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ORIGINAL ARTICLE

Mineralisation patterns in the subchondral bone plate of the humeral head

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Abstract

Purpose Pathologic changes of the glenohumeral joint, like a long-standing overloading or an accident often lead to severe glenohumeral osteoarthritis, and a glenohumeral joint replacement could be necessary. Joint instability and glenoid loosening are the most common post-operative complications, which can be caused by eccentric loading of the glenoid, if the humeral head is malcentered. If these malcentered cases could be identified pre-operatively, the pathologic position of the humeral head could be fixed intra-operatively and complication may be prevented. Computed tomography osteoabsorptiometry (CT-OAM) is a useful method to determine the distribution of mineralisation in the subchondral bone as a marker for the long-term loading history of a joint. The objective of this study was to gain information about the mineralisation distribution in the subchondral bone plate of the humeral head.

Methods By the use of CT-OAM, the distribution of the subchondral mineralisation of 69 humeral heads was investigated and groups of mineralisation patterns were built. To evaluate if differences in age exist, the mean values of the two groups were compared using *t* test.

Results 49 humeral heads (71% of 69 specimens) showed bicentric subchondral mineralisation patterns with ventral and dorsal maxima, 20 humeral heads (29% of 69 specimens) could be classified as monocentric with a centrodorsal maximum. We found no statistical significant difference between the age of the monocentric and the bicentric group on a significance level of 95%.

Conclusion We could show that stress distribution at the humeral head is typically bicentric with a ventral and dorsal maximum. However, other mineralisation patterns may occur under pathologic circumstances. The pre-operative identification of such cases by the use of CT-OAM could help to improve the post-operative results in shoulder surgery.

Keywords Mineralisation · Subchondral bone · Humeral head · Glenohumeral joint · CT-OAM

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Introduction

The loading history of a joint is represented by specific mineralisation distribution patterns of the subchondral bone plate [10]. It is well known that subchondral bone plate reacts to different stress situations with integration and degradation of material and therefore builds unique mineralisation patterns [4, 10, 11, 15]. Several authors [5, 12, 13] investigated the mechanical and architectural properties of the subchondral bone at the glenoid cavity. Schulz et al. described predominance of bicentric mineralisation patterns and in rare cases a central maximum. Mimar [5] showed that larger values of bone value fraction (BV/TV) are generally found in the posterior regions of the glenoid, whereas the anteroinferior edge was more porous. As far as we know, the subchondral mineralisation of the humeral head never has been investigated so far, although knowing subchondral bone density patterns in the humeral head might be interesting for the clinician. In case of resurfacing, it is important to know subchondral density patterns to get an optimal primary fixation of the prosthesis. Our results might also be interesting for osteosynthesis, as the subchondral bone plate is the only solid bone where screws are to be anchored in case of open reduction and primary fixation. Computed tomography osteoabsorptiometry (CT-OAM) is a useful method to gain information about subchondral bone mineralisation patterns in vivo and in vitro. Using a maximum intensity projection, the density distribution of the subchondral bone plate can be evaluated and a final densitogram displaying the distribution pattern can be achieved. In contrast to the usual methods of CT densitometry, which deal with the calculation of an absolute value for bone density in a larger area including compact and cancellous bone, CT-OAM is a procedure for demonstrating differences in relative concentration within a joint surface [7].

Our hypothesis was that we found the same subchondral mineralisation patterns in the humeral head as others have found in the glenoid (particularly bicentric and monocentric patterns). Therefore, the objective of this work was to analyse the subchondral bone plate of the humeral head in macroscopically healthy shoulder specimens, to gain information about the distribution of mineral density in the subchondral bone plate of the humeral head.

Materials and methods

Specimens analysed

This study included 69 shoulder specimens fixed in formalin (from 47 body donors, 24 men, 22 women, 1 unknown gender, aged 19–96 years) from the dissecting course at the University of Basel and from the Anatomical Institute of Ludwig Maximilian University in Munich. The average age was 63 years. All specimens <30 years (9 specimens) were considered as a control group. We examined all shoulders macroscopically, specimens with obvious signs of degeneration or traumatic findings as well as specimens with a known medical history were excluded.

CT-osteoabsortpiometry (CT-OAM)

Since CT-OAM [10] is based on conventional CT datasets the previously dissected shoulder specimens were scanned in a GE Lightspeed 16 X-ray CT scanner (General Electric Healthcare Corporation, Waukesha, WI). Afterwards, the datasets were uploaded into a workstation (IBM, RISC System/6000), and an image analysing program (ANALYZE, Mayo Clinic, Rochester, MN, USA) was used.

