109*) on the treatment of scapholunate ligament tears, some authors have reported good results with an STT arthrodesis for treating Kienböck's disease (fig 1b) (*82,109*). It has been shown that this procedure unloads the lunate to a similar degree as a joint levelling procedure. The STT arthrodesis can also be combined with a VBG or other revascularisation procedure (Stage 3a). Most authors (mostly German and

Japanese) (*18,60,62,63,73,95,97,101,110*) recommend this procedure as a primary treatment. The outcomes are good with Mayo wrist scores between 62 and 66 and a DASH score of 24.8. There were no significant differences between the STT fusion and radial shortening (*18,97*) and the outcome was better than following full radiocarpal fusion (*95*). In contrast however Van Der Dungen *et al* (*104*) reported better outcomes with a non-operative treatment than with an STT fusion.

Other intracarpal procedures include scaphocapitate arthrodesis (fig 1c), a capitate shortening (fig 1d) osteotomy and triquetro-capito-hamate fusion combined with lunate resection (fig 1e).

Although capitate shortening decompresses the lunate, clinical and radiological results have been poor (*8*).

Scaphocapitate fusion has a similar biomechanical effect as the STT fusion. Sennwald and Ufenast (*87*) also found satisfactory results in 10 of their 11 procedures. It is also the primary choice for Moy and Peimer (*68*).

Capitatohamate fusion resulted in excellent outcome in the series of Inoue (*42*) (8 patients, all painfree) and Oishi *et al* (45 patients, 42 painfree) (*72*).

A more sophisticated procedure was proposed by Wilhelm *et al* (*113*). After resection of the lunate, a transverse osteotomy of the capitate is perfomed and the proximal fragment of the capitate is brought into the empty space by callus distraction (fig 1f). They performed this in 14 patients, with a relatively short follow-up. Lu *et al* (*57*) had a larger series (30 patients) with reasonable results. Personally, we do not see any advantage as compared with a simple PRC. The procedure is contraindicated in pre-existing wrist stiffness. Main complications for this procedure are non-union, hardware failure and last but not least impingement between the radial styloid and the scaphoid with the development of osteoarthritis. This complication is hard to deal with since it appears to progress even following a radial styloidectomy.

Salvage procedures

Once osteoarthritis is present (stage IV) or in stiff wrists (stages IIIB), a reliable salvage procedure is preferred. As in other joints the options are arthrodesis, arthroplasty or denervation. Our experience with a total wrist fusion was less satisfying. We noted a high percentage of complications and unsatisfactory results (*21*) similar to Dap's series (*17*). Our follow-up studies have demonstrated that preservation of some wrist motion is needed in order to achieve a good outcome, but the amount of ROM is not very important (*24*). Partial radiolunate (fig 1n) and radioscapholunate (fig 1o) fusions have been proposed to overcome the poor results of full wrist arthrodesis (*42*). Kilgus *et al* (*49*) found acceptable results in 5 cases of radioscapholunate fusion but the Wrightington group had 50% failures of radiolunate fusions (*94*).

Full radiocarpometacarpal arthrodesis (fig 1q) resulted in 55% pain reduction, a DASH of 51.4 and 70% return to previous occupations in the large series of Sauerbier (*81*). This was confirmed in a smaller series by Tambe *et al* (*95*).

Arthroplasty by simple resection is obviously the first step in a complete carpal collapse (fig 1a). Replacement by a silastic spacer was proposed by Swanson and de Groot Swanson (*93*) (fig 1g). The appearance of intraosseous cysts is the major drawback for this technique. Kaarela *et al* (*46*) had to remove 41% of the spacers in 39 patients. Wachtl and Sennwald (*105*) found similar problems and both authors do not recommend this technique any more.

Partial denervation of the wrist joint by sectioning the posterior and anterior interosseous nerve is a common adjunctive procedure. An isolated full denervation of the wrist joint is possible and is indicated in specific situations such as in older patients, moderate pain, and in patients desiring to retain full range of motion (ROM) and accepting only partial pain relief and probable further detoriation of the wrist joint (fig 1r).

