CLINICAL STUDY

USE OF HYALURONIC ACID IN PERIODONTAL DISEASE

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Guided tissue regeneration is achieved thanks to a surgical technique aimed at creating a new attachment to correct bone defects by triggering mechanisms responsible for the physiological repair of the damaged tissue. Various authors have demonstrated that in periodontal surgery, guided tissue regeneration obtained using biomaterials is a reliable and effective method that does not require use of a membrane. The aim of this work is to assess the efficacy of the polymer derived from esterified hyaluronic acid (EHA) as a coadjuvant of grafting processes using autologous bone obtained from the intra-oral site in treating infra-bone defects without the aid of a membrane. A controlled clinical experiment was conducted on 10 patients with periodontal defects (5 males and 5 females, all non-smokers and in good health), with a mean age of 42 years and a mean infra-bone defect depth of 8.3 mm as revealed by intra-operative probes. All patients underwent non-surgical periodontal treatment to reduce the FMPS and FMBS indexes to zero. Each graft was characterized by 0.5 cc of autologous bone taken from intra-oral sites, two bundles of EHA fibres, and a few drops of physiological solution. 24 months after surgery, clinical and radiographic re-evaluations showed satisfactory filling. In conclusion, the esterified hyaluronic acid fibres allow the re-creation of an ideal microenvironment for tissue regeneration and thus foster faster repair and healing processes.

The main aim of periodontal therapy is to remove the pathogenic causes leading to loss of the dental support apparatus and, if possible, to restore this structure. Bone grafting is one of the various methods available to achieve this goal. According to Schallhorn (1), bone grafts must focus on three targets: elimination/reduction of the pocket, reconstruction of the alveolar process, and regeneration of a functional support apparatus. The first attempted bone grafts in periodontal therapy date back to 1923, when Hegedus reported the successful treatment of six cases of "severe pyorrhea" with the application of autologous bone obtained from the tibia. Today, a large quantity of data demonstrates that bone grafting in humans is effective in obtaining a "new dental support apparatus" consisting of regenerated ligaments, cementing processes, and, of course, new bone tissue. Naturally, it lacks the physiological characteristics typical of the original apparatus. Nevertheless, there is still considerable debate in the field over a number of fundamental issues ranging from the patient selection process to the importance of underlying causes of defects to the choice of materials used in the graft.

Key words: Guided tissue regeneration, bone graft, hyaluronic acid, biomaterials, hyaluronan in morphogenesis, differentiation

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Generally speaking, there are four principal groups of grafts:

- Autologous grafts: transplanted from one site to another within the same individual.
- Allogenic grafts: transplanted from one individual to another within the same species.
- Heterologous grafts: transplanted from one individual to another of a different species.
- Alloplastic grafts: made of artificial or synthetic material (2-3)

Many research projects were conducted during the 1980's to identify the cells responsible for the regeneration of the periodontal ligament and root cement. From the studies supported by Melcher, it was found that after an open surgical flap procedure with curettage, the root surface of a dental element with an infra-bone periodontal defect can be re-populated by four cell types: epithelial cells belonging to the gingival epithelial layer, cells deriving from the gingival connective tissue, cells deriving from the bone connective tissue, and cells deriving from the periodontal ligament. The fact that new cementing processes are observed only in roots with an intact periodontal ligament shows that this ligament tissue contains cells with the potential to create new attachments. Thus, the re-colonization and multiplication in a coronal direction of the cells deriving from the periodontal ligament is an essential condition for obtaining a new attachment. Guided tissue regeneration is achieved thanks to a surgical technique aimed at the creation of new attachments: correcting bone defects by triggering mechanisms responsible for the physiological repair of the damaged tissue.

Various authors have demonstrated that in periodontal surgery, guided tissue regeneration obtained using biomaterials is a reliable, effective method that does not require use of a membrane (1, 4). The aim of this study is to assess the efficacy of a polymer derived from esterified hyaluronic acid (EHA) as a coadjuvant of grafting processes employing autologous bone obtained from the intra-oral site in treating infra-bone defects without the aid of a membrane.

MATERIALS AND METHODS

A controlled clinical experiment was conducted in 10 patients with periodontal defects (5 males and 5 females, all non-smokers and in good health), with a mean age of 42 years and with a mean infra-bone defect depth of 8.3 mm as revealed by intra-operative probes. The patients provided written consent for the publication of this study. Potential subjects with the following criteria were excluded: smokers >10 cigarettes per day, pregnant or breastfeeding women, patients with severe systemic diseases, patients with plaque and bleeding indexes > 25%, patients with infra-bone defects < 3mm, sites with stabilized teeth (no M2, M3), patients treated with drugs that could interfere with the tissue regeneration processes, and patients failing to observe recommended oral hygiene measures.

All patients underwent non-surgical periodontal treatment to reduce the FMPS (full mouth plaque surfaces) and FMBS (full mouth plaque surfaces) indexes from initial mean values of 70%, to zero. Preoperative endo-oral X-rays with a Rinn Centering were performed (Fig. 1). To assess the treatment results, the following pre-operative and intra-operative clinical parameters were analyzed:

• FMPS
• FMBS
• PPD (periodontal pocket depth) (Fig. 2);
• R (gingival recession, i.e. the position of the gingival margin with respect to the cement enamel junction [CEJ]);
• CAL (clinical attachment level, i.e. the position of the attachment with respect to the CEJ)
• IBPD (intrabony pocket depth, i.e. distance between the CEJ and the bone crest)

Surgical Technique

After anaesthesia and vasoconstrictor administration, vestibular and palatal/lingual intrasulcus incisions were made with a Bard-Parker straight-handled lancet and a n° 15 surgical blade at least one tooth away from the mesial portion, distally to the graft site, to create access for the tools and enable visualization of the lesion site (Fig. 3-4). The interproximal papillae were incised and gently raised according to Takey's technique (Papilla Preservation) to protect them and ensure good mobility. A full-thickness flap was detached and the granulation tissue was eliminated. When the defect was exposed, accurate root-planing was performed using manual and ultrasound tools (Fig. 5). Subsequently, the graft material was prepared and positioned: 0.5 cc of autologous bone were taken from intra-oral sites and blended with two bundles of EHA fibres (Biopolimero Hyaloss® Matrix) and a few drops of physiological solution (Fig. 6). Excess fluid was removed with a sterile gauze, and the graft material was inserted into the host site. Finally, the flap

was re-positioned and sutured with single stitches, and firm pressure was then exerted with the fingers for 2 or 3 minutes using a gauze dipped in physiological solution to reduce blood clotting and promote healing (Fig. 7-8).

Hyaluronic acid

Hyaluronic acid (HA) is one of the main polysaccharide components of the extracellular matrix and is also abundant in embryonal mesenchymal tissues (5). It was originally discovered in the vitreous humour of the eye but was later proven to be an important constituent of the synovial fluid of the joints as well as of the skin and most organs and tissues. Thanks to its hygroscopic, rheologic, and viscoelastic properties, hyaluronic acid can affect the cell functions that modify the surrounding micro- and macro-environments. It presents completely ionized carboxyl groups and negative charges with PH 7.0, making it water-soluble and inducing the formation of highly viscous solutions (6). This characteristic is largely responsible for the consistency of the active ingredient, which can bar bacteria from penetrating tissues. It is commercially produced by fermenting specific strains of streptococchi or cock crest extract.

Physiochemical characteristics

HA has hygroscopic and viscoelastic properties, which are essential in the regulation of tissue hydration, especially during inflammatory processes triggered by tissue damage when particularly high levels of hyaluronic acid are registered (7).

Biological characteristics

HA has a primary role in principal biological processes such as tissue hydration, cell organization, and differentiation. In a sense, it acts as a protective layer for the cell membrane. Moreover, the chemico-physical properties of HA can be further modified by binding it to specific cells or components of the extracellular matrix through three main classes of surface receptors: CD44, RHAMM, and ICAM-1 (8-11).

HA and modulation of the inflammatory response

Inflammation occurs when the entire organism reacts to penetration of pathogenic agents inside a wound and all the possible defence systems are activated (7, 12-13). When a wound becomes inflamed, a series of growth factors and cytokines are generated to aid healing. These factors promote the migration of inflammatory cells, fibroblasts, and endothelial cells to the wound. It has been shown that fibroblasts cultured with increasing doses of HA have an increased production of pro-inflammatory cytokines such as TNF-a, IL-Iβ, and IL-δ, triggered by the CD44 receptors (14-17).

HA: cell migration and proliferation

Cell migration and proliferation are essential phases in tissue regeneration. The specific interaction with HA receptors CD44, ICAM-1, and RHAMM on fibroblasts, endothelial cells and mesenchymal cells induces migration of these cells to the site of the lesion (18-20).

The role of HA in angiogenesis

It has been shown that high molecular weight HA is an angiogenesis inhibitor, while low molecular weight HA oligosaccharides had a marked angiogenic effect in a series of experimental models and also stimulated the production of collagen in endothelial cells (21-23). The HA oligosaccharides can affect the function of endothelial cells both directly and indirectly: directly, by binding to ICAM-1 receptors present on the endothelial cell surface, and indirectly, by binding to CD44 receptors present on the macrophages, thus triggering the release of various inflammatory cytokines such as TNF-α and IL-Iβ, that will then activate the vascular adhesion molecules, ICAM-1.

The "carrier" function

HA can be an ideal vector for the bone morphogenic proteins (BMP), the only growth factors universally acknowledged as stimulating the formation of new bone tissue (24-27).

RESULTS AND CONCLUSIONS

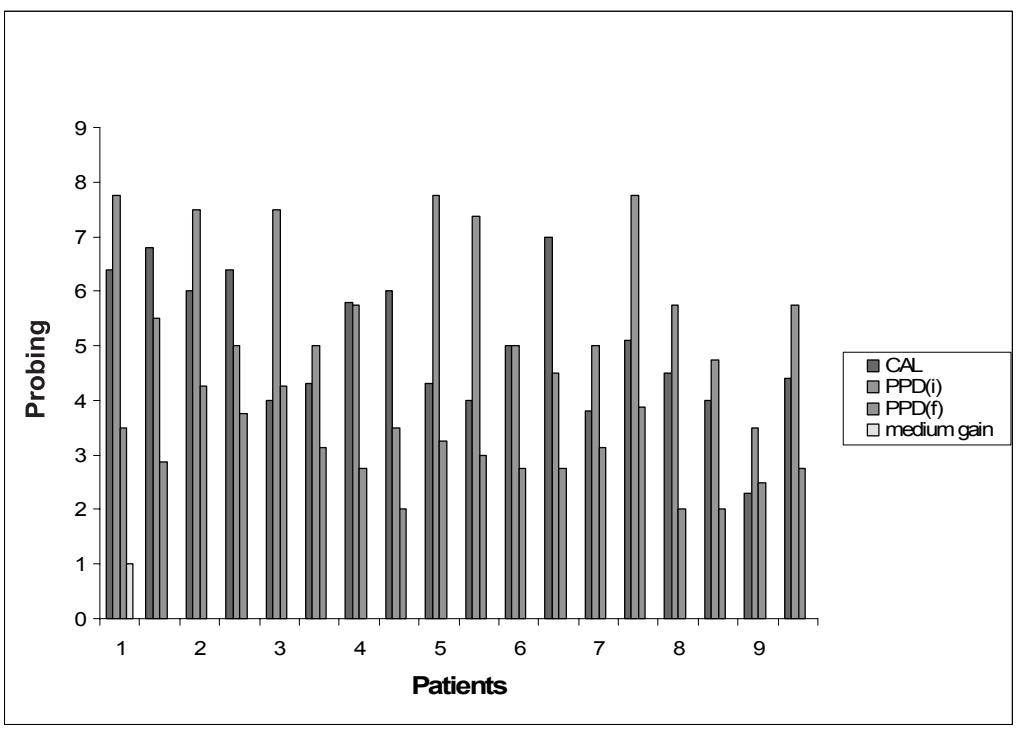
All these properties make HA useful in periodontal regenerative therapy as a coadjuvant of autologous bone grafting. In contact with the patient's blood or saline solution, the Hyaloss® matrix forms a gel almost instantly, thus facilitating the application of bone fragments. The Hyaloss® matrix is highly versatile because, at room temperature, it can form a biodegradable, biocompatible gel that can be adapted to the desired consistency by regulating the blood and saline volume. In fact, the Hyaloss® matrix has a dual function: On one hand, its chemico-physical properties facilitate the application of the bone graft in the damaged site, and, on the other hand, it creates an HA -rich environment. The management of the soft tissues was not particularly difficult and high rate healing occurred after first treatment. On removal of the sutures, only very minor inflammation of the tissues was observed.

On the 10th day, postoperative clinical assessment demonstrated gingivitis grade O or 1 and a more efficacious control of bacterial contamination of the surgical wound, thanks to the

Table I. *Medium gain obtained during Surgical treatment with Hyaloss® matrix.*

Patient	Age	Sex	FMPS	FMBS	Osseous defect	Surgical site	PPD(i)	PPD(f)	Cal	Medium gain
1	44	F	100	100	Defect combineted 1 and 2 wall	32 - 33	7.8 - 5.5	3.5 - 2.9	6.4 - 6.8	4.3 – 2.6
2	40	M	50	50	Defect at 3wall	35 - 36	7.5 - 5.0	4.3 - 3.8	6 - 6.4	3.3 – 1.3
3	40	M	50	50	Defect at 3 wall	44 - 45	7.5 - 5.0	4.3 - 3.1	4 - 4.3	3.3 – 1.9
4	28	M	60	100	Defect combineted 1 and 3 wall	41 - 42	5.8 - 3.5	2.8 - 2,0	5.8 - 6	3 - 1.5
5	34	F	100	100	Defect combineted 1 and 2 wall	11 - 21	7.8 - 7.4	3.3 - 3.0	4.3 - 4	4.5 - 4.4
6	36	F	60	40	Defect combineted 1 and 3 wall	15 - 16	5.0 - 4.5	2.8 - 2.8	5 - 7	2.3 - 1.8
7	44	F	50	20	Defect combineted 1.2 and 3 wall	45 - 46	5.0 - 7.8	3.1 - 3.9	3.8 - 5.1	1.9 - 3.9
8	52	M	60	60	Defect combineted 2 and 3 wall	11 - 12	5.8 - 4.8	2.0 - 2.0	4.5 - 4	3.8 - 2.8
9	60	F	80	80	Defect combineted 1 and 2 wall	42 - 43	3.5 - 5.8	2.5 - 2.8	2.3 - 4.4	1 - 3

Table II. *Graphical representation of Medium gain obtained during surgical treatment with Hyaloss® matrix.*



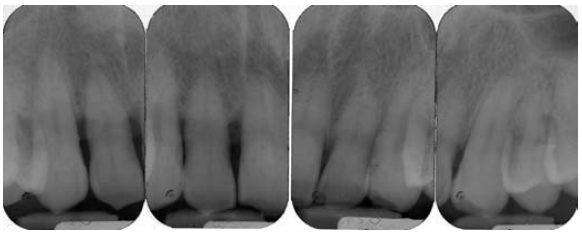


Fig. 1. *Pre-operative X-rays.*

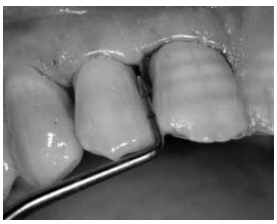


Fig. 2. *Initial probing.*

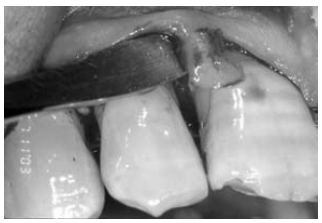


Fig. 3 *Incision of the surgical flap.*

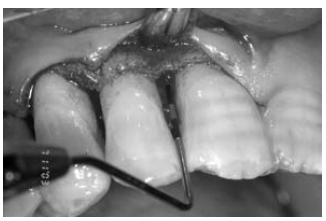


Fig. 4. *Flap elevation, evalutation of the intra-surgical parameters and surgical toilette of the intra-osseous defect.*

Fig. 5. *Autogenous bone graft harvested by a mini-bone scraper (Safescraper curve or Micross).*

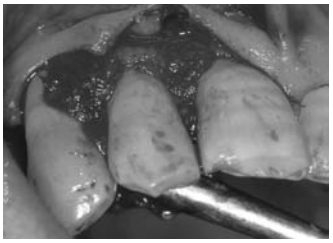
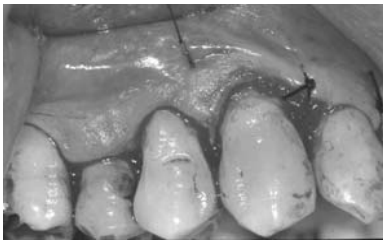


Fig. 6. *Autogenous bone graft mixed with Hyaloss® matrix.*



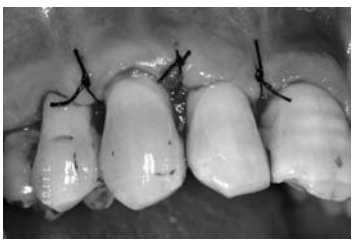


Fig. 7 and 8. *Flap replacement with nylon 4-0 sutures.*

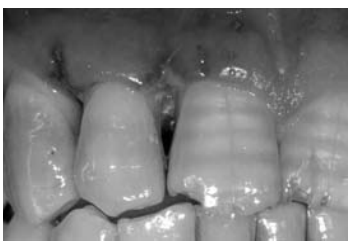


Fig. 9. *Clinical re-evalutation after 10 days from surgery.*

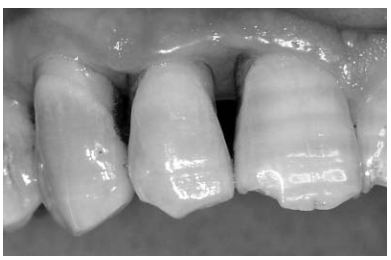


Fig. 10. *Clinical re-evalutation after 6 months from surgery.*

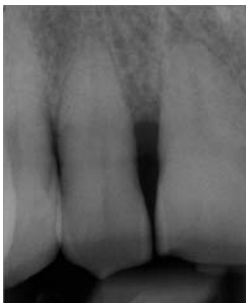


Fig 11. *X-rays 6 months from surgery.*

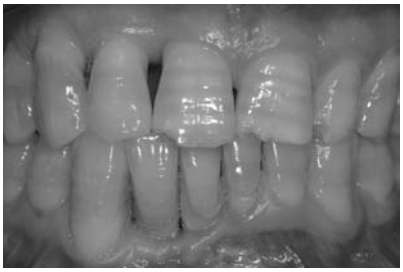


Fig.14. *Clinical re-evalutation 24 months from surgery.*

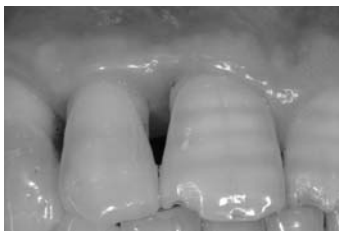


Fig. 12. *Clinical re-evalutation 9 months from surgery.*

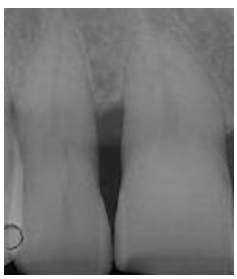


Fig. 15. *X-rays 24 months from surgery.*

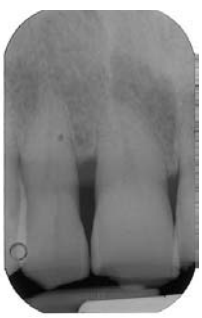


Fig. 13. *X-rays 9 months from surgery.*

bacteriostatic properties of the tested polymer (Fig. 9). X-rays showed absence of bone remodelling, good substance of the graft material *in situ*, and satisfactory filling of the defective substance of the graft material *in situ.* After 6 months, X-rays showed presence of bland bone remodelling and excellent substance of the graft material *in situ* (Fig. 10-11). Nine months after the procedure, the dental elements were virtually stable, with a mean *gCAL* (gain hi clinical attachment) of 2.6mm; radiography showed filling of the defect and a good prognosis (Fig. 12-13). After 24 months, clinical (Fig. 14) and adiograph (Fig. 15) re-evalutation showed a present and satisfactory filling (Table I-II).

