and source servers were set in the center virtual servers. The reference medical institutions expanded to neighbor prefecture and to homecare.

Results

After the patient was registered in our patient identifier cross reference (PIX) server, SS-MIX Gateway server started to gather the registered patient's SS-MIX data from the SS-MIX server of each hospital. The DICOM gateway of the center also started to gather the registered patient's DICOM images from DICOM server of each hospital. The SS-MIX Gateway server converted the SS-MIX data to XDS repository and changed the hospital patient's ID to the integrated patient's ID. The DICOM gateway server also changed the hospital patient's ID of DICOM data to the integrated patient's ID and transferred them to XDS-I source server. One patient's data from hospitals were gathered to one XDS repository and one XDS-I source server like as one regional electronic health record (EHR). Each gateways gathered registered patient's data daily. This year information provided medical institutions were increased. The gateways should be increased twice in virtual server. The licenses of vpn were incresed for increase of users. SS-MIX2 is derived from the HL7, however, it was a problem that laboratory exam code and drug code were not input enough at each hospital.

Conclusion

We developed the system, which was combined the new system with the old system on SBC cost-effectively and the user operation was similar to the previous system. Because the patient's data were integrated and stored in one XDS/XDS-I system from different hospitals, they were shown as one EHR. We expected that it seemed to be convenient to get a time series of laboratory results, prescription medicines and image examinations from different hospitals. The long series of laboratory results and prescription medicines seemed to support clinical decisions more efficiently than one hospital series of data. Especially it seemed to be efficient to eliminate redundant prescriptions from several hospitals.

Original IHE-XDS and XDS-I system were planned the repository servers are set in hospitals, but we thought it will take more time to show data and the total cost will increase such as distributed storing system. IHE technical frame works permitted to gather repositories. As this system stored the data of EPR and DICOM images in the center server, the storage should be increased in future and it should be a problem. But from the concept of the secure thin client system, data should be gathered. After data were gathered in the center server, data also could be used analytically and efficiently (Fig. 1).

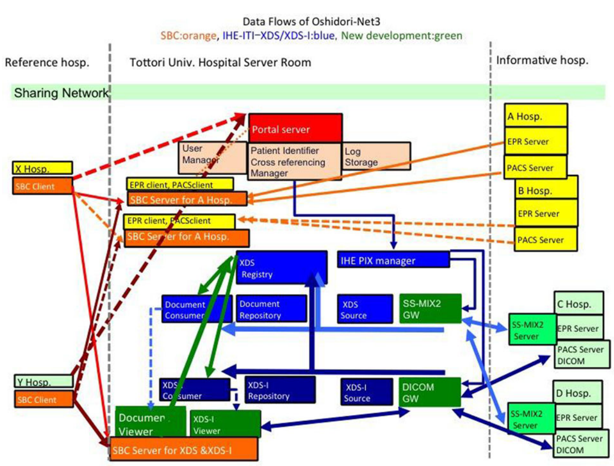

Fig. 1 The dataflows of the system. The lefts are referencing hospitals and the rights are informant hospitals. The upper of the center is portal server, which control connections of thin client servers. The thin client servers shows EPR and PACS viewers of the hospitals and viewer of XDS and XDS-I

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Towards an accurate 3D reconstruction of fractured long bones from plain 2D radiographs

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Keywords Preoperative planning · Fracture reduction · 2D-3D reconstruction · shape prior

Purpose

Radiographic examinations play an essential role during treatment of traumatized long bones. In case the treatment requires a surgical intervention, a preoperative planning with the aim of the identification of an ideal bone fragments reposition and the best fitting bone plate is commonly involved. Such planning is usually based on 3D models segmented from computed tomography (CT) images of the anatomy of interest. However, the CT examination exposes the patient to higher doses of ionizing radiation and adds more time and costs in comparison to the plain radiographic imaging. Therefore, the possibilities of the preoperative planning based only on plain radiographic images have been investigated in recent years. Reconstruction of the 3D bone shape from the small number of 2D X-ray images is a crucial moment of such planning approach. Most of the reconstruction methods proposed so far focus only on the 2D–3D reconstruction of a single part of the bone and only very few works deal with a 2D–3D reconstruction of the fractured bone [1].

The main goal of this work is a 2D–3D reconstruction with a simultaneous 3D reduction of the fractured bone. The proposed method focuses on the displaced oblique fractures of a femoral shaft. The main contribution of the method is an accurate 3D bone reconstruction and reduction without a prior knowledge of the ground-truth length of the bone. It is assumed that for each bone fragment, X-ray images taken from anterior-posterior and lateral views are available and the relative poses of the radiographs are known. Without loss of generality it is also assumed that each radiograph captures exactly one fully visible fragment of the injured bone.

