Predicting thumb osteoarthrosis using morphology: a 3D statistical shape analysis

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Abstract: Shape variations are linked with the development of osteoarthritis in various joints, but the correlation between morphologic variations and osteoarthritis in the first carpometacarpal joint is not yet proven. The purpose of the present work was to find morphologic variations in the first carpometacarpal joint, composed of the first metacarpal and trapezium, that could be correlated with the development of osteoarthritis. This was achieved by using multi-object statistical shape modelling to analyse the variation in shape within, and between, three populations, including two pathological populations: a progressive one, where the osteoarthritis level increased from I to II over time; and a stabilised population where the osteoarthritis remained in stage I through time. The control group consisted in a healthy population that did not develop osteoarthritis over time.

The analysis of the differences amongst populations was conducted by a qualitative and quantitative approach. The qualitative approach aimed to compare two bone models based on a distance map that point out the sites where there were differences. The quantitative approach resulted in the measurement of four morphologic parameters, namely the tilt angle, torsion angle on the first metacarpal and width and length on the trapezium.

Despite the variability in bone shape, pathological people tended to have the first metacarpal shorter and thicker and the articulating surface of the trapezium more convex. Regarding the morphological parameters, the tilt angle was found to be significantly different between healthy and stabilised populations, which supports the hypothesis that bone shape may help predict osteoarthritis.

Key words: First carpometacarpal joint, early stage osteoarthrosis, statistical shape modelling, osteoarthrosis predictor, tilt angle, morphology.

1. Introduction

Osteoarthrosis (OA) is the most common joint disease in the world. Approximately 1.5 million people in the UK alone have sought treatment for OA of the hand or wrist, over a seven-year period (Arthritis Research UK, 2013). Although this is not the most common site for OA, it is highly impairing in the late stages of disease (Kalichman, Hernández-Molina, 2010). The joint that most impairs hand function when affected by OA is the first carpometacarpal (CMC) joint, which is located at the basis of the thumb, connecting the first metacarpal and trapezium. Being responsible for thumb mobility, it is fundamental for hand functionality. First CMC-OA diagnosis is a complex multifactorial process. It requires qualitative assessment of a patient's history of pain, physical assessment and a classifier. There are two classifiers: the Eaton that recognizes four stages of this condition through radiography of the thumb(Ladd *et al.*, 2015), and the Badia score that categorizes patients into three stages through an arthroscopy (Gillis, Calder & Williams, 2011). Despite the continual development and improvement of these tools, the diagnosis can be ambiguous, especially in the early stages of this condition (Neumann & Bielefeld, 2003).

Early detection of first CMC-OA is fundamental since this disease is only perceived when it is already having an impact on people's lives. Moreover, as this condition progresses, the impact on people's lives increases substantially. Developing methods that allow an early detection may have a great impact in delaying the evolution of the disease. The impact of this condition on daily routine is significant. Note that little hand movements like grasping, the most common daily hand movement performed (Schieber & Santello, 2004), becomes impossible to perform when this disease progresses.

Although first CMC-OA physiological, etiological and pathological mechanisms are not yet fully

understood, there is research that supports the hypothesis that, amongst other factors, the shape of the bones in first CMC joint can be correlated with the development of OA (Schneider *et al.*, 2018). Yet, research is needed in order to reinforce this correlation, such as, quantitative parameters, that allow a more objective analysis. Often, the study of shape is performed, using statistical shape modelling (SSM). This method allows us to perceive the shape of a certain set of structures, giving as output, the mean model shape of this set of structures and its variations (Cootes *et al.*, 1995).

With this work our intent was to find a predictor to identify early stage OA, based on the differences that might exist in bone shape. The identification of morphological predictors would allow prevention, stopping disease progression and/or increasing the treatment options based on the first CMC bone's shape.

2. Methods

This investigation was conducted through the application of a 3D multi-object SSM analysis on healthy and pathological populations. The It was carried out quantitative and qualitative analyses in each population, followed by a comparative analysis to assess the differences in bone shape, in both approaches. The qualitative analysis was conducted by assessing the difference between two bone models. To perform the quantitative analysis, four morphologic parameters were measured. In the first metacarpal, the tilt and torsion angles and, in the trapezium, the width and length were measured. Posteriorly, the measured parameters were compared between healthy and pathological people. In order to verify if there was a parameter that correlates with OA development and/or evolution.

