Efficacy and economic impact evaluation of a navigation system for assisted lung biopsy

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This Letter reports on the testing and assessment of an optical computed tomography-navigation system for percutaneous lung interventional, SIRIO, showing how the lesion diameter affects the bioptic procedure. Clinical data, relating to 501 patients, were collected at the Department of Interventional Radiology of Policlinico Universitario Campus Bio-Medico. This Letter shows that the diameter of lesion affects only the procedure duration (50.91 ± 18.87 min for lesions of diameter $\leq$20 mm and 44.98 ± 19.43 min for lesions of diameter >20 and $\leq$40 mm). For the nodules with a diameter $\leq$20 mm, there is a significant increase in the duration of the procedure (for each mm less the time increases by 6 s). Other parameters like the mean effective radiation dose and the presence of a diagnostic or non-diagnostic specimen do not depend, instead, on the lesion size. The economic analysis based on the biopsy procedure with SIRIO shows the necessity to adopt a new reimbursement system for percutaneous biopsy performed using navigation systems to stimulate their use to get important non-economic gains such as early diagnosis, reduction of the absorbed dose of X-rays and increasing number of lung cancers in a curable early stage.

1. Introduction: The biopsy is one of the most important diagnostic tools to detect the presence of anomalies, such as cancer. It consists in the removal of tissue from a precise point, usually with the assistance of imaging technologies like ultrasound, computed tomography (CT), magnetic resonance (MR) and fluoroscopy, depending on the anatomical district. Nowadays, navigation systems are promising tools in the field of percutaneous imaging-guided procedures; they facilitate the execution of the entire biopsy procedure, thanks to the implementation similar to the commercial global positioning system. Such systems allow electromagnetic, optical or hybrid tracking of the devices used during interventions [1–3]. Once tracked, devices are immediately visualised in a virtual model obtained from a set of previously acquired CT, MR or ultrasound images. At this point, a superimposition of the tracked device onto the target lesion is possible without requiring additional imaging for each advancement of the tracked devices, because navigation systems inform the doctor, in real-time, about the exact position of the tools [4].

The electromagnetic tracking is made possible by an electromagnetic field generator that is positioned close to the patient's body; it generates an electromagnetic field that enables a simultaneous monitoring of the position and orientation of the sensors placed on the needle and on the patient. Veran IG4 is an example of a CT-guide electromagnetic navigation system for lung percutaneous biopsies; the needle contains, inside its tip, an electromagnetic sensor that superimposes its position when the field is generated, in correspondence to CT images previously obtained [5]. UltraGuide 1000 is an electronic and an electromagnetic device for guiding needle placement during ultrasound guided percutaneous interventions. The base unit generates a weak magnetic field over the operating surface; small lightweight position sensors are attached to the sonographic transducer and to the biopsy needle handle and their position and orientation in the space are detected by the base unit [6]. The greatest risk of electromagnetic systems is the malfunction resulting from the proximity of other ferromagnetic instruments commonly adopted in the operating room, with inevitable distortions and accuracy alterations.

Optical navigation systems are similar to electromagnetic navigation systems but they use a tracking camera and reflective markers. These systems have greater use than electromagnetic ones, thanks to the higher accuracy, and because they can be used with instruments of any type of material, without problem of interference. However, the nature of the optical navigators does not permit connection to the components of the monitoring system in any part of the instrument that comes into contact with the patient, in fact these systems monitor only the components which are in line with the visual system, and then determine the position of any non-visible parts through geometric parameters. CT-Guide® navigation is a variant of traditional optically-based tracking systems that employs three main components; it consists of a sterile, self-adhesive, registration sticker with coincident video and radiological x-ray imaging visible reference markers, a miniature disposable video camera with an easy attachment that is clipped onto or off any standard interventional instrument (so the miniature video camera provides a real-time video stream of the markers to the computer) and finally a 3D navigation software displayed on a flat screen monitor located on a mobile workstation and loaded into a computer that is housed by a mobile workstation inside the CT room. During intervention, the miniature video camera is clipped onto the proximal end of an instrument [7]. The Polaris system is typically used in computer-assisted interventions and consists of a pair of cameras, i.e. locators' position (Polaris Spectra or Polaris Vicra), which are able to emit or receive infrared rays from markers placed on the instrument [8]. Aimnav is an optical navigation device, operating similar to the Polaris system, which has been created to satisfy the growing medical needs in the neurosurgical field [9].