In most series however the first choice is the PRC (fig 1p) in stiff stage III and in all stage IV wrists. Despite the theoretical possibility of damage to the lunate fossa, a proximal row carpectomy has led to very satisfying outcomes in most series and also in our hands (*20*).

Severe damage of the cartilage in the lunate fossa, ulnar translocation of the wrist (caution with

previous radial styloidectomy), a damaged capitate head or previous intracarpal arthrodeses do not allow a PRC. Although most reported series are small, proximal row carpectomy in Kienböck's disease generally results in a favourable outcome (*10, 15,21,29,41,58,69,91*). We assessed the outcomes in 21 patients (mean age 39 years) with advanced Kienböck's disease treated with PRC (*21*). Thirteen patients had no or mild pain, 3 had moderate pain and 5 had no change of their complaints. Grip strength increased from 19 kg preoperatively to 26 kg postoperatively (or 65% of the normal contralateral side). The DASH score was 22 points. Begley and Engber (*10*) reported satisfactory results in 14 patients, with decreased wrist pain in all patients, grip strength of 72% of the contralateral side. El Mowafi *et al* had 11 good results in 12 patients (*29*), Lumsden *et al* in 12 of 13 (*58*), Croog *et al* in 18 of 21 patients (*15*), Streich *et al* had a successful outcome in all their 17 patients (*91*). Although it is suggested in the literature that the outcome of a PRC for other conditions is more favourable, it is a good option for advanced Kienböck's disease, with results comparable to other procedures for this wrist problem.

CONCLUSION

Kienböck's disease is a progressive chronic wrist disorder due to aseptic necrosis of the lunate, leading to osteoarthritis of the wrist. It usually affects young and active adults.

Non-operative treatment is recommended for children or juvenile patients and in older patients with mild symptoms. Otherwise, surgical treatment is the first choice. However, surgical options are numerous. Based on current literature, it is impossible to clearly define specific indications for each procedure. What appears to be an absolute contraindication for a certain technique for one author does not seem to be important for another. Contradiction prevails. No obvious conclusions can be drawn and no evidence based recommendations can be given. Case series are small without randomized control trials, follow-up is generally short, and outcome measures are different and not comparable.

The choice of the procedure depends on the stage of the disease, the ROM of the wrist, the length of the ulna, the shape of the sigmoid notch of the radius and the presence of a lunate fracture. The surgeon's experience, preference and skill also are important in decision-making.

For stage I and II we prefer a VBG with temporary scapho-capitate fixation. An alternative is a radial shortening osteotomy provided that the ulna is short and that the geometry of the DRUJ is convenient.

For stage IIIa, a VBG with an STT arthrodesis is our first choice, provided that the ROM is acceptable and there is no fracture of the lunate.

For stage IIIb and for stage IIIa with a fractured lunate and acceptable ROM, a solitary STT arthrodesis or a scaphocapitate fusion is recommended.

For stage IV and a stiff stage III wrist, a PRC gives excellent outcomes, even better than reconstructive procedures for earlier stages.

For those in which a PRC seems impossible due to severe damage to the lunate fossa of the distal radius, a full wrist arthrodesis in younger patients and a denervation in the older low-demand patients are proposed.