Methods

The proposed method consists of two parts. The first part performs the shape reconstruction and works as an intensity-based deformable 2D–3D registration. It fits a single shape prior of a complete and uninjured femoral bone into the radiographs capturing the individual bone fragments. As a shape prior, the statistical shape and intensity model (SSIM) [2] created from 22 CT images is involved. Beyond the shape variations, the SSIM describes the bone densities using higher-degree Bernstein polynomials, allowing the rendering of digitally reconstructed radiographs (DRRs) [3]. We formulate the registration as a non-linear least squares problem solved using the iterative Levenberg–Marquardt algorithm [4], which is the well-established optimization method with the high rate of convergence. In the each iteration, the DRRs are rendered from the SSIM, the similarity between the DRRs and the original X-ray images is evaluated using the normalized mutual information (NMI) measure and the poses and the shape parameters of the SSIM are adjusted for the next iteration. The registration is finished when the differences between the original X-ray and DRR images are minimal; the reconstructed 3D model of the patient's femur is represented by the specific instance of the shape prior.

The second part of the proposed method simultaneously performs the 3D bone reduction. As it might be expected, the shape of femoral bones varies mainly in the length, which is independent on other morphometric features of the bone. Therefore, it is not possible to estimate the bone length only by the deformable 2D–3D registration itself. With respect to the assumptions stated above, the key observation is that each vertex of the shape model must belong to exactly one fragment of the bone. Consequently, each vertex must be rendered only in the radiographs depicting the related fragment. As the least squares formulation of the problem allows involvement of multiple metrics, the registration is extended to maximize the count of the SSIM vertices that are assigned to exactly one fragment and rendered in all its DRRs. The maximization ensures the correct estimation of the bone length and the accurate bone reduction.

Results

The method has been evaluated on a data set created from CT images of 8 people. 12 virtual cases of femoral shaft fractures have been created from each individual, resulting in 96 cases in total. Each case consists of two pairs of the orthogonal virtual X-ray images ray-casted from a segmented CT image. For every case, a tested bone was split approximately in the middle of its shaft. A typical test case is illustrated in Fig. 1, the corresponding reconstructed 3D model is depicted in Fig. 2.

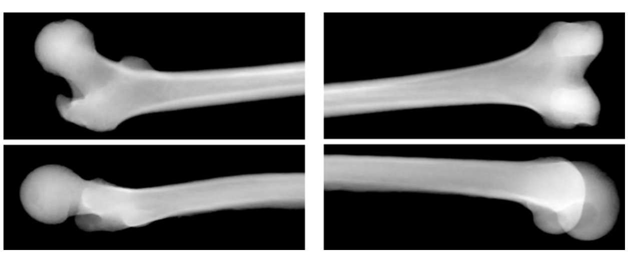

Fig. 1 The sample test case. Two pairs of orthogonal radiographs capturing the proximal (left) and the distal (right) part of the virtually fractured femoral bone

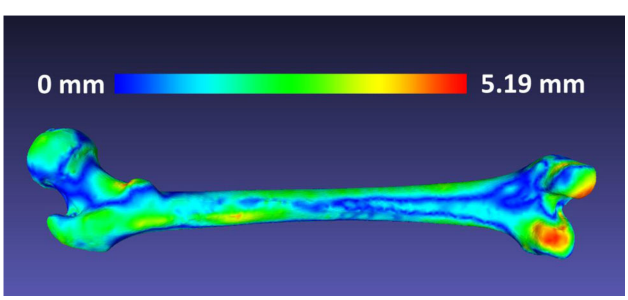

Fig. 2 A polygonal model reconstructed from the sample case. The heat map visualizes the differences from the ground-truth model, mean error was 1.53 mm

The initial estimates of the SSIM pose were generated randomly. The bones used for the evaluation were not included in the training set of the SSIM. First, as a baseline solution, only the 2D–3D registration itself was performed for the test cases. Then the evaluation of the proposed method, including the 3D bone reduction, was performed. The reconstructed 3D models and the ground-truth models segmented from CT images were compared using the symmetric Hausdorff distance [5]. The results are shown in Table 1.

Table 1 The average accuracy of the proposed method is sufficient for the purposes of the preoperative planning, while the results of the baseline solution are significantly inaccurate

	Mean distance [mm]	RMS	Maximal distance [mm]
Proposed method	1.38	1.74	7.26
Baseline	2.52	3.41	11.90

Conclusion

We proposed a novel method for the 2D–3D reconstruction of fractured long bones with accuracy sufficient for the application in the preoperative planning. The results clearly confirm that the 2D–3D reconstruction of a fractured long bone must be performed simultaneously with the 3D bone reduction, as the plain deformable registration fails for not being capable of recovering the bone length. With respect to the promising results reached on the synthetic evaluation data set, the ongoing work will focus on the real world cases evaluation. The proposed method is suitable for straight parallelization and consequent acceleration using graphics hardware (GPU), which makes it applicable within the clinical preoperative planning software.

Acknowledgement

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