CASE REPORT

ASSESSING POST-SURGICAL BONE DEFORMATIONS: INTEGRATING ANATOMY WITH COMPUTERIZED 3D MORPHOMETRY

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ABSTRACT

Geometric morphometrics, a powerful method for analysing structural shapes, has become increasingly significant in various disciplines, including anatomy, morphology, and clinical medicine. Unlike traditional morphometric approaches, geometric morphometrics offers a comprehensive understanding of shape structure, particularly when enhanced by 3D imaging techniques. In this study, we explored the potential of this method in a clinical setting, applying it to post-operative evaluations of surgically treated bones. Utilizing computerized tomography (CT) scans, we compared the shapes of surgically treated bones to their healthy, symmetrical counterparts, focusing on the changes that occurred during the healing process. The study involved CT images from patients who had previously undergone bone surgery, sourced from the archives of Istanbul University-Cerrahpaşa Veterinary Faculty Animal Hospital. Advanced software tools, including Slicer and the ALPACA module, were employed to generate 3D models and facilitate precise comparisons between operated and non-operated bones. Our findings revealed that while shape deformations in control group bones were minimal, surgically treated bones exhibited more pronounced changes. These deformations were often localized to regions affected by surgery, suggesting that the method is effective in detecting post-operative alterations. The computerized approach used in this study not only allowed for detailed morphological analysis but also demonstrated the potential for future applications in clinical practice. As technology continues to advance, integrating computerized methods with anatomical studies can enhance the accuracy of surgical evaluations and improve patient outcomes. This study highlights the importance of combining anatomical knowledge with computer-assisted techniques to develop more effective clinical tools for assessing surgical success.

Keywords: Computerized analysis, point cloud analysis, shape analysis, surgical outcomes

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INTRODUCTION

Geometric morphometrics is a contemporary method that enables the analysis of structural shapes across various disciplines, including anatomy, morphology, palaeontology, and biology (Mitteroecker and Gunz, 2009; Klingenberg, 2016). Unlike traditional morphometry, which primarily provides information on distances, angles, and ratios between points, geometric morphometrics offers a more detailed and comprehensive understanding of shape structure (Slice, 2007; Gündemir et al., 2023). Recently, the advent of 3D geometric morphometrics has further refined shape analysis, allowing researchers to explore new research questions with greater precision.

The foundation of geometric morphometrics lies in the placement of landmarks on structures (Slice, 2007). These landmarks, when mapped onto a Cartesian plane, form the basis for statistical analysis (Klingenberg, 2016; Boz et al., 2023). Landmarks can be identified manually or automatically through specialized software. One such tool, the ALPACA (Automated Landmarking through Point Cloud Alignment and Correspondence Analysis) module, facilitates automatic landmarking (Porto et al., 2020). This method achieves comparable landmark accuracy by relying on a single reference sample and less frequent sampling of the structure's surface. ALPACA uses a point cloud-based approach to find the optimal parameter set that best aligns a source model (with predefined landmarks) to a target model (where landmarks are to be transferred), allowing for the geometric comparison of two different objects.

In recent years, the integration of computer technologies into clinical skill evaluation has gained momentum. For instance, one study investigated the assessment of laparoscopic surgical skills using computer simulations (Grantcharov et al., 2001). Similar studies have employed artificial intelligence and computer-based software to evaluate clinical skills or provide objective measures of surgical success (Aucar et al., 2005; Reiley et al., 2011; Khalid et al., 2020). Another study highlighted the potential of explainable artificial intelligence in medicine, serving as a reference for both medical experts and AI scientists in designing medical AI applications (Zhang et al., 2022). As these studies suggest, advancing technology can serve as a valuable tool for evaluating clinical skills.

In this study, we utilized computer-based landmarking software to evaluate surgically treated bones. By employing geometric morphometrics, we compared the shape of the surgically treated bone with that of its healthy, symmetrical counterpart, monitoring changes after the healing process. The objective is to investigate the potential of geometric morphometrics as a tool for assessing the success of bone surgeries.