Dataset description

The dataset used was provided by a research group from Brown University (Halilaj et al., 2014) who made a comprehensive study to analyse the development of OA in the first CMC joint throughout time. This study was meant to provide a broader understanding about CMC-OA. The dataset contained CT (Computed Tomography) scans of the hand and classification of OA stage. The selection of subjects to be analysed in the present study followed three criteria considering the aim of having different populations evaluated over time. Each group had to have more than twenty subjects to have good representability. The subjects grouped together had to have the same OA stage in the baseline assessment and the same evolution over time. Only subjects diagnosed with stage 0, I and II were considered, this criterion was defined since it is easier to analyse less damaged bones. Furthermore, if a correlation between shape and OA development can be made on early stage OA, shape correlation is likely to exist as well on advanced stage OA.

Among the selected subjects, some were healthy at the beginning, some already had OA. In the end, some subjects remained healthy or maintained their OA level, whereas others worsened throughout time. In order to find the morphologic variations in the first CMC joint associated to OA, it was necessary to select which data was relevant for analysis to be analysed. From the 136 subjects in the dataset, three populations were formed: healthy, stabilised and progressive. The dataset allowed the progression study of OA since it contained at least two CT scans of every subject at different moments in time. An initial time (T0) was established at baseline and final time (T1) one year and half or six years later. Given that the present study was mainly focused on the subjects OA stage, the amount of time between observations was not considered. Therefore, although three populations were defined, each population comprised two groups (T0 and T1), resulting in a total of six groups that were analysed.

The healthy population was composed of subjects that were asymptomatic in the initial (T0) and final moments (T1). It comprised 22 subjects, 8 and 14 of which were male and female, respectively. This population was the control group, since allows to perceive the normal joint shape. The stabilised population included subjects with stage I CMC-OA at T0 that did not evolve at T1. This population had 27 subjects, from which 13 were males and 14 were females. The final group, denoted as progressive population, included subjects whose CMC-OA stage evolved from type I to type II. This group comprised 36 subjects, 19 males and 17 females. Both stabilised and progressive populations are pathological.

Data Correction

The hand CT scans were already segmented using the software Mimics (v.17, Materialise, Belgium) and contained all hand bones in separate files. Left hands were mirrored to the right hand so that all files were displayed in the same orientation. Although the data given comprised thirteen hand bones, only the first

metacarpal and trapezium were relevant for the present study. Yet, due to its proximity and possible interest of study in advanced cases of OA, the scaphoid, bone close to the trapezium, also underwent the process of correction for post segmentation errors.

The correction of post segmentation errors is a key step since it smoothens the surfaces and corrects segmentation inaccuracies, allowing a sounder statistical shape analysis (Liu, Dong & Peng, 2010). The software Geomagic Studio 12 (Raindrop Geomagic, Research Triangle Park, NC, USA) was used for this purpose. Three tools from this software were used: Reduce noise, Relax polygons and Mesh Doctor. These tools have different levels of strength that were chosen after a careful analysis. After application of each tool, the variation in shape could be observed, allowing the evaluation of which level performed better in smoothing the surface without removing the characteristic features in each shape.

Statistical Shape Modelling

In this research, a multi-object SSM was performed. The technique used was developed in-house by Wan Rusli (Rusli & Kedgley, 2019) in Matlab (R2016B, Mathworks, Natick MA, USA) and in RStudio. This method is split into two parts. The first part enables the alignment and registration (Myronenko & Song, 2010; Rodolà *et al.*, 2015; Li, Sumner & Pauly, 2008) process that altogether allowed point comparison among samples, as output the shape vector was generated, which describes the coordinates of the points of each subject. The shape vector presents 3N columns, being N the number of landmark points and M lines, being M the total number of samples in a group. The second part consists in a statistical method, PCA (Principal Component Analysis), which allows the down-sampling and creation of PC models. This is achieved by computing the covariance matrix among the structures studied. From the covariance matrix the eigenvectors, that translate the main directions and the eigenvalue (a magnitude coefficient attached to the eigenvector) are attained, allowing the PC construction.