In conclusion, because the EHA fibres act as a guide and support for the growth factors and satisfactory periodontal tissue cells, they allow the recreation of an ideal rnicroenvironment for tissue regeneration and thus foster faster repair and healing processes.

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ASSESSMENT OF OUTCOME IN PATIENTS UNDERGOING THE AVON PATELLOFEMORAL KNEE REPLACEMENT

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This study aimed to assess the outcome of the first 42 consecutive Avon patellofemoral knee replacements in 38 patients performed by 4 consultant surgeons, each with a special interest in knee arthroplasty, between 2002 and 2006. There were 30 females and 8 males with a mean age of 63. Range of follow-up was from 25 months to 6 years (mean 42 months). Outcome was measured using the SF-36 questionnaire, Oxford Knee and the Bartlett Patella Score. Significant improvement was seen at 2 and 5 years following surgery ($p<0.01$). There was 1 revision to total knee replacement. A statistically significant difference in outcome was noted in those with and without comorbidities.

Isolated patellofemoral arthritis is an uncommon and relatively neglected clinical pattern. One large study demonstrated radiographic evidence of isolated patellofemoral disease in 13.6% to 24% of women, and 11% to 15.4% of men with arthritic knee symptoms in the 55 to 60 years old age group (1). It is likely that significant numbers of patients with symptomatic disease could benefit from patellofemoral resurfacing.

Historically, patellofemoral prosthetic replacements, despite the potential advantage of retaining the natural kinematics of the knee joint by the retention of the menisci and cruciate ligaments (2-4), has been shown to have poor durability (5-11). The Avon knee (12-13) may have reversed this trend and if it proves as successful in the longer term and in general use as has been reported by the manufacturer to date, then this implant will have made the selective resurfacing of the patellofemoral joint a far more viable option than before (14-15) (Fig. 1).

The aim of this study was to assess clinical improvement after Avon patellofemoral joint replacement. In addition we selectively reviewed outcome in patients with other chronic diseases.

MATERIALS AND METHODS

A retrospective review of 42 consecutive primary Avon patellofemoral arthroplasties between 2002 and 2006 in 38 patients was made. These were performed by 4 consultant surgeons, each with a special interest in knee arthroplasty. The age range was 52 to 81 years with a mean of 63 years. There were 30 women and 8 men. In all knees advanced patellofemoral arthritis (Kellgren-Lawrence grade 4) was found and in 27 (70%) of these, lateral facet disease was evident (Fig. 2). Two (5%) patients had trochlear dysplasia with patellar subluxation and 1 (3%) patient secondary osteoarthritis following a road traffic accident. Six (16%) patients had an arthroscopy proceeding surgery which confirmed advanced and isolated patellofemoral arthritis. Follow-up ranged from 25 months to 6 years

Key words: patellofemoral replacement, Avon, comorbidities, knee, arthroplasty

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Table I. *PCS*

Co-morbidity	Estimated mean difference in outcome from patients with no co-morbidity	95% c.i.
Regular medical	-5.69	(-10 to -1.4)
Mental health	-3.37	(-8.1 to 1.4)
	Overall, p=0.014	

Table II. *MCS*

Co-morbidity	Estimated mean difference in outcome from patients with no co-morbidity	95% c.i.
Regular medical	4.91	(2 to 7.8)
Mental health	5.29	(-1.1 to 11.7)
	Overall, p=0.003	

Table III. *Oxford Knee Score*

Co-morbidity	Estimated mean difference in outcome from patients with no co-morbidity	95% c.i.
Regular medical	-2.1	(-3.6 to -0.5)
Mental health	-4.29	(-5.2 to -3.4)
	Overall, p<0.0001	

Table IV. *Bartlett Patellofemoral Score*

Co-morbidity	Estimated mean difference in outcome from patients with no co-morbidity	95% c.i.
Regular medical	-3.15	(-5.8 to -0.5)
Mental health	-8.00	(-10.3 to -5.7)
	Overall, p<0.0001	

from the time of surgery, with a mean of 42 months.

Each patient's record was reviewed for suitability of inclusion and completeness of recorded data. Thirty patients had been reviewed in a multidisciplinary pre-assessment clinic, and assessed by a resident medical officer, nurse, physiotherapist, pharmacist and occupational therapist. Information regarding pre-operative pain and disability were recorded using the Oxford Knee, the Bartlett Patella and the SF-36 version 2 scoring systems. Radiographs including a weight bearing anteroposterior (AP) and lateral, tunnel views, and tangential X-rays of the patella at 30 degrees of knee flexion (16-18).

Indication for surgery was pain uncontrolled by conservative measures and accompanied by signs and symptoms of patellofemoral disease including knee effusion, crepitus and patellar malignment, anterior knee pain usually worse while ascending and descending stairs, and standing from a seated position in patients with radiographically proven severe (Kellgren grade 4) patellofemoral disease with no main joint arthritis.

Contra-indications were fixed flexion deformity of the joint and varus or valgus of 4 degrees or more. Older patients were warned of the possibility of conversion to total knee replacement should more advanced disease be discovered at the time of surgery (19-22). In none of our patients had previous re-alignment or reconstructive surgery (23-24) been performed. None had any evidence

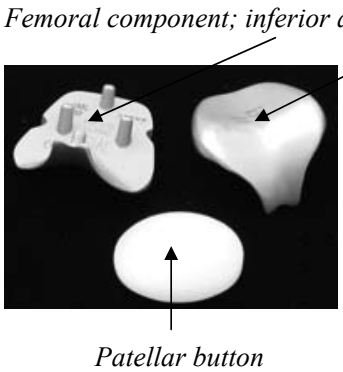

Fig. 1. *Avon patellofemoral implant, Stryker Howmedica Osteonics.*

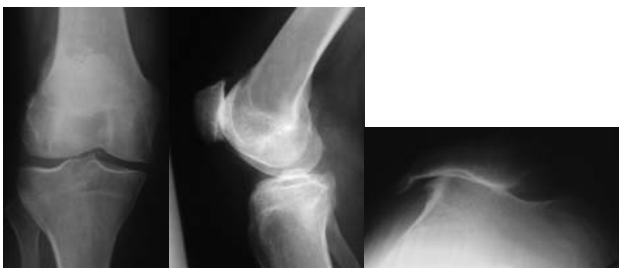

Fig. 2. *Typical pre-operative radiographs, anteroposterior, lateral and tangential view of patella, in patient with isolated severe patellofemoral arthritis and lateral facet disease and subluxation.*

of algodystrophy, regional pain syndrome (25-26), or substantial patella alta or infera, defined as more than a 20% deviation from the normal 1:1 ratio of patellar tendon length to length of patella. Range of movement in all patients was at least from 0 to 110 degrees of flexion. All patients consented to inclusion in this review. Outpatient review was performed by the primary author. An Oxford Knee Score, Bartlett Patellofemoral Score and 36 Question Short Form version 2 (SF-36 V2) questionnaire (27) was sent by post to this group in advance of their attendance at the out-patients department and their content discussed and explained where appropriate. Out-patient department assessment also consisted of an enquiry of the patients' subjective view of their intervention (28).Operative and post-operative complications noted. Weight bearing AP, lateral and tangential X rays were performed if none were available within 3 months from the time of interview. The position of the implant was noted in addition to any tibio-femoral joint osteoarthritis. Pre-operative and post-operative range of movement was noted.

RESULTS

We divided our patients into 2 main groups, the first without co-morbidities (19 patients) and the second with co-morbidities (19 patients). This second group was further divided into 2 groups. Firstly, were those with chronic medical conditions (11) (29) including hypertension, ischemic heart disease, inflammatory bowel disease, diverticular disease, and hypothyroidism for which regular medication and attendance with health care professionals was required (30). Second, those with mental health disease (8), including 6 with mild to moderate and 2 with severe depression. The aetiology of each depressive episode was considered independent of their knee symptoms in each case.

All patients completed the Oxford Knee (Fig. 3), SF-36 (Fig. 4,5) and Bartlett Patellofemoral scores (Fig.6)

Statistics

A linear regression model was used to investigate whether patients with different co-morbidities experienced different outcomes. The outcome was the PCS (Table I) and MCS (Table II) components of the SF 36 scoring system, and the Oxford (Table III) and Bartlett (Table IV) scores after operation. Some patients had both knees operated on. To account for this within patient correlations a robust Huber-White variance estimator was used. To increase the efficiency of analysis estimates were adjusted for scores before operation. Estimates presented give mean difference in outcome between otherwise healthy patients and those with regular medical and mental health co-morbidities respectively. P-values tested overall the null hypothesis that with all three co-morbidities outcomes were the same.

Seven patients demonstrated radiological evidence of disease progression (tibio-femoral osteoarthritis) and in 4 of these cases it was symptomatic. One of these required conversion to TKR 38 months post-operatively and remains pain-free 27 months following this.

Median range of movement in the healthy group was from 111° of knee flexion before operation to 125° of flexion 2 years post-operatively. In the chronic disease group this was from 113° to 124°, and in the mental health group from 110° to 121°.

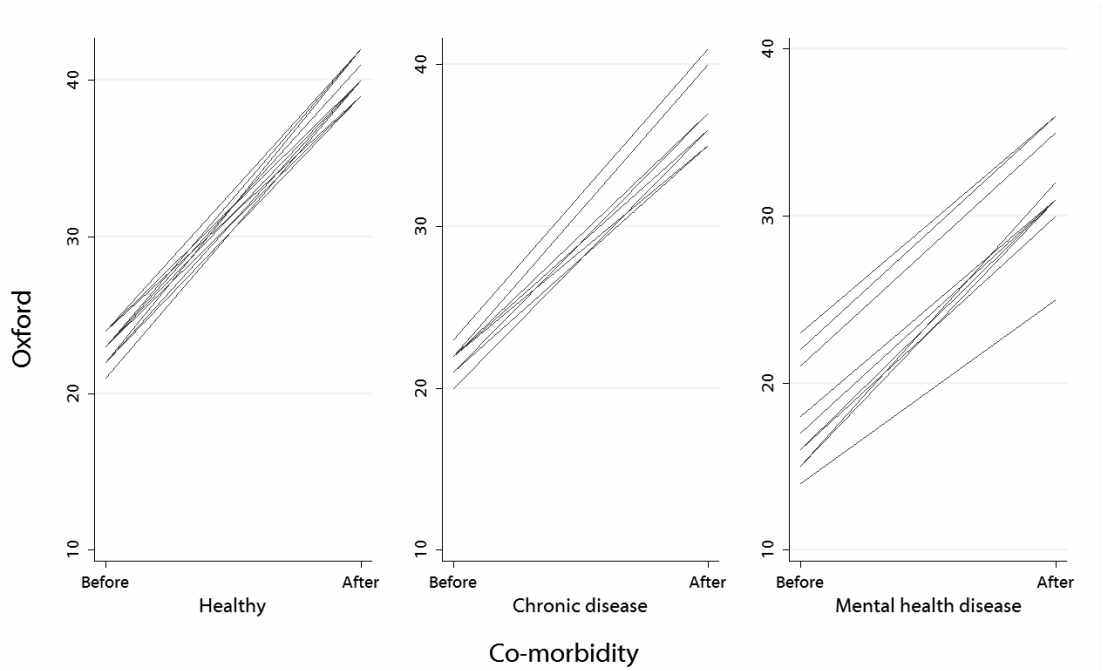

Fig. 3. *Results comparing pre-operative and post-operative Oxford Knee Scores in each of 3 groups of patients.*

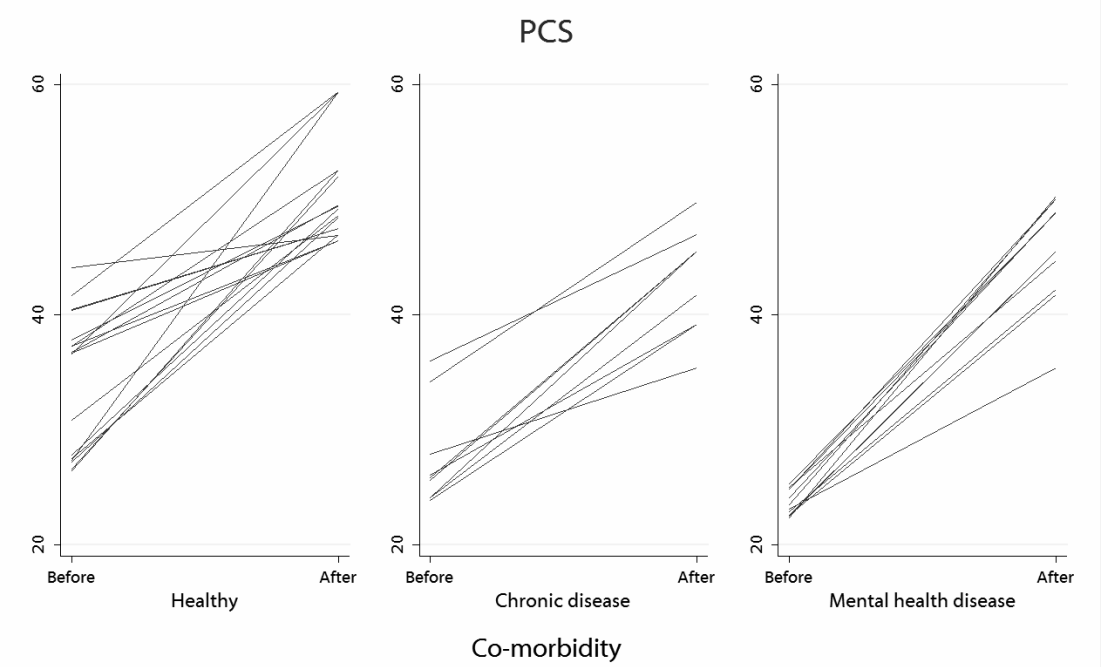

Fig. 4. *Results comparing pre-operative and post-operative Physical Component Score (PCS) component of the SF-36 in each of 3 groups of patients.*

One patient continued to complain of pain of equal severity to that experienced prior to surgery and required further management from the pain control clinic. One patient received a manipulation under anaesthesia at 9 months following surgery, as her range of movement was restricted from 10 to 30 degrees of flexion. It subsequently improved to 5 to 95 degrees of flexion recorded 9 months following