REFERENCES

1. **Allan CH, Joshi A, Lichtman DM.** Kienböck's disease : diagnosis and treatment. *J Am Acad Orthop Surg* 2001 ; 9 : 128-136.
2. **Almquist EE, Burns JF Jr.** Radial shortening for the treatment of Kienböck's disease : a 5- to 10-year follow-up. *J Hand Surg* 1982 ; 7-A : 348-350.
3. **Amillo S, Martinez-Peric R, Barrios RH.** Radial shortening for the treatment of Kienböck's disease. *Int Orthop* 1993 ; 17 : 23-26.
4. **An KN.** The effect of force transmission on the carpus after procedures used to treat Kienböck's disease. *Hand Clin* 1993 ; 9 : 445-454.
5. **Armistead RB, Linscheid RL, Dobyns JH, Beckenbaugh RD.** Ulnar lengthening in the treatment of Kienböck's disease. *J Bone Joint Surg* 1982 ; 64-A : 170-178.
6. **Arora R, Lutz M, Deml C *et al.*** Long-term subjective and radiological outcome after reconstruction of Kienböck's disease stage 3 treated by a free vascularized iliac bone graft. *J Hand Surg* 2008 ; 33-A : 175-181.

7. **Axelson R.** [Niveau operations in necrosis oft he lunate bone.] (in German). *Handchirurgie* 1973 ; 5 : 187-196.
8. **Bartelmann U, Richter N, Landsleitner B.** [Graner operation in therapy of semilunar bone necrosis. Review of the literature and personal results.] (in German). *Handchir Mikrochir Plast Chir* 1998 ; 30 : 165-174.
9. **Beckenbaugh RD, Shives TC, Dobyns JH, Linscheid RL.** Kienböck's disease : the natural history of Kienböck's disease and consideration of lunate fractures. *Clin Orthop Relat Res* 1980 ; 149 : 98-106.
10. **Begley B, Engber W.** Proximal row carpectomy in advanced Kienböck's disease. *J Hand Surg* 1994 ; 19-A : 1016-1018.
11. **Bengoechea-Beeby MP, Cepeda-Uña J, Abascal-Zuloaga A.** Vascularized bone graft from the index metacarpal for Kienböck's disease : a case report. *J Hand Surg* 2001 ; 26-A : 437-443.
12. **Bochud RC, Büchler U.** Kienböck's disease, early stage 3-height reconstruction and core revascularization of the lunate. *J Hand Surg* 1994 ; 19-B : 466-478.
13. **Calandriello B, Palandri C.** [The treatment of lunatomalacia by radius shortening.] (in German). *Z Orthop* 1966 ; 101 : 531-534.
14. **Coe MR, Trumble TE.** Biomechanical comparison of methods used to treat Kienböck's disease. *Hand Clin* 1993 ; 9 : 417-429.
15. **Croog AS, Stern PJ.** Proximal row carpectomy for advanced Kienböck's disease : average 10-year follow-up. *J Hand Surg* 2008 ; 33-A : 1122-1130.
16. **Daecke W, Lorenz S, Wieloch P, Jung M, Martini AK.** Lunate resection and vascularized os pisiform transfer in Kienböck's disease : an average of 10 years of follow-up study after Saffar's procedure. *J Hand Surg* 2005 ; 30-A ; 677-684.
17. **Dap F.** [Wrist arthrodesis : alternative to resection of the proximal carpal bones ?] (in French). *Ann Chir Main Memb Supér* 1992 ; 11 : 285-291.
18. **Das Gupta K, Tünnerhoff HG, Haussmann P.** [STT-arthrodesis versus radial shortening osteotomy for Kienböck's disease.] (in German). *Handchir Mikrochir Plast Chir* 2003 ; 35 : 328-332.
19. **De Smet L, Fabry G.** Orientation of the sigmoid notch of the distal radius. *Act Orthop Belg* 1993 ; 59 : 269-272.
20. **De Smet L, Robijns P, Degreef I.** Proximal row carpectomy in advanced Kienböck's disease. *J Hand Surg* 2005 ; 30-B : 585-587.
21. **De Smet L, Truyen J.** Arthrodesis of the wrist for osteoarthritis : outcome with a minimum follow-up of 4 years. *J Hand Surg* 2003 ; 28-B :575-577.