In the end, using the software *MATLAB*, the mean model was computed. The principal component models are generated according to equation (1), adapted from Rusli & Kedgley, (2019):

$$x_{ik} = \bar{x} + k\sqrt{\lambda_i}\varphi_i, \qquad (1)$$

where $\bar{x}$ represents the mean model and φ_i represents the $i-th$ eigenvector that varies between $1 < i < M$, where M is the number of samples inserted on the PCA. The term $k\sqrt{\lambda_i}$ is the weighing factor, in which λ_i represents the eigenvalue that translates the variance and the square root of variance ($\sqrt{\lambda_i}$) is the standard deviation. By multiplying $\sqrt{\lambda_i}$ by k the user can assess a wide range of variation. Considering normal distribution, k is usually set to $-2 < k < 2$ to obtain a confidence interval of 95%. Therefore, the variance present in each PC should vary linearly with k.

Shape analysis

In order to conduct analysis of the shape two approaches were conducted, a qualitative one, in which the global bone shape within and between groups was compared; and a quantitative approach, in which morphologic parameters of the first CMC were defined, measured and statistically analysed. The aim of both approaches was to detect differences between healthy and pathologic populations.

It is important to state that the samples that were analysed in each group were the mean and the first two principal components. In each PC, the variation was considered setting $-2 < k < 2$, thus, besides the mean, four more models were assessed (-2SD, -SD, SD and 2SD). The SD (Standard deviation) models were analysed to guarantee an analysis of a wide range of variation in each PC. Moreover, it also allows the validation of the linear relation of the morphologic parameters measured in the SD models. Regardless of the number of modes that were found relevant to be analysed, the measurement of the morphological parameters was only carried on the first two modes of each population because, from the third mode on, the articulating surfaces exhibited lack of definition, especially on the borders' surface, amongst other details that altered its usual shape. This made the protocol unpracticable from the third PC on. This lack of definition was more prevalent on the populations that already suffered from OA, who presented more modifications in shape. However, for sake of consistency, the same procedure was applied in all groups.

The qualitative comparison was conducted in *Materialise 3-matic* software, using the tool *Create Part Comparison*. This analysis is characterized by the comparison between two bone models, assessing its differences in a qualitative way. This analysis is meant to oversee the morphologic

changes of the bone shape. Firstly, it is necessary to assess the number of PCs that are relevant to the analysis. Afterwards, the characterization of each population was achieved, and finally comparisons between groups were made to understand if there were differences between populations.

The measurement of morphologic parameters allows quantifying bone shapes and making comparisons between groups that have different characteristics. These measurements were done using *Materialise 3-matic* software. To measure these parameters, each bone of the first CMC joint, first metacarpal and trapezium, followed a different protocol, according to Rusli & Kedgley, (2019), due to their different bone morphology. As displayed in Figure 1, in the first metacarpal two angles were measured. The tilt angle, $\theta = 90 - \sigma$, and the torsion angle β. In the trapezium articulating surface, both the width (orange) and length (green) were measured.

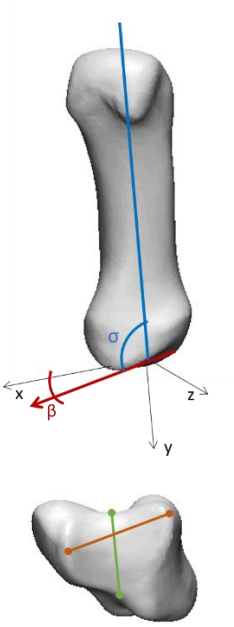


Figure 1 – Illustration of the morphological parameters measured on the first metacarpal. The tilt angle θ=90-σ is represented in blue and the torsion angle β is represented in red. And in the trapezium articulating surface, width in orange and length in green.

Statistical analysis

The statistical analysis was carried to examine the measurements done. Correlation and statistical significance need to be assessed in order to take robust conclusions. The statistical analysis was performed using IBM SPSS Statistics (ver. 25 IBM Corp., Armonk, USA).

Pearson correlation coefficient, i.e R, was calculated, between the measurements done in each PC of each morphologic parameter and the trend {-2, -1, 0, 1, 2} that translates the SD behaviour. To decide which PC best fit a given morphologic parameter (tilt, torsion, width and length), the correlation strength was given by R value. The R value is statistically significant if p-value is bellow 0.05.