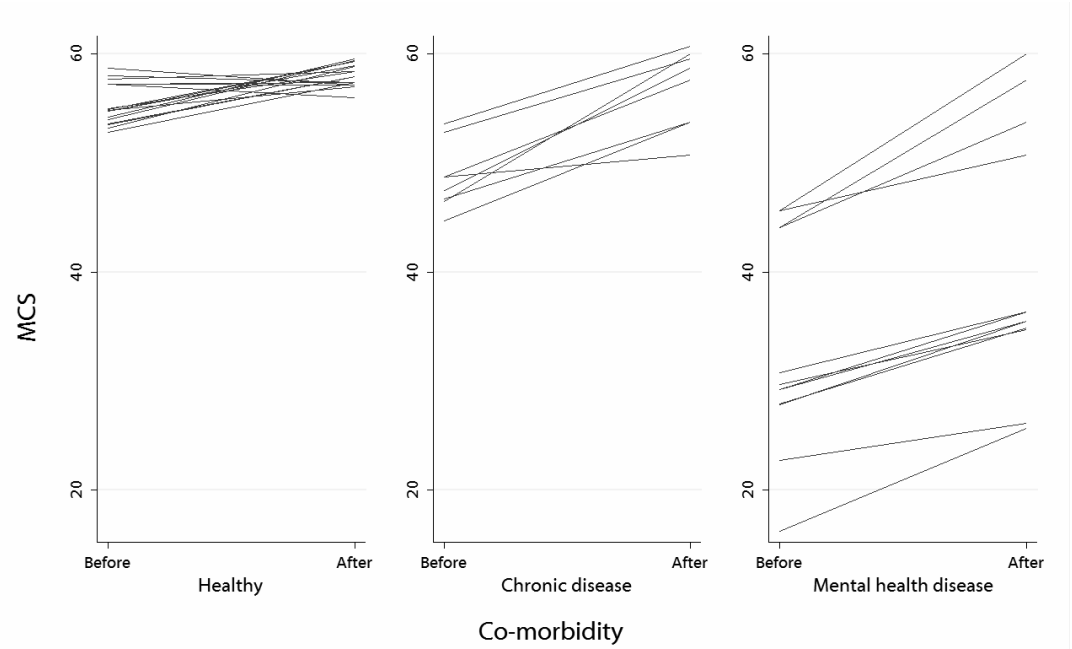

Fig. 5. *Results comparing pre-operative and post-operative Mental Component Score component of the SF-36 scores in each of 3 groups of patients.*

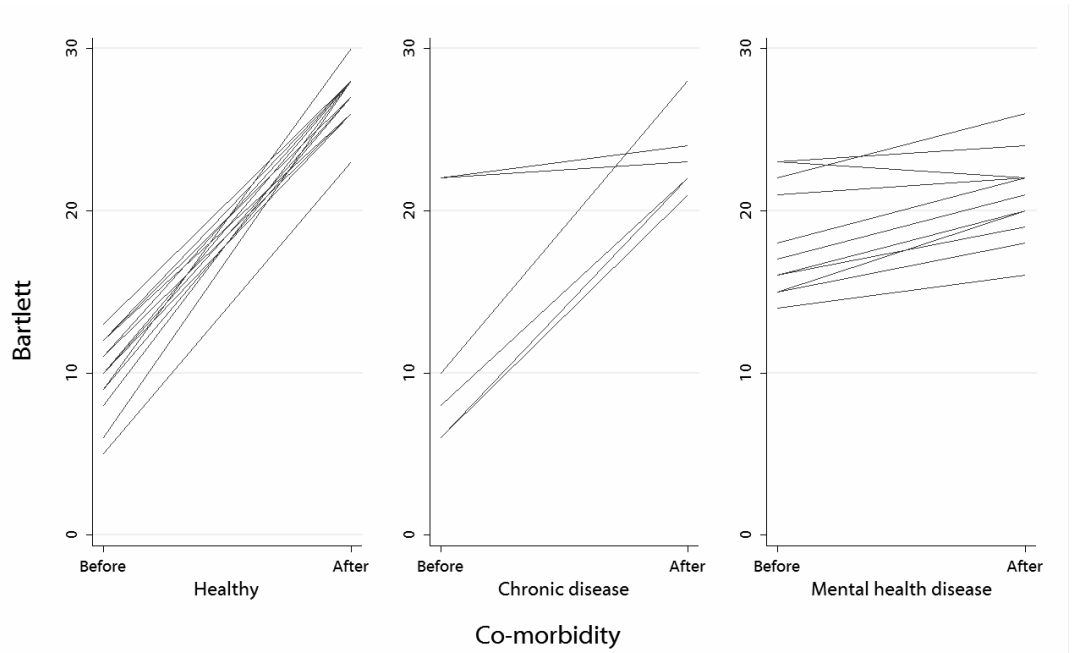

Fig. 6. *Results comparing pre-operative and post-operative Bartlett Patellofemoral scores in each of 3 groups of patients.*

manipulation. No cases of deep infection, component wear or loosening, or patellar fracture are noted.

Complications

2 superficial wound infections were diagnosed and successfully treated with oral antibiotics. One below knee deep venous thrombosis was diagnosed by Doppler ultrasound and managed according to local protocol. One patient received a manipulation under anaesthesia at 9 months following surgery, as

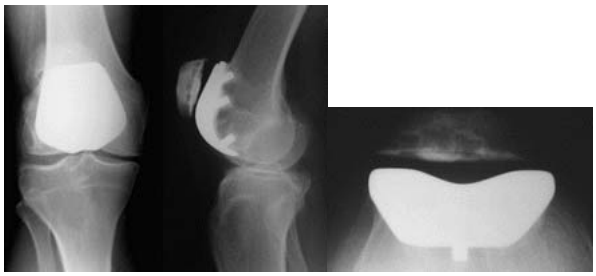

Fig. 7. *5 year post-operative anteroposterior, lateral and tangential radiographs in same patient as Fig. 2 with excellent clinical outcome.*

her range of movement was restricted from 10 to 30 degrees of flexion. It subsequently improved to 5 to 95 degrees of flexion recorded 9 months following manipulation. No cases of deep infection, component wear or loosening, or patellar fracture were noted.

DISCUSSION

Patellofemoral arthroplasty for patellofemoral osteoarthritis is a controversial subject. Patellectomy (31) is associated with poor long term results and is reported to fail in up to 47% of patients. Pain relief is variable and significant loss of extensor power, instability and extensor lag often result. The Avon patellofemoral prosthesis, available since 1996, produces significantly better results compared with previous patellofemoral implants and patellectomy. Its design is based on the patellofemoral component of the Kinemax total knee replacement, for which long term data is available (32-33). Current indications for patellofemoral arthroplasty include isolated patellofemoral osteoarthritis with minimal or no malalignment, advanced chondral or arthritic changes.

Seventy percent of our patients experienced post-operative discomfort located on the lateral aspect of the knee. It is apparent that placement of the implant in external rotation is necessary to avoid a prominence of the lateral trochlear ridge and may have lead to lateral retinacular impingement. Disease progression was noted in 4 patients, isolated to the medial tibio-femoral joint in 3 of these. Co-morbidity, as in other studies (34), influenced our outcome measures, and these accounted for 50% of our study group. The most important longer term issue is disease progression. Clinical and radiological evidence (35) may not be sufficiently accurate to exclude tibio-femoral disease, indicating patellofemoral replacement rather than TKR, although intra-operative inspection allows for the opportunity to convert to TKR. Only 6 patients in our series included arthroscopy as part of their pre-operative work-up. We now perform this as part of the pre-operative work up and recommend this practice. 4 patients in 26 (15%) cases recruited for patellofemoral joint replacement since this study were found to have tibio-femoral disease not evident on pre-operative radiographs.

The Avon knee is a valuable surgical option in a motivated patient with isolated patellofemoral disease, with similar advantages to those proposed by surgeons advocating unicompartmental replacement of the medial or lateral tibio-femoral joint. Overall our patients performed well (Fig. 7), with 90% of patients describing their outcome as good or excellent, but less successful than the Bristol series, indicating that further review, in particular regarding patient selection, is needed before this procedure is routinely performed.

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AO TYPE C3 DISTAL RADIUS FRACTURES: OPEN REDUCTION AND INTERNAL FIXATION WITH VOLAR LOCKING PLATES

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Comminuted intra-articular fractures of the distal radius (AO type 23-C3) are difficult injuries which require surgical treatment. The purpose of this prospective study was to determine the clinical and radiographic outcome in a series of 34 cases. They were treated with a volar Henry's approach and a 2.4 mm distal radius locking plate (Synthes). Wrist mobilization was started at 2 weeks. The patients were reviewed with an average follow-up of 21 months (range: 13-35). We recorded residual pain, range of motion, grip strength and activity level. The DASH questionnaire and the Green and O'Brien scoring system were administered. Radiographic measurements included articular steps and gaps, volar tilt, radial inclination and degenerative changes. Average pain at follow-up (range 0-10 points) was 0.9 points at rest and 1.7 during activities. The average DASH score was 13.4 points. Thirtyone (91%) patients resumed the preinjury occupation and one had to change his job because of the fracture. Range of motion of the injured wrist averaged 93% of the normal side and grip strength was 88%. There were 16 (47%) excellent, 11 (32%) good and 7 (21%) fair results. Nine (26%) reductions were considered unsatisfactory because of residual dorsal tilt (7 cases, 21%), radial inclination <15° (1 case, 3%) and articular step >2 mm (2 cases, 6%). Moderate to severe post traumatic arthritis was found in 6 (18%) cases. Flexor tendonitis was found in 5 (15%) cases and required implant removal in 2. In conclusion, type C3 fractures of the distal radius are challenging injuries. Most of these were successfully reduced with the single volar approach. A volar locked plate was effective to stabilize fracture fragments and allow early motion which prevented post operative stiffness. Overall 79% of the cases were satisfactory.

Displaced intra-articular fractures of the distal radius are severe injuries. Frequently they cannnot be reduced, are unstable or require surgical treatment. Open reduction and internal fixation (ORIF) is a widely used approach. Direct visualization of the fracture fragments allows anatomical reduction and stable fixation. The aim of treatment is to restore the anatomy and to achieve a stable fixation in order to allow mobilization of the involved and neighbouring joints. Early mobilization limits stiffness and allows a faster return to activities of daily living (ADL) (1-8)

Non-locking plates have been successfully used in a buttress mode for the treatment of volar displaced fractures. However non-locking plates have never achieved wide acceptance for dorsally displaced fractures because of insufficient stability in an often osteoporotic or comminuted bone. The introduction of locking plates designed specifically for the distal radius has improved the success rate of

Key words: distal, radius, fractures, locked, plate, intra-articular, volar

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ORIF in these fractures (9-15).

Locking plates behave like an internal fixator. The plate does not need to be compressed against the bone by the screws to achieve stability. This offers several advantages (16). Adequate stability can be achieved even in osteopenic bone. Incomplete contouring of the plate does not lead to loss of initial reduction when the screws are tightened. Secondary loss of fracture reduction under functional loads is avoided. Bone vascularization under the plate is less affected since compression between plate and bone is reduced.

Dorsal, volar and radial approaches have been proposed to perform an ORIF of the distal radius (3,17). The dorsal approach has been linked to extensor tendon irritation, attrition and rupture (7, 18-21). The modified Henry's volar approach over the flexor carpi radialis (FCR) tendon has gained widespread acceptance because it is technically simple and allows treatment of both dorsally and volarly displaced fractures (10-11).

The purpose of this prospective study was to evaluate the clinical and radiographic results of a series of distal radius fractures consecutively treated using a volar approach with a locking plate. Only the most demanding comminuted intra-articular fractures (AO type C3) were included.

MATERIALS AND METHODS

We prospectively studied 34 complete intra-articular fractures of the distal radius (34 patients). The study group included 22 (65%) males and 12 (35%) females. The study was approved by the local ethics committee. Accordingly all patients gave informed consent prior to being included in the study. The study was performed in accordance with the Declaration of Helsinki. The average age was 46 years (range 18-79). The dominant hand was involved in 19 (56%) cases. Twentyfive (74%) cases were caused by a high energy trauma including motor vehicle accidents (20 cases), falls from a height (4 cases) and sport injury (1 case). Nine (26%) fractures were low energy osteoporothic fractures due to a fall from standing height. All fractures were closed and involved patients with closed physes.The average interval between injury and surgery was 5.4 days (range 0-17).

All the fractures were complete intra-articular fractures with comminution of the articular surface (23-C3 according to the AO classification) (22). The articular fracture was considered comminuted with 3 or more articular fragments. Patients with carpal instability, associated fractures or injuries of the upper limb and polytrauma patients were excluded.

The fractures were consecutively treated with ORIF by two senior surgeons. All fractures admitted to our department in the period 2002-2005 that satisfied the inclusion criteria were included in the study. All the patients had brachial plexus anaesthesia and antibiotic prophylaxis. An arm tourniquet was routinely used.

All the procedures were performed using a modified Henry's volar approach. The FCR tendon was retracted ulnarly to protect the palmar branch of the median nerve. Reduction and plating were done with fluoroscopic assistance. Fracture fragments were reduced using manual traction and direct manipulation. Preliminary fixation was achieved with 1.25 mm Kirschner (K) wires introduced through the styloid aiming proximally and/or parallel to the articular surface.

We used a 2.4 mm titanium distal radius palmar plate (Synthes, Oberdorf, Switzerland). The plate is low-profile and precontoured for volar application with right and left implants. The inclination of the distal locking screws is 5° proximal to reduce the risk of joint perforation. Subchondral positioning of these screws is recommended to achieve a better articular support (Fig. 1). Screw insertion is begun on the ulnar side to avoid intrarticular penetration. At the end of the procedure an effort was made to reattach the pronator quadratus to separate the plate from the flexor tendons. We did not use bone graft or bone substitutes in this series.

Although the locked-plate offers immediate stability, a short palmar splint in light extension was applied for two weeks to protect the surgical incision until suture removal. Full range of motion (ROM) of the fingers and forearm was encouraged from the day of surgery. Sutures were removed at two weeks and wrist motion was encouraged. Resistance exercises were not allowed before fracture healing.

Postoperatively patients were reviewed clinically and radiographically at 6 and 12 weeks by an independent observer.

At follow-up subjective and objective outcomes were recorded. Wrist pain during activities and at rest and subjective satisfaction were quantified with a 0-10 visual analog scale (VAS). The Disabilities of the Arm, Shoulder and Hand questionnaire (DASH) (23) was used. The patients were interviewed about time to return to work, changing or giving-up their pre-injury occupation. The subjective level of activity at follow-up was compared to the preoperative level.

The wrists were observed for any residual deformity. Wrist range of motion was measured with a goniometer. Pronation and supination was measured aligning the

goniometer with a pencil held by the patient. The functional ROM of the fingers was considered full when patients were able to touch the distal palmar crease with the tip of their fingers and to extend completely the fingers. Grip strength was measured with a Jamar dynamometer (Therapeutic Equipment, Clifton, NJ, USA).

The clinician based outcome was recorded according to a modified Green and O'Brien clinical scoring system (2). The ROM evaluation was based on dorsiflexion-palmarflexion of the injured hand.

Radiographic evaluation at follow-up included postero-anterior and lateral facet views. Articular steps were classified according to Knirk and Jupiter (24). A reduction was considered satisfactory with steps and gaps up to 2 mm, a volar tilt 0°-20° and a radial inclination over 15°. Arthritic changes were classified in four grades (24).

Statistical evaluation was performed using the Fisher exact test and the minimum level of significance was set at p=0.05.

RESULTS

All the patients were reviewed clinically and radiographically with an average follow-up of 21 months (range 15-35). No patient was lost at follow up. There were no intra- or post-operative complications including intra-articular hardware placement, neurovascular injuries, infections, reflex sympathetic dystrophy or hardware failure. There was no need for subsequent carpal tunnel release.

Wrist pain at rest was 0.9 on average (range 0-4.5) and 1.7 during activities (range 0-8.5). Four (12%) patients scored 3 or more points. The DASH score averaged 13.4 points (range 0-88.3) and 5 (15%) patients had a score over 30 points. The unsatisfactory results scored significantly lower compared to the satisfactory ones in questions regarding sport activity in 2 cases, sport activity and ADL in 1 case and sport activity, ADL and pain in 2 cases.

Pre-injury activities included 12 (35%) white collar workers, 6 (18%) heavy manual workers, 11 (32%) light manual workers, 2 (6%) retired persons and 3 (9%) students. Thirty one (91%) patients were able to return to their pre-injury occupation within an average of 2 months (range 1-6). Three (9%) patients changed their job, one due to the wrist fracture. The subjective level of activity at follow-up was 89% of the pre-injury level.

