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Original Article

Three-dimensional analysis of the gap space under forearm casts

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A B S T R A C T

Purpose: Secondary displacement represents a frequent complication of conservative treatment of fractures, particularly of the distal radius. The gap space between skin and cast may lead to a certain degree movements and this increased mobility might favor redisplacement. The aim of this study was to develop a new 3D method, to measure the gap space in all 3 geometrical planes, and to validate this new technique in a clinical setting of distal radius fractures.
Methods: This study applies 3D imaging to measure the space between plaster and skin as a potential factor of secondary displacement and therefore the failure of conservative treatment. We developed and validated a new methodology to analyze and compare different forearm casts made of plaster of Paris and fiberglass. An unpaired *t*-test was performed to document differences between the investigated parameters between plaster of Paris and fiberglass casts. The significance level was set at $p < 0.05$.
Results: In a series of 15 cases, we found the width of the gap space to average 4 mm, being slightly inferior on the radial side. Comparing the two different casting materials, plaster of Paris and fiberglass, we found a significantly larger variance of space under casts made of the first material (p=0.39). A roughness analysis showed also a markedly significantly higher irregularity of the undersurface of plaster of Paris as compared with fiberglass.
Conclusion: This study allows for a better understanding of the nature of the “gap space” between cast and skin and will contribute to develop and improve new immobilization techniques and materials.

Introduction

Distal radius fractures are of central clinical interest due to their high frequency, representing around 20% of all fractures.[1] Treatment alternatives include conservative treatment by cast immobilization and various operative procedures. In the case of elderly patients, considering the operative risks and costs of operation, reduction followed by cast immobilization should be the first choice of treatment. Unfortunately secondary displacement is quite frequent, leading to malunion and poor function.[2–4] For this reason and considering the advantages of early mobilization, operative therapy is often indicated. Lafontaine et al.[5] described 5 risk factors that favor redisplacement after closed reduction, and showed that the presence of 3 or more of these parameters is correlated with loss of reduction, despite adequate cast immobilization. Ramoutar et al.[6] observed that improving the cast technique under the supervision of an experienced surgeon could significantly reduce the rate of redisplacement. Several studies were performed so far to measure the pressures exerted by the cast on the skin, but little is known about the acceptable space between the rigid cast and the skin. This space is filled with padding materials and presents a space, where redisplacement can occur to a certain extent.[7] In paediatric orthopedics, several cast indices have been developed.[8,9] Malviya et al.[10] described the gap index which correlates the distance between plaster and skin with the cross section diameter of the wrist; they found a high rate of secondary displacement when the score exceeded 0.15. Alemdaroğlu et al.[11] also agreed that the casting technique plays a major role in the success of conservative treatment. They proposed the 3-point-index in anteroposterior and lateral radiographs. Jordan et al.[12] stated that both the cast index and the gap index were higher in the redisplacement group, but not reaching statistical significance. In another study, though Aurora et al.[13] stated that with rise of the cast index, chances of redisplacement increase. They agreed that the cast index is a useful tool to predict redisplacement. This was supported by a study of Williams and colleagues.[14] Bullen et al.[15] compared recently the

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moulding ability of plaster of Paris (PoP) and polyester cast material by quantitative CT. They used axial tomographic slices in healthy volunteers to measure the distance between cast and skin. They stated that a closely moulded fit is more consistently achieved when using PoP.

The aim of this study was to develop a new 3-dimensional (3D) method, to measure the gap space in all 3 geometrical planes, and to validate this new technique in a clinical setting of distal radius fractures. In order to avoid radiation to patients for the development of the method, we chose to perform the clinical validation in a series of patients with distal radius fractures who had received a circular forearm cast and had had a CT-scan for various reasons (usually to evaluate the quality of articular reduction of a distal radius fracture). The material used for forearm and wrist immobilization was either PoP or fiberglass (FG).

