

Digital Preoperative Planning of Total Hip Arthroplasty

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Abstract

Preoperative templating of total hip arthroplasty consists of determining the magnification of the hip on a radiograph and applying identical magnification to the radiograph and the template. The traditional planning relies on visually comparing acetate templates and analogue radiographs over a white light-box. When it is done manually, a template may be inaccurately selected and it must be corrected in the operation theatre, in this case a new prosthesis have to be ordered meanwhile the patient is under anaesthesia. Preoperative planning of total hip arthroplasty may be supported by computer technology in order to reduce the planning errors. The automation of arthroplasty requires a precise calibration for adjusting to the real dimensions in order to use templates in PDF format. In this paper, HipOrtho a digital preoperative planning of total hip arthroplasty is presented, as an open source plugin on OsiriX. HipOrtho Plugging is developed using OsiriX viewer as a tool that uses multiple libraries for rendering, DICOM management and plugins. The plugin architecture is expanded to other orthopaedic plugins, such as Osteotomy and Knee Replacement. Preliminary evaluations have been conducted using Exactech templates and digital radiographs obtained from patients at the Imbanaco Medical Centre. Currently, the plugin is under evaluation by a group of orthopaedists at the Imbanaco Medical Centre in Cali.

1 Introduction

Hip arthroplasty surgery consists of using metal, ceramic, or plastic parts to replace the ball at the upper end of a femur and resurface the hip socket in a pelvic bone. The surgery requires a preoperative planning in order to select the proper prosthesis – material, size and prosthesis type. The preoperative planning is done manually, as shown in Figure 1.

Automatic pre-operative planning requires a precise calibration for adjusting templates in PDF format to the real dimensions and measuring patient's anatomy in radiograph. SECTRA Orthopaedics [2], Orthoview [3] and TraumaCAD [4] perform a step-by-step process to assist surgeons in preoperative planning. However, those applications require buying a license. A conceptual framework for digital preoperative planning in total hip replacement, based on a geometric construction of hip joint implant templates using AutoCAD, is presented in [5].

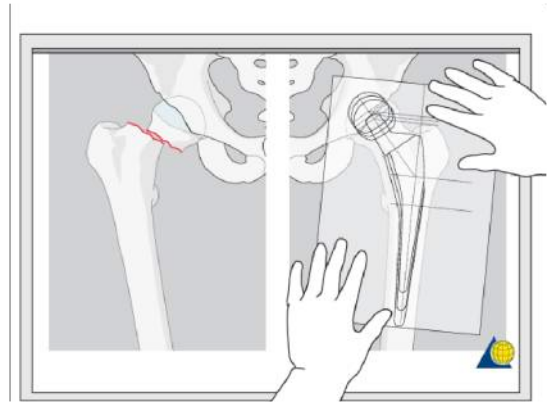


Figure 1: Illustration of manual preoperative planning [1].

However, the authors did not include any information about geometric transformations, measurement processes, calibration, and evaluation results. A cost-analysis of the preoperative planning from the hospital perspective is presented in [6]. The authors concluded that increasing radiation exposure is required to obtain the image quality. It is associated with a slightly higher but justifiable cost per patient. PowerPoint (PP) (2007 Version; Microsoft, Redmond, Wash) method was used for measuring polyethylene liner wear after total hip arthroplasty [7]. The authors concluded that PowerPoint method is useful for monitoring linear wear after total hip arthroplasty. However, PowerPoint was used for manipulating radiographs, such as magnifying images to 400% and comparing visually images. A camera calibration approach by calculating the transformation matrix is presented in [8]. Nevertheless, the authors did not use information available in DICOM files. A manual approach for scaling – based on comparing on the screen an acetate and a manipulated image using the magnification tool – is presented in [9]. An image processing driven approach – for X-Ray segmentation – is presented in [10]. The proposed segmentation is twofold: landmark detection as an input to shape regularisation for refining the initial segmentation. Finally, the Legacy plugin is a step-by-step guide for surgeons and allows loading templates in PDF format [11].

In this paper, HipOrtho, a digital preoperative planning of Total Hip Arthroplasty (THA), is presented. HipOrtho is deployed as a plugin on OsiriX [12]. OsiriX is a platform for development of processing tools and is distributed [13] under

Open Source licensing – LGPL. The OsiriX viewer is open-source imaging software designed to manipulate and visualise large sets of medical images. OsiriX supports a complete plug-ins architecture that allows expanding the capabilities of OsiriX. This plug-in architecture gives access to the Cocoa framework with the Objective-C language.