Wrist extension averaged 69° (range 50°-80°) in the normal side and 65° (range 40-80°) in the injured side (94%). Wrist flexion averaged 72° (range 50-90°) in the normal side and 63° in the injured side (range 40°-90°) (87%). Average ulnar deviation was 35° (range 20°-50°) in the normal side and 32° (range 20°-45°) in the injured side (91%). Radial deviation averaged 28° (range 10°-45°) in the normal side and 24° (range 10°-40°) in the injured side (89%). Pronation averaged 90° (range 85°-95°) in the normal side and 89°(range 80°-95°) in the injured side (99%). Supination averaged 90° (range 80°-95°) in the normal side and 89° (range 75°-95°) in the injured side (99 %). Overall the range of motion of the injured wrist was 93% of the normal

Table I *Clinical results according to the Green and O'Brien scoring system (2)*

Result	#	Pain	Functional status	Range of motion	Grip strength
Excellent	16	25	24.7	25.0	18.4
Good	11	24.5	23.6	23.2	12.7
Fair	7	22.1	22.1	14.3	13.6
P value		0.038	0.089	0.002	0.051

The P value refers to the difference between satisfactory (excellent + good) and unsatisfactory (fair) results

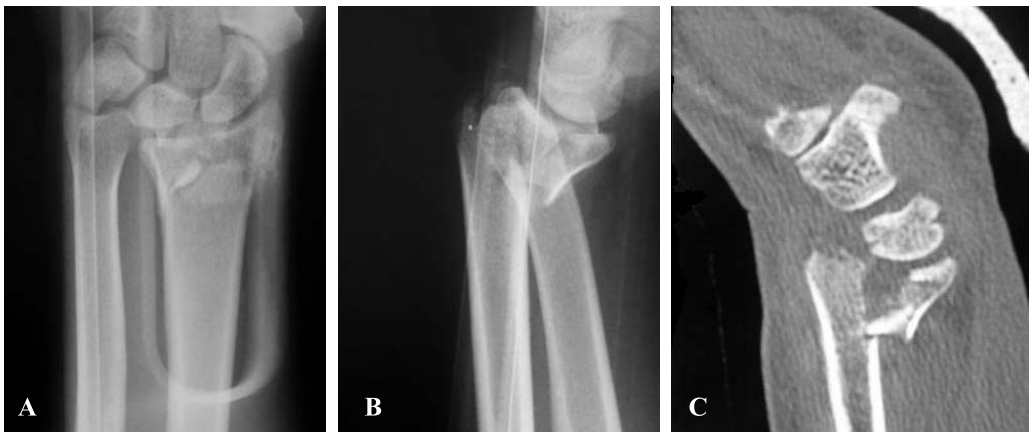

Fig.1 A, B and C *Antero-posterior, lateral radiograph and CT scan of a distal radius fracture in a 34 year old male.*

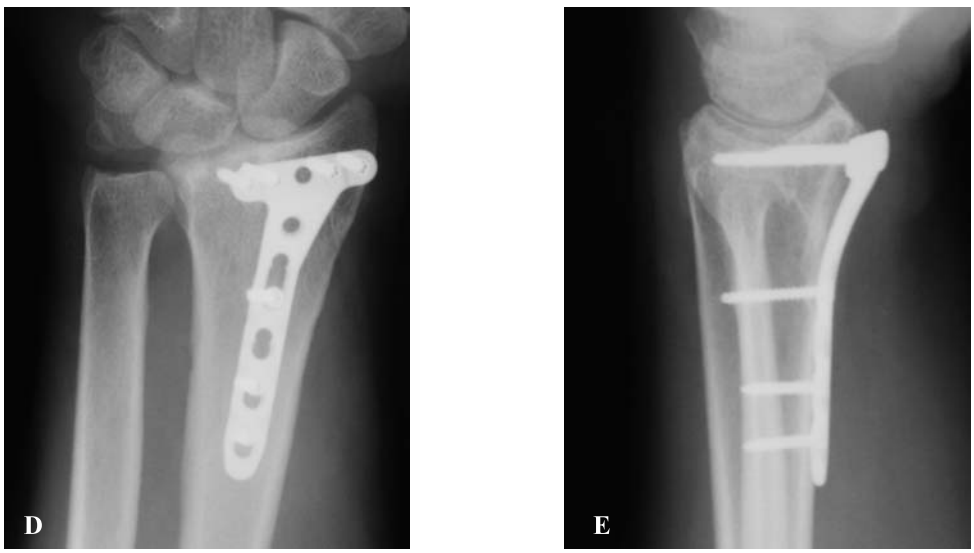

Fig. 1 D and E *Radiographs at two-year follow-up.*

side. In 3 (9%) patients a loss of circumduction was observed. Mild tenderness in the distal radio-ulnar joint was present in 2 (6%) cases.

All the patients had a full functional ROM of the fingers. A prominent ulnar stiloid were observed in 3 (9%) cases. Grip strength averaged 35.7 Kg (range 15-64) in the normal side and 31.3 Kg (range 10-60) in the injured side (88 %).

The results according to the Green and O'Brien clinical scoring system (2) showed 16 (47%) excellent, 11(32%) good and 7(21%) fair results. The average score for pain, functional status, range of motion and grip strength are presented in Table I. The seven unsatisfactory (fair) results were significantly lower compared to the satisfactory group (excellent and good) in grip strength in 2 patients, in ROM in 3 cases, in grip strength and ROM in 1 case and in grip, ROM and pain in 1 case.

All the fractures were healed at the 3 month-radiogram. At follow-up radial inclination averaged 22° (range 14°-30°) and palmar tilt averaged 2° volar (range -11°,+14°). Seven (21%) cases showed a dorsal tilt. Comparison between postoperative and follow-up radiograms revealed no changes in radial

inclination and palmar tilt.

The articular step in postoperative radiographs was grade 0 (0-1 mm) in 27 (79%) patients, grade 1 (1-2 mm) in 5 (15%) patients, grade 2 (2-3 mm) in 1 (3%) patient and grade 3 (>3 mm) in 1 (3%). The articular gaps in the postoperative radiographs were grade 0 (0-1 mm) in 32 (94%) cases, grade 2 (2-3 mm) in 1 (3%) patient and grade 3 (>3 mm) in 1 (3%) patient.

The reduction was considered unsatisfactory because of a dorsal tilt in 7 (21%) cases, because of a decreased radial inclination <15° in 1 (3%) and because of an articular step higher than 2 mm in 2 (6%) cases. Overall there were 9 (26%) wrists with an unsatisfactory reduction. There was no statistical correlation between reduction, the Green and O'Brien score or the development of arthritis.

Arthritic changes were absent in 12 (35%) patients, grade 1 (joint space narrowing) in 16 (47%), grade 2 (marked joint space narrowing and osteophytes) in 3(9%) cases and grade 3 (joint space obliteration) in 3 (9%) patients. There was no correlation between arthritis and the Green and O'Brien score.

Five (15%) patients had flexor tendonitis. Three (9%) patients were treated conservatively with success while 2 (6%) required implant removal with the resolution of symptoms. There were no further operations performed or scheduled during the follow-up period.

DISCUSSION:

This prospective study reports the results of a homogeneous series of 34 comminuted intra-articular fractures of the distal radius treated with the volar approach using a single volar locking plate. Other studies (10-12, 14-15) have reported good results with volar plating using locking implants and the volar approach.

Orbay and Fernandez (11) reported on 31 dorsally unstable distal radius fractures with a follow-up of 13 months. A precontoured implant was applied using a volar approach. The average flexion-extension arc was 112° and the average pronation-supination arc was 158°. One patient complained of irritation of the dorsal tendons due to the excessive length of a screw.

Constantine et al. (25) reported the results of a series of 20 dorsally displaced distal radius fractures. Eighty per cent were intra-articular. With a 12-month follow-up the Authors observed no loss of reduction, a 123° flexion-extension arc, a 156° pronation-supination arc and few complications.

Musgrave and Idler (10) studied a series of 32 distal radius fractures with dorsal displacement. Two-thirds were intra-articular. In 23 cases a single volar 2.4 mm LCP distal radius plate was used while in 9 cases a radial styloid plate was added. At a 13-month follow-up the flexion-extension and pronation-supination arcs averaged 112° and 151° respectively. There was no significant loss of fixation. The average dorsal tilt at follow-up was 0°.

Murakami et al (14) retrospectively followed 24 fractures of distal radius. Half of these were type C3. Three different implants with locking screws were used. With a mean follow-up of 9 months the average flexion-extension and pronation-supination arcs were 116° and 174° respectively without any evidence of reduction loss. The mean volar tilt was 8.1°.

Rein et al (26) retrospectively studied 29 type C3 fractures treated by volar (15 cases) or dorsal (14 cases) plating. Three different implants were used, including locking and non-locking plates. They found more complications after dorsal plating but no difference in functional parameters.

Our investigation included only the most severe C3 injuries. They were stabilized with a single volar locking plate. Using the Green and O'Brien scoring system (2) we obtained 27 (79%) excellent and good results.

The introduction of fixed-angle plate and screw systems has allowed the successful stabilization of distal radius fractures, so that early ROM can be achieved. Using this implant we had no hardware failures or reduction loss even in osteoporotic bone. Care should be taken to place the distal screws in a subchondral position to maximize the supporting effect. The implant can be successfully used to stabilize some small marginal volar fragments from the lunate facet that are important for radio-carpal stability. Care should be taken to bend the plate over the radial styloid using the threaded drill guides in order to avoid irritation of the FCR tendon. If the implant is correctly positioned, tendinitis is rarely observed.

Regarding reduction of the fracture the most common mistake is a mild residual dorsal tilt. This is a possible consequence of the volar approach. We suggest that the quality of the reduction should be carefully assessed in both the anteroposterior and lateral view. Preliminary fixation with K wires does not ensure perfect stability and traction should be maintained until at least two screws have been inserted in the epiphysis. If a satisfactory reduction is not obtained consideration should be given to add a dorsal approach and possibly a dorsal plate.

Moderate to severe degenerative changes of the radiocarpal joint were present in 6 (18%) cases. Although there was no statistical correlation between clinical outcome and the development of arthritis , we believe a longer follow-up is needed to assess this aspect.

A bone graft was not used in this series of fresh fractures. All the fractures healed within 3 months. The respect of the vascularity of the articular fragments and the stable fixation made it unnecessary.

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STAGED LENGTHENING IN ACHONDROPLASTIC DWARFS. 27 YEARS OF CLINICAL AND SURGICAL EXPERIENCE

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Achondroplasia is a genetic disorder characterized by disproportional short limbs with several lower and upper extremity deformities. The purpose of our therapy has always been to correct limb deformities, to lengthen limbs improving their function and to contribute in forming a body with correct proportions between body and lower limbs. In this paper we will come to a definite conclusion about our original protocol of the so-called "staged lengthening" that we started at the beginning of 1982 and that now includes over 100 achondroplastic children. After more than 27 years we have decided to control the clinical results, to evaluate the increase of the lower and upper limbs function and to make a final consideration about the satisfaction of these patients, after such a long period of operations, physiotherapy and pain. After having controlled all complications after the operation of so many patients we have reached the conclusion that the method is well tolerated, it offers the chance to achieve a satisfactory correction of deformities, improves the limbs and body function and gives psychological support to these children. We conclude that "staged lengthening" of limbs is a valid surgical procedure for achondroplastic children, improving function and quality of life.

Achondroplasia (ACH) is a kind of autosomal dominant genetic disorder that is one of the most common causes of dwarfism. The incidence of ACH is reported to be as high as 1 per 25000 live births (1-3). Originally described by Parrot (4), achondroplasia is typically characterized by short lower extremities, macrocephaly and hyperlordosis. However, the most striking feature is the rhizomelic shortening of the limbs, with genu varum, overlong fibulas and internal tibia torsion (Fig. 1) (5-6). Achondroplastic dwarfs have short stature with disproportional short limbs. The average height of an adult with achondroplasia is 131 cm in males and 124 cm in females.

ACH has been associated with mutations in the FGFR-3 (Fibroblast Growth Factor Receptor-3) gene that maps to chromosome 4p16.3 (7-8). Sporadic mutations amount to 80%, and 20% of children inherited achondroplasia as an autosomal dominant trait. The FGFR-3 mutations are fully penetrant meaning that all infants with the mutation express ACH. However, some variations in expression of the gene can be present (9). Most infants suffering from ACH are born from parents without FGFR mutation; additionally, some authors described a strong correlation with increasing paternal age (over

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35 years) (10). Studies (11-13) emphasized the role of spermatogenesis and a selective advantage of sperm bearing mutant gene over sperm bearing normal gene. FGFR3 encodes a membrane receptor that is involved in the development and maintenance of bone and brain tissue. The receptor has an intracellular domain that contains a split tyrosine kinase subdomain. Researchers (14-23) believe that two mutations can occur to the receptor and as a consequence a gain of function of the receptor itself can be developed.

The clinical features of ACH and its clinical complications can be summarized as follows: long and narrow trunk with short limbs (24); large head with frontal bossing (25) but hypoplastic midface; hyperextensibility of some joints (especially knees and hands, but restricted extension and rotation of the elbows); thoracolumbar gibbus with a typical "C-sitting" position due to hypotonia and disproportion between trunk and head (26-27); spinal stenosis with cervicomedullary compression, dental malocclusion (usually class III malocclusion due to disproportionate growth of the cranial base); ventricular shunting with hydrocephalus (28). Several complications are described in children and young adults due to these abnormalities (29-39). Genu varum afflicts about 10% of patients younger than 5 years and about 40% of adult patients (28).

The aim of the surgical therapy is to correct deformities and to ameliorate the function of the limbs. Therefore the bow knee and the axial deformities must be corrected to avoid the early development of osteoarthritis (40). At present, there is no actual treatment for achondroplasia besides surgery. Although some authors studied the effects of human growth hormone (42) in the treatment of short stature, in ACH patients the hormonal therapy cannot be taken because no long-term effects are described. We have always claimed that the surgical lengthening of the limbs should correct deformities at the same time, improve function and result in a regular proportion between lower extremity and trunk (41).

Although the majority of orthopedic surgeons start to lengthen limbs in the adults, since 1982 we have been proposing to start the treatment in young children, at 5-6 years of age and we have proposed the so-called "fractionated (or staged) limb lengthening". For this purpose, we have used several surgical techniques (42-45), achieving satisfactory results. In this paper we describe 27 years of experience in lower limb lengthening, applying our operative protocol and our post-operative care.

METHODS

Protocol Description

Since 1982 we have been performing extremity lengthening using external fixators or intra-medullary devices. Our surgical protocol has undergone only a few changes in the past 27 years. In 1982 it was as follow: four steps lengthening 1/3, or slightly more, of the initial length of the bone segment; first surgical approach on the tibias when the child was 5-6 years old (about 5 cm of lengthening); second surgical approach on femurs when the child was 6-7 years old (about 6 cm of lengthening); third surgical approach on the tibias when the patient was 11-12 years old (about 8-10 cm of lengthening); fourth surgical approach when patient was 12-14 years old (about 9-12 cm of lengthening).

In 1992 we decided to modify our protocol, adding some pre-operative and post-operative health care, such as the assistance of a pediatrician and a psychologist (see below); additionally, we decided to start the lengthening when the patient was 6 years old. In fact, earlier treatment presented in our opinion two disadvantages due to the short length of the limbs: first, the limitation of the possible attainable surgical lengthening in this first step, as only 1/3, or slightly more, of the original length was planned for each step; second, the technical difficulties in placing the fixator in such a short lower limb and, therefore, the increased surgical risks. In 1999 we introduced a fifth surgical approach on the upper arm, following the request of achondroplastic patients to improve the function of their upper extremities: they were too short to reach the perineum for self-care and to perform some manual work, drive cars or play sports. We were able to lengthen the upper arm even more than 1/3 of the initial length (usually, from 8 to 12 cm); lengthening of the upper arm is scheduled when the child is 16 years old and only if the patient needs it. There are no differences in gender in scheduling the time of surgery. Using this protocol we are able to obtain an overall lower extremity lengthening of

about 28 to 36 cm with few permanent complications (Table I).

In accordance with several other authors (46, 48-51), we lengthen 1 mm per day starting between the second and the fourth day after surgery, depending on the age of the patient. When neurological, joint or muscle complications arise from the lengthening, we divide the same rate into 2-4 steps per day.

Currently, before starting surgery we believe it is important:

- for the patient to undergo a careful clinical evaluation by a pediatrician, an orthopedic specialist and psychologist to evaluate the child's and family's motivations and the presence of any other genetic pathology;
- for us to determine an estimate of final growth using modified tables for achondroplastic patients (Fig. 2);
- to inform the child and the family about the advantages and complications that they may encounter during the surgical and post-surgical periods;
- that a physiotherapist make a careful clinical and functional evaluation; the physical therapy should start immediately, before surgery and it is programmed for the different periods: pre-operative, immediately post-surgical, post-surgical, consolidation period and, finally, after the removal of the apparatus;
- to perform a careful imaging study, using weight bearing radiographs (anterior-posterior X-Ray and lateral-lateral X-Ray) and, if necessary, CT-scan.

Surgical Techniques

Our surgical approach is based on the work by Wagner, De Bastiani and Ilizarov which in the 1980's changed the opinions about limb lengthening and distraction osteogenesis (52-55). We practice three surgical techniques depending on the segment treated and its original dimensions. All these techniques require symmetrical lengthening (i.e. both tibias or femurs or humeri).

We use the Ilizarov external fixator to lengthen tibias, usually consisting of two circular frames connected to the lower limbs with intertwined Kirschner wires (two for each frame) and with one bone pin for each frame, if necessary. We usually use wires of 1.6 mm in young children and 1.8 in older patients, applying a slow drill speed and constant pressure while the wires are inserted. The first step of the operation consists in performing a complete fibula corticotomy distally and to fix the distal tibiofibular joint with a Kirschner wire; then, we apply the circular external fixator after having performed an incomplete tibia corticotomy. We then complete the tibia corticotomy after having fixed the device to the bone with wires proximally and then distally, as necessary. The periosteum is repaired when possible. To assure that complete bone division is made, a gap is detected with a fine probe or observed radiologically.

The axial external fixator used for femurs and humeri lengthening is applied to the patient by using two or three bi-cortical pins for each clamp. Corticotomy is performed at the metadiaphyseal region of the bone. The periosteum is then repaired and after skin closure, some knee or elbow flexions are made in order to stretch muscles and fascia. The amount of daily lengthening is 1 mm per day and it can be reduced to 0.5 mm per day when important soft tissue complications or joint stiffness arise during the distraction phase.

We have only once applied intramedullary nailing to femur lengthening in achondroplasia, because its application is possible only when important axial deviations are absent.

Study group and post-operative care

Our study group consists of 116 achondroplastic patients (65 males, 51 females) who underwent surgical lower limb lengthening between 1982 and 2008 (follow up: 1 to 25 years). We performed 688 limb lengthening during this period (Table II, 36 of which were humeri).

35 patients underwent only tibia and femur lengthening; 22 patients have completed the entire surgical protocol for lower limbs, performing tibia and femur lengthening two times and 16 completed the lower and upper limb lengthening (Fig. 3, 4 and 5).