Methods

Newly developed procedure

For the 3D analysis and measurement of the gap space, defined as the space between the undersurface of the plaster and the skin, a new reliable and reproducible procedure based on CT imaging has been developed, validated and used. The procedure started with the identification of 3 landmarks: 2 points as the centers of 2 distinct cross-section areas of the radius (Fig. 1) and 1 point at the most proximal part of the lunate (Fig. 2A).

The long axis of the radius was thus identified by the line passing through the 2 points in the geometric center of the radius in 2 different axial CT cuts (Fig. 1). Then a plane perpendicular to this axis based on the proximal aspect of the lunate bone was determined (Fig. 2A).

The CT-scan images were re-oriented successively in order to present the radius axis in a vertical position for convenience (Fig. 2B). The region of interest for this study was identified by 2 planes, located proximally and distally at 25 mm on each side of the first plane. The studied zone corresponded therefore to a volume with a standardized height of 50 mm, containing the patient's bones and soft tissues, surrounded by the gap space and the cast (Fig. 2C). A 4th point, represented by the geometric center of the ulna (Fig. 2D), allowed to define a frontal and a sagittal plane trough the proximal aspect of the lunate (Fig. 3).

The region of interest could therefore be subdivided in 4 quadrants: palmar, dorsal, ulnar and radial. After identification of these regions, 3D imaging reconstruction using Mimics 17.0 (Materialise, Leuven, Belgium) was used to calculate the volume of the arm, the plaster and the gap space, identified as the volume between the internal surface of the plaster and the skin of the forearm (Fig. 3). The software enabled automatically the determination of the volume once the selection and segmentation of the region had been done by the user. The volumes have been reconstructed for all the patients and the profile of the undersurface of the cast has been analyzed in each of the previously defined quadrants. Section area and surface roughness have been especially analyzed and compared.

Given a certain profile of the cast in a certain anatomical plane (Fig. 4) and its linear fit, it is possible to calculate, for each point, the deviation as the difference (distance) between the real profile and the linear fit (in absolute value).

Once the deviation is determined it is possible to calculate, for the entire profile, the deviance as the mean of the deviation and the roughness as the difference between the maximal value and the minimal value of the deviation. An unpaired t-test was performed to document differences between the investigated parameters between PoP and FG casts. The significance level was set at $p < 0.05$.

Analyzed group

After obtaining the consent of our institutional ethics committee board (P2015/051), a databank research was performed for all patients having received a CT scan of the wrist with a circular forearm cast in place. Several these CT sets had to be excluded, since the scan field did not cover the full area needed for evaluation. This led to the final inclusion of 8 patients with a PoP and 7 patients with a FG cast.

Results

Several tests were performed to assess the accuracy of our procedure. In order to prove the repeatability of the volume reconstruction and estimation, the CT image reconstruction was