In a first step we isolated the articular surface of the humeral head for 3D reconstruction and recorded it in a frontal view. Then, the subchondral bone plate was segmentated in the individual CT-cuts and 3D reconstructions were rendered using a maximum intensity projection (MIP), to allow visualisation of the density distribution. Then, steps of 100 Hounsfield units (HU) were assigned to false colors, high density values (>1,200 HU) were typified black, followed by red, orange, yellow and green, very low density values (<200 HU) were blue. The final densitogram was achieved by superimposing the false color images over the reconstructed humeral heads (Fig. 1). The final densitograms displayed the individual subchondral mineralisation patterns of the humeral head. For better comparison of the individual distribution patterns, a standardised grid (21×21 units) was projected onto the humeral head. This allowed us to determine the exact coordinates of the mineralisation maxima and to compare them in a summary chart.

Statistical analysis

In a first step, groups of corresponding maxima were built visually using a summary chart (21×21 units). To test if the differences in age between the monocentric and the bicentric mineralisation patterns exist, mean values and standard deviations of each group were calculated. To evaluate possible statistical significance, the mean values of the two groups were compared using *t* test. The level of significance was defined at 95%.

Results

The evaluation of the summary charts revealed two different mineralisation patterns. 49 humeral heads (71% of 69 specimens) showed bicentric subchondral mineralisation patterns with ventral and dorsal maxima (Fig. 2). The localisation of the maxima was determined by coordinates x/y. The mean value for x_1 (ventral maximum, $n = 49$) was 5.0 ± 1.5 IU, the value for y_1 was 12.9 ± 3.2 IU. The dorsal maximum was determined by the coordinates x_2/y_2. The mean value for x_2 was 16.1 ± 1.2 IU and for y_2 13.7 ± 1.8 IU. The mean age of the bicentric group was 59 ± 25 years. 20 humeral heads (29% of 69 specimens) could be classified as monocentric with a centro-dorsal accentuated maximum (Fig. 3). The mean value was 13.3 ± 3.9 IU for x_3 and 13.6 ± 3.1 IU for y_3. The mean age of the monocentric group was 69 ± 20 years.

All specimens of the control group (<30 years old, 9 specimens) showed bicentric mineralisation patterns.

We found no statistically significant difference between the age of the monocentric and the bicentric group on a significance level of 95%.