22. **De Smet L, Verellen K, D'Hoore K *et al.*** Long-term results of radial shortening for Kienböck's disease. *Acta Orthop Belg* 1995 ; 61 : 212-217.
23. **De Smet L.** Kienböck's disease in a 12-year-old girl. *Acta Orthop Belg* 2003 ; 69 : 361-362.
24. **De Smet L.** Relationship of impairment, disability and working status after reconstructive surgery of the wrist. *Hand Surg* 2007 ; 12 : 67-71.
25. **Delaere O, Dury M, Molderez A, Foucher G.** Conservative versus operative treatment for Kienböck's disease. A retrospective study. *J Hand Surg* 1998 ; 23-B : 33-36.
26. **D'Hoore K, De Smet L, Verellen K, Vral J, Fabry G.** Negative ulnar variance is not a risk factor for Kienböck's disease. *J Hand Surg* 1994 ; 19-A : 229-231.
27. **Ducarmois P, Van Innis F.** [Long-term results of 9 cases of elongation of the ulna in treatment of Kienböck's disease.] (in French). *Ann Chir Main Memb Supér* 1997 ; 16 : 16-24.
28. **Eiken O, Niechajev I.** Radius shortening in malacia of the lunate. *J Plast Reconstr Surg* 1980 ; 14 : 191-194.
29. **El-Mowafi H, El-Hadidi M, El-Karef E.** Proximal row carpectomy : a motion-preserving procedure in the treatment of advanced Kienböck's disease. *Acta Orthop Belg* 2006 ; 72 : 530-534.
30. **Fostner H.** [The morphology of the distal radioulnar joint : aspects and implications for orthopaedic surgery.] (in German). *Hand Chir Microchir Plast Chir* 1990 ; 22 : 296-303.
31. **Gabl M, Lutz M, Reinhart C *et al.*** Stage 3 Kienböck's disease : reconstruction of the fractured lunate using a free vascularized iliac bone graft and external fixation. *J Hand Surg* 2002 ; 27-B : 369-373.
32. **Garbuio P, Obert L, Tropet Y, Vichard P.** [Kienböck's disease treated by shortening osteotomy of the radius. Analysis of the results a propos of 13 cases.] (in French). *Ann Chir Main Memb Supér* 1996 ; 15 : 226-237.
33. **Garcia-Elias M, An KN, Cooney WP, Linscheid RL.** [Lateral closing wedge osteotomy for treatment of Kienböck's disease. A clinical and biomechanical study of the optimum correcting angle.] (in French). *Chir Main* 1998 ; 17 : 283-290.
34. **Gelberman RH, Bauman TD, Menon J, Akeson WH.** The vascularity of the lunate bone and Kienböck's disease. *J Hand Surg* 1980 ; 5-A : 272-278.
35. **Gomis R, Martin B, Idoux O, Chammas M, Allieu Y.** Kienböck disease : treatment by shortening osteotomy of the radius.] (in French). *Rev Chir Orthop Réparatrice App Mot* 1994 ; 80 : 196-204.
36. **Hermans S, Degreef I, De Smet L.** Vascularised bone graft for Kienböck's disease : Preliminary results. *Scand J Plast Reconstr Hand Surg* 2007 ; 41 : 77-81.
37. **Herzberg G, Mercier S, Charbonnier JP, Got P.** Kienböck's disease in a 14-year-old gymnast : a case report. *J Hand Surg* 2006 ; 31-A : 264-268.
38. **Horii E, Garcia-Elias M, Bishop AT *et al.*** Effect on force transmission across the carpus in procedures used to treat Kienböck's disease. *J Hand Surg* 1990 ; 15-A : 393-400.

39. Hulten O. [Anatomic variants of hand bones.] (in German). *Acta Radiol* 1928 ; 9, 155-169.

40. Illarramendi AA, Schulz C, De Carli P. The surgical treatment of Kienböck's disease by radius and ulna metaphyseal core decompression. *J Hand Surg* 2001 ; 26-A : 252-260.

41. Inoue G, Miura T. Proximal row carpectomy in perilunate dislocations and lunatomalacia. *Acta Orthop Scand* 1990 ; 61 : 449-452.