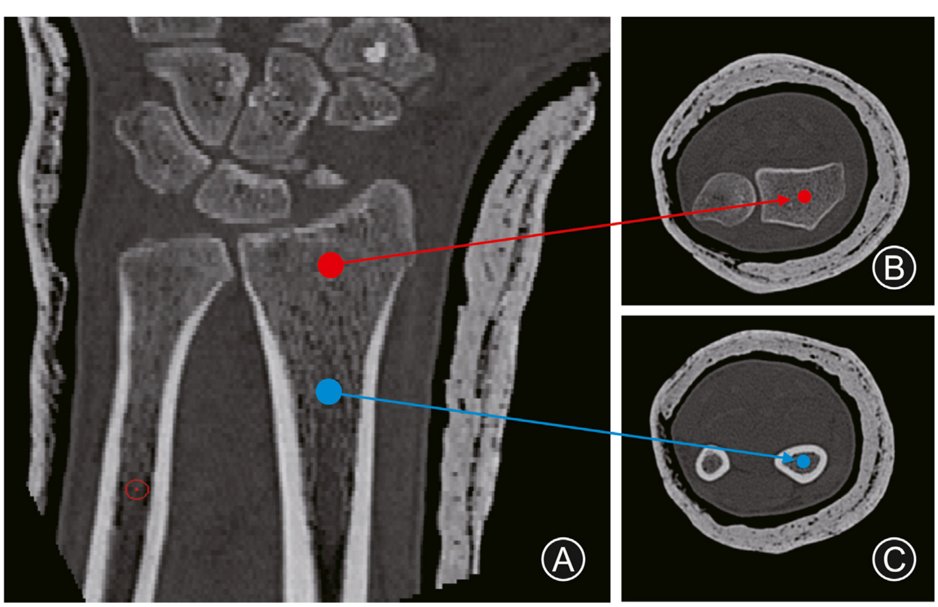

Fig. 1. (A) Identification of 2 points in the center of the radius to define the long axis of the radius. (B) The distal point is marked in red and (C) proximal point is marked in blue.