MATERIALS AND METHODS

The study utilized computerized tomography (CT) images obtained from patients who had previously sustained fractures in long bones and received surgical treatment after recovery. These images were sourced from the archives of Istanbul University-Cerrahpaşa Veterinary Faculty Animal Hospital (Table 1). Specifically, the study focused on samples that had undergone bone surgery and were re-imaged after healing, with the data collected between 2021 and 2023. CT scans were conducted using Siemens Somatom Scope vc30b and Siemens Somatom Sensation 16 systems. The scanning parameters for all samples were consistent: a slice thickness of 0.6 mm, 110 kV, and 28 mA, with a total scan time of 14 seconds. Segmentation of the images was performed using Slicer software (version 5.3.0) (Dyaksa et al., 2023), and soft tissues were removed to isolate the bone structures. Models of both surgically treated bones and symmetrical, untreated bones were generated and saved in ply format.

Table 1 Samples

Sample	Species	Surgically Treated Bone	Clinical Diagnosis	Surgical Treatment
Nr1	Dog (French Bulldog)	Left Humerus	Humerus distal metaphyseal comminated fracture	A 2.5 mm thick 2.7 mm screw compatible 8-hole locking anatomic plate was applied. Screw thickness was 2 x 24 mm and 6 x 22 mm long. Mineralized callus formation was seen on the 60th day control radiographs.
Nr2	Dog (French Bulldog)	Right Humerus	Right distal humerus intercondylar and supracondylar fracture	Osteosynthesis was performed with 1 intercondylar pin, 1 pin from the lateral condyle to the humerus medulla, and 1 pin from the lateral condyle to the humerus medulla. Mineralized callus formation was detected on the 90th day radiographs.
Nr3	Jackal	Left Femur	Left femur mid-diaphyseal oblique fracture, comminated fracture of left ischia and pubis, and right coxofemoral dislocation	It was treated with a 10-hole locked compression plate compatible with 2.7 screws of 2 mm thickness. Mineralized callus formation was detected on the radiographic controls on the 90th day after the operation. The plate was removed 15 days later under general anaesthesia.

In the study, bones were compared as surgically treated and non-operated. However, the bones were anatomically symmetrical to each other, with structures on opposite sides. For example, when viewed from behind, the head of the humerus is on the left side of the right humerus but on the right side of the left humerus. To ensure accurate comparison, mirror images of the non-operated bone samples were created using the Slicer program (Figure 1A). This allowed the bones to be aligned in shape, enabling a more precise comparison between the treated and non-operated bones.

To ensure consistent orientation, a 3D image of one symmetrical sample was first obtained. For automatic landmark placement, a preliminary draft landmarks were created using non-surgical samples as references (Figure 1B). This draft landmark set was generated using the 'PseudoLMGenerator' module in Slicer (version 5.5.0) with a 10% range tolerance. The draft landmark set was then applied to the symmetrical samples one by one using the ALPACA module. This method created point clouds of the solid samples based on the reference landmarks, which were subsequently superimposed (Figure 1C and 1D). After superimposition, the point clouds were solidified, and the bone shapes were compared (Figure 1E). Protruding areas were evaluated to determine the exact location and extent of shape differences, which were then examined morphologically.

RESULTS

In the study, 3D images of two opposing bones were superimposed to evaluate shape differences morphologically. The unoperated, healthy bone (shown in bone colour in the Figures) served as