The preoperative template-planning using HipOrtho is a guide but surgeons have to determine the final size and position of the prosthesis intra-operatively. Evaluations of HipOrtho have been performed using Exactech templates in PDF format. Currently, the plugin is under evaluation by a group of orthopaedists at the Imbanaco Medical Centre in Cali, Colombia.

The rest of the paper is organised as follows: Section 2 contains a brief description of the Orthopaedic Digital Preoperative Planning (ODPP) framework. Section 3 presents a detailed description of the HipOrtho Plugin functionalities. Section 4 includes final remarks.

2 Orthopaedic Digital Preoperative Planning

The Orthopaedic Digital Preoperative Planning (ODPP) framework consists of three components: planning of total hip arthroplasty, planning of osteotomy and planning of knee arthroplasty. Although the core of the software suite is OsiriX, ODPP expands the capabilities of OsiriX for orthopaedists need.

The general architecture of ODPP framework is shown in Figure 2, including different levels – OS, libraries, frameworks and hardware elements – that participate in the plugin execution.

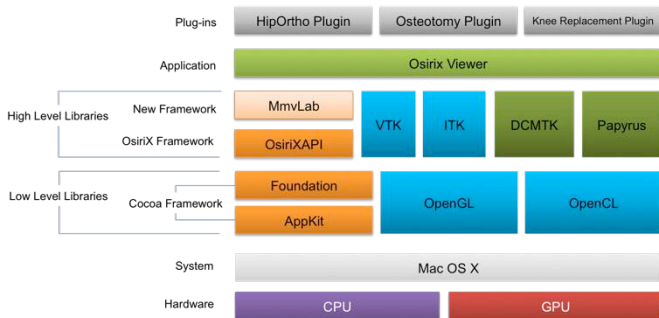


Figure 2: Architecture of the orthopaedic digital preoperative planning framework – an adaptation of [15].

System and Hardware elements (CPU and GPU) are at the bottom level, where OsiriX takes advantage of graphic processor power. The plugin runs over Mac OS X system, using 10.9 Mavericks and OsiriX Viewer. OsiriX is based on open source libraries, such as: OpenGL, for graphic rendering and processing, and OpenCL, for parallel processing in CPU and GPU. Foundation and AppKit frameworks are the low-level libraries. AppKit works at the user interface application elements. Foundation framework defines the basic behaviour of the base object types. Cocoa technology is based on Foundation and is the base for all native OS X applications. VTK and ITK are at the high level libraries. They are open source libraries that provide virtualisation elements and image analysis tools. DCMTK and Papyrus toolkit are libraries for

reading and manipulating DICOM data. OsiriXAPI contains headers that join the low-level libraries and the high-level libraries in order to render and process medical images, and perform visualisation.

The MMV-Lab Framework is defined over OsiriXAPI and contains headers with functions that perform operations common to orthopaedic fields. MMV-Lab includes the manipulation of ROI (Region of Interest) layers by adding a rotation point and identifying automatically rotation angle of a ROI layer.

A central aspect of the MMV-Lab Framework is the calibration function. That is, the template and the radiograph have to be scaled to obtain identical magnifications.

2.1 Calibration

The accuracy of preoperative planning will be effective if measures of the body parts in the image and templates correspond to real-world measurements. Based on this, the prosthesis will be selected for a surgery. However, the Digital Imaging and Communications in Medicine (DICOM) files use the metric system (millimetres and centimetres) [16] contrary to PDF templates that contains inch-based dimensions – depending the way that it was drawn or how the template image was obtained. Thus, the radiograph and the template have to be calibrated. The DICOM standard defines not only an efficient way to store data – pixel values – in contiguous bytes of memory, but also patient’s information is stored converting it into information for diagnostics, in the metadata definition [17]. In DICOM files, a data-element contains the X (row) and the Y (column) spacing for a pixel matrix, as illustrated in Figure 3.