Paired t-tests were done to understand if there were a significative difference in the morphologic parameters measured between T0 and T1.

Independent t-test were done to understand if there were significative differences between populations morphologic parameters.

3. Results

Qualitative analysis

Populations characterization

This analysis was meant to observe the differences regarding bone shape between different populations.

Firstly, it is important to characterize each population. From the analysis of the variations in healthy population, it was observed that concerning the head of the first metacarpal variation on the distal side was observed. This variation, whether positive or negative, is related with the bone length increase or decrease, with stronger variation found for the first two PC. Shaft thickness variations were also detected in some of the PCs that presented length variation. As the PC shaft got longer, it became less thick and vice-versa. On the palmar side of the head of the first metacarpal, there were two protuberances that concentrated variation. Some variation in the condyles and in the extremities of the head on the ulnar and radial sides were also found. Regarding the base of the first metacarpal, there was variation all around, meaning that there was thickening and shrinking occurring at the base. Variations on the volar beak of the base were prominent. The articulating surface exhibited greater variation on the ulnar side. With respect to the trapezium articulating surface, variation was more concentrated on the periphery. By examining all PCs, it can be seen that both ulnar and radial ridges presented variation, with the radial variation being more prominent. The palmar depression presented variation in most PCs.

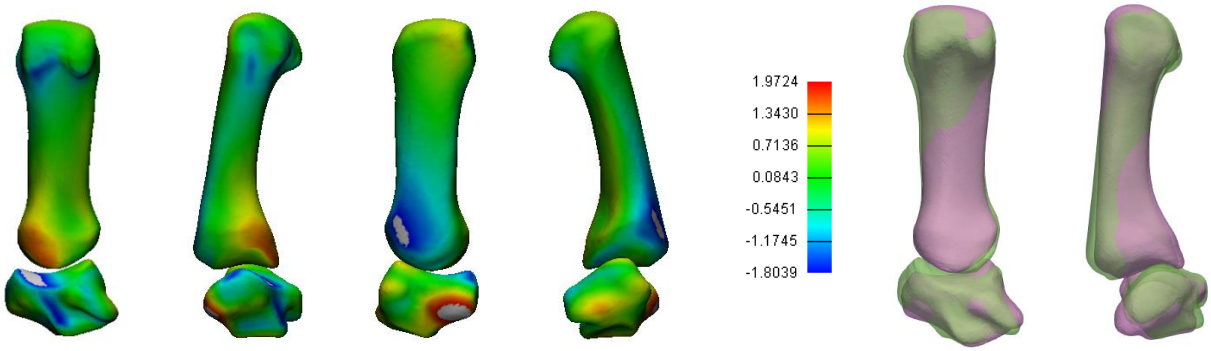
The analysis of stabilised population allowed the following observations: regarding the first metacarpal, it is noteworthy that the stabilised population exhibited more marked variation, mostly in the shaft, compared to the healthy population; the variations in the shaft occurred mostly in the ulnar and radial sides. However, there are also PCs that presented variation all around the shaft. The distal and palmar sides, and the protuberances of the head exhibited, once again, variation in almost all PCs. Variations in the base were also found. All PCs presented variations on the volar beak, except the first and third PC that presented variation in the ulnar or the radial side. The articulating surface presented more variation in the palmar/radial ridge in the two first PCs, while the remaining PCs presented more variation in the palmar ridge. Concerning the trapezium articulating surface, variation concentrated more on the periphery in all PCs. The ulnar and radial ridges presented variation, from the third PC onwards. The palmar depression presented variance in all PCs.

Finally, the progressive population was characterized for the following variations. The first metacarpal variations in this population were similar to those of the healthy and stable populations. The base of the first metacarpal presents strong variation, towards the volar region. The articulating surface exhibits more prominent variation in the palmar/ulnar ridge. Regarding the trapezium, the variance was mostly observed on the periphery of the articulating surface and it was more concentrated. The first mode - that accounts for most of the cumulative variation - showed, generally, a small variation, which is more concentrated on the palmar depression and ulnar ridge.