Hybrid devices have both tracking systems; Medarpa combines an optical and an electromagnetic tracking system to allow tracking of the swivelling transparent display, the head of the radiologist, as well as the needle tip at the same time. The optical tracking consists

of a pair of cameras equipped with infrared filters and they are mounted on a stand attached to the trolley. The alignment of the cameras is designed to minimise optical occlusions during the monitoring of the display and of the radiologist's head, made possible thanks to the reflective markers placed on the display itself and on a pair of glasses worn by the doctor. These optical sensors permit the determination of the position and orientation of the radiologist head and of the display. Together with optical solution, an electromagnetic system has been chosen for monitoring the instrument used during surgery; a field generator and an electromagnetic sensor are assembled on the needle handle [10]. Stealth Station S7 uses an electromagnetic or optical tracking system, depending on the situation. The Stealth station S7 system is used in particular for the skull tumours and diseases of the spine; it is equipped with a camera for the optical mode, a computer-assisted planning station, a spring-arm system mounted on the ceiling, to make more accessible the operative field, and a removable monitor for intraoperative visualisation [11]. Finally there are also robotic navigators, such as the innomotion system, a robotic system for minimally invasive surgery compatible with MR imaging [12], and the NeuroMate, providing a 3D visualisation and interactive anatomy of brain structures [13].

This Letter presents an assessment of the efficacy and an evaluation of the economic impact of SIRIO, based on the data collected by the Department of Interventional Radiology of Policlinico Universitario Campus Bio-Medico. The goals of the study are to increase the base of clinical evidence, to underline possible technological improvements of the device and to assess the economic impact of SIRIO.

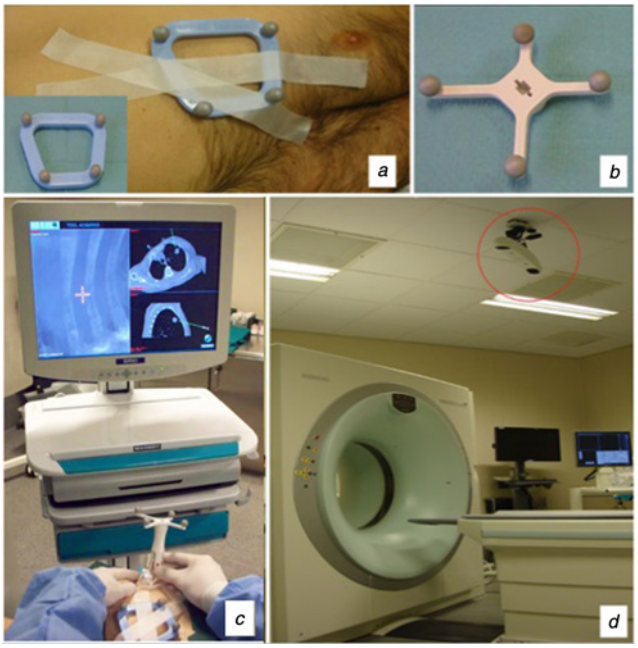

Fig. 1 *SIRIO optical CT-guided real-time tracking system used in interventional radiology*
a Patient tool
b Needle tool
c Visualisation and elaboration unit
d Infrared optic sensors on the CT room ceiling

2. System description: SIRIO, produced by MASMEC Biomed (Modugno, Bari, Italy), is an optical CT-guided system for interventional radiology used for percutaneous interventions such as biopsy and thermal ablation in different anatomical districts, such as lungs, bones and kidneys. This device provides a real-time visual feedback to the interventional physicians to identify the ideal trajectory of the insertion of needles and cannulas to reach deep and small lesions. In this way, it significantly reduces not only the radiation dose absorbed by the patient (reduction of the absorbed dose of about 50%), with a decrease in the number of CT scans (reduction in the number of CT scans by about 43%) compared with traditional biopsy, but also the intervention time (reduction of the intervention time by about 30%), because SIRIO provides automatic calibration procedures and then it permits an early diagnosis [14].

SIRIO reconstructs a 3D model from a dataset of acquired CT images through automatic procedures [14, 15]. In particular, SIRIO is able to compensate respiratory movements thanks to an initial record of chest's excursion and related spatial positions of the tracking system, attached to the patient's skin. During the CT first acquisition, the patient is invited to hold the breath to avoid image artefacts. Then the 3D reconstruction, merged with the CT data acquired, is automatically compared with the spatial position of the tracking system. The system, during the patient's free breathing, warns the radiologist, through a green signal, when the patient breath phase allows the overlapping of anatomical structures with the 3D reconstruction, displayed on the monitor. The hardware components of the system are shown in Fig. 1. The disposable sterile kit is composed of the patient tool (Fig. 1*a*), the needle tool (Fig. 1*b*), the direction tool, the posture tracking system, the breathing sensors and the needle support. The visualisation and elaboration unit (Fig. 1*c*) and the infrared optical sensor (Fig. 1*d*) complete the SIRIO system. Following a proper recording of the patient with a selection of DICOM files of interest, it is possible to see the 3D view of the needle and the anatomical region of interest, starting from the reconstructed tomographic scans. The accuracy of the path in that system is <2 mm.