42. Inoue G, Tamura Y. Radiolunate and radioscapholunate arthrodesis. *Arch Orthop Trauma Surg* 1992 ; 111 : 333-335.

43. Iwasaki N, Minami A, Oizumi N *et al.* Radial osteotomy for late-stage Kienböck's disease. Wedge osteotomy versus radial shortening. *J Bone Joint Surg* 2002 ; 84-B : 673-677.

44. Irisarri C. Aetiology of Kienböck's disease. *J Hand Surg* 2004 ; 29-B : 281-287.

45. Jones NF, Brown EE, Vögelin E, Urist MR. Bone morphogenetic protein as an adjuvant in the treatment of Kienböck's disease by vascular pedicle implantation. *J Hand Surg* 2008 ; 33 : 317-321.

46. Kaarela OI, Raatikainen TK, Torniainen PJ. Silicone replacement arthroplasty for Kienböck's disease. *J Hand Surg* 1998 ; 23-B : 735-740.

47. Kam B, Topper SM, McLoughlin S, Liu Q. Wedge osteotomies of the radius for Kienböck's disease : a biomechanical analysis. *J Hand Surg* 2002 ; 27-A : 37-42.

48. Keith PP, Nuttall D, Trail I. Long-term outcome of non-surgically managed Kienböck's disease. *J Hand Surg* 2004 ; 29-A : 63-67.

49. Kilgus M, Weishaupt D, Künzi W, Meyer VE. [Radioscapholunate fusion : long-term results.] (in German). *Handchir Mikrochir Plast Chir* 2003 ; 35 ; 317-322.

50. Koh S, Nakamura R, Horii E *et al.* Surgical outcome of radial osteotomy for Kienböck's disease-minimum 10 years of follow-up. *J Hand Surg* 2003 ; 28-A : 910-916.

51. Kristensen SS, Søballe K. Kienböck's disease – the influence of arthrosis on ulnar variance measurements. *J Hand Surg* 1987 ; 12-B : 301-305.

52. Kristensen SS, Thomassen E, Christensen F. Kienböck's disease – late results by non-surgical treatment. A follow-up study. *J Hand Surg* 1986 ; 11-B : 422-425.

53. Kuhlmann JN, Kron C, Boabighi A, Baux S, Mimou M. Vascularised pisiform bone graft. Indications, technique and long-term results. *Acta Orthop Belg* 2003 ; 69 : 311-316.

54. Lamas C, Mir X, Llusà M, Navarro A. Dorsolateral biplane closing radial osteotomy in zero variant cases of Kienböck's disease. *J Hand Surg* 2000 ; 25-A : 700-709.

55. Ledoux P, Lamblin D, Wuilbaut A, Schuind F. A finite-element analysis of Kienböck's disease. *J Hand Surg* 2008 ; 33-B : 286-291.

56. Lichtman DM, Alexander AH, Mack GR, Gunther SF. Kienböck's disease – update on silicone replacement arthroplasty. *J Hand Surg* 1982 ; 7-A : 343-347.

57. Lu L, Gong X, Liu Z, Zhang Z. Capitate transposition to replace necrotic lunate bone with a pedicle for Kienböck's disease : review of 30 cases. *Chin Med J,* 2003 ; 116 : 1519-1522.

58. Lumsden BC, Stone A, Engber WD. Treatment of advanced-stage Kienböck's disease with proximal row carpectomy : an average 15-year follow-up. *J Hand Surg* 2008 ; 33-A ; 493-502.

59. Makino M. Vascularized metacarpal bone graft for scaphoid non-union and Kienböck's disease. *J Reconstr Microsurg* 2000 ; 16 : 261-266.

60. Meier R, van Griensven M, Krimmer H. Scapho-trapeziotrapezoid (STT)-arthrodesis in Kienböck's disease. *J Hand Surg* 2004 ; 29-B : 580-584.