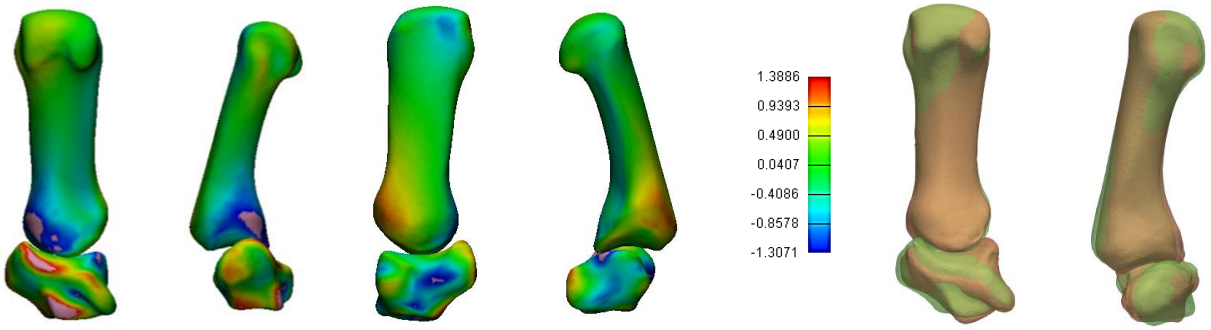
Populations comparison

Accordingly, comparisons between healthy and stabilised populations, as well as between groups presenting the same CMC-OA stage, were performed Figure 2 illustrates the outcome of all comparisons performed.

The comparison between heathy and early stage OA showed a marked variation on the ulnar side of the volar beak. The overlapped bones showed that



(a)



(b)

Figure 2 - Comparison between groups that were diagnosed with stage I OA at the first CMC joint. Comparison between groups diagnosed with stage I OA at the first CMC joint: (a) Healthy T0 VS Stabilised T0, (b) Stabilised T0 VS Progressive T0, 1. The colour grid represents the distances between models in millimetres. Models on the left life are corresponding to: purple-healthy T0, green-stabilised T0, orange-progressive T0

for the early stage OA population the bone suffered a backwards translation. The trapezium ulnar ridge was flat in the healthy population and more convex in stabilised population.

From the comparison of the two populations that were diagnosed with stage I OA, i.e., stabilised T0 and progressive T0 groups, a negative variation at the volar beak in the ulnar region was identified at the base. In the radial region, a similar, but positive, variation was observed. Examining the trapezium, the variation was widely spread, and more visible along the radial ridge of the articulate surface. Both comparisons presented wider variation. Although both groups were classified as stage I OA, there was significant variation between them.

These comparisons could be interesting if the morphologic aspects that are linked with OA development are inherent to the individual and not an aspect that develops through time. More research is needed

Quantitative analysis

Having the first PCs of each group measured for all four morphologic parameters, the Pearson correlation coefficient was calculated. Based on this value the PC for each morphologic parameter in each group was chosen. The following statistical analysis was made with these PCs.

To assess if there were statistically significant differences between T0 and T1 in each population, a paired t-test was performed. This test was done with the parameters obtained. Before performing this test, the normality of the difference between the paired groups was confirmed.

As displayed in Table 1, the tilt angle, torsion angle, and width measurements did not exhibit statistically significant differences between T0 and T1 across all populations. The stabilised population presented a significant difference regarding the length of the trapezium articulating surface.

*Table 1 – P-values resulting from the paired t-test for the healthy, stabilised and progressive populations, between T0 and T1. *Statistically significant, p-value below 0.05.*

T0 VS T1	*Tilt*	*Torsion*	*Length*	*Width*
Healthy	0.408	0.358	0.637	0.143
Stabilised	0.565	0.105	0.012*	0.952
Progressive	0.981	0.550	0.511	0.506

With the aim of understanding if the parameters measured were significantly different between populations, and therefore able to distinguish OA condition, independent t-tests between populations were performed and charts displaying the mean and SD are presented. For each population, T0 groups were used for the comparisons. T0 groups were used because in the previous analysis all parameters, except trapezium's length on stabilised population, were considered changeless between T0 and T1.

The independent t-tests were performed comparing two populations at a time. The independent t-test has some constrains that needed to be verified previously. Apart from the torsion angle in the healthy T0 group, all measurements followed a normal distribution. For the healthy group, the torsion angle of the T1 group was used instead since it satisfied the normal distribution constraint.