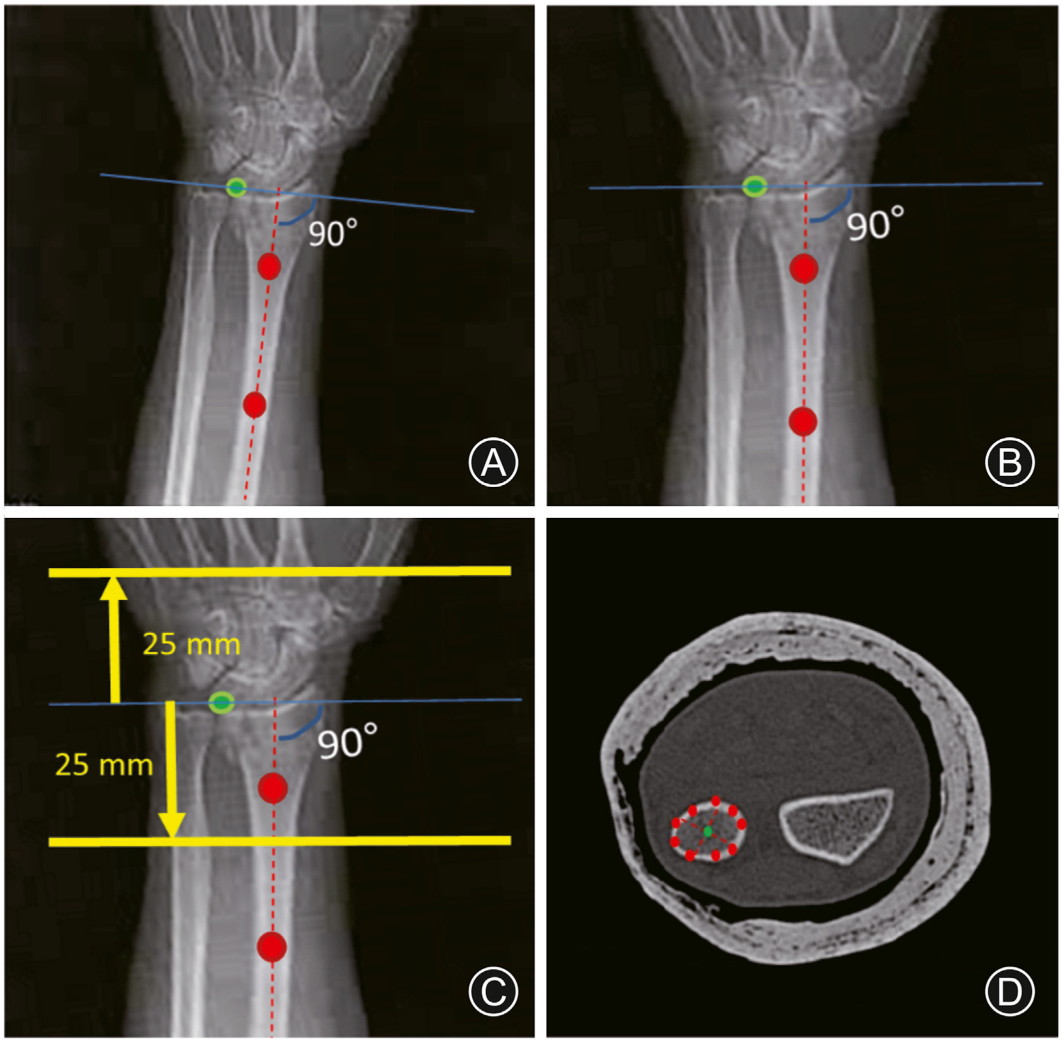

Fig. 2. Identification of the region of interest: (A) Phase 1: Identification of the plane orthogonal to the radius axis (red dotted line) passing through the most proximal part of the lunate; (B) Phase 2: Realignment of the CT scans; (C) Phase 3: Definition of the region of interest of 50 mm (the yellow lines represent the limits of the region of interest); (D) Phase 4: Determination of the center of the ulna to define the frontal and sagittal planes.

done independently 3 times for the same patient. Comparing the 3 volumes calculated by the software, the maximum error margin estimated for the gap-space was lower than 4%. Since different patients could be characterized by different CT-scan settings, we checked the validity of our procedure by testing the effect of different slice thicknesses. In detail, we determined the volumes starting from CT-scans with a slice distance of 0.6 mm. Selecting only every second slice, we artificially created a CT-scan with a slice thickness of 1.2 mm. The reconstructed volumes of this second CT-scan were compared with the initial CT-scan. The estimated maximum error margin for the reconstruction of the volume of the arm was 16%, while the calculation of the gap space presented virtually no error (less than 1%). As several techniques of volume reconstruction include smoothing procedures, we also tested if the smoothing algorithm of the software used during reconstruction would affect the final outcomes. We used a smoothing factor of 0.4. For this value, an error margin of less than 1% has been estimated for all the reconstructed volumes as compared with the volumes obtained without the use of the smoothing algorithm.

Once the reproducibility of the methodology had been checked, it could be independently applied on both of the patients' arms for different purposes of analysis and clinical correlations. Using the reconstructed data of the 15 included casts, we determined the gap space to average 4.0 mm in the different planes (Fig. 5).

Subgroup analysis showed no significant difference of this space in PoP casts (4.13 mm, SD 1.94) compared to FG (3.85 mm, SD 0.90) with a p value of 0.39. PoP casts however showed a significantly higher variance of the gap space, with a range between 1.7 mm and 7.4 mm for the PoP cast patients compared to a range between 2.8 mm and 5.5 mm for the FG cast patients. We further measured the distribution of the gap space in the coronal and sagittal planes (Fig. 6). On the radial side, the area between skin and cast was slightly inferior in comparison to the ulnar, palmar and dorsal aspects, but the difference was not significant.

The roughness analysis resulted in a statistically significant higher roughness of the undersurface of PoP casts ($p = 0.0016$), with an average value of 2.9 (SD 0.9) for the PoP, the value being of 1.7 (SD 0.4) for the FG casts (Fig. 7).

Finally we analyzed if the gap space was correlated to the patients' different wrist circumference. Plotting the total volume against the gap volume we could show no correlation between the gap space and the patient's wrist (Fig. 8).

