Chapter 10

Summary
Part I - Introduction

Osteochondritis dissecans (OCD) of the capitellum is a devastating elbow condition in adolescent athletes who participate in overhead sports such as baseball and tennis, or in upper-extremity weight-bearing sports such as gymnastics. In Chapter 1 a general introduction on the history, etiology and epidemiology is given, as well as the role of advanced imaging and surgical management is discussed. The aim and outline of this thesis are presented.

Part II - The role of advanced imaging methods

The evaluation of OCD of the capitellum by means of advanced imaging methods, computed tomography (CT) en magnetic resonance (MR) imaging, is important in guiding the type of treatment and predicting prognosis. In Chapter 2 the reliability was determined of a quantitative 3-dimensional CT technique for the measurement of OCD size and the reliability was determined of a mapping technique for pattern analysis. Using our institutional database, we identified 17 patients with capitellar OCD who had undergone a preoperative CT scan between 2001 and 2016 (slice thickness ≤1.25 mm). The median age was 15 years (range, 12-23). After reconstruction of 3-dimensional models, the OCD surface areas were measured by two authors (see Chapter 2 for a detailed description). Measurements of the OCD surface showed almost perfect intra-observer (intraclass correlation coefficient [ICC] = 0.99) and inter-observer agreement (ICC = 0.93). The median OCD surface was 101 mm² (range, 49-217 mm²). Our mapping technique revealed that the posterolateral zone of the capitellum was most frequently affected, with the centroid located 56° anteriorly relative to the humeral shaft.

Post hoc analysis showed that OCDs with lateral wall involvement were associated with a larger OCD surface area, longer duration of symptoms, and worse elbow extension. Our data demonstrates that quantitative 3-dimensional CT and mapping technique are reliable methods and in the assessment of capitellar OCD and should be considered when detailed knowledge of lesion size and location is desired.

Accurate classification of a capitellar OCD lesion is useful for guiding treatment and predicting prognosis, as well as for comparing the outcomes of different studies. MR imaging has become the most widely used imaging method. In Chapter 3 the inter-observer reliability of existing MR classifications was determined. MRs of 20 patients with capitellar OCD were reviewed by 33 observers using a web-based study platform, 18 orthopaedic surgeons specializing in shoulder/elbow/sports-related injuries and 15 musculoskeletal radiologists. Observers were asked to classify the stage of an OCD
according to 3 classification systems. Also, observers were asked to apply the criteria of instability for each OCD. Overall, the inter-observer reliability ranged from slight to fair: Hepple (fair, k = 0.23); Dipaola/Nelson (slight, k = 0.19); Itsubo (slight, k = 0.18); DeSmet/Kijowski (slight, k = 0.16); Satake (slight, k = 0.12); lesion size (fair, k = 0.24). The reliability significantly improved (fair to moderate) when classifications and instability criteria were simplified (i.e., stable versus unstable lesion). Subgroup analysis revealed that the reliability was independent of the number of years in medical practice or the number of capitellar OCD cases treated per year ($p > .05$). There was more agreement among radiologists for two classifications and lesion size assessment ($p < .05$). This investigation adds to a growing body of evidence indicating that relatively simple distinctions on MR imaging are more reliable and that this is independent of clinical experience.

**Part III - The role of patient-related and OCD-related factors in outcomes following surgical treatment**

Previous studies have highlighted the influence of patient-related and OCD-related factors in the management and prognosis of patients with capitellar OCD. In Chapter 4 we present the clinical outcomes following arthroscopic debridement and microfracture in the treatment of advanced capitellar OCD. Between 2008 and 2015, 71 patients (75 elbows) with a minimum follow-up of one year were included. The mean age was 16 years (SD ± 3.3) and the mean follow-up was 3.5 years (SD ± 1.9). Based on CT/MR imaging, 71 lesions were deemed as unstable and 4 as stable. The mean postoperative OES (Oxford Elbow Score, range 0-48) was 41 (SD ± 8.0), indicating satisfactory elbow function in most patients. Sixty-two percent of patients returned to their primary sport. Both an open capitellar growth plate ($p = .025$) and the removal of loose bodies ($p = 0.0020$) were independent predictors of good elbow function. Preoperative lesion width ($p = .060$) and depth ($p = .10$) did not correlate with clinical outcome. Also, there was no difference in elbow function between medial and lateral OCDs. A worrisome finding of our investigation was the time between the onset of symptoms and the first visit in our orthopaedic practice; 18 months. Also, patients with longer preoperative symptoms had poorer elbow function postoperatively ($p = .029$). In conclusion, arthroscopic debridement and microfracture for advanced capitellar OCD provide good clinical results in terms of pain, function, and range of motion. Especially in patients with an open growth plate, loose body removal, and shorter duration of symptoms. However, only 62% of our patients returned to their primary sport.

Subchondral bone supports the articular cartilage and distributes loads across the joint surface. Subchondral bone that function suboptimal may result in disturbed load
distribution across the articular surface, failed cartilage repair and may eventually lead to osteoarthritis. In Chapter 5 we focused on subchondral bone healing following arthroscopic debridement and microfracture or advanced capitellar OCD. Between 2009 and 2016, 67 patients underwent treatment of whom 54 patients with pre-operative and postoperative CT scans were included (81% follow-up rate). Mean follow-up time was 29 months (SD ± 9.0). There were 30 females and 24 males, with a mean age of 15.7 years (SD ± 3.2). Defect size significantly decreased (i.e., improved) in all 3 directions (medial-lateral x anterior-posterior x depth): from preoperatively 7.9 ± 2.8 x 8.0 ± 3.2 x 4.1 ± 1.5 mm to postoperatively 3.5 ± 3.3 x 4.0 ± 3.5 x 1.6 ± 1.4 mm (p < .001). Healing of the subchondral bone was either good or fair in 85% of OCDs and poor in only 15%. We found satisfactory elbow function after treatment (OES, 40 ± 8.4). Interestingly, neither postoperative defect size nor healing grade correlated with clinical outcome. Additional analysis revealed no prognostic factors for favourable OCD healing (e.g., open growth plate, OCD grade, lateral wall involvement). This is the first study that investigated defect size changes following microfracture. These data indicate that arthroscopic debridement and microfracture for advanced capitellar OCD lead to osseous filling of the lesion, both in width and in depth.