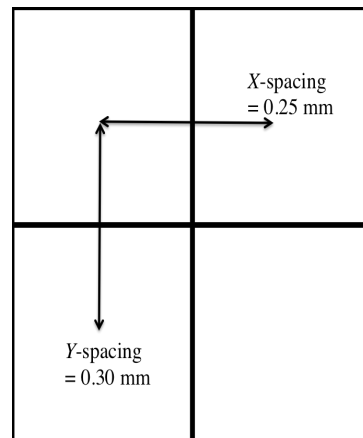


Figure 3: Illustration of *PixelSpacing*.

Consequently, *PixelSpacing* is calculated by dividing Y-spacing and X-spacing, as shown in Equation 1.

$$PixelSpacing = \frac{Y-spacing}{X-spacing} = \frac{0.30}{0.25} \quad (1)$$

The *PixelSpacing* provides information for calculating length and area. Thus, sizes of body parts are calculated using *PixelSpacing* information. Additional elements are used in the calibration process, such as the magnification factor, a modification on the *PixelSpacing*.

2.2 Magnification Factor

A scale is the relation between the real dimension of an object and the dimension of the drawing object. In technical drawing, scale is symbolised by a pair of numbers, G and R, and the scale relation symbol \cdot . The scale is represented by $G:R$, where G is the radiograph measure units and R is the body part measure units, e.g. 1:1 scale means that 1 unit in the radiograph is equals to 1 unit in the body part. The basic idea of scaling leads to the magnification factor equation:

$$\text{magnificationFactor} = \frac{\text{Radiograph Dimension}}{\text{Body Dimension}}. \quad (2)$$

2.3 Image Calibration

Image calibration consists in relating body parts dimensions with digital radiograph dimensions. Usually an image is taken with a calibration marker along patient's organs for calibrating a Computed Radiograph (CR).

The calibration marker is placed at the same level of the body parts that will be operated [16]. MMV-Lab applies a correction factor to the PixelSpacing using the magnification factor as shown below:

$$X - \text{spacing} \div = \text{magnificationFactor}, \quad (4)$$

$$Y - \text{spacing} \div = \text{magnificationFactor}. \quad (5)$$

Figure 4 illustrates the calibration process where the pixel spacing is corrected by the magnification factor.

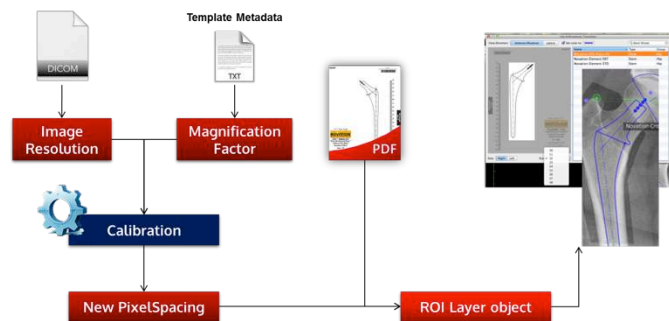


Figure 4: Illustration of the calibration process.

2.4 Template Calibration

Template calibration consists in converting inches (PDF files) to millimetres. MMV-lab uses the template metadata, in PDF files, which includes relevant information about the prosthesis, e.g. five markers position in the stem for head rotation using X and Y coordinates, product name, family name, reference, size, and information on the scale, as shown in Novation Press-fit template size: 10 at the bottom of Figure 5.

For instance, using a *Novation Press-fit* template of size 10, the dimension calculated by HipOrtho is 125mm, as shown in Figure 5. The corresponding dimension on the *Novation Press-fit* template is 5.865 inches, or 148.986 mm,

the magnification factor is:

$$\text{TemplateMagnificationFactor} = \frac{125 \text{ mm}}{148.986 \text{ mm}} \cong 0.839. \quad (3)$$

Additional information is the scale that is used for calibrating the template and the image.