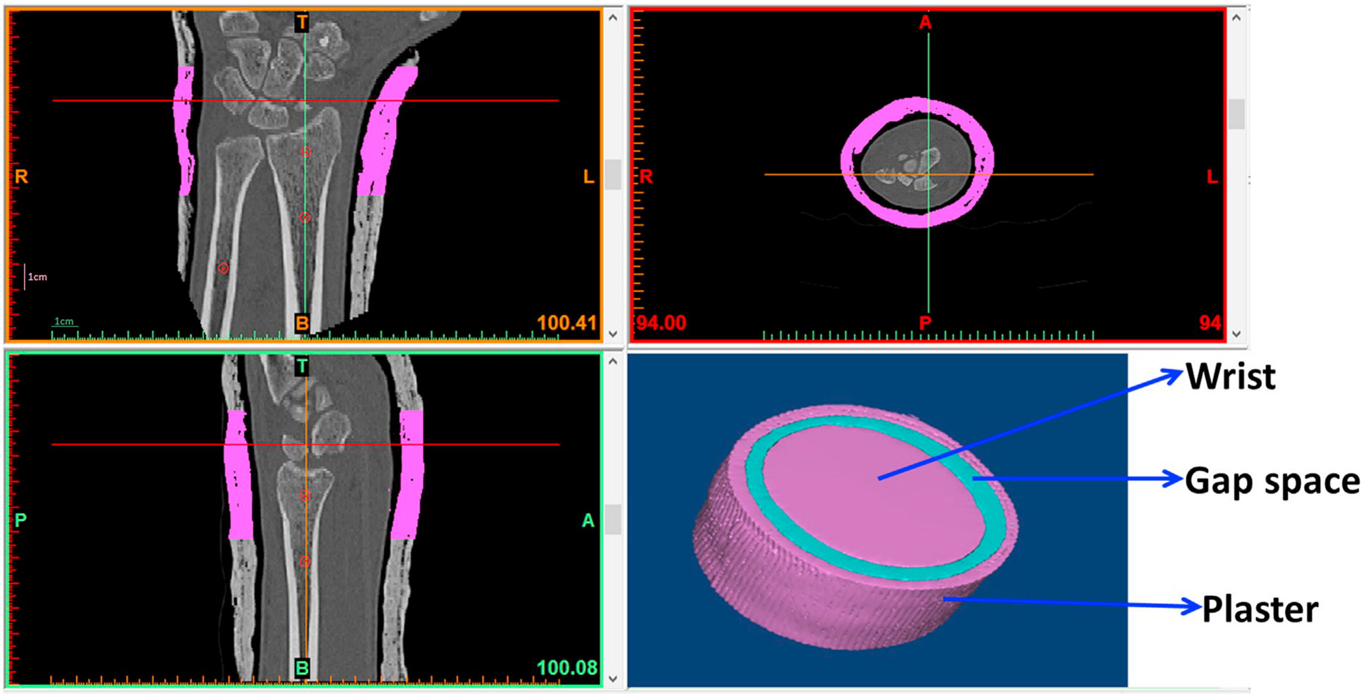

Fig. 3. The plaster is reconstructed on the 2D projection of the CT scans (underlined in pink). The bottom right quadrant shows the reconstructed volumes (wrist, gap space and plaster) for the region of interest.

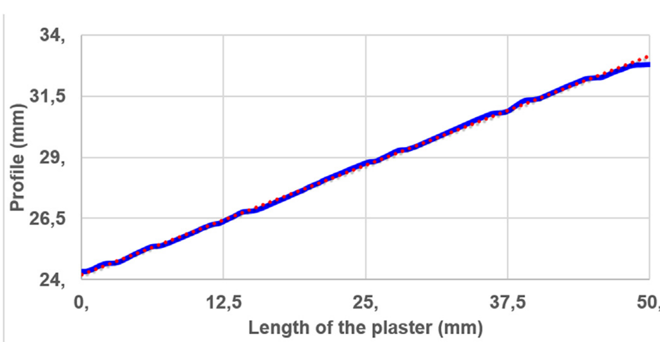

Fig. 4. Graph of the profile plotted *vs.* the length of the plaster (blue line) and overlapped the linear fit (red dotted line).