At first day after surgery, all patients started bed exercises. Patients were encouraged to stand and perform wheelchair transfers early to regain independence and confidence. Responsibility for pin site care was carried out by the doctor for the first 10 days and then by the patient and/or the family

(after appropriate explanations and supervision). Distraction was always started between the second and the fifth day after surgery. Doctors performed the distraction at first, and then, after proper teaching, the patient was usually able to do it by him/herself. A radiograph was taken immediately postoperatively and on the tenth postoperative day to assess the distraction. When the patient and his/her family acquired satisfactory pin care ability, good mobility and progress at physiotherapy, they were discharged from the hospital. Doctors, nurses, physiotherapists and families were further instructed on discharge. Patients were generally reviewed monthly. Each post-operative visit involved a clinical evaluation in order to assess pin sites, joint range of motion, muscle tightness, joint deformity, unexplained pain, neurovascular complications, axial deformities, and fixator maintenance. Moreover, an x-ray was taken in order to assess the callus formation, angular deviation, and bent or torn wires or screws. At the end of the lengthening phase, the fixator could be blocked or, instead, in case of poor callus formation, it could be made more elastic (dynamization). Callus formation should increase until the time of removal of the apparatus. Fixator removal usually occurred when at least three cortices can be seen in two orthogonal radiographs, usually after as long as double-triple the time of the duration of the distraction phase; it depends on age, type of fixator, and quality of new bone formation. After fixator removal, physiotherapy plays a crucial role in treating all contractures with the purpose of reaching a satisfactory and stable level in mobility and motility of all joints around the lengthened bone. Follow-up visits should be continued in order to schedule new surgical approaches on bones and/or on skin to treat deep scars (frequent especially in the thigh).

Fixator removal is performed with a light general anaesthesia in all cases. We usually remove hydroxyapatite pins under brief drug sedation in young patients. In our experience, it is advisable to sedate the patient only when the surgeon actually unscrews the pin.

Rehabilitation Program

Patients who undergo surgical limb lengthening require close follow-up and an intensive rehabilitation program in order to maintain functionally active limbs. We have identified three main rehabilitation periods: 1) before surgery, 2) after the surgical procedure (distraction and consolidation phases) and 3) after removal of the fixators.

Before surgery, care must be taken to increase joint mobility and reduce muscle contractures, by performing stretching and strengthening exercises. Iliopsoas, quadriceps, hamstring and gastrocnemius stretching should be encouraged to obtain a better joint and muscule condition before surgery.

Immediately post-surgery, patients are encouraged to perform isometric contractions even if still in bed. This will avoid vascular edema and will maintain a good muscle condition. Physical therapy starts within 2 days after surgery and should continue daily throughout the entire distraction phase. We suggest keeping the ankle at a 90 degree angle using an elastic band and to keep the knee in complete extension and not to place pillows under the knee and to prefer the prone position when resting in bed. Patients must be encouraged to bear weight on the lengthening limbs and to avoid the sitting position for long periods as it may produce a contracture of the iliopsoas and of other thigh muscles. The sitting position may also generate a hyperlordotic position of the lumbar spine. Our protocol includes one physical therapy session each day (45 minutes long) with a physical therapist; additionally, patients are encouraged to perform the exercises during the day, 10 minutes each session, with one-two hours of rest.

The aim of the therapy is to obtain knee flexion and maintain knee extension. These can be obtained with passive and active exercises. Knee flexion is usually limited due to the presence of the Ilizarov upper rings (in case of tibias lengthening) or to the stiffness of the tensor fasciae latae muscle (in case of femurs lengthening, pins used in femurs lengthening can block the iliotibial tract on the bone itself). Patients should always have a knee flexion of 60 degrees at least and a complete knee extension. Stretching and strengthening exercises are mostly focused on the hip abductors, hamstrings and the quadriceps. Particular care was taken during the physiotherapy program in order to reduce the pelvis obliquity, to enhance appearance and reduce social problems. Upper extremity strengthening should be considered to improve the use of walking aids

and to facilitate any kind of movement. During the distraction phase, joint mobility can be loosened, subluxation and other complications can occur. At the first sign of any of these complications, we usually modify the lengthening rate, in order to allow the soft tissues to adapt to the new anatomy of that specific body segment. In general, we can state that joint or muscle functions should never be sacrificed for length. In case of muscle contracture we discontinue lengthening, but instead we increase the time for physiotherapy exercises. If this is not sufficient, we may also decrease the rate of daily lengthening.

Care should be taken when a patient complains of pain or hypo/hyperesthesia in the dorsum of the foot or hypotonia of the tibial or peroneal muscles. In fact, this could be due to nerve stretching during the distraction phase. In this case, the distraction rate should be decreased and physical therapy should be increased.

The distraction and consolidation phases are followed by the removal of the fixators. After their removal, the patient should never stop the rehabilitation program. When the skin tracks heal and the bone formation is good enough to bear full body weight, patients can gradually return to full activity and they can also practice a sport like swimming, running, soccer, cycling. The patients should always continue physical therapy in order to maintain knee, ankle, and hip mobility. Knee flexion should gradually achieve 90 degrees at least and foot should not be plantar flexed because of a contracture of calf muscles or of a rigid ankle joint. Dynamic splinting of the foot in order to prevent equinus contracture must be recommended. Clinical and radiological evaluation should be performed every one-three months as control and in order to avoid malalignment of the extremities or loss of joint mobility.

RESULTS

We have been able to revise 352 operations out of the 688 performed, which means all patients who underwent complete lower limb lengthening and all patients who completed the entire lower and upper limb lengthening program; the patients not included are currently concluding their surgical and rehabilitation program. In particular, 19 patients performed only the first surgical step (tibia lengthening), 26 patients performed the first and the second surgical step (tibia and femur lengthening), 31 patients performed the third and 24 patients performed the third and the fourth surgical step, respectively. Only 16 patients completed the surgical program performing the upper arm lengthening (Table II). In all cases, we were able to lengthen the bone the planned amount which means about 1/3 of the initial length. In some selected cases, and more often during the second surgical operation on the same body segment, we were able to lengthen more than planned. In our case series, patients that have been lengthened more than estimated were checked in order to save a good joint mobility, muscle strength and flexibility, pelvis and lower limb posture, during the rehabilitation program performed before, during and after lengthening. Only three patients interrupted the lengthening protocol after the second operation and one after the third.

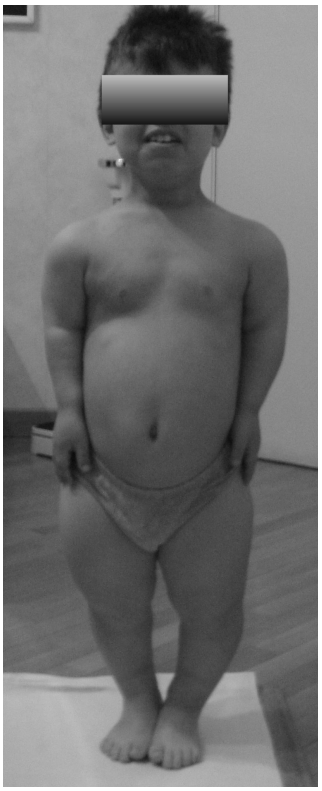

Fig. 1. *Common physical appearance of a child affected by achondroplasia*

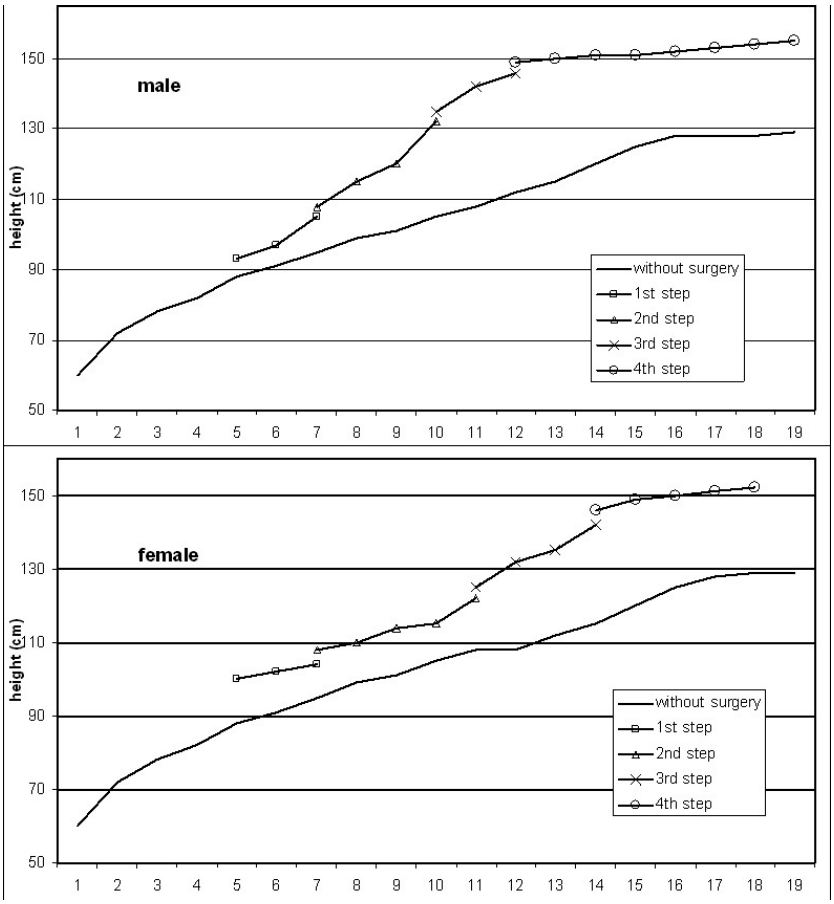

Fig. 2. *Modified growing tables for male and female achondroplastic patients*.

Regarding the extent of the consolidation phase, we observed the following average periods: in children 6-9 years old, the consolidation phase lasted 45-60 days; in children 11-14 years old, the consolidation phase lasted 75-90 days; in patients over 15 years old, the consolidation lasted 90-120 days.

Complications

All patients suffered intraoperative or postoperative complications, as shown in Table III and many of them had more than one complication on one side or on both limbs at the same time. On 352 reviewed operated limbs (176 operations), the number of complications was 430, most of which recovered during the lengthening process and without sequelae. The most important intraoperative complications were 2 vascular lesions and 3 neurological lesions (2 of them of the radial nerve in the same patient). Other intraoperative complications were 10 incomplete osteotomies and 4 incorrect applications of the device. In 6 cases the bone section was completed by the distraction; the other cases were corrected under anesthesia a few days after the operation. 12 Kirschner wires were torn at follow-up; this complication was solved by substituting the broken wires (6 were in the same patient). Generally, all patients suffered from superficial skin infections; in 250 operations they were of little importance and treated with local medications whereas in 50 they required general antibiotic therapy; only in 5 cases we removed pins or wires and in one case we changed their position. Delayed consolidation was registered in 12 cases, 4

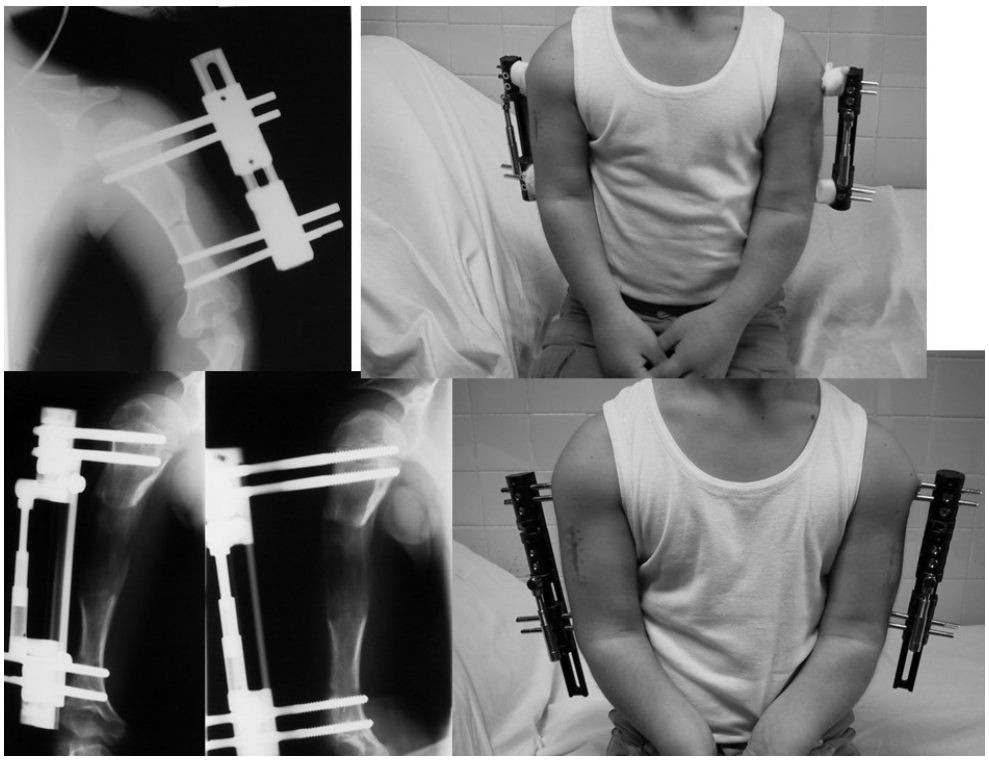

Fig. 3. *Case 1: bilateral humerus lengthening. Note the middle diaphyseal osteotomic level at the beginning and at the end of the lengthening program.*

of them required the fracture of the regenerated bone that was done under general anesthesia in order to stimulate new bone formation. We encountered 25 cases of muscle or tendon contracture that always resolved with physiotherapy, during or after the removal of the device; we never performed surgical lengthening of the Achilles tendon or the iliotibial tract and only twice we sectioned the tendons inserted on the anterior superior iliac spine, during the lengthening program. This was done in order to reduce the increase of the hyperlordosis that was often observed at different degrees during the second surgical lengthening of the femurs (fourth surgical lengthening step). Regarding the axial deformities, 12 were corrected during lengthening and 8 required a second operation. In those patients we registered also 45 cases of paresis of peripheral nerves that recovered spontaneously by diminishing the rate of lengthening.

Discussion

Many histological studies (46, 51) focus on muscle modifications during lengthening, including loss of myofibrils, Z line disorganization, endothelial cell dystrophy. Slower rates of daily distraction have been shown to minimize muscle and vascular damage. According to other authors (47), neurological complications during limb lengthening occur in about 20%. The lesions always involved the external sciatic peroneal nerve, especially during tibial lengthening. We observed that transient neurological palsy of peronal nerve is more common when performing the second tibia lengthening. Signs of neurological problems usually appear or become worse after the second surgical approach to the same segment, maybe because the nerve has lost its relative reserve of length and due to lengthening it undergoes progressive myelin changes. Diminishing the rate of lengthening per day is usually sufficient to decrease the amount of palsy or to resolve it. Moreover, we noticed that the lesions in the peripheral nerves are more frequent in cases of excessive distraction. We observed 45 cases of transient nerve palsy. The patients complained of

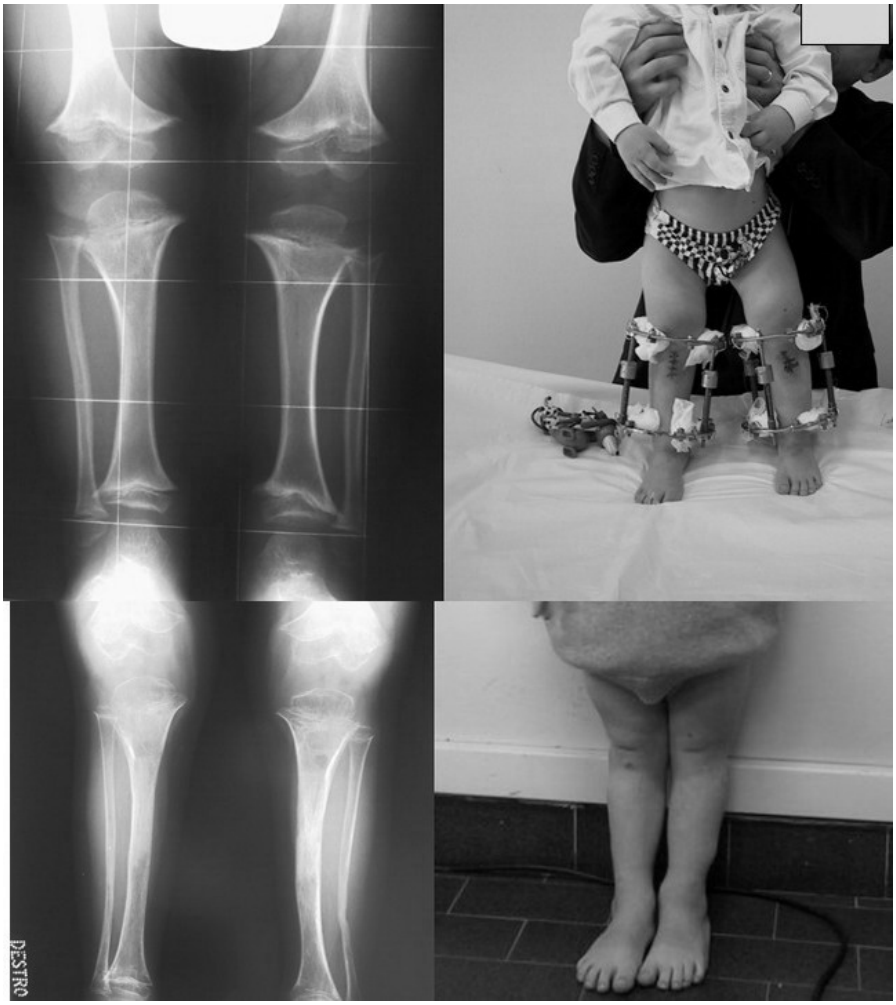

Fig. 4. *Case 2: bilateral legs lengthening*.

a gradual onset of dysaesthesia and impossibility to contract the extensor hallucis, the extensor digitorum or tibialis anterior muscle. In one case only we decided to remove the upper fibula Kirschner wire. Other patients needed to have their daily lengthening rate reduced, without stopping their lengthening program. Physiotherapy and EMG stimulation were suggested to all patients and no persistent palsy was reported. After fixator removal the transient palsy resolved gradually.