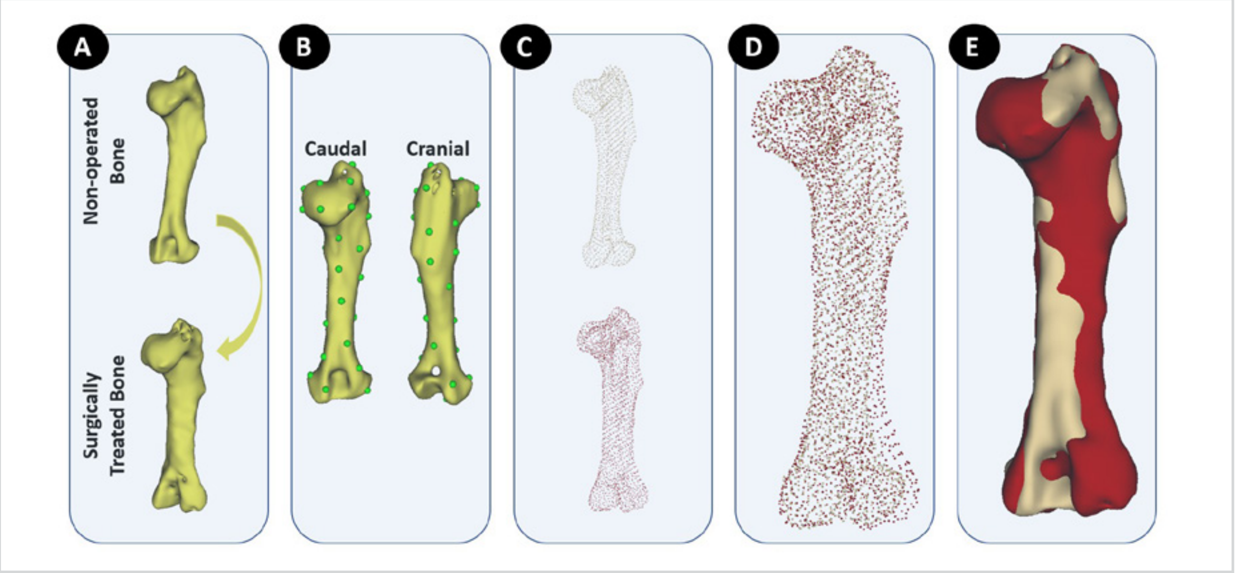

Figure 1A: The mirror images; **B:** The draft landmarks; **C:** The point clouds; **D:** The point clouds