Part IV - The role of donor sites in the setting of osteochondral autologous transplantation for capitellar osteochondritis dissecans

Reconstruction of the articular surface by means of osteochondral autologous transplantation (OATS) may be indicated in large (diameter >10 mm), unstable OCD lesions that extent the lateral capitellar wall or if bone marrow stimulation procedures have failed. Although OATS has shown promising short- and mid-term outcomes with regard to pain relief, elbow function and return to sports, donor-site morbidity remains subject of debate. In Chapter 6 is presented a systematic review in which we sought to determine the donor-site morbidity rate following OATS in the treatment of capitellar OCD. Eleven studies including 190 patients met our criteria: ≥10 patients; ≥1 year follow-up; and reported outcomes related to donor sites. There were 8 knee-to-elbow studies and 3 rib-to-elbow studies. Donor-site morbidity was defined as the presence of persistent symptoms (≥1 year) or complications related to the donor site requiring intervention. Donor-site morbidity occurred in a considerable group of patients: 7.8% of patients (10 of 128) in the knee-to-elbow group and in 1.6% of patients (1 of 62) in the rib-to-elbow group. Knee pain during activity (7.0%) and locking sensations (0.8%) were reported after harvesting from the knee; one pneumothorax (1.6%) was reported following harvesting from the rib. One major limitation of the systematic review is that most studies only briefly report outcomes related to the donor site. Most studies lacked either objective or
subjective assessment. These data indicate donor-site morbidity in a considerable group of patients following OATS for capitellar OCD and may be underreported.

Ideally, the curvature of the donor graft is equal to that of the recipient site (i.e., perfect topographic match) to maintain the biomechanical properties of the radiocapitellar joint. To avoid the risk of donor-site morbidity of an asymptomatic knee or rib area when performing OATS, we sought to find alternative donor sites within the affected elbow. In **Chapter 7** we investigated two alternative donor sites of the ipsilateral elbow: the non-articulating part of the radial head and the lateral side of the olecranon tip. We selected 20 patients with an unremarkable CT scan (slice thickness ≤1.25 mm), with a mean age of 15.9 years (range, 12-18 years). After reconstruction of 3-dimensional models, we created 4 common lesion locations on the capitellum (recipient site), as well as 3 donor locations on the non-articulating part of the radial head and 3 on the lateral side of the olecranon tip. For each of 24 donor-recipient combinations, the donor graft surface (radial head or olecranon) was virtually placed on the capitellar surface to quantify the mean distance between surfaces (see chapter 7 for a detailed description). For a central 40° lesion, the mean distance across all 6 donor-recipient combinations ranged from 0.085 ± 0.023 to 0.118 ± 0.036 mm; for a central 60° lesion, the mean distance ranged from 0.075 ± 0.018 to 0.117 ± 0.062 mm; for a lateral 40° lesion, the mean distance ranged from 0.087 ± 0.030 to 0.182 ± 0.226 mm; and for a lateral 60° lesion, the mean distance ranged from 0.084 ± 0.048 to 0.115 ± 0.045 mm. There were no differences in topographic matching between donor-recipient combinations ($p > .05$). Overall, analysis revealed a less than 0.2 mm difference in topographic subchondral bone match between all 4 lesion locations on the capitellum and both alternative donor sites of the ipsilateral elbow. There was no difference in topographic matching between donor-recipient combinations. Our findings suggest that both the non-articulating part of the radial head and the lateral side of the olecranon tip provide an appropriate topographic match with the capitellum.

Besides the importance of a proper topographic match between the donor graft and the recipient site, it is thought that cartilage thickness plays a crucial role in the ingrowth of the donor graft. In **Chapter 8**, we compared the morphological and histological properties of the capitellum with the aforementioned alternative donor grafts of the ipsilateral elbow (Chapter 7). Ten human cadaveric elbow specimens with macroscopically normal articular surfaces, were used to obtain 5 mm osteochondral grafts: 10 from the capitellum; 10 from the non-articulating part of the radial head, and 4 from the lateral side of the olecranon tip. Grafts were fixated in formalin (4% formaldehyde), decalcified and processed into standard 8 μm thick Haematolxylin and Eosin and Toluidine Blue stained sections. Mean cartilage thickness was 1.5 mm (SD ± 0.22) at the capitellum; 1.3 mm (SD ± 0.34) at the radial head; and 1.9 mm (SD ± 1.0) at the olecranon. There was no
difference between the capitellum and radial head ($p = .062$). Also, according to the ICRS (International Cartilage Repair Society) II scoring system, there were great similarities between the capitellum and either donor site in terms of cell and matrix morphologies. These results indicate that from a histopathological point of view, there are no obstacles to use grafts from the ipsilateral elbow for repair of the capitellum.

**Part V - General discussion**

In Chapter 9 we summarize our findings and discuss them in the context of the existing literature.