



Complex fracture reduction by exact identification of the fracture zone

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ARTICLE INFO

Article history:

Received 10 April 2020

Revised 20 May 2021

Accepted 24 May 2021

Available online 1 June 2021

Keywords:

Automatic bone fracture reduction

Complex fractures

Fracture alignment

Fracture reconstruction

Fracture zone identification

Region filtering

Seed points

ABSTRACT

Planning of a fracture reduction is important in order to reduce the surgery time, with the consequent improvement of the recovery process. There are no fully automatic methods that solve an adequate fracture reduction without the intervention of a specialist. Usually there are parameters that must be supervised or adjusted by the specialist, in order to obtain a satisfactory reduction. Furthermore, most of the studies in the literature focus on a certain type of bone and area on it. This paper presents an approach that tries to reduce to some extent the intervention of the specialist, so that it can be closer to an automatic approach. The proposed method can be applied to a wide variety of bones and areas, based on the identification of the complete fracture zone and the use of an ICP algorithm modified to work with the distance between fragments. The cases in which it has been tested are clinical cases of real fractures obtained from CT scan. This method allows working with a wide range of fractures, as well as complex fractures or deformed fragments. Unfortunately, all possible cases and situations could not be obtained and proved, but the method can be successfully applied to cases that meet a set of characteristics. The proposed technique has been validated by experts, both visually and empirically, using a framework based on virtual reality (VR). This VR framework has allowed comparing the reduction performed by the method with a reduction made virtually by specialists. This technique has also been compared with other existing techniques, obtaining a significant improvement over these.

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1. Introduction

Planning a fracture reduction offers significant advantages in terms of the time spent on the intervention, with the consequent benefit to the patient after the surgery, as well as the success rate of the procedure. Knowing the fracture zones of each fragment, the correct orientation of the fragments for reduction, as well as the identification of the fragments that will be joined to each other, are the objectives of this planning. Fracture reduction planning could be defined, at the scope of this paper, as the process that leads to obtaining for each bone fragment, its position and rotation within the fracture. After proper positioning of the fragments it may be necessary to design a plate for fracture fixation (Liu et al., 2019), but this issue is outside the scope of the method proposed in this work.

The motivation of planning for fracture reduction is derived, from a clinical point of view, from the need to reduce the intervention time, as previously mentioned. Once the optimal position

of the fragments is determined, the fracture must be fixed, usually with the insertion of elements such as plates or screws (Jiménez-Delgado et al., 2016). Ideally, it would also be necessary to take into account the tissues that surround the bone structures, in addition to the way of approaching the intervention, whether it is open or closed. All these aspects must be considered in surgical simulations, especially, in which assistance with virtual reality techniques (Jiménez-Delgado et al., 2020) and haptic devices are of great help (Kovler et al., 2015). For some types of comminuted fracture reductions, in which optimal position of the fragments relative to fixation elements is essential, another type of planning must be done. In this work, it has been considered to perform the reduction without taking into account external elements for fixation or surrounding tissues, solving, in an adequate way, the best position of fragments, as well as the resolution of the pairing of fragments in complex fractures.

The existing literature usually solves the reduction either by identifying some significant points of the fracture zone or by manual identification for later alignment (Chowdhury et al., 2006; 2009). Conventional approaches ignore some of the information, so the results can be improved and are not as accurate as they could be. These significant points are used for reduction using

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The evaluation of this process has been conducted using a subjective validation of the results obtained and performed by experts, both visual and objective, by means of a virtual reality system for fracture reduction, in which the result obtained by our semi-automatic system has been compared with the virtual reduction made by experts. In addition to the above, an empirical analysis of the results obtained has been done, based on the overlap, translation and rotation error obtained in the experiments, and compared with other similar fracture reduction works.

Regardless of the different types of bones and areas covered in this study, there may be specific areas or cases that have not been taken into account. It is considered necessary to further test the method developed in further real clinical cases. Finally, unless the technique is improved regarding the automation of the processes, for multiple fragments could be necessary a coarse rotation or alignment of the fragments. In the cases described in the results section, no rotation or alignment was needed.

As a future work, it is proposed the development of an automatic alignment of the fragments for complex cases when necessary, based on the topology of the fragments. The fully automatic calculation of the different parameters for obtaining the fracture zone is also proposed, as well as the study of the impact of different ranges of values for these parameters in the reduction finally obtained. At last, more fracture cases should be used to validate the system, although it is complex to obtain real cases of particular types of fractures. To this aim, work is being done on the automatic generation of fracture cases on geometric bone models, which simulate the properties of certain types of fracture.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Adrián Luque-Luque: Conceptualization, Methodology, Software, Validation, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Francisco Daniel Pérez-Cano:** Validation, Investigation, Resources, Writing - original draft. **Juan José Jiménez-Delgado:** Conceptualization, Resources, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Supervision, Project administration, Funding acquisition.

Acknowledgments

This work has been supported by the Ministerio de Economía y Competitividad and the European Union (via ERDF funds) through the research project DPI2015-65123-R.

References

Buschbaum, J., Fremd, R., Pohlemann, T., Kristen, A., 2015. Computer-assisted fracture reduction: a new approach for repositioning femoral fractures and planning reduction paths. *Int. J. Comput. Assist. Radiol. Surg.* 10 (2), 149–159. doi:10.1007/s11548-014-1011-2.