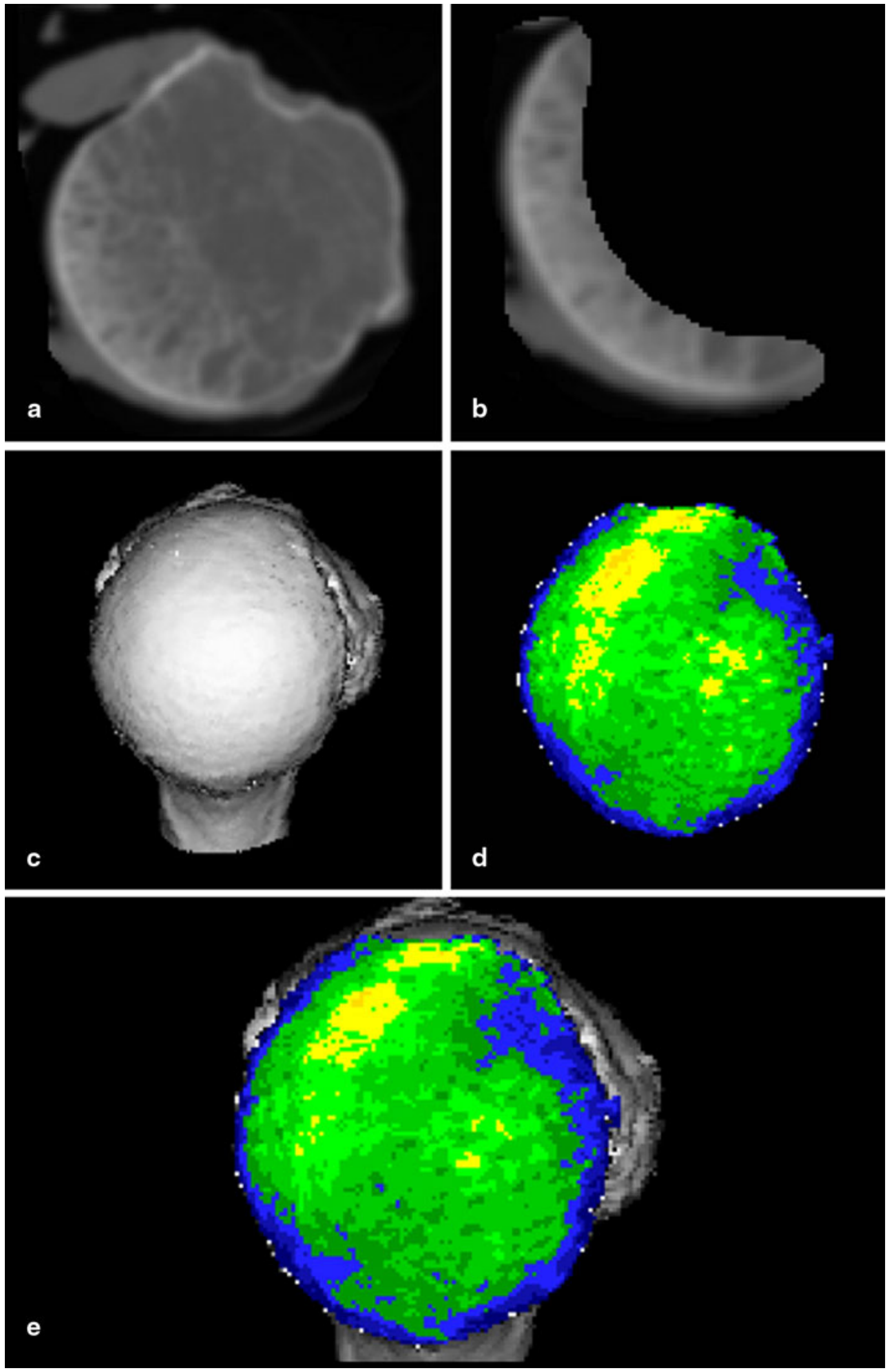

Fig. 1 Procedure of CT-OAM. **a** Isolation of the articular surface. **b** Isolation of the subchondral bone plate. **c** 3D reconstruction of the articular surface. **d** Visualisation of the subchondral mineralisation distribution by use of MIP-algorythm. **e** Superimposition results in a finished densitogram

Discussion

Subchondral mineralisation patterns reflect the loading history in diarthrodial joints [2, 10]. The distribution of subchondral bone mineralisation is not only dependent on compression, but also on tension and bending [3] and can be used as a morphological correlate of stress. It is well known that mineralisation patterns of the subchondral bone plate are dependent on the shape, geometry, side, age, and individual functional demand of a joint [1, 4, 9, 11, 15]. Density maxima are always located in regions with increased stress over longer periods of time. Muller-Gerbl [9] demonstrated that younger individuals often showed a higher density level of subchondral mineralisation compared with older specimens. The reason for this could be a higher level of activities and more individual muscle power in younger individuals [9, 10]. Some authors demonstrated that pathologic conditions may alter subchondral bone

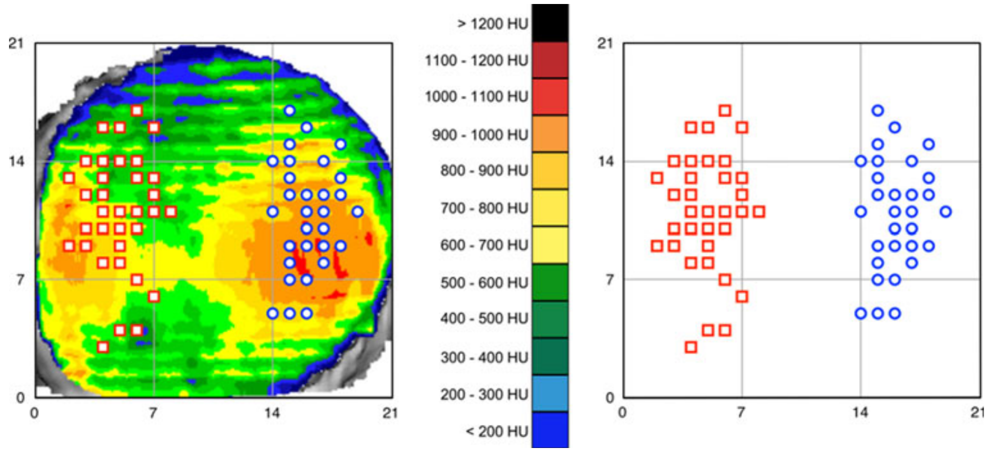

Fig. 2 Summary chart of all bicentric humeral heads (ventral is on the *left*, dorsal on the *right*)