When considering humerus lengthening, we found 10% of transient radial palsy. We suggest reducing the rate of the daily lengthening; in fact, it was never necessary to overhaul the apparatus or to interrupt the lengthening. After removal of the fixator, no patient had signs of neurological suffering.

The surgical and post-surgical complications we have encountered during our experience are comparable to those described by other authors (1, 46-47). Twenty-five years after the beginning of this surgical program for ACH patients, we can try to draw some conclusions from our experience, achieving an even balance between the satisfaction of our patients and the objective modifications regarding function, correction of the deviations and, finally, the transformation of a disharmonic patient into a harmonic one.

Even if we do not report in this paper the psychological problems which our patients have suffered, we can claim that only two patients declared to be unsatisfied with the final results. This is why we can say we have reached our goal to make our patients more comfortable and feel less

Fig. 5. *16 year-old female: left panel: before limb lengthening. Middle panel: after lower limb lengthening. Right panel: after both upper (10 cm) and lower (36 cm) limb lengthening.*

Table I

Protocol description					
surgical approach	age (yrs)	segment	initial length of the segment (cm)	forecast lengthening (cm)	final length (cm)
first	5 to 6	tibiae	13-16	5 to 6	18 to 22
second	6 to 7	femuri	15-19	5 to 7	20 to 26
third	11 to 12	tibiae	22-27	7 to 10	29 to 37
fourth	12 to 14	femuri	25-29	8 to 12	33 to 41
fifth	16	humeri	12-20	8 to 12	20 to 32

Table II

Patients		
patients who underwent	number of patients	number of operations
one surgical lengthening	11	22
two surgical lengthenings	30	120
three surgical lengthenings	23	138
four surgical lengthenings	19	152
five surgical lengthenings (humeri)	16	160
TOTAL	99	592

Table III

Complications		
type of complications	number of cases	% of patients
vascular damage	2	0.09
Transient nerve palsy	45	20
nerve damage during wires insertion	1	0.45
incomplete osteotomy	8	3.63
wrong application of the fixator	3	1.36
kirschner wire breakage	6	2.73
shifting of the fastening rings	5	2.27
bars breakage	1	0.45
skin infection (grade I)	166	75.45
skin infection (grade II)	25	11.36
tendon and muscle retraction	25	11.36
subluxation of femur head (bilaterally)	1	0.45
increased lumbar lordosis	4	1.81
delayed consolidation	2	2.09
axial deformities	10	4.54
axial defomities which underwent surgical correction	4	1.81
Total of operations revised 592 (Operations that completed the protocol: 220)		

like dwarfs but just people with little differences compared to others. The method of the so-called "staged limb lengthening" has proved to be a winning possibility compared with other surgical methods: less complications, early growth, good correction of limb deformities, good proportion between trunk and lower limb length. The idea to start with the lengthening when the patient is 6-7 years old has given good results because the bone elongates easily and the regenerated bone ossifies more rapidly; in addition, psychological trauma is reduced.

We would like to point out that many aspects should be considered when performing limb lengthening: age and sex of the patients, estimation of the final height, initial segment length, initial axial deformities, estimation of the potential lengthening, elongation obtained, type of fixator used, time for consolidation, complications and problems encountered, type of rehabilitation programs, psychological aspects of the child and family.

We use different instruments which may be adapted to different skeletal parts and may be modified during the distraction phase, if necessary. However, we generally prefer to use external axial fixators for femurs and humeri and circular external fixators for tibias. We realize that the circular external fixators provide great stability, although they present some disadvantages, for instance that they take up greater space and can be obstructive for adjacent joints; moreover, they can be exposed to a relative higher risk of infection due to the presence of several wires and pins. Another disadvantage of the circular fixator is the difficulty in assembling

and adapting it to a short achondroplastic limb. On the other hand, the axial external fixator is less stable and more rigid, while the intramedullary nails are highly limited, because they can be used only in the presence of a straight bone and in patients at the end of the growing age. Finally, we believe that an external extendable fixator should be able to reduce technical difficulties and complications as it is able to adapt to small-sized bones, achieve high stability and adjustable dimensions and allow the correction of axial deformities even during the distraction phase as well as being a low cost system.

During lengthening we have encountered many problems and complications, but all of them have been solved during the distraction period. All local infections were resolved by local care or oral antibiotics; a great number of axial deviations were treated acting on the fixator and in only 4 patients a surgical approach was needed to correct the deformity. Muscle contractures were resolved with intensive physical therapy and we never performed tendon or fascia lengthening.

After 25 years, during which our experience has progressively grown, we can carefully plan and perform leg lengthening procedures combined with a multidisciplinary approach, in order to reduce complications and have good clinical results. However, limb lengthening remains high-risk surgery, even if complications are usually transient and resolve after removal of the fixator.

Considering the number of operations performed, we found that our data are more consistent than those of other authors (1, 56). As shown in Table III, our complications were not serious or life-threatening. Moreover, we have reduced them, over the years, by using a more meticulous and standardized method, that allows us to prevent complications and to propose a better treatment for achondroplastic children. In our previous reports (57-58), we analyzed 208 operations made on achondroplastic and hypochondroplastic short stature patients, even if preoperative and postoperative heights of patients were similar to those presented in this paper, we have modified our principles of the limb lengthening technique with the result of decreasing complications and reaching better final results in functional activities.

In spite of the described complications, good results represent the majority of the cases; we also believe that the good spirit and the positive disposition that we have generally encountered in the ACH dwarfs make them generally satisfied with the final result, even in cases where we believe that something could have been done better.

These considerations induce us to encourage the ACH patients to undertake the procedure of staged lower limb lengthening. Our experience demonstrates that good clinical, functional and aesthetic results can be obtained when a good collaboration is established between doctors, surgeons, nurses, physiotherapists, patients and their families.

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DISTAL FEMORAL REPLACEMENT COMPLICATED BY DEEP INFECTION BY *LEISHMANIA DONOVANI*.

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Deep infection, local recurrence of tumour, implant and mechanical failure are the major complications of tumour resection and limb sparing surgery with endoprostheses (1-2). Deep infection may require either revision surgery or amputation. Staphylococcus and streptococcus are the commonest implicated pathogens in the United Kingdom, however our increasing numbers of patients previously resident overseas, in this case an Indian migrant worker resident in Zimbabwe, is likely to correspond to an increase in atypical micro-organisms, especially in the immuno-compromised patient. We report the case of a 26 year old male with a distal femoral osteosarcoma treated with surgical resection and massive endoprosthesis complicated by deep infection by leishmaniasis. 8 weeks following surgery he deteriorated, becoming systemically unwell, developed pancytopaenia and organomegaly. Ultrasound guided biopsy demonstrated Leishman-Donovan bodies, pathonomonic for Leishmaniasis. Despite chemotherapy and antimicrobials our patient died of disease progression complicated by sepsis and multi-organ failure 7 months post-operatively. We conlude that immunosuppression secondary to malignancy and neo-adjuvant therapy may predispose to infection or reactivation with rare opportunistic infections such as Leishmaniasis. Early identification of infecting organism is essential in providing appropriate antimicrobial agents.

Deep infection, local recurrence of tumour, implant and mechanical failure are the major complications of tumour resection and limb sparing surgery with endoprostheses (1-2). Deep infection may require either revision surgery or amputation. Staphylococcus and streptococcus are the commonest implicated pathogens in the United Kingdom, however our increasing numbers of patients previously resident overseas, in this case an Indian migrant worker resident in Zimbabwe, is likely to correspond to an increase in atypical micro-organisms, especially in the immuno-compromised patient.

MATERIALS AND METHODS

A 26 year old male presented to the unit with a 3 month history of a painful mass over the anteromedial aspect of his distal right thigh. MRI scan (Fig. 1) demonstrated a mass in the distal femur, likely osteosarcoma, not involving the neurovascular structures. Further imaging revealed this was isolated disease, and needle biopsy

Key words: osteosarcoma, distal femoral replacement, massive endoprosthesis, deep infection, Leishmaniasis.

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confirmed high grade osteosarcoma.

The patient responded well to pre-operative neoadjuvant chemotherapy and underwent a distal femoral replacement (Fig. 2). Histological analysis demonstrated a high degree of tumour necrosis (Fig. 3). Excision margins were in excess of 6mm.

Further cycles of chemotherapy were administered, during which time the patient presented, 8 weeks following surgery, with collapse, pyrexia and malaise. Examination revealed a temperature of 39.5° Celsius, profound hypotension, tachycardia and massive splenomegaly. Pancytopenia with near absent neutrophils was recorded. A technetium-99m methyl diphosphonate bone scan (Fig. 4) and magnetic resonance imaging were performed and suggested infection rather than disease recurrence. Tissue biopsy revealed Leishman-Donovan bodies (Fig. 5). Amphotericin B was administered and the patient improved clinically. 6 weeks later the infection relapsed with presentation similar to that previously, with the addition of classical skin lesions. Chest radiograph revealed right lower lobe consolidation, effusion and pneumthorax. Thoracocentesis revealed mycobacterium avium intracellular. Anti-tuberculous medication in addition to amphotericin B and cefuroxime were all given.

Acute exacerbation of pain in the distal thigh prompted repeat MRI scan which revealed recurrence of osteogenic osteosarcoma. Subsequent computerised tomography revealed multiple pulmonary metastases (3) and the patient died, 7 months post-operatively, a combination of disease progression, sepsis aggravated by immuno-suppression and multi-organ failure.

DISCUSSION

Superficial and deep infection, local recurrence of tumour and mechanical loosening are well recognised complications of massive endoprosthesis in bone tumour surgery (4). Reported incidence of infection varies greatly but may be as high as 1 in 5 cases. The majority of cases involve infection with either staphylococcus or streptococcus species.

Our patient presented in extremis 8 weeks following surgery, and while receiving chemotherapy. Tissue biopsy revealed the nature of the infection. Repeated blood cultures failed to identify any other organism.

He denied any previous infection of leishmaniasis, his health was excellent up to the point of referral. He had worked as a heavy goods vehicle driver in India and subsequently throughout Southern Africa

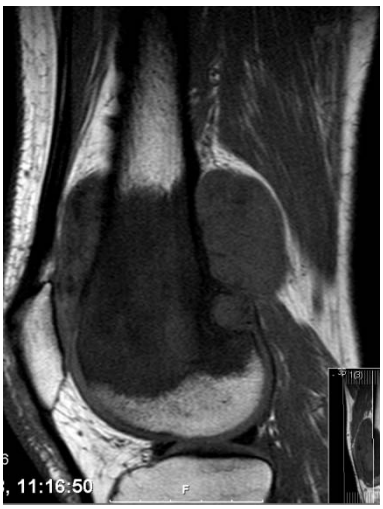

Fig. 1. *MRI scan revealed mass in distal femur.*

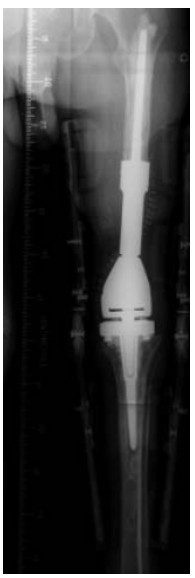

Fig. 2. *Distal femoral replacement.*

Fig. 3. *Histological analysis revealing tumor necrosis.*

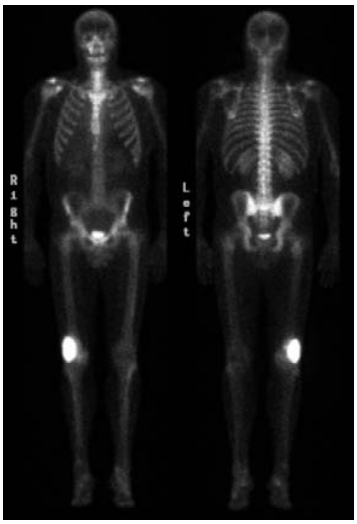

Fig. 4. *Technetium-99m methyl-diphosphonate bone scan suggests infection.*

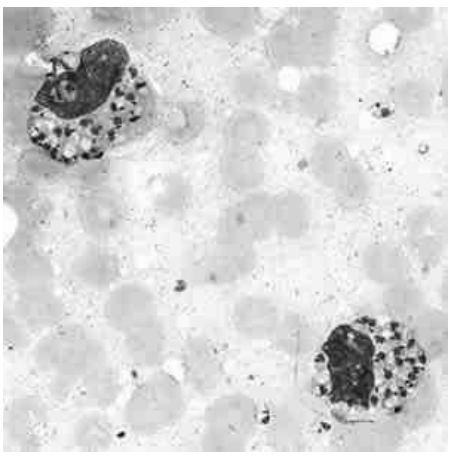

Fig. 5. *Tissue biopsy revealing Leishman-Donovan bodies.*

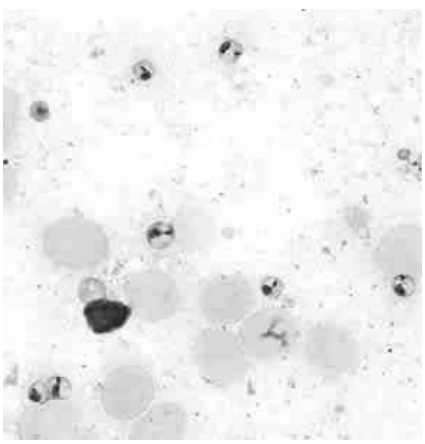

Fig. 6. *Stained slides.*

and was separated from his wife and 4 children. We considered this an opportunistic infection as a direct consequence of the immunosuppression caused by his chemotherapy and malignancy (5).

While magnetic resonance imaging, computerised tomography and bone scan can be useful in determining infection and loosening in such situation, a positive identification of the organism involved is vital. White cell labelled scan may be of some help also (6-8). Limitation in the diagnostic accuracy of bone scan in the 12 months following surgery is well established.

There are no reported cases of Leishmanisais deep infection of endoprosthesis for sarcoma in the literature (9-10).

Leishmaniasis is transmitted by the phlebotomine sandfly (11). These are intra-cellular parasites and are taken up by cells of the reticuloendothelial system resulting in massive hepatosplenomegaly, as happened in our patient. In addition, bone marrow can become heavily infiltrated, resulting in characteristic findings on magnetic resonance imaging. There are four main forms of leishmaniasis; visceral, cutaneous, diffuse cutaneous and mucocutaneous. Visceral leischmaniasis is the most serious form and potentially fatal if untreated, or in the compromised patient. The incubation period may extend to several years, the initial infection being either mild or subclinical. Severity may depend on the hosts immunity and concomitant disease. In Western Society Leishmaniasis is most prevalent among patients with AIDS, or those immunosuppressed secondary to medical intervention (12). For diagnosis, buffy-coat preparations of peripheral blood or aspirates from marrow, spleen, lymph nodes or skin lesions are spread on a slide to make a thin smear, and stained with Leishman's or Giemsa's stain (Fig. 6). Amastigotes can be seen within monocytes or, less commonly in neutrophils in peripheral blood and in macrophages in aspirates. They are small, round bodies 2-4um in diameter with indistinct cytoplasm, a nucleus and a small rod shaped kinetoplast. Occasionally amastigotes may be seen lying free between cells. There are two common therapies containing antimony (known as pentavalent antimicrobials), meglumine antimoniate (*Glucantime*) and sodium stibogluconate (*Pentostam*). It is not completely understood how

these drugs act against the parasite; they may disrupt its energy production metabolism. The parasite is often resistant to antimony and amphotericin is now the treatment of choice (13).

CONCLUSION

Rare opportunistic infections must be considered following endoprosthesis for bone tumours further suppressed by neoadjuvant therapy. Early tissue diagnosis may be key to eradication and prevention of massive and early deterioration.

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TECHNICAL NOTE

A DEDICATED SYSTEM FOR MOVEMENT ANALYSIS

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Objectification of human movement in healthy and pathological conditions is currently desirable in many fields such as rehabilitation, orthopaedics, kinesiology and sports science. Although many systems have been developed for movement analysis their complexity greatly reduces their routine application, particularly in the clinical setting. This paper describes a new movement analysis system, based on image analysis and software object recognition. This system tracks and reconstructs the 3D pose and movements of a body region by using images acquired by 4 webcams and then by using image processing and computer vision techniques. As an example we describe the system applied to the recording of hand and finger pose and movements. However, following the same logical approach, it is possible to use it for other specific systems (such as shoulder, elbow, knee, ankle).

Movement analysis is the quantitative measurement and assessment of human movement. Since the systems for capturing human movement patterns have developed in the last decades, movement analysis is now applied in almost all fields of human movement, healthy and pathological: biomechanics, rehabilitation medicine, orthopedics, sports science and other related fields.

In some of these research areas the goal has been to develop models of the human body that explain how it functions mechanically and how one might increase its movement efficiency. A typical procedure involves obtaining 3-D joint data, performing kinematic analysis, and computing the corresponding forces and torques for a movement of interest. 3-D data are usually obtained by placing markers on the human body (1).

In the clinical setting, movement analysis can be used to improve and to objectify clinical assessment during the diagnostic process to determine the severity and extent of injury, to predict outcomes with or without intervention, and to monitoring the progress of a patient's condition either following intervention or in its absence, for numerous orthopedic neurological and sport-related pathologies.