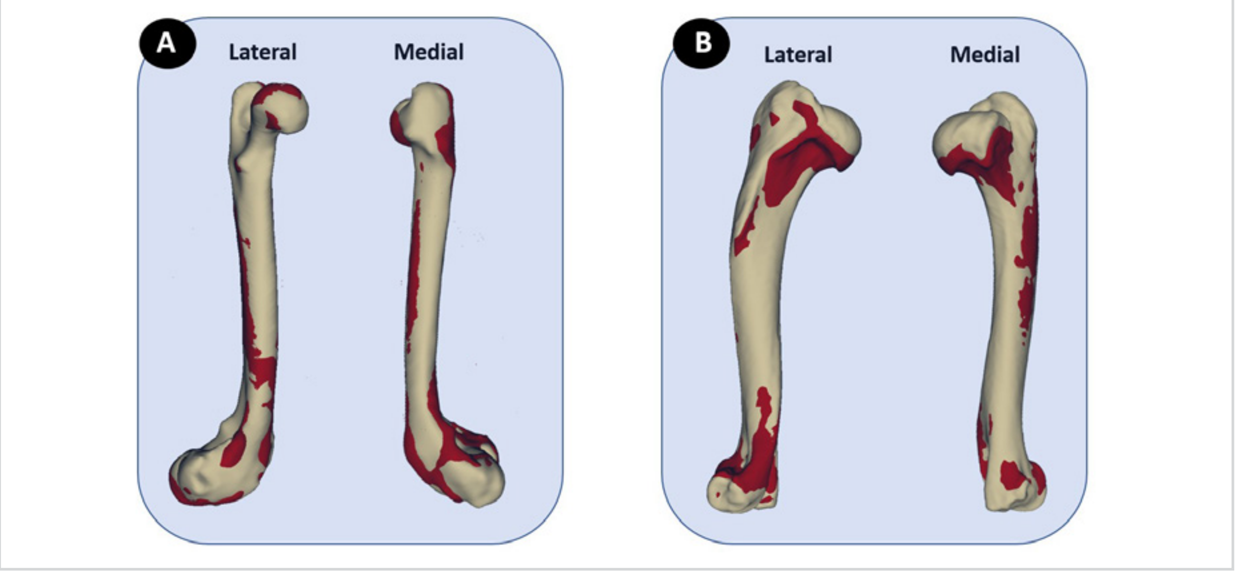

Figure 2 Control group. **A:** Femur models of a healthy dog. **B:** Humerus models of a healthy dog. Bone colour represents the left bone, red colour represents the right bone

the source bone, and the shape deformations of the surgically treated bone were compared against this reference. Deformed areas on the surgically treated bone were highlighted in red in the Figures, allowing us to assess the extent of overhangs and deformations relative to the healthy bone.

As a result of the study, bone pairs were superimposed in 3D, and shape differences were evaluated morphologically. Initially, the control group was assessed, revealing that the shape differences between the right and left bones in the control group were less pronounced than those in the surgically treated bones (Figure 2). The changes in the control group were not concentrated in any specific area, although a slightly more noticeable difference was observed in collum humeri. Despite this, the shape changes resulting from the surgical operations were significantly more pronounced compared to the control group.

Significant morphological differences were observed when comparing the surgically treated bone with its healthy counterpart (Figure 3). In the case of Nr1, where the distal metaphysis of the left humerus had been fractured, the models were analysed after healing. The shape deformation in the surgically treated bone was quite evident, particularly towards the lateral side. This deformation began at the caput humeri, extended along the lateral surface of the bone, and continued to the lateral condyle.

In Nr2, the distal humerus fracture was treated. As a result of healing, the shape deformations of the surgically treated bone compared to the healthy bone were evident in the distal region of the humerus.

In the case of Nr3 (Jackal), fractures were present in the coxae and femur. A particularly notable finding was the upward deformation of the caput femoris. Additionally, post-healing, there was a noticeable expansion in the body of the bone, which was likely a result of the healing process. Overall, the changes in the surgically treated bone were significantly more apparent compared to the unoperated sample.

DISCUSSION AND CONCLUSION

A method based on shape analysis was employed in this study to evaluate the post-operative outcomes of surgically treated bones. Notably, no prior clinical application of this method was found in the literature, making this study a pioneering effort. The results were promising, demonstrating