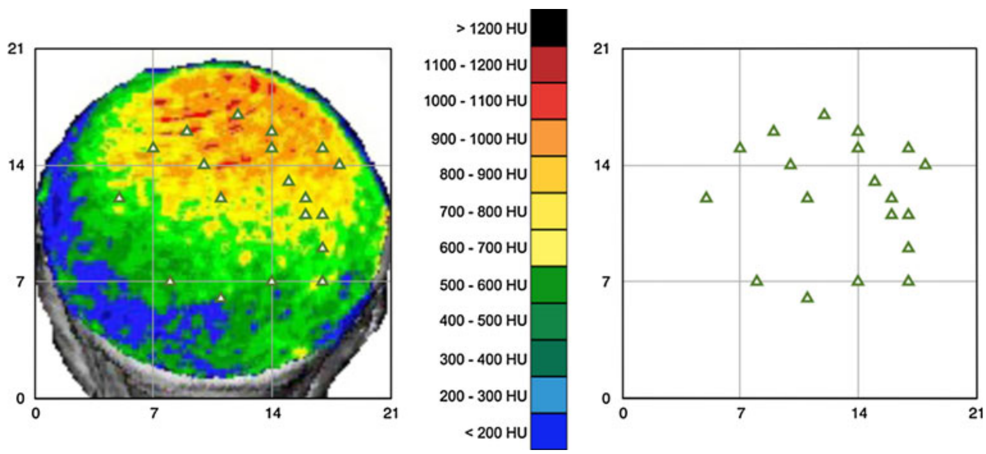

Fig. 3 Summary chart of all monocentric humeral heads (ventral is on the *left*, dorsal on the *right*)

mineralisation patterns. Patients suffering from a cuff arthropathy with a fixed decentering of the glenohumeral position to superior reflect these pathologic circumstances in a superiorly decentered mineralisation pattern in the subchondral bone plate [16]. These findings show that the changes of the kinematic situation influence the long-term stress distribution of a joint. This underlines the importance of an early pre-operative identification of such cases, to fix subluxation tendencies intra-operatively and improve post-operative results.

A method for pre-operative identification is the CT-OAM as described by Muller-Gerbl [10]. Based on conventional CT datasets, the CT-OAM is known to be a reproducible and highly sensitive method to determine the mineralisation of the subchondral bone plate. The method is particularly sensitive to small changes in concentration of subchondral bone mineralisation [7]. In contrast to the usual methods of CT densitometry, which deal with the calculation of an absolute value for bone density in a larger area including compact and cancellous bone, CT-OAM is a procedure for demonstrating differences in relative concentration within a joint surface [10]. Another advantage of this method is the applicability in vitro as well as in vivo.

We assumed to find different mineralistion patterns in the subchondral bone plate, including the position of maxima and the extension of density areas. Such inhomogenous mineralisation distribution has already been demonstrated for the glenoid cavity and for many other joints of the human body [6, 12].

As expected, we found an inhomogenous distribution of the subchondral mineralisation. More precisely, we found two different mineralisation patterns. 49 of our 69 specimens were classified as bicentric with a ventral and dorsal maximum of subchondral mineralisation. These findings can be explained by the physiologic incongruence of the glenohumeral joint as a principle of physiologic stress distribution to prevent osteoarthritis [1, 9, 10, 15]. This concept of a physiologic mismatch is supported by Soslowsky [14], who described the importance of the articular cartilage for glenohumeral congruity. Other authors described the predominance of bicentric mineralisation patterns at the subchondral bone plate of the glenoid [12], which indirectly supports our findings on bicentric patterns in the humeral head and the concept of physiological mismatch for the glenohumeral joint [9, 10].

20 humeral heads showed a monocentric pattern with centro-dorsal accentuated density distribution. Muller-Gerbl mentioned a loss of incongruity with increasing age, which would explain the more centrally accentuated mineralisation maxima [8, 9]. Schulz et al. [12] described the preponderance of several muscles (infraspinatus muscle and teres minor muscle) of the rotator cuff during internal rotation, which could be another explanation for these monocentric mineralisation patterns. This preponderance leads to a ventrally decentered humeral head, the ventral contact area shifts towards the center of the humeral head.

The results in our control group with specimens aged under 30 years underline the preponderance of bicentric mineralisation patterns in younger people.

The distribution of mineralisation and bone density in the subchondral bone represents the loading history of a joint. We conclude from our findings that long-term stress on a healthy shoulder is typically bicentric with a ventral and dorsal maximum. In about one quarter of the glenohumeral joints, a monocentric pattern with a centro-dorsal maximum occured, which can be explained by a loss of incongruity with increasing age. The knowledge of these two mineralisation patterns should make it possible to identify aberrant pathologic circumstances to treat them early enough.

All experiments comply with the current laws of Switzerland.

Conflict of interest The authors declare that they have no conflict of interest.

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