61. Mikkelsen SS, Gelineck J. Poor function after non-operative treatment of Kienböck's disease. *Acta Orthop Scand* 1987 ; 58 : 241-243.

62. Minami A, Kato H, Suenaga N, Iwasaki N. Scaphotrapeziotrapezoid fusion : long-term follow-up study. *J Orthop Sci* 2003 ; 8 : 319-322.

63. Minami A, Kimura T, Suzuki K. Long-term results of Kienböck's disease treated by triscaphe arthrodesis and excisional arthroplasty with a coiled palmaris longus tendon. *J Hand Surg* 1994 ; 19-A : 219-228.

64. Mirabello SC, Rosenthal DI, Smith RJ. Correlation of clinical and radiographic findings in Kienböck's disease. *J Hand Surg* 1987 ; 12-A : 1049-1055.

65. Miura H, Sugioka Y. Radial closing wedge osteotomy for Kienböck's disease. *J Hand Surg* 1996 ; 21-A :1029-1034.

66. Moneim MS, Duncan GJ. Kienböck's disease : treatment by implantation of vascular pedicle and bone grafting. *Iowa Orthop* 1998 ; 2018 : 67-73.

67. Moran SL, Cooney WP, Berger RA, Bishop AT, Shin AY. The use of the 4 + 5 extensor compartmental vascularised bone graft for the treatment of Kienböck's disease. *J Hand Surg* 2005 ; 30-A : 50-58.

68. Moy OJ, Peimer CA. Scaphocapitate fusion in the treatment of Kienböck's disease. *Hand Clin* 1993 ; 9 : 501-504.

69. Nakamura R, Horii E, Watanabe K *et al.* Proximal row carpectomy versus limited wrist arthrodesis for advanced Kienböck's disease. *J Hand Surg* 1998 ; 23-B : 741-745.

70. Nakamura R, Imaeda T, Miura T. Radial shortening for Kienböck's disease : factors affecting the operative result. *J Hand Surg 1990* ; 15-B : 40-45.

71. Nakamura R, Tanaka Y, Imaeda T, Miura T. The influence of age and sex on ulnar variance. *J Hand Surg* 1991 ; 16-B : 84-88.

72. Oishi SN, Muzaffar AR, Carter PR. Treatment of Kienböck's disease with capitohamate arthrodesis : pain

relief with minimal morbidity. *Plast Reconstr Surg* 2002 ; 109 : 1293-1300.