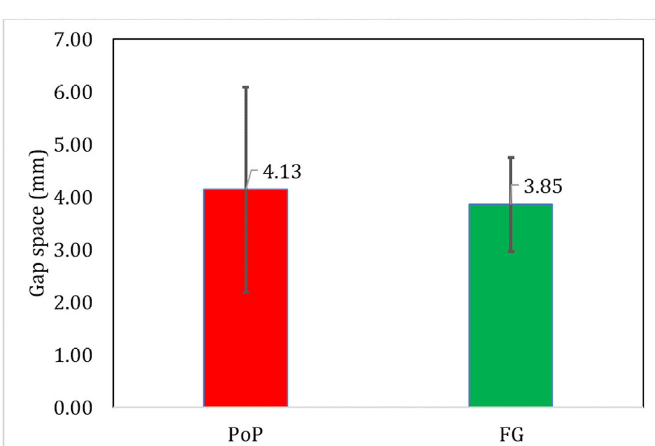

Fig. 5. Comparison of the average gap space for plaster of Paris and fiberglass casts.

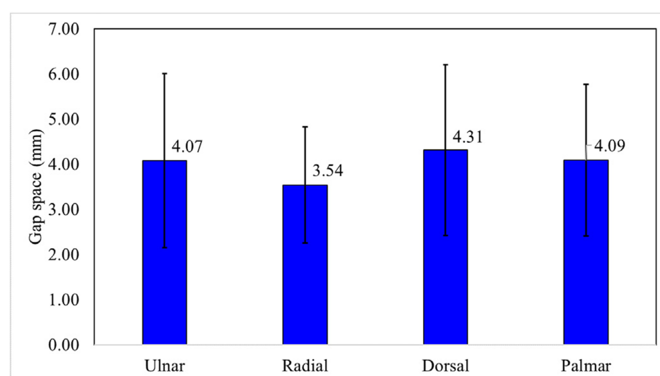

Fig. 6. Comparison of the gap space values (in terms of average and SD) for plaster of Paris and fiberglass casts in the four anatomical directions.

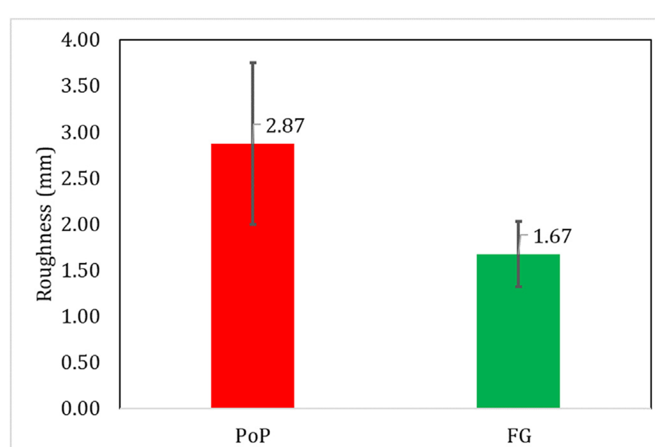

Fig. 7. Comparison of the roughness of the undersurface in plaster of Paris casts and fiberglass casts.

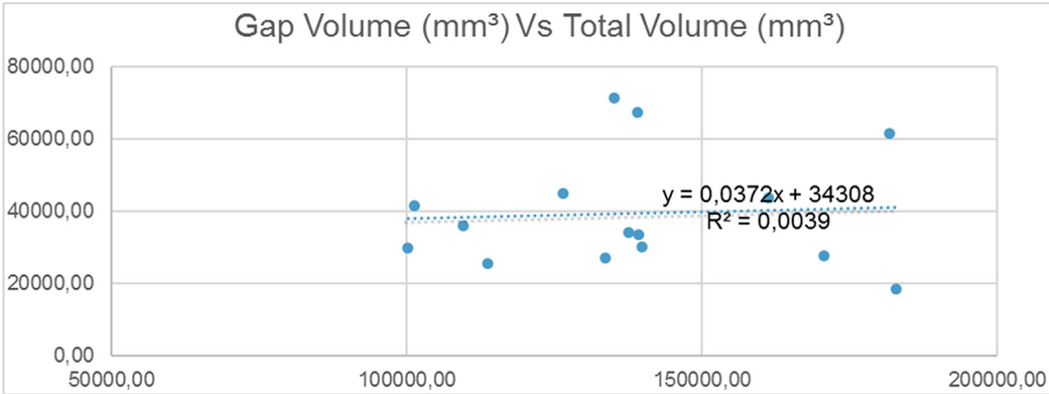

Fig. 8. Graph of the correlation between total volume and gap volume.