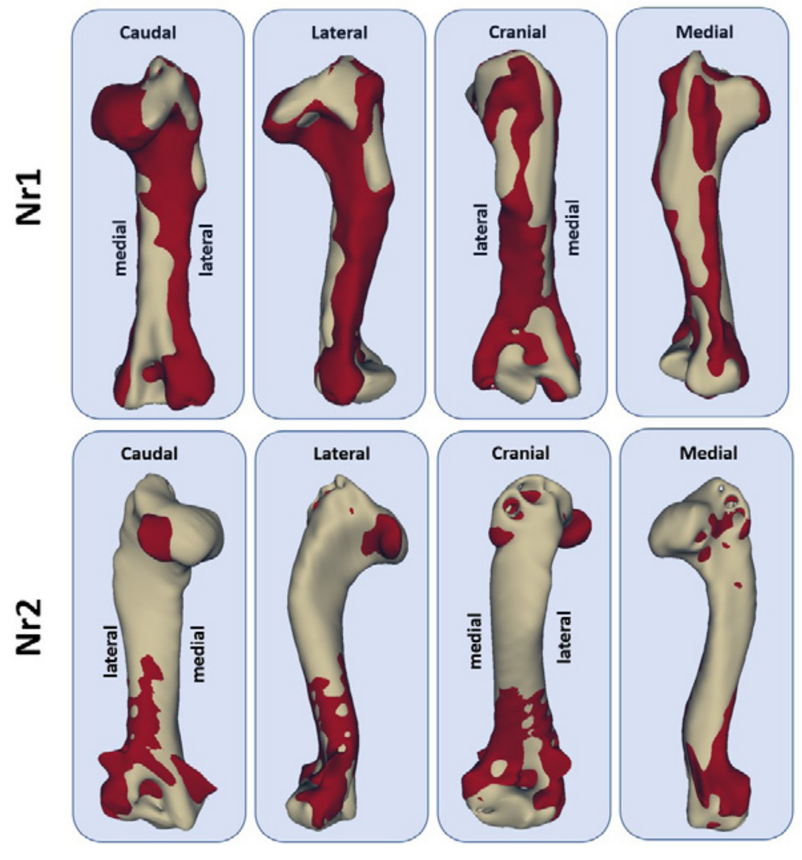

Figure 3
Superimposed models of healthy bone (shown in bone colour) and surgically treated bone (shown in red colour)

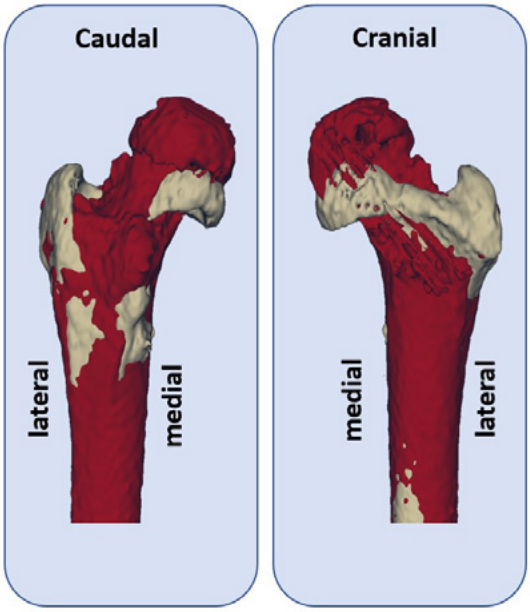

Figure 4

Superimposed models of healthy bone (shown in bone colour) and surgically treated bone (shown in red colour) of Jackal

that 3-dimensional visual analyses could be effectively utilized for morphological evaluations. This innovative approach allowed for the precise comparison of bone structures, revealing the extent of deformations that occurred as a result of surgical intervention.

The study utilized CT images to analyse recovery outcomes in two control groups and three animals that had undergone bone fracture surgery. In the control group, where no surgical intervention had taken place, deformations between the right and left bones were minimal and limited. However, in the surgically treated bones, deformations were significantly more pronounced. Importantly, these deformations corresponded closely to the regions of the bone that had been operated on, suggesting that this technique has strong potential for future clinical applications.

For instance, in the case of Nr1, the deformation occurred in areas where the brachialis muscle, one of the strongest arm muscles, attaches. This observation suggests that during the healing process, deformations may be influenced by the surrounding muscle groups, leading to shifts in bone structure towards these strong muscle attachments. Similarly, in Nr2, the distal humerus fracture showed a broader healing pattern than normal, which could be indicative of compensatory bone growth or remodelling during recovery. In the Jackal case, the significant positional change in the caput femoris due to healing raises concerns about potential long-term lameness or mobility issues, highlighting the importance of monitoring such changes post-surgery.

Despite these promising observations, the study faced limitations in drawing definitive conclusions regarding the accuracy of the applied technique or the success of the surgical interventions. The primary aim of the study was to explore the applicability of this novel shape analysis method and assess its potential for yielding meaningful results. Future studies with more homogeneous samples could further validate the technique and allow for the evaluation of surgical success based on post-operative bone healing.

One of the key limitations of this study is the inability to perform statistical evaluations of the results. Since each operated bone could only be compared to its healthy symmetrical counterpart, obtaining statistically significant data from these binary comparisons proved challenging. This limitation hinders the ability to make broader scientific conclusions from the data. Consequently, the current method allows for primarily visual and morphological assessments, which, while insightful, may be best suited for clinical evaluation rather than comprehensive statistical analysis.