There are many available systems to record human movements. Many of these are videocamera-based systems (e.g. Elite, BTS Bioengineering Technology and Systems, Italy; Vicon, Oxford Metrics Ltd., England.)

With these systems, during the movement analysis, high-speed cameras and skin markers are used to track the changing positions and orientations of the body segments (kinematic), floor mounted force plates are used to measure the magnitudes and directions of the resultant forces exerted on the ground (dynamics), and surface electromyography (sEMG) electrodes are used to record the sequence and timing of muscle activity (neuromuscular

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activations) (2).

Generally, movement analysis data collection protocols, measurement precision, and data reduction models have been developed for these systems. In this manner the requirements specific for research, sport, or the clinical setting are satisfied.

However, movement measurement protocols in a research setting might include an extensive physical examination to characterize the anthropometric data for each subject. This time expenditure may not be feasible in a clinical setting, hence measurements are less accurate.

Moreover, almost three sources of errors typically affect these systems: instrumental errors, soft tissue artifacts and marker misplacement (3-6).

In clinical and research settings, these systems should consent that the time needed for subject preparation and data acquisition be kept below one hour; that the post-processing procedure should not require more than 30 minutes; that errors caused by skin markers moving should be reduced to a minimum or eliminated and that outdoor data acquisition be improved.

Currently the most frequently used movement analysis systems do not fulfil these requirements.

We describe a method that, based on image analysis and pattern reconstruction, provides a solution to some of these limitations. The idea is to track human movements (here we describe a hand and finger model) by using a set of video cameras opportunely positioned on the vertices of a cube and then using imaging processing techniques. When using this system for hand movement analysis, it is possible to monitor the movements of each finger and the whole hand and attribute to these movements the degree of function in comparison to the other side or to an ideal performance. A pattern recognition algorithm enables the retrieval of information about the hand joints without any marker positioning. Moreover, we can measure the forces applied by the subject's hand or fingers indirectly from deformations impressed on some elastic objects with known elastic coefficients (rubber balls of various sizes and robustness, peg boards, etc.) grasped by the subject. The deformation of the object can be recorded and measured by the pattern recognition system making it possible to calculate the force induced by each finger from the depth of the depression produced. These forces can also be deduced from hand or finger movements when an object is grasped. We present a schematic description of the system's components and functioning.

MATERIALS AND METHODS

Our system is based on bodily segments or whole body posture detection and tracking (7-8). It requires the collection of hand movement data and data concerning grasped object, if any, while reducing the number of occlusions due to the presence of a grasped object and those implicit to a hand. For this reason, we use more than one camera together with a simple hand model reconstruction technique and a reduced degree of freedom, described in literature (9), to design our system.

The system is composed of three main components: a set of real objects of given shapes and stiffness with which exercises are performed; a cube with a set of four video cameras mounted on some of its vertices; a software tool for bodily segment (i.e. hand) motion tracking (8), model reconstruction and the calculation of forces using the images captured the video cameras. The components are shown in Fig. 1.

Set of Objects used for manipulation exercises

The set of objects that the subject will grasp can be supplied by the operator and are standard and low cost objects, such as DigiKeys, peg boards, rubber balls, whose elastic properties and numerical models are color-coded and contained in a table stored in the system's memory.

Video cameras positioning

The positions of the video cameras in relation to that of the hand are shown in Fig. 1 (see inset A for a better visualization of the video cameras position). The hand must be inserted inside an open cube which has video cameras positioned at some of its vertices. To achieve sufficient coverage of the field of view, the video cameras are placed on opposite vertices on each face of the cube. For this configuration the number of required video cameras is 4. In this way, each face of the cube is homogeneously "lighted" by the video cameras. It is always possible to collect information from at least three orthogonal video cameras and use the fourth video camera to reduce occlusions due to the grasped object. Obviously, if more than four video cameras are used the hand visibility will be improved, but this would make the analysis of the collected videos even more complex. The number of video cameras and their position can be varied on the basis of the intrinsic difficulties of the problem to be solved, but it is important

to maintain all information in order to ensure achieving the exact solution to the problem. In this way, it is possible to eliminate occlusions intrinsic to the hand shape or due to the presence of the grasped object. In fact, though the reduction of some of them will reduce the computational overhead of the tracking system, it is important to ensure an exact solution of the tracking movement problem. The video cameras used are commercially available webcams, interfaced using WI-FI technology in order to eliminate cables between them and a dedicated PC. Further webcam specifications are: to support MPEG-4 compression; to have a maximum resolution of 640*480. Each camera points toward the center of the cube. With this configuration, each marker (corresponding to a joint) is imaged by at least two views. Once each pair of cameras is calibrated (calibration is the process to estimate the intrinsic and extrinsic parameters of a pair (10)), these views can be used to reconstruct the 3D coordinate of the imaged joint through a simple triangulation. For this reason we calibrated all possible pairs of cameras by using the Camera Calibration Toolbox (11) for Matlab. The cameras' positions are shown in Fig. 1. Each pair of cameras has its own coordinate reference system that can be placed either in the camera considered as "left camera" or in the camera considered as "right camera". We report all coordinates of all pairs of cameras to the reference system placed on the camera "CAM1". This is trivial since the system is calibrated; we know $T_{i,j}$ and $R_{i,j}$ (for i=1..4 and j=1..4), the matrices of translation and rotation of each camera with respect to the others. The accuracy of the system in determining the position is less than 1mm. This is calculated by measuring objects of known dimensions. Once the cameras have been placed and calibrated the next step is to calibrate the numerical hand. This step consists in the measurement and storage of the length of the link between the joints. This is simply performed by simultaneous acquisition of some views of the real hand. These views are used in pairs to compute, by triangulation, the length of the fingers which are used as constants in the proposed numerical hand model.

Software tools:

The hand model

The method which is used to collect and measure hand and finger movements consists of the construction of a numerical model of a hand based on the information collected by the webcams. In fact, after the segmentation of the hand silhouette from the video streams, an articulated hand model is fitted onto 2D masks of the hand. The human hand consists of connected parts composing kinematical chains so that hand motion is highly articulated. The full degree of freedom (DOF) hand model has up to 30 DOFs resulting in a very high dimensional problem. The bones in the skeleton form a system of rigid bodies connected together by joints with one or more degree of rotation freedom, as shown in Fig. 2. The position of the hand is represented by these angular DOFs and by 6 DOFs of the palm (three translations and three rotations). The length of the links between joints are assumed to be fixed and can be estimated and stored with a calibration procedure, as described above. By approximating the structures and constraining the angular motion of some joints, as reported in literature (12), it is possible to reduce the number of DOFs. In particular, considering the palm triangle (indicated with the joints j00 - j01 - j04 in Fig. 2) as a rigid body and considering the static constraints:

$$\theta_{MCP}=\theta_{DIP} \text{ and } \theta_{DIP}=2/3*\theta_{PIP} \quad (1)$$

the DOFs decrease to 16 (six for the palm triangle and four for each finger). θ_{MCP}, θ_{DIP} and θ_{PIP} are the angles indicated in Fig. 2 (MCP stands for metacarpo-phalangeal, DIP stands for Distal Interphalangeal and PIP stands for Proximal Interphalangeal). The used numerical hand model was implemented in Matlab/Simulink by using the SimMechanincs toolbox. The parameters collected by the recognition algorithm and necessary to reconstruct the spatial position of the hand is reported in Fig. 3. The main schematic SimMechanics block of the hand is shown in Fig. 4. The model is built by using 16 rigid bodies: one for the palm triangle and three for each finger. These bodies are connected by 15 joints:

- one bushing joint representing the radiocarpal (wrist) articulation. It is a composite joint with 3 translational DOFs as 3 prismatic primitive joints and 3 rotational DOFs as 3 revolute primitive joints.
- 20 revolute joints representing the fingers' articulations where, for each finger, the MCP joint is composed of two revolute joints while the DIP and PIP joints are simple revolute joints (see Fig. 5).

The model consists of a kinematic chain that connects the 16 rigid bodies of the hand with the above mentioned joints.

The palm and the phalanges are modeled using Body blocks, in which the body's mass, the moment of inertia tensor, the coordinates for the body's center of gravity (CG) and one or more body coordinate systems (CSs) can be customized. Each body has the CG and CSs expressed with respect to the CS of the body placed before it. In this way it is possible to specify the dimensions of the body. Each joint is actuated using a Joint Actuator block, providing the value of the rotation angle and the translation values for the palm triangle. The values of the rotation angles and the translations are computed with a Matlab function, that take in as input the values of the coordinates of the joints.

Grasped object recognition and forces calculation

The virtual hand behaviour is based on a 3D hand and

fingers model reconstruction from a set of video cameras as previously described. In order to evaluate the positions of the fingers in respect to a grasped object, a model of the object is also necessary. This can be automatically set up by the system which recognises a grasped object by its colour, according to a table stored in the system's memory, a given numerical model and a corresponding k value. Differences in elastic objects can be obtained by grasping different objects of different colours.

After model reconstruction, the forces impressed by each finger on the grasped object are calculated on the basis of applied deformations using Hooke's deformation law, the same used to drive haptic devices (13):

$$\vec{F} = k \cdot d \cdot \vec{N}_S \quad (2)$$

where k is the stiffness of the object, d is the distance along the vector $\vec{N}_S$ normal to the surface of the grasped object, between the previous and present position of the finger (due exclusively to bending, as rotation and translation effects have been eliminated). Forces are calculated only when the finger is touching the object. This is performed by the software through a direct reconstruction and analysis of the numerical model of the scene.

Database and networking

Subject data are stored during the exercise. Both finger and hand movements or calculated forces can be organized and saved in tables reporting personal data, grasped object information and exercise data. The database can also store some video streams in compressed mpeg format for use by the therapist. The database can be constructed and managed by a web-based User interface (13) in a web-based distributed architecture. Both subject and operator can access the database to input data, perform queries, modify data, upgrade exercises and delete records or videos. The operator can also control a file log listing the number of sessions opened by the subject, the types of exercises performed, duration and performance. Data measured (movements) or calculated (forces) by the system can be displayed to be further processed in order to evaluate important parameters such as mean force, standard deviation and integral force (effort) for each finger in a given session. A historic (temporal) table can be created to record the corresponding parameter values for a given exercise, in order to produce a graphical representation of the improvement (or worsening) of hand and fingers in time. For example, a physician or physiotherapist can use this table to monitor the treatment's efficacy and the subject's speed of recovery.

This database is stored on the server side, as shown in Fig. 1 (13). The operator has remote access to all these data without having to travel to the subject's home. Data can be automatically downloaded into a clinical database or the operator might decide to access and download them through the web. Through the web, the operator can also access the webcams and modify their direction in order to improve the quality of the information collection.

The client site runs the system software: the subject can control the system using a simple web based interface or his voice (13). The graphical interface allows the subject to start exercises or to open tutorial files explaining the correct execution of the exercises. The subject can consult the operator by video conference or phone. The presence of the server on the subject's side ensures that the system is independent of the speed of the web connection because most communications are of the store and forward type. Other choices can be made (13) without loss of data.

Operative description

The video collected by the 4 webcams are sent to a computer and processed by a series of software modules, including the software tool described above. In particular, a first module, named classifier, serves to collect and classify the initial position, shape and size of the analysed hand before grasping an object. In this module, a numerical model of the real hand, including pre-existing conditions, is created and a set of a-priori information is stored for future use (see above for details). It is obvious that this module is created only when the system is set up and then skipped for subsequent measurements. A second module obtains information, by means of a corresponding table, about the object the hand is grasping, such as its type and elastic properties; this module uses the colour of an object to differentiate between objects of different shape or elastic properties.

A third module collects and identifies the current information about hand position and movements and reconstructs the hand numerical model as previously described. A fourth module calculates the forces impressed by each finger onto the grasped object of known elastic properties, on the basis of the deformation effects. The numerical information is assembled to produce temporal data for each finger and for each exercise in a fifth module. This information is stored in a web based database by a sixth module which also includes the initial hand status information. The same module also includes functions for networking and remote access.

In the proposed system, the feedback forces required by the haptic device and the haptic device itself (with the associated mechanical devices) are completely absent. The subject's hand is used directly as the source of information collected by the video cameras and the software performs the majority of the necessary work.

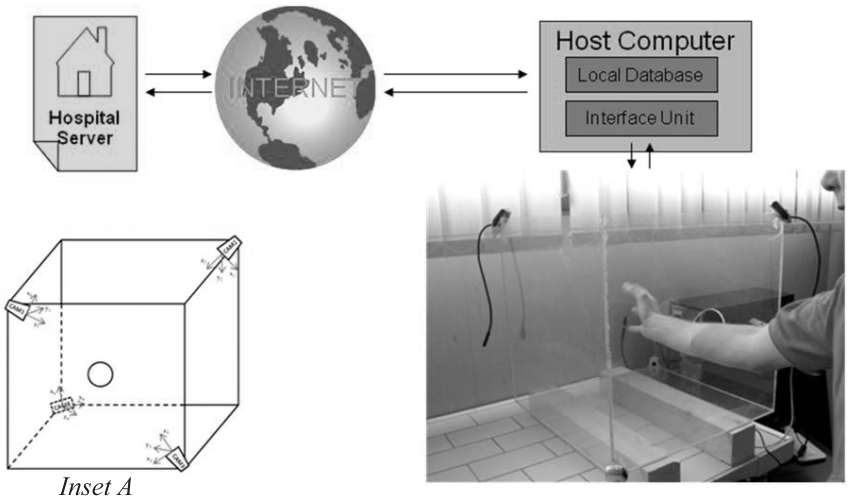

Fig. 1. *Scheme of the proposed system. The photo shows a prototype of the system with the hand inserted into the Perspex box on which web cameras have been installed, as better explained in the inset A.*

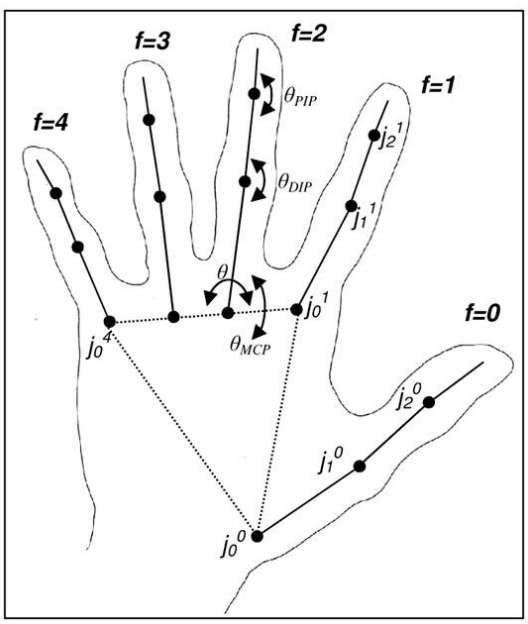

Fig. 2. *Numerical hand model composed by 16 rigid bodies (15 phalanges and the palm triangle that is indicated by the joints j_0^0-j_0^1-j_0^4) connected by 15 joints. Each joint (indicated with j_f^i) is localized with a computer vision process.*

DISCUSSION

In the last few years, computer vision has been used in the sector dealing with the analysis of images involving humans such as face recognition, gesture recognition and whole-body tracking. There are a number of potentially important applications in computer vision involving humans, including virtual reality or motion analysis. The specific area of application in motion analysis ranges from personalized training in sport activities (e.g. golf, tennis, etc.) to clinical studies of orthopedic patients. A completely software-based body segment monitoring system, that uses webcams for visual tracking movements and calculating forces, has been presented in this paper for movement analysis purposes. This system does not depend upon marker positioning hence it avoids artefacts which can be caused by skin movements under the markers. The space occupied by whole setup is greatly reduced, and the weight and costs are also much less. The re-usability of the system is ensured. Moreover, the system can be assembled using WI-FI technology in order to eliminate cables between the video cameras and a dedicated PC or between the dedicated PC and the web server. The subject's hand remains free from markers, cables and cumbersome heavy devices.