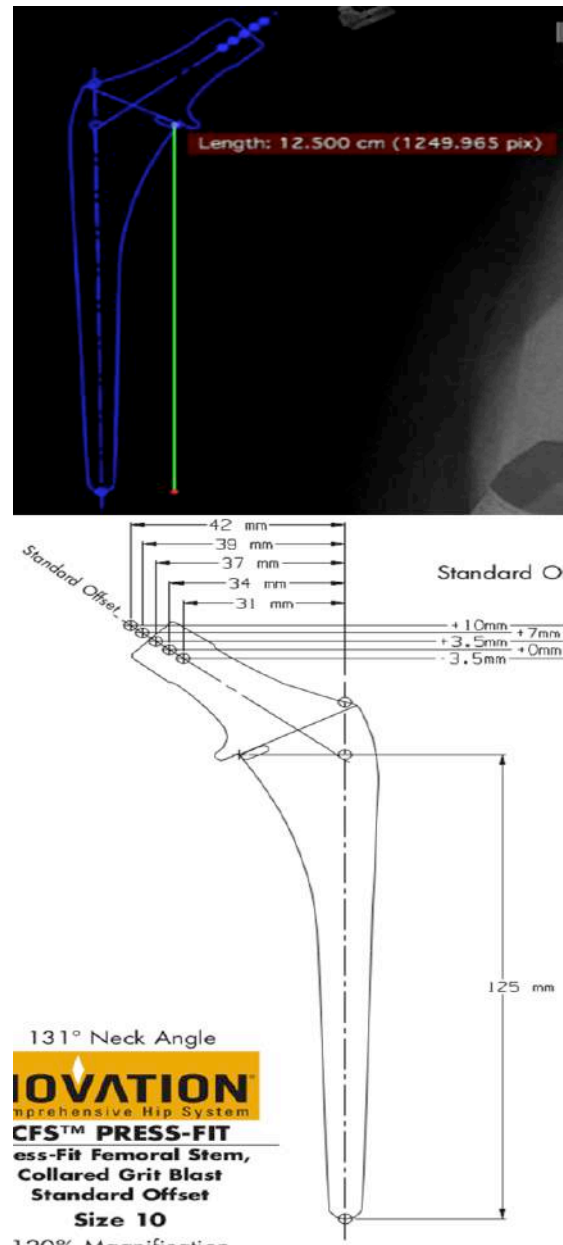


Figure 5: Illustration of a PDF file (size: 10 and Novation Press-fit template) and the ROI layer produced by HipOrtho.

3. HipOrtho Plugin functionalities

HipOrtho is based on HipArthroplasty Templating Plugin – a plugin made by OsiriX Team [11, 18]. HipOrtho improves usability, reduces redundant information and includes keyboard shortcuts for manipulating templates.

The plug in is developed in Objective-C (file extension: *.h, *.m, *.mm, *.xib), using Cocoa framework, Foundation framework, AppKit framework and OsiriXAPI framework, the IDE is Xcode v.5, with design pattern Model-View-Controller and compiled in universal architecture 32/64 bits.

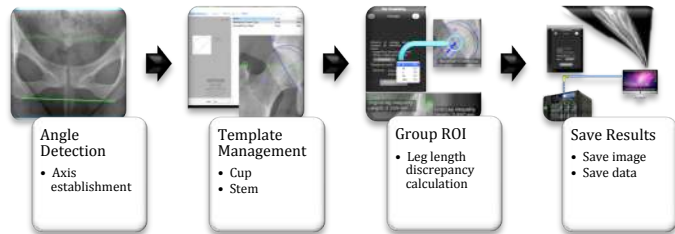


Figure 6: Functionalities of HipOrtho Plugin.

HipOrtho includes the following functionalities: calibration, angle detection, template management, group ROI and save images, as shown in Figure 6.

HipOrtho consists of a step-by-step guide throughout a preoperative planning.

Step 1: Initial data. The surgeon provides the horizontal axis, using the ischium or the teardrops, for calculating the leg length discrepancy by placing a marker on each greater trochanter of the femur, as illustrated in Figure 7 and a ROI layer on the femur of interest is required.

Step 2: Femoral landmarks. The surgeon selects two landmarks on the greater trochanters. Two parallel lines are used for calculating the leg length discrepancy, in Figure 8.

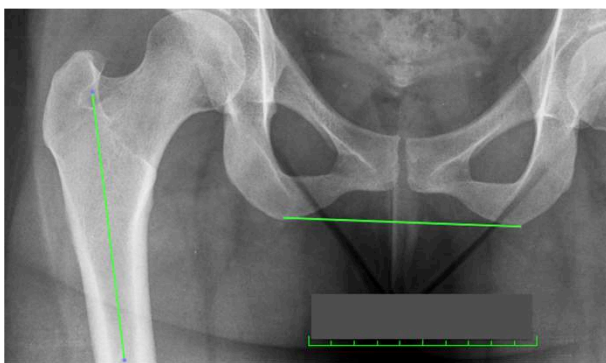


Figure 7: Step 1. A surgeon draws a line on the horizontal axis and femur of interest.