3. Materials and methods: In a previous study [15], the standard technique for lung biopsy in comparison with the SIRIO-based procedure was analysed. In particular, in a previous study, the authors analysed data collected by the Department of Interventional Radiology of Policlinico Universitario Campus Bio-Medico: 54 patients (mean age 66.5 ± 3.0 years) were enrolled and subjected to lung biopsy under the guidance of SIRIO and 18 patients (mean age 70.1 ± 4.8 years) were subjected to lung biopsy under the guidance of the standard CT-guided technique. Both procedures were carried out with the patient in a given position (prone, supine, or lateral) to provide the shortest distance between the lesion and the pleural surface. Analysing the results, it was possible to confirm that biopsies performed with SIRIO showed more beneficial/patient-friendly values than those acquired without SIRIO. In particular, the benefits identified for the patient were the reduction of absorbed ionising radiation doses, the increase of the accuracy, especially for small lesions, and the improvement of the physical comfort during the procedure. The number of CT scans and the procedural time were also reduced. Improvements in the bioptic procedure, such as minimum size of the operative field, the increase of success in the sample to be analysed, the increased reliability and the repeatability of the procedure, the planning of the trajectory of the needle insertion before the operation based on the 3D reconstruction of the model were discussed in a previous study [15].

The present study is, thus, based on a previous study [15], but it is focused on how the effectiveness of SIRIO-based procedures depends on the size of the lesion. The analysis in this Letter started at the end of September 2015. The data were collected on patients who underwent lung biopsies with the help of SIRIO, in the period between June 2011 and October 2015. The clinical procedures were previously assessed by the Ethical Committee of Università Campus Bio-Medico di Roma and an informed consent from the patients is obtained before the clinical trials. All data are grouped into a database composed of patient demographics (sex and age), date of the procedure, duration of procedure, site of

the lesion, lesion size, absorbed dose, diagnostic or non-diagnostic specimen, presence of complications.

(i) *Group A:* includes all cases of biopsies about lesions of diameter ≤20 mm (133 female and 157 male).
(ii) *Group B:* includes all cases with lesion diameter >20 and ⩽40 mm (77 female and 134 male).

Lesion sizes are calculated by means of the maximum diameter displayed on CT axial images and the lesion location are estimated relative to the pulmonary lobes.

The duration of the procedure is expressed in minutes and it is registered from the preliminary CT scout image recorded to localise the lesion to the moment of needle withdrawal. The specimen is considered diagnostic if the pathologist can make a cytological and histological analysis without problems; otherwise the specimen is non-diagnostic for example because of the small size of the specimen or because of the large presence of necrotic materials.

The radiation dose to the patient's chest is estimated by means of the total dose-length product and then the effective radiation dose was obtained by applying the following formula:

$$\text{Effective radiation dose} = \text{TDLP} \cdot k, \tag{1}$$

where k is the conversion factor (chest: $k = 0.017$ mSv mGy^{-1} cm^{-1}) [16].

The occurrence of possible complications during the biopsy, in particular, pneumothorax (PNX), hemoptysis and pulmonary haemorrhage is assessed but is considered only if the event created a modification in the planned management of the patient.

In this Letter, a statistical analysis is performed to understand if there are statistically significant differences between Group A and Group B about the acquired data. A chi-squared test was used for a diagnostic/non-diagnostic specimen and for the presence of complications; a Z test was used for the duration of the procedure and for the absorbed dose. Once chi-squared and Z test results are obtained, it was possible to obtain the p-value, comparing χ^2 and Z values with pre-set values. Finally, in some cases, the increment between Group A and Group B is calculated, as follows:

$$\Delta X\% = [(xA - xB)/xA]\% \tag{2}$$

Then an economic analysis was carried out and the MASMEC contract options were analysed: *Sale*, *Free loan* and *Rent*. This analysis is focused on the *Free loan* option, because it is the solution adopted by the Interventional Radiology of Policlinico Universitario Campus Bio-Medico. Then the contract options were compared with reimbursements of Italian National Healthcare System.

4. Results: The average age is 71.53 ± 9.47 years in Group A and 72.97 ± 9.62 years in Group B. The gender distribution is similar in both groups but there is an increase in the female gender because of smoking habits.