Table 2 displays the p-values that resulted from the independent t-tests. Concerning the tilt angle, there were statistically significant differences between the healthy and stabilised populations, diagnosed with stage 0 and stage I OA, respectively. Between the healthy and progressive, and stabilised and progressive, populations the differences were not significant. Yet, the p-value between the healthy and progressive populations was closer to 0.05 than between the stabilised and progressive populations.

*Table 2 – P-value of the independent t-tests performed between populations for each morphological parameter. For first metacarpal, tilt and torsion angles were considered, and for the trapezium articulating surface, length and width were considered. *Statistically significant, p-value below 0.05.*

	Tilt	*Torsion*	*Length*	*Width*
Healthy - Stabilised	0.041*	0.955	0.734	0.138
Healthy - Progressive	0.128	0.937	0.000*	0.000*
Stabilised - Progressive	0.948	0.843	0.000*	0.000*

Regarding the torsion angle, no statistical significance was found. The p-values were close to 1. The comparison between the healthy and progressive, and stabilised and progressive, populations demonstrated to be statistically significant for the length. The comparison between healthy and stabilised populations revealed high p-

values. Finally, considering the width, the progressive population was statistically significantly different from both stabilised and healthy populations, as found for the length. Although the healthy-stabilised comparison was not significantly different, its p-value was close to 0.05.

4. Discussion

Qualitative analysis

Regarding the characterization of populations, some hypotheses can be formulated. In the stabilised and progressive populations, the variance in the shaft of the first metacarpal was more prominent than in the healthy population. These populations exhibited PCs with negative and positive variations in the ulnar and radial sides of the first metacarpal alternately. This could mean, that one of the possible variations was a small rotation of the bone. Most of the PCs exhibited variation on the palmar ridge of the articulating surface of the first metacarpal, which could be linked with the length enlarging or even with rotation along the length of the bone. The trapezium articulating surface often exhibited variations on both ulnar and radial ridges. This could signify that there is a change in the articular surface concavity, which could influence the mobility of the first CMC joint and, ultimately, be linked with OA evolution. Although all three populations presented a broad variation, differences existed between them. Variations were stronger on the progressive population, and the variation distribution was different. The qualitative analysis of the differences in bone shapes reinforces the hypothesis that a difference exists between the healthy and stabilised or progressive populations. Moreover, it provides the characterization of these populations for future work.

Finally, the three populations were compared directly. While comparing a healthy population with a population with early stage OA, Schneider et al. (2018) concluded that people who suffered from CMC-OA exhibited a lower aspect ratio (length to width ratio) exhibiting a shorter and thicker first metacarpal. The results obtained in the present work agree with these findings. The comparison between healthy and stabilised populations, that suffers from early stage OA, revealed that the first metacarpal of the healthy population was slightly longer and narrower than the first metacarpal of the stabilised population. Besides that, this comparison also brought to the attention that the stabilised population had the volar beak of the first metacarpal indented comparatively to the healthy population. This deterioration may be linked to the volar ligament degeneration that has been previously associated with OA (Doerschuk et al., 1999; Pellegrini, 1991). In addition, Halilaj et al., (2015a) reached the conclusion that the higher variation towards dorsovolar curvature of both metacarpal and trapezium, was linked to OA development. This is in agreement with the findings observed in this research in the comparison between healthy and stabilised populations. Concerning the trapezium, the present work shows that while the healthy population exhibited the ulnar side of the articulating surface flat, the stabilised population presented this ridge elevated, deepening the subchondral articular surface. This is displayed when directly comparing the healthy and progressive population. These findings are similar to those reported by Schneider et al., (2018) and Kovler et al., (2004), which were not considered to cause OA development, but instead were associated with joint degeneration as a consequence.

In addition to this, through the comparison of stabilised and progressive population, the difference between populations for whom the disease progressed or not was also assessed. Although both groups compared were diagnosed with the same OA stage, the variation between them was relevant. However, it presented less variation than the previous comparison between two populations with different OA scores. There was major variation on the ulnar side of the volar beak, which could be linked, as stated before, with the volar ligament degeneration. The trapezium variations concentrated more on the periphery, and this behaviour was previously linked to osteophyte formation (Kovler et al., 2004), which was expected since these populations suffer from OA. The qualitative analyses performed suggest that there might exist differences among populations.