Discussion

This study was conceived to better understand the nature of the gap space between cast and skin in a retrospective study. While pressures under the cast were addressed early due to compartment syndrome, there is still little information available regarding the gap space as a factor for secondary displacement. Further development and evaluation of the casting indices showed correlation of these indices with secondary displacement, but sometimes it was in a specific plane only that any significance could be found.[16] Increase in the use of 3D imaging modalities as well as broader availability and advancements in corresponding 3D editing software allowed us to better evaluate the space between cast and skin.

We found the gap space to average 4.0 mm, with a slightly inferior extent on the radial side, which is most likely due to a higher local degree of swelling at this location. The PoP showed a significantly higher variance of this space, which might be due to discrepancies in the application technique performed in the emergency room where the treatments are often performed by junior surgeons. If this technical disparity leads to an increase in gap space, it may result in secondary displacement, while diminution poses a risk for other complications including compartment syndrome. This would support the hypothesis of Ramoutar et al.,[6] who showed that technical deficiencies in cast application favor secondary displacement. The undersurface of the cast was, as expected, much less smooth in PoP than in FG casts. Though both materials are applied in a circular fashion using cast rolls, the differences inherent to the materials result in a rather inhomogeneous undersurface in PoP casts, which could explain skin problems related to local compression. The development of 3D printed casts might solve this problem in most cases.

The gap space does not only depend on the way the cast is applied initially. It also changes over time. While the cast itself is rather rigid, the soft tissues increase in volume due to post-traumatic swelling. The maximum of swelling was shown to occur between 36 h and 48 h after the trauma.[17] Since we performed a retrospective analysis, our investigation did not allow to provide the data to study gap space changes over time. This needs a prospective study.

This study does not allow us to answer the clinical important question of the relationship between gap space and secondary displacement. In a prospective study possibly based on MRI to avoid irradiation, our new method however allows studying the relationship between gap space and secondary displacement. Moreover, the biomechanical function of casts (compression points, 3-point-index) and the changes of soft tissue swelling can be analyzed with the methodology deployed in this scientific work. This is particularly interesting for the development of 3D printed casts already used in clinical trials at the moment.[18] Our study did not include 3D printed casts, since there is very little retrospective data available for the moment. The methodology however will allow comparing 3D printed immobilization devices to casts made of FG or PoP for all the herein mentioned parameters in the near future.

The gap space between cast and skin averaged 4.0 mm in our distal radius fractures patient group. Significant variability of this space was noted especially in PoP casts, eventually indicating higher mobility and increased risk for secondary displacement and skin problems. Due to the retrospective study design, the data available is not sufficient to answer the question of a possible relationship between gap space and secondary displacement. The described methodology will pave the way for a prospective study including also newer immobilization techniques to address these questions.

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Ethical statement

This study obtained the consent from our institutional ethics committee board (P2015/051).

Declaration of competing interest

The authors declare no conflicts of interest regarding the publication of this article.

Author contributions

Conception or design of the work: Frédéric Schuind, Roman Wirtz.

Data collection: Roman Wirtz.

Data analysis and interpretation: Roman Wirtz, Silvia Pianigiani, Bernardo Innocenti, Frédéric Schuind.

Drafting the article: Roman Wirtz, Frédéric Schuind.

Critical revision of the article: Roman Wirtz, Silvia Pianigiani, Bernardo Innocenti, Frédéric Schuind.

Final approval of the version to be published: Roman Wirtz, Silvia Pianigiani, Bernardo Innocenti, Frédéric Schuind.

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