In conclusion, this study demonstrates that shape analysis methods can provide valuable insights into post-operative bone healing. Although statistical validation remains a challenge, the visual and morphological differences observed in this study suggest that this approach could become a useful tool in clinical settings, offering a new way to assess surgical outcomes and guide future treatment strategies.

In conclusion, the use of shape analysis for post-operative evaluation of surgically treated bones proved to be a promising approach, offering detailed insights into bone deformations that are otherwise difficult to quantify. The method allowed for precise 3D comparisons between operated and healthy bones, highlighting significant morphological changes that corresponded with surgical intervention sites. While this study primarily focused on demonstrating the applicability of the technique, the findings suggest that shape analysis could become a valuable tool in clinical settings for assessing surgical outcomes and guiding future treatments. However, the limitations regarding statistical evaluation emphasize the need for further research with larger, more homogeneous sample sizes to validate these preliminary findings and enhance the method's clinical relevance. Despite these challenges, the study opens new avenues for integrating advanced imaging techniques into veterinary and possibly human orthopaedic practices.

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CONTRIBUTIONS

Concept and Design: SO, GS; Supervision: OG; Fundings: GS; Materials: YA, GS; Data collection and Processing: GS, OG; Analysis and Interpretation: YA; Writing and Critical review: SO, OG

CONFLICT OF INTEREST

The authors declared that there is no conflict of interest.

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PROCJENA POSTOPERATIVNIH KOŠTANIH DEFORMACIJA: INTEGRACIJA ANATOMIJE I KOMPJUTERIZIRANE 3D MORFOMETRIJE

SAŽETAK

Geometrijska morfometrija, moćna metoda u analizi strukturnih oblika, naglo poprima sve veći značaj u različitim disciplinama, uključujući anatomiju, morfologiju i kliničku medicinu. Za razliku od tradicionalnih morfometrijskih pristupa, geometrijska morfometrija nudi sveobuhvatno razumijevanje strukture oblika, posebno ako je potpomognuta sa 3D tehnikama snimanja.

U našem istraživanju smo ispitali mogućnosti ove metode u kliničkim uvjetima, primjenjujući je kod postoperativnih evaluacija operativno tretiranih kostiju. Korištenjem snimaka kompjuterizirane tomografije (CT), izvršili smo usporedbu oblika operativno tretiranih kostiju sa kontralateralnim zdravim kostima, fokusirajući se na promjene koje nastaju u procesu cijeljenja. U istraživanju su korišteni CT snimci pacijenata koji su prethodno bili podvrgnuti koštanim operacijama, čiji izvor je arhiv Univerziteta u Istanbulu – Bolnica za životinje Veterinarskog fakulteta Cerrahpaşa. Korištene su napredne softverske alatke, uključujući module Slicer i ALPACA, kako bi se generirali 3D modeli i olakšale precizne komparacije operiranih i neoperiranih kostiju. Naši rezultati su pokazali da operativno tretirane kosti su pokazale izraženije promjene, dok su deformacije oblika u kontrolnoj grupi kostiju bile minimalne. Ove deformacije su često bile lokalizirane u operiranim područjima, što ukazuje na uspješnost metode u otkrivanju postoperativnih promjena. Kompjuterizirani pristup korišten u ovom istraživanju nije omogućio samo detaljnu morfološku analizu, nego je i pokazao potencijal za buduće aplikacije u kliničkoj praksi. Sa nastavkom napredovanja tehnologije, integriranje kompjuteriziranih metoda i anatomskih studija će povećati preciznost operativnih evaluacija i poboljšati ishode za pacijente. Ovo istraživanje naglašava značaj kombiniranja anatomskog znanja sa kompjuteriziranim tehnikama kako bi se razvile učinkovitije kliničke alatke za procjenu operativnog uspjeha.

Ključne riječi: Analiza oblika, kompjuterizirana analiza, operativni ishodi, point cloud analiza