Figure 8: Step 2. Femoral landmark selection.

Step 3: Femur identification as a ROI. The surgeon draws points – as a contour – around the femur of interest. A ROI

layer is created from the points, in Figure 9.

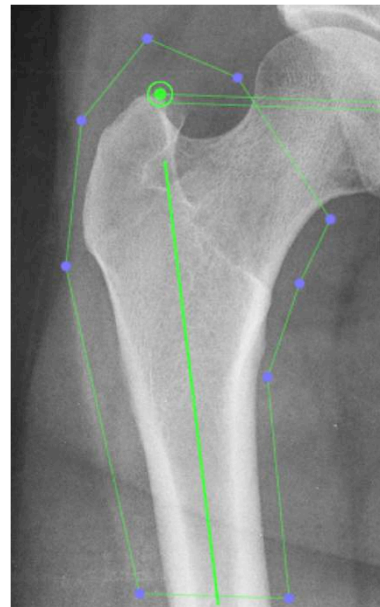


Figure 9: Step 3. ROI layer on femur of interest.

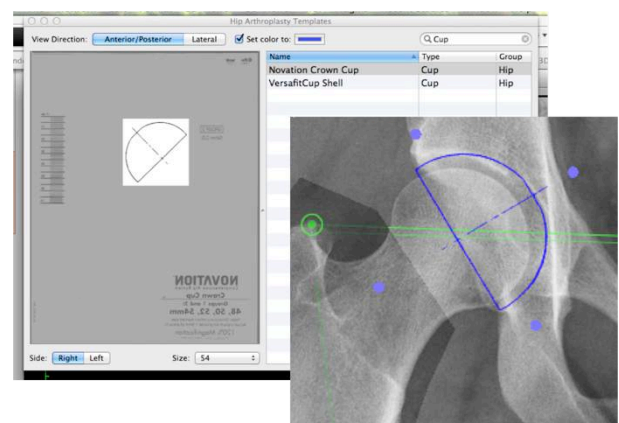


Figure 10: Step 4. Cup template selection.

Step 4: Cup template selection. HipOrtho loads a template manager for determining the type, the size and the orientation in the calibration step. The surgeon selects a template by dragging-and-dropping over the radiograph in order to decide whether the cup template fits the real dimensions of the acetabulum, in Figure 10.

Step 5: Stem template selection. The surgeon decides whether the selected stem template fits the real dimensions of the acetabulum, in Figure 11.

Step 6: Leg length discrepancy. HipOrtho selects the stem marker closer to the cup's centre, modifies the femoral landmarks positions detected in Step 2 and updates the leg length discrepancy. The surgeon may select other stem markers from the remaining four markers using keyboard shortcuts or from the plugin panel, in Figure 12.

Step 7: Saving. The planning radiograph, the leg length discrepancy, the templates placed on the femur and the

acetabulum and information on manufacturer, reference number, size and rotation, are stored, in Figure 13. Also, data can be sent to a Picture Archiving and Communications System (PACS).

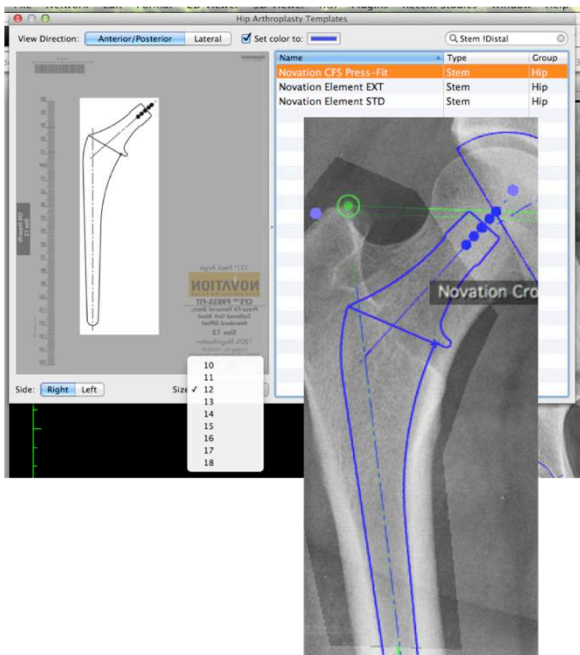


Figure 11: Step 5. Stem template selection.