Quantitative analysis

The present research aimed to quantify morphologic parameters and correlate them with OA stage using multi-object SSM. Previous studies have tried to measure morphologic parameters in the first CMC joint, such as angles, in X-rays (Kurosawa, Tsuchiya & Takagishi, 2013). Yet, due to the incongruent configuration of the first CMC and to the 2D limitation of the X-ray, contributions to assess joint's stability have been limited. Research done

with fluoroscopy, has dazed this limitation, and made possible the assessment of morphologic parameters (Miura, Ohe & Masuko, 2004). Using this technique, volar tilt angle was studied amongst pathologic and control groups and found to be greater in pathological people. Despite the current study using CT data, this is consistent with the finding of Miura, Ohe & Masuko (2004). The tilt angle of the first metacarpal was found to be a statistically significant factor differentiating populations regarding their OA condition. The first metacarpal could be translated dorsally with high stress between the dorsal aspect of the articulating surfaces of the first metacarpal and trapezium (Kurosawa, Tsuchiya & Takagishi, 2013). This could explain why cartilage degradation is frequently observed to be initiated at the dorsal-radial region of the trapezium (Koff *et al.*, 2003). In this research, the same variation of the trapezium was found in the pathological population, further supporting this hypothesis. The torsion angle did not show specificity differentiating populations.

Concerning the trapezium articulating surface parameters, i.e., width and length. While on one hand they revealed to be significantly different between healthy and progressive populations, on the other hand, they showed differences between the stabilised and progressive groups, but no identifiable differences between the healthy and stabilised populations. The trapezium is a small bone that is under a lot of stress since its sides are all articulate surfaces of other joints, which can hamper its analysis and relations with CMC-OA. Besides that, by the analysis of the mean values for each population, it is possible to assess that pathological (progressive) people had greater length and width, which might contribute for the degradation of joint's stability and allow wider movements that ultimately could disrupt other structures.

Regarding the comparison of the same population between T0 and T1, the morphologic parameters did not show significant differences. This goes in agreement with Chu *et al.*, (2012) that had previously stated that OA was a condition that takes decades to develop. In fact, in the present work, even when comparing progressive population between T0 and T1, there was no significant difference in bone morphology according to the parameters measured. If bone structure does not vary significantly over time, the parameters assessed could be suggested to be inherent over time. Thus, by their examination at any moment in time, the health status of the first CMC could be predicted. For this hypothesis to stand, the healthy and pathological populations should be significantly different from each other. As previously stated, the tilt angle revealed to be significantly different between the healthy and stabilised groups. However, no statistical significance was found between the healthy and progressive groups, even though the p-value was low.

Despite the analysis performed on the principal components relevant to be analysed, only the first two PCs were considered for the measurements of the morphological parameters discussed here. From the third PC on, measurements could not be performed due to the lack of definition in the bone shapes. Nonetheless, it is worth noting that the exclusion of all PCs apart from the first and second is expected to have little impact on the results since these two first PCs represented a significant share of variance.

5. Conclusion

The present work aimed to find if people with first CMC-OA and healthy people could be distinguished by assessing the morphology of their bones. To attain this goal a multi-object SSM was used in three populations, one healthy and two pathological. Followed by a qualitative and quantitative analysis, that assessed four morphological parameters, the tilt and torsion angle in the first metacarpal, and the length and width in the trapezium.

The results revealed that the tilt angle of the first metacarpal showed significant differences between healthy and early stage OA populations. This was the parameter, that together with the qualitative analysis, showed more robustness. No difference was detected when T0 and T1 were compared, demonstrating that aging did not influence bone morphology. The qualitative analysis also exhibited results supporting that it is possible to differentiate healthy and pathological populations through bone morphology. Pathological first metacarpals were narrower and thicker.

This study provided further insight into the morphological changes between healthy and CMC-OA populations, and suggested a novel morphological parameter that may be able to distinguish healthy from pathological people and possibly help predict OA. This would enable physicians to better diagnose and catch the disease in a less severe stage. The greater impact would be felt in the daily life of patients, whose life is impaired by this condition.

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