Mean lesion size is 13.96 ± 4.21 mm in Group A and 29.98 ± 5.87 mm in Group B. The interesting aspect is that 15% of the analysed patients have a lesion diameter <10 mm, i.e. nodules that, in the absence of SIRIO, would not be sampled percutaneously but had to wait until the lesion increases in diameter and the dimensions are in line with the percutaneous approach.

The average duration of the procedure is 50.91 ± 18.87 min in Group A and 44.98 ± 19.43 min in Group B. This difference is statistically significant ($p < 0.05$) and in Group A there is a time increment of 12% with respect to Group B.

In particular, from the regression analysis, the duration of the procedure increases by about 6 s for each millimetre less on the lesion size. Fig. 2 shows the procedure duration in both groups.

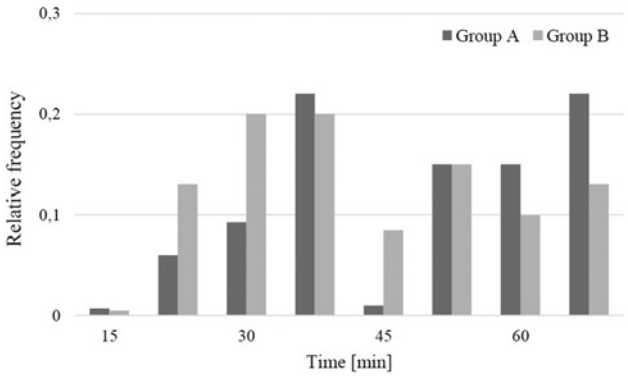

Fig. 2 *Procedure duration comparison between Group A and Group B*

Then, the mean effective radiation dose is analysed (Fig. 3). The general thought was that the mean effective radiation dose would be higher in Group A and statistically significant because the absorbed dose is directly proportional to the exposure time and so, partly, also to the procedural duration.

From the analysis, the mean effective radiation dose in Group A (5.42 ± 4 mSv) is higher than Group B (4.28 ± 3.2 mSv) but not statistically significant ($p > 0.05$), so it is not related to the size of the lesion and to the duration of procedure.

An interesting aspect to analyse is to study the presence of a diagnostic or non-diagnostic specimen (Fig. 4). From 501 analysed patients, only 8.8% did not receive a diagnostic specimen, i.e. the pathologist could not make cytological or histological analysis, for example because of the exiguity of material taken from the nodule or because most of the sampled tissue was necrotic. In particular, non-diagnostic specimens are 10% in Group A and 7% in Group B. This difference is not statistically significant ($p > 0.05$).

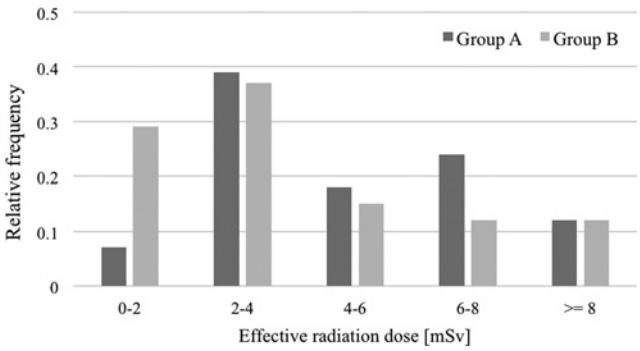

Fig. 3 *Effective radiation dose comparison between Group A and Group B*

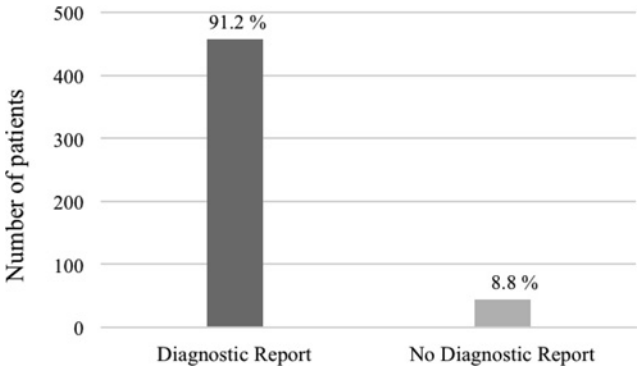

Fig. 4 *Percentage of diagnostic and non-diagnostic specimens in both groups*

The complication rate in Group A (13.02%) is higher than Group B (7.98%) but not statistically significant ($p > 0.05$). In both groups, the most frequent complication was the PNX, i.e. the needle penetrates in some small bronchi and air passes in the pleural cavity, with a consequent collapse of a small/large part of the lung. In Figs. 5 and 6, complication rate and types of complications are shown.