73. **Prommersberger KJ, Krimmer H, Häusser D, Lanz U.** [Treatment of lunate necrosis in an advanced stage.] (in German). *Handchir Mikrochir Plast Chir*. 1998 ; 30 : 181 187.
74. **Quenzer DE, Dobyns JH, Linscheid RL, Trail IA, Vidal MA.** Radial recession osteotomy for Kienböck's disease. *J Hand Surg* 1997 ; 22-A : 386-395.
75. **Ovesen J.** Shortening of the radius in the treatment of lunatomalacia. *J.Bone Joint Surg* 1981 ; 63-B , 231-233.
76. **Razemon JP.** [Treatment of Kienböck's disease with segmentary shortening of the radius. A propos of 28 cases.] (in French). *Chirurgie* 1984 ; 110 : 600-607.
77. **Rosemeyer B, Artmann M, Viernstein K.** [Kienböck's disease. Follow-up studies and therapeutic considerations.] (in German). *Arch Orthop Unfallchir* 1976 ; 85 : 119-127.
78. **Saffar P.** [Replacement of the semilunar bone by the pisiform. Description of a new technique for the treatment of Kienboeck's disease.] (in French). *Ann Chir Main* 1982 ; 1 : 276-279.
79. **Sagerman SD, Zogby RG, Palmer AK, Werner FW, Fortino MD.** Relative articular inclination of the distal radioulnar joint : a radiographic study. *J Hand Surg* 1995 ; 20-A : 597-601.
80. **Salmon J, Stanley JK, Trail IA.** Kienböck's disease : conservative management versus radial shortening. *J Bone Joint Surg* 2000 ; 82-B : 820-823.
81. **Sauerbier M, Kluge S, Bickert B, Germann G.** [Subjective and objective outcomes after total wrist arthrodesis in patients with radiocarpal arthrosis or Kienböck's disease.] (in French). *Chir Main* 2000 ; 19 : 223-231.
82. **Sauerbier M, Tränkle M, Erdmann D, Menke H, Germann G.** Functional outcome with scaphotrapeziotrapezoid arthrodesis in the treatment of Kienböck's disease stage III. *Ann Plast Surg* 2000 *; 44 : 6*18-625.
83. **Schattenkerk M, Nollen A, Van Hussen F.** The treatment of lunatomalacia : radial shortening or ulnar lengthening ? *Act Orthop Scand* 1987 ; 58 : 652-654.
84. **Schmitt R, Fellner F, Oblet*ter* N, Fiedler E, Bautz W.** [Diagnosis and staging of lunate necrosis. A current review.] (in German). *Handchir Mikrochir Plast Chir* 1998 ; 30 : 142-150.
85. **Schuind F, Eslami S, Ledoux *P.*** Kienböck's disease. *J Bone Joint Surg* 2008 ; 90-B : 133-139.
86. **Schulz C, De Carli P, Anetzberger H, Illarramendi A.** [Stress osteotomy of the distal radius- and ulna metaphysis (Illarramendi procedure) : an alternative treatment method in lunate necrosis.] (in German). *Handchir Mikrochir Plast Chir* 1998 ; 30 : 188-195.
87. **Sennwald GR, Ufenast H.** Scaphocapitate arthrodesis for the treatment of Kienböck's disease. *J Hand Surg* 1995 ; 20-A : 506-510.
88. **Siala A, Ben Ayeche ML, Frikha R, Ghannouchi G, Moula T.** [Results of diaphyseal shortening of the radius in the treatment of Kienböck's disease : a series of 31 cases.] (in French). *Rev Chir Orthop Réparatrice Appar Mot* 2000 ; 86 : 151-157.
89. **Shin AY, Bishop AT.** Vascular anatomy of the distal radius : implications for vascularised bone grafts. *Clin Orthop Relat Res* 2001 ; 383 : 60-73.
90. **Soejima O, Iida H, Komine S, Kikuta T, Naito M.** Lateral closing wedge osteotomy of the distal radius for advanced stages of Kienböck's disease. *J Hand Surg* 2002 ; 27-A : 31-36.
91. **Streich NA, Martini AK, Daecke W.** [Proximal row carpectomy in carpal collapse.] (in German). *Handchir Mikrochir Plast Chir* 2003 ; 35 : 299-303.
92. **Sundberg SB, Linscheid RL.** Kienböck's disease. Results of treatment with ulnar lengthening. *Clin Orthop Relat Res* 1984 ; 187 : 43-51.
93. **Swanson AB, de Groot Swanson G.** Implant resection arthroplasty in the treatment of Kienböck's disease. *Hand Clin* 1993 ; 9 : 483-491.
94. **Tambe A, Ali F, Trail I, Stanley J.** Is radiolunate fusion a viable option in advanced Kienböck disease ? *Acta Orthop Belg* 2007 ; 73 : 598-603.
95. **Tambe AD, Trail IA, Stanley JK.** Wrist fusion versus limited carpal fusion in advanced Kienböck's disease. *Int Orthop* 2005 ; 29 ; 355-358.
96. **Taniguchi Y, Nakao S, Tamaki T.** Incidentally diagnosed Kienböck's disease. *Clin Orthop Relat Res* 2002 : 121-127.
97. **Tatebe M, Hirata H, Iwata Y, Hattori T, Nakamura R.** Limited wrist arthrodesis versus radial osteotomy for advanced Kienböck's disease for a fragmented lunate. *Hand Surg* 2006 ; 11 : 9-14.
98. **Tatebe M, Horii E, Majima M *et al.*** Radial osteotomy for Kienböck's disease with displaced fracture of the lunate. *J Hand Surg* 2007 ; 32-A : 1343-1347.
99. **Thienpont E, Mulier T, Rega F, De Smet L.** Radiographic analysis of anatomical risk factors for Kienböck's disease. *Acta Orthop Belg* 2004 ; 70 : 406-409.
100. **Tilberg B.** Kienböck's disease treated with osteotomy to lengthen the ulna. *Act Orthop Scand* 1968 ; 39 : 359-368.
101. **Tränkle M, Sauerbier M, Linsner G, Bickert B, Germann G.** [STT arthrodesis for treatment of stage III semilunar bone necrosis : functional outcome.] (in German). *Handchir Mikrochir Plast Chir* 2000 ; 32 : 419-423.
102. **Trail IA, Linscheid RL, Quenzer DE, Scherer PA.** Ulnar lengthening and radial recession procedures for Kienböck's disease. Long-term clinical and radiographic follow-up. *J Hand Surg* 1996 ; 21-B : 169-176.
103. **Tsuge S, Nakamura R.** Anatomical risk factors for Kienböck's disease. *J Hand Surg* 1993 ; 18-B : 70-75.