- Chowdhury, A.S., Bhandarkar, S.M., Robinson, R.W., Jack, C.Y., 2009. Virtual multi-fracture craniofacial reconstruction using computer vision and graph matching. *Comput. Med. Imag. Graphic.* 33 (5), 333–342. doi:10.1016/j.compmedimag.2009.01.006.
- Chowdhury, A.S., Bhandarkar, S.M., Robinson, R.W., Yu, J.C., 2006. Virtual craniofacial reconstruction from computed tomography image sequences exhibiting multiple fractures. In: 2006 International Conference on Image Processing. IEEE, pp. 1173–1176. doi:10.1109/ICIP.2006.312766.
- Fedorov, A., Beichel, R., Kalpathy-Cramer, J., Finet, J., Fillion-Robin, J.-C., Pujol, S., Bauer, C., Jennings, D., Fennessy, F., Sonka, M., et al., 2012. 3d slicer as an image computing platform for the quantitative imaging network. *Magnetic Reson. Imag.* 30 (9), 1323–1341. doi:10.1016/j.mri.2012.05.001.
- Fürnstahl, P., Székely, G., Gerber, C., Hodler, J., Snedeker, J.G., Harders, M., 2012. Computer assisted reconstruction of complex proximal humerus fractures for preoperative planning. *Med. Image Anal.* 16 (3), 704–720. doi:10.1016/j.media.2010.07.012.
- Jiménez-Delgado, J.J., Calzado-Martínez, A., Pérez-Cano, F.D., Luque-Luque, A., 2020. Virtual reality environment for the validation of bone fracture reduction processes. In: 15th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2020), Vol. 1: GRAPP. INSTICC, pp. 399–405.
- Jiménez-Delgado, J.J., Paulano-Godino, F., Pulido-Ramírez, R., Jiménez-Pérez, J.R., 2016. Computer assisted preoperative planning of bone fracture reduction: simulation techniques and new trends. *Med. Image Anal.* 30, 30–45. doi:10.1016/j.media.2015.12.005.
- Kobbelt, L., 2019. Openmesh. <http://www.openmesh.org/>.
- Kovler, I., Joskowicz, L., Weil, Y.A., Khoury, A., Kronman, A., Mosheiff, R., Liebergall, M., Salavarieta, J., 2015. Haptic computer-assisted patient-specific preoperative planning for orthopedic fractures surgery. *Int. J. Comput. Assist. Radiol. Surg.* 10 (10), 1535–1546. doi:10.1007/s11548-015-1162-9.
- Kronman, A., Joskowicz, L., 2013. Automatic bone fracture reduction by fracture contact surface identification and registration. In: 2013 IEEE 10th International Symposium on Biomedical Imaging. IEEE, pp. 246–249. doi:10.1109/ISBI.2013.6556458.
- Liu, B., Zhang, S., Zhang, J., Xu, Z., Chen, Y., Liu, S., Qi, W., Yang, L., 2019. A personalized preoperative modeling system for internal fixation plates in long bone fracture surgery—a straightforward way from CT images to plate model. *Int. J. Med. Robot. Comput. Assist. Surg.* 15 (5). doi:10.1002/rcs.2029.
- McGuire, M., 2000. The half-edge data structure. http://fractal.dam.fmph.uniba.sk/~samuelcik/dgs/half_edge.pdf.
- Meinberg, E.G., Agel, J., Roberts, C.S., Karam, M.D., Kellam, J.F., 2018. Fracture and dislocation classification compendium—2018. *J. Orthopaedic Trauma* 32, S1–S10. doi:10.1097/bot.0000000000001063.
- Okada, T., Iwasaki, Y., Koyama, T., Sugano, N., Chen, Y.-W., Yonenobu, K., Sato, Y., 2008. Computer-assisted preoperative planning for reduction of proximal femoral fracture using 3-d-CT data. *IEEE Trans. Biomed. Eng.* 56 (3), 749–759. doi:10.1109/TBME.2008.2005970.
- Paulano, F., Jiménez, J.J., Pulido, R., 2014. 3d segmentation and labeling of fractured bone from CT images. *Visual Comput.* 30 (6–8), 939–948. doi:10.1007/s00371-014-0963-0.
- Paulano-Godino, F., Jiménez-Delgado, J.J., 2017. Identification of fracture zones and its application in automatic bone fracture reduction. *Comput. Method. Program. Biomed.* 141, 93–104. doi:10.1016/j.cmpb.2016.12.014.
- Vlachopoulos, L., Székely, G., Gerber, C., Fürnstahl, P., 2018. A scale-space curvature matching algorithm for the reconstruction of complex proximal humeral fractures. *Med. Image Anal.* 43, 142–156. doi:10.1016/j.media.2017.10.006.
- Willis, A., Anderson, D., Thomas, T., Brown, T., Marsh, J.L., 2007. 3d reconstruction of highly fragmented bone fractures. In: Medical imaging 2007: image processing, Vol. 6512. International Society for Optics and Photonics, p. 65121P. doi:10.1117/12.708683.
- Winkelbach, S., Westphal, R., Goesling, T., 2003. Pose estimation of cylindrical fragments for semi-automatic bone fracture reduction. In: Joint Pattern Recognition Symposium. Springer, pp. 566–573. doi:10.1007/978-3-540-45243-0_72.
- Zhou, B., Willis, A., Sui, Y., Anderson, D., Thomas, T., Brown, T., 2009. Improving inter-fragmentary alignment for virtual 3d reconstruction of highly fragmented bone fractures. In: Medical Imaging 2009: Image Processing, Vol. 7259. International Society for Optics and Photonics, p. 725934. doi:10.1117/12.810967.