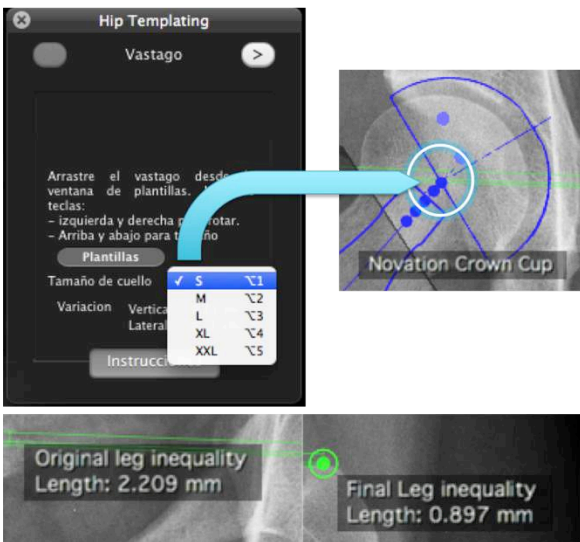


Figure 12: Step 6. Leg length discrepancy.

Evaluations of HipOrtho Plugin have been done using Exactech templates, Novation Element and Press-fit family for stem and Novation Crown cup family for cup – templates are in PDF files.

A screenshot of HipOrtho Plugin on OsiriX Viewer is shown in Figure 14. The Plugin is installed on OsiriX. On the left hand side there is a menu of options with information about the patient and on the right hand side there is a panel

with information of the step by step process, as shown in Figure 15. When a user has chosen a template, the user should drag-and-dropped the template on the radiography, then he/she should place the template in the required region. The user may rotate the template with the left and the right keyboard arrows and also may resize it with the up and down keyboard arrows. The main panel also contains the *ArthroplastyTemplatingTableView* and the *SelectablePDFView*. The former is at the right hand side of the panel and it contains a list of the template families along with other information; the latter is at the left hand side of the panel and it shows the selected template family.



Figure 13: Step 7: Saving image or sending it to PACS.



Figure 14: Screenshot of HipOrtho Plugin on OsiriX Viewer.

4 Final Remarks

Acquired knowledge on OsiriX structure and internal functionality allows us to design an architecture focused on interoperability with other plugins for orthopaedic surgery planning, like osteotomy and knee replacement. This paper presented HipOrtho Plugin as part of the MMV-Lab framework for orthopaedic digital preoperative planning.

HipOrtho Plugin includes an accurate calibration processes since all the calculations have to be precise due to small imprecisions may produce secondary effects, such as: leg length discrepancy [18] and bone exposure – a bigger stem prosthesis is dangerous to the bone, existing the risk of break it, also a smaller stem may not fit correctly and the patient has to return to the operation theatre.

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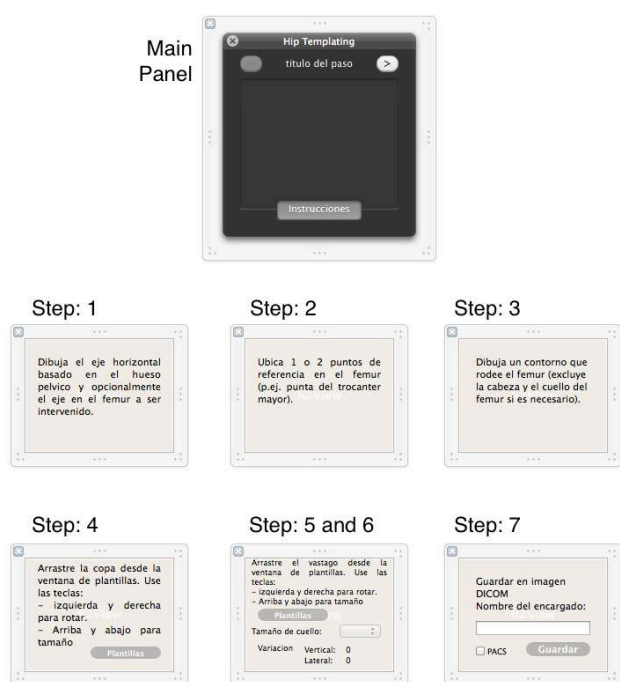


Figure 15: HipTemplatingView panel in the Interface Viewer.

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