104. Van den Dungen S, Dury M, Foucher G, Marin Braun F, Loréa P. [Conservative treatment versus scaphotrapeziotrapezoid arthrodesis for Kienböck's disease. A retrospective study.] (in French). *Chir Main* 2006 ; 25 : 141-145.

105. Wachtl S, Sennwald G, Rodriguez M. [The value of silastic prostheses in Kienböck's disease.] (in German). *Schweiz Rundsch Med Prax* 1994 ; 83 : 129-132.

106. Wada A, Miura H, Kubota H, Iwamoto Y, Uchida Y, Kojima T. Radial closing wedge osteotomy for Kienböck's disease : an over 10 year clinical and radiographic follow-up. *J Hand Surg* 2002 ; 27-B : 175-179.

107. Wagner JP, Chung KC. A historical report on Robert Kienböck (1871-1953) and Kienböck's Disease. *J Hand Surg* 2005 ; 30-A : 1117-1121.

108. Watanabe K, Nakamura R, Horii E, Miura T. Biomechanical analysis of radial wedge osteotomy for the treatment of Kienböck's disease. *J Hand Surg* 1993 ; 18-A : 686-690.

109. Watson HK, Hempton R. Limited wrist arthrodesis. The triscaphoid joint. *J Hand Surg* 1980 ; 5-A : 320-327.

110. Watson HK, Monacelli DM, Milford RS, Ashmead D IV. Treatment of Kienböck's disease with scaphotrapezio-trapezoid arthrodesis. *J Hand Surg* 1996 ; 21-A : 219-215.

111. Weiss AP. Radial shortening. *Hand Clin* 1993 ; 9 : 475-482.

112. Werner FW, Palmer AK. Biomechanical evaluation of operative procedures to treat Kienböck's disease. *Hand Clin* 1993 ; 9 : 431-443.

113. Wilhelm K, Hierner R, Brehl B. [Callus distraction for progressive lengthening of the capitate bone after resection of the lunate bone in stage III lunate malacia. Surgical technique and 1 year results.] (in German). *Handchir Mikrochir Plast Chir* 1997 ; 29 : 10-19.

114. Wintman BI, Imbriglia JE, Buterbaugh GA, Hagberg WC. Operative treatment with radial shortening in Kienböck's disease. *Orthopedics* 2001 ; 24 : 365-371.

115. Zafra M, Carrasco-Becerra C, Carpintero P. Vascularised bone graft and osteotomy of the radius in Kienböck's disease. *Acta Orthop Belg* 2005 ; 71 ; 163-168.