As described, the system configuration requires distinct devices for data acquisition and processing (dedicated PC) and for storing data (local Server): this choice ensures the implementation of data acquisition/processing functions directly on a portable PC, such as a pocket PC, which can

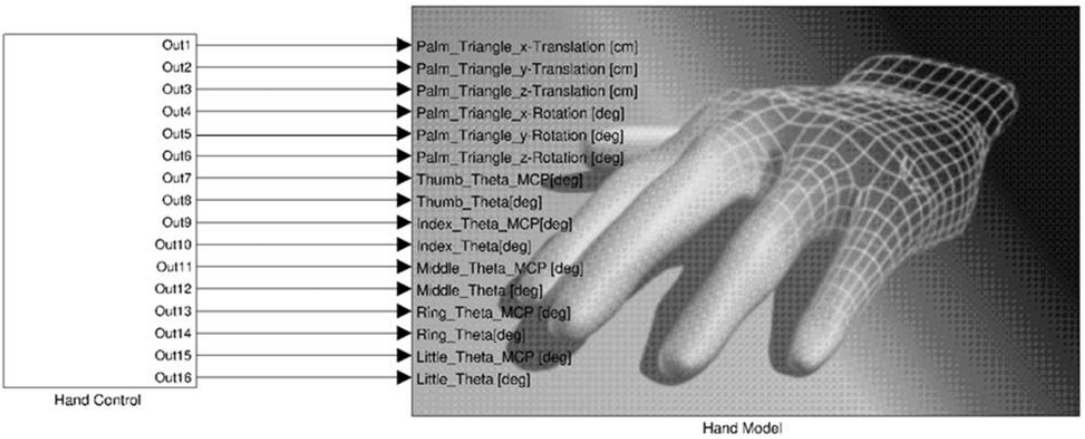

Fig. 3. *Input Parameters necessary to indicate the 3D spatial position of the SimMechanics hand model. These parameters (geometrical hand rotation/translation and joints angles) have been calculated by a specific software tool which elaborates the spatial measurements collected by the recognition algorithm.*

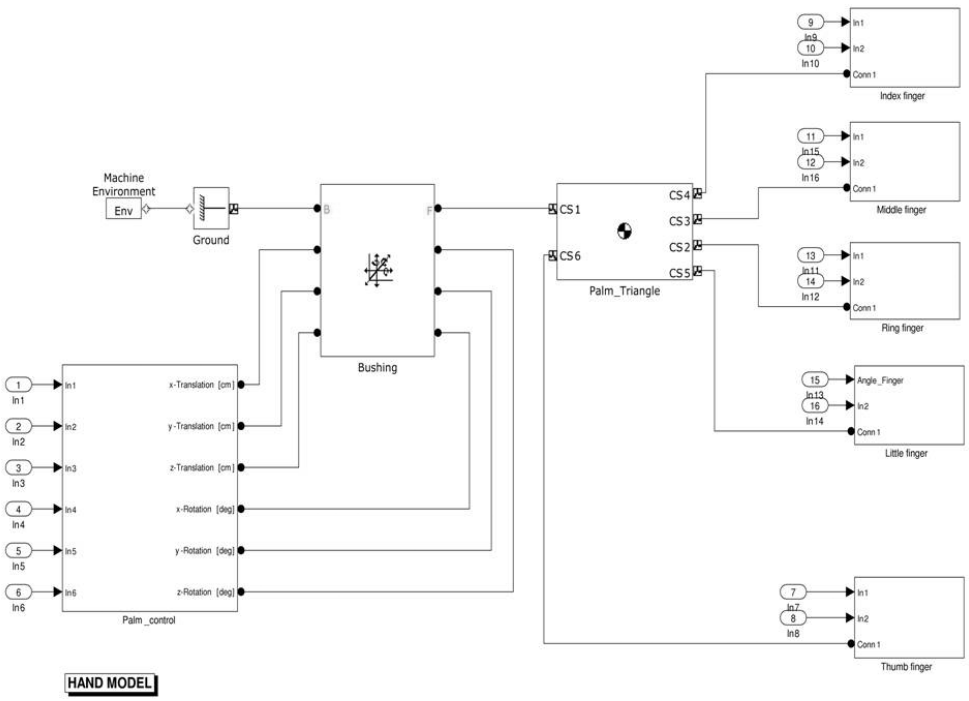

Fig. 4. *The SimMechanics hand model.*

be carried by the subject, together with the web cams box, for outdoor exercising. The server, a cumbersome commercially available PC connected to Internet, can be left at home.

This system can be extremely useful and adaptable to various situations: to collect initial information about the hand and finger of a subject, for example, establish the number, if any, of missing fingers or the presence of some constraining disease (bent or blocked fingers, etc.), which need

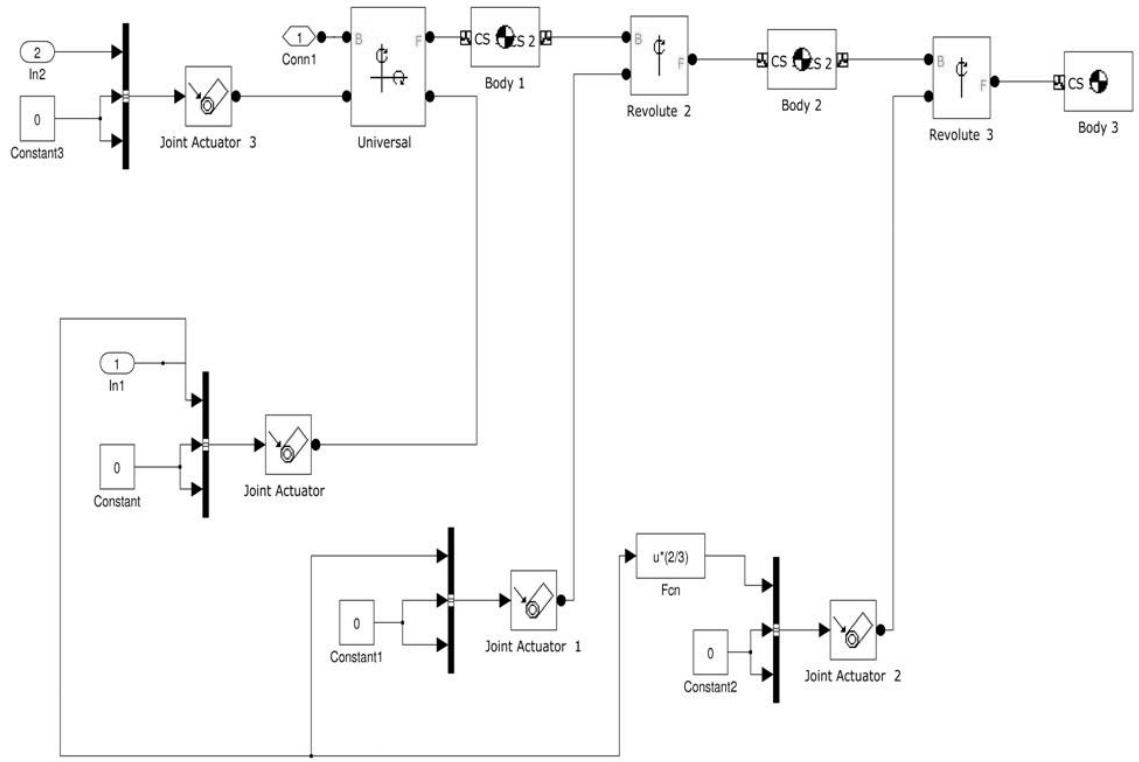

Fig. 5. *The SimMechanics finger model. It represents a detailed description of each box (representing a finger) on the right of Fig. 4.*

to be taken into account in successive calculations; to collect information, register and transmit information about hand and finger movements as graphical plots or video-streams of the scene via web; to evaluate the degree of physical recovery by numerical comparison of plots representing the performance of the same exercise at different times; to collect information about the performance of a set of exercises by grasping different physical objects. Hence, the described system is excellent for testing subjects of any age, with different sized hands, residual infirmities and/or impairments. Exercises can be performed in both the domestic and the clinical environment.

Our system does not exclude the possibility of using virtual reality to simulate functional recovery exercises as well. In fact, as previously described, it can be included in a virtual reality environment in which the virtual hand represents the reconstruction of the recorded real hand in a virtual world including some virtual objects located in virtual space. For these exercises, force measurements or feedback are unnecessary: the only requirement is for the subject to recover his hand and finger skills.

A critical point will be optimizing the number and the position of the webcams in respect to the position of the hand in order to reduce the complexity of tracking and simultaneously preserving accuracy. Some efficient acquisition/reconstruction methods, which have been particularly useful in medical tomography (14,15), will be adapted in order to reduce the hand tracking complexity. Our system will also be applied to the development of other specific virtual remote rehabilitation systems (for the shoulder, elbow, knee or ankle) and for total body measurements.

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THE USE OF DIGITIZED RADIOGRAPHS IN DETERMINING THE CONSISTENCY OF THE AO AND NEER CLASSIFICATIONS OF FRACTURES OF THE PROXIMAL HUMERUS

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For any system used to classify fractures, a high level of intraobserver reproducibility and interobserver reliability is desirable. We compare the consistency of the AO and Neer classifications of fractures of the proximal humerus with an assessment of the digitized radiographs of 100 fractures by 10 orthopedic surgeons and 5 radiologists using the General Electric Picture Archiving and Communications System (PACS), allowing manipulation of the image. This process was repeated 1 month later. Intraobserver reproducibility and interobserver reliability was moderate for both the AO and Neer systems. In each case reproducibility using the AO/ASIF system was slightly greater. The assessor's level of experience and specialty affected accuracy. The ability to electronically manipulate images does not appear to improve reliability compared to the use of traditional hard copies, and their sole use in describing these injuries and comparing similarly classified fractures from different centers is not recommended.

Fractures of the proximal humerus are common, occurring most frequently in patients aged over 65 years (1). With the expected expansion of the ageing population, their incidence is likely to increase. The majority of these fractures are either undisplaced or minimally displaced, and are most appropriately treated conservatively. Up to one fifth of these, with improvements seen in both technique and implants, may benefit from surgical intervention (2-5). As decisions regarding treatment are essentially based on the type of fracture present, a radiological fracture classification should ideally be easy to use and have a high degree of interobserver reliability and intraobserver reproducibility to serve as a useful discriminator, creating standards by which treatment can be recommended and outcomes compared (6-8).The 2 systems most commonly used, the Neer Classification (9) and that introduced by the AO group (10) have been examined in the past for reliability with the use of radiographs, and computerized tomography (11-15). We report on the assessment by the largest number of assessors of the largest number of extended radiograhic trauma series in digitized radiographs, allowing electronic manipulation of images.

MATERIALS AND METHODS

Radiographs of 100 fractures of the proximal humerus

Key words; proximal humerus fractures, Neer Classification, AO/ASIF Classification, interobserver, intraobserver reliabilty, consistency.

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were selected by the primary author with consideration for quality, and representing an even spectrum of fracture configuration and severity. Radiographic views included a true anteroposterior (arm flat on the abdomen), a true scapular lateral (arm in the same position), and an axillary radiograph with the arm held in 40 to 70 degrees of abduction. 10 orthopedic surgeons and 5 radiologists were recruited as assessors, including 5 specialist registrars (surgeons in training) in trauma and orthopedics, the others consultants in their respective specialty.

Each assessor was given a printed description of both the Neer and AO classifications for use during the assessment (16), a goniometer and a ruler. The assessment period was preceded by a short lecture on each system.

Radiographs could be manipulated digitally using General Electrics Picture Archiving and Communications System (PACS), for size, contrast, brightness, orientation and the negative image displayed as required. The Neer classification relates to 4 distinct anatomical segments, the articular segment, the greater and lesser tuberosity, and the humeral shaft (Fig. 1). For a segment to be considered displaced, it was displaced by more than 1.0cm and angulated by more than 45 degrees. These were classified as 2, 3 or 4 part fractures based on the number of displaced segments. Group 1 represented undisplaced fractures.

In the AO/ASIF system, fractures were classified into one of 3 types, each of which was divided into 3 groups (Fig. 2). Each group can be divided into further subgroups. We did not ask our assessors to determine subgroups for reasons of simplicity.

Intraobserver reproducibility and interobserver reliability were analyzed using Kappa statistical methods (17). A comparison was then made comparing reproducibility between radiologists and surgeons, and then between consultant orthopedic surgeons and trainees. We did not assess accuracy, as that would require a definitive classification for each fracture. It is important to note that agreement does not necessarily reflect accuracy.

Statistical methods

The kappa co-efficient for multiple raters (18) was calculated according to the guidelines proposed by Landis and Koch (19). Values less than 0.00 indicate poor reliability, between 0 and 0.2 represent slight agreement, 0.21 to 0.4 fair, 0.41 to 0.60 moderate, and 0.61 to 0.8 substantial agreement. Values above 0.8 are considered excellent or almost perfect. This analysis involves adjustment of the observed proportion of agreement between observers by correction for the proportion of agreement that could have occurred by chance. Kappa coefficients for agreement among the orthopedic surgeons were compared to those for the 5 radiologists using the Student t test that incorporated the standard errors of kappa for these 2 groups. A similar method was employed to compare the performance of orthopedic consultants to trainees.

RESULTS

3 assessors reported to be regularly using the AO Classification, while 20 were 'familiar' with it. All 15 assessors reported familiarity with the Neer Classification and 10 used it regularly. 2 assessors denied routinely using any system. We did not perform category specific testing for the expanded classification subgroups within the AO system.

In each case the AO/ASIF system was statistically ($p< 0.01$) more accurate. Agreement was greater for less complex (one and two part, and type A) fractures. Level of experience (trainee vs consultant staff) produced a statistically ($p<0.01$) significant difference in accuracy. Specialty (radiology consultant vs orthopedic consultant) did not.

DISCUSSION

Classification systems for fractures are extremely important in the practice of trauma and orthopedics. They are a means by which fractures, and fracture dislocations may be described and provide important guidance on treatment and the results of treatment. Ideally, a classification system would distinguish groups that behave in predictable ways, require certain treatment and where parallel clinical outcome exist. This system would ideally have a high degree of reproducibility.

Our analysis comparing the Neer and AO systems uses the largest group of assessors reviewing the largest number of radiographs reported in the literature. This is done using digitized radiographs allowing the manipulation of images as described. At best, the interobserver error in the popular Neer classification was only moderate. As is typical of comparative studies, intraobserver reproducibility scored higher as it reflects reproducibility independent of agreement. Incorrect responses that are repeated will show good intraobserver reproducibility but often low interobserver reliability. Our results are similar or slightly better compared to those in published literature. This is perhaps due to the selection of good quality radiographs, with complete

Table I. *Interobserver reliability*

	AO kappa value	range	Neer kappa value	range
Orthopedic trainee	0.53	0.51-0.55	0.48	0.46-0.50
Orthopedic consultant	0.59	0.57-0.62	0.54	0.51-0.57
Radiology consultant	0.58	0.57-0.61	0.52	0.51-0.56

Table II. *Intraobserver reproducibility*

	AO kappa value	range	Neer kappa value	Range
Orthopedic trainee	0.64	0.63-0.65	0.63	0.62-0.66
Orthopedic consultant	0.72	0.68-0.74	0.71	0.69-0.72
Radiology consultant	0.72	0.68-0.73	0.7	0.69-0.71

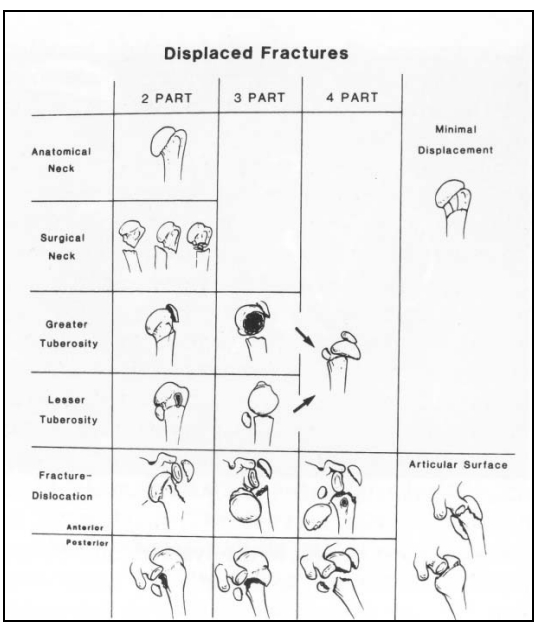

Fig. 1. *Neer Classification of Proximal Humeral Fractures*.

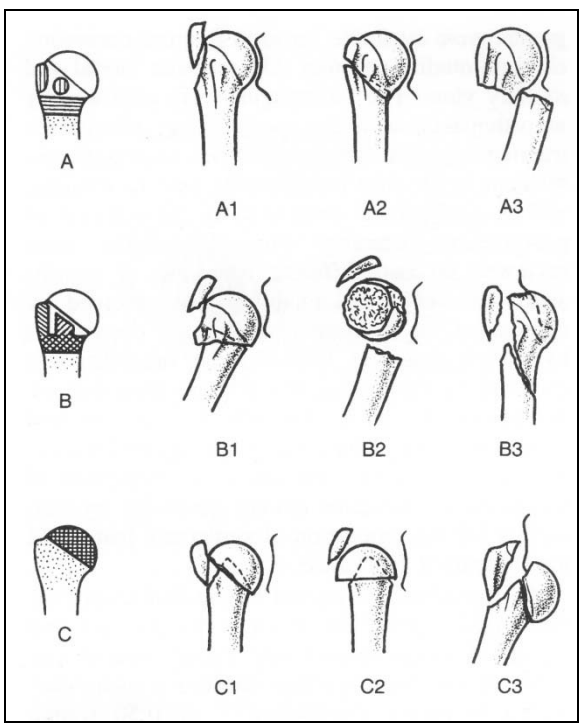

Fig. 2. *AO Classification of Proximal Humerus Fractures.*

trauma series, and the ability to manipulate these digitally (20). We have not attempted to quantify the individual effect of these however.

There are significant differences however in terms of the various components of these studies, the assessors (specialties and experience), radiographs (21) (numbers and views used), addition of computerized tomography (CT) (22-23) and classifications used (including modifications). The very definition of a trauma series, as described by

Neer, is variable. He defined this as anteroposterior (AP), scapular lateral and either a transthoracic, axillary or rotational radiograph. Evaluation of the actual degree of displacement remains difficult. Also described is the Velpeau axillary radiograph, which does not require the injured patient to move the arm, but does require him to be capable of remaining upright. The apical oblique is similar to this but does not require the patient to sit up. Wallace found the axillary view to be of particular value in imaging the tuberosities. We also found that greater experience produced greater interobserver reliability and intraobservor reproducibility. Comparing consistency between experienced orthopedic surgeons and radiologists did not reveal any difference.

We concur with others in concluding that using these systems in isolation in determining treatment and comparing results following treatment cannot be recommended. In particular, that multicentre analysis of classified fractures from different centers is not scientifically valid. Interestingly, our findings are consistent with published results in the analysis of classification systems designed to qualify injuries at other anatomical sites (24-27), highlighting the need for caution in interpreting clinical outcomes for treatment of injuries at these sites.

Additional research is required to devise criteria that may produce a more accurate system in proximal humeral fractures, perhaps requiring observations based on CT and CT reconstructions as opposed to the traditional radiograph.

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