This analysis shows that only the duration of the procedure is significantly higher in Group A. The general thought might be to consider that the increase of the procedure duration is the consequence of the presence of complications (which is higher in Group A, even if it is not statistically significant). The patients without complications were re-analysed and, once again, the duration of the procedure is greater in Group A in a statistically significant way. It is thus normal and physiological that, for small lesions, the operator proceeds in a more cautious manner and also Fitts' law explained this concept [17]

$$\mathrm{MT} = a + b\log_2(2A/W + 1), \tag{3}$$

where MT is the movement time, a and b are the regression coefficients, A is the distance between the start point and point of arrival, W is the width of the target measured along the axis of motion.

In Table 1, the results of the time, the dose, the diagnostic/non-diagnostic specimen, the complication rate and the types of complications are summarised.

5. Economic analysis: From an economic perspective, the MASMEC contract options are analysed: *Sale* (device price: €100,000.00 + €280.00 for each disposable kit), *Free loan* (€750.00 for each procedure, kit included) and *Rent* (device price: €3,750.00 per month + kit price: €280.00).

This analysis is focused on the *Free loan* option, because it is the solution adopted by the Interventional Radiology of Policlinico Universitario Campus Bio-Medico.

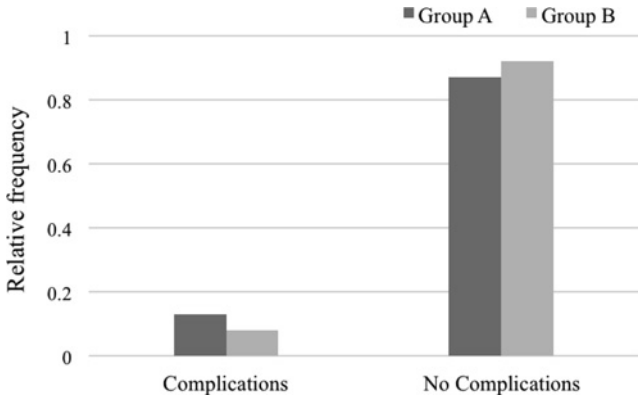

Fig. 5 *Complication rate in both groups*

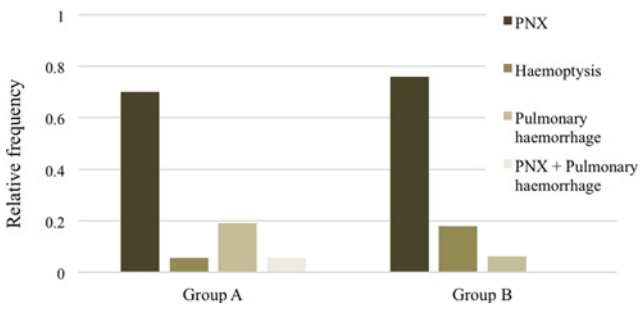

Fig. 6 *Type of complication in both groups*

Table 1 Mean and standard deviation of the fundamental parameters

	Group A Mean ± SD	Group B Mean ± SD	p value
procedure duration, min	50.91 ± 18.87	44.98 ± 19.43	$p < 0.05$
effective radiation dose, mSv	5.42 ± 4.01	4.28 ± 3.21	$p > 0.05$
procedure duration without complications, min	48.18 ± 16.73	42.83 ± 16.38	$p < 0.05$
	Percentage, %	Percentage, %	p value
diagnostic specimen	90.00	93.00	$p > 0.05$
complication rate	13.02	7.98	$p > 0.05$

A lung biopsy performed using outpatient complex procedures, i.e. the patient remains under observation for a few hours after the biopsy, that has a specific code for the diagnosis of the lung nodule (P2357), has a reimbursement from the Italian National Healthcare System lower than the cost incurred from the hospital (there is a negative gross operating margin of about €300.00, considering SIRIO price, the cost of the occupation of a CT room, the cost of the medical staff and the cost of histological/cytological examination). If we consider the option of renting and the performing 10 lung percutaneous biopsies per week than the reimbursements will cover the cost of the sterile disposable kits and there will be a negative gross operating margin of about €3,750.00 per month.

If we take into account the complete acquisition of the equipment and 45 biopsies per month that could be a normal level for a high throughput centre, the hospital will get a positive gross operating margin of €2,700.00 per month that will cover a complete amortisation of the system in <4 years.

6. Discussion and conclusions: This Letter presents that the diameter of lesion affects only one parameter: the procedure duration. This result is explained by the fact that probably, in organs like lungs that are subjected to the movement due to respiration, for very small dimensions, the operator proceeds in a more cautious manner, manoeuvring the instrument more slowly to reach the lesion and to perform the desired biopsy, with a very high percentage of success. Another possible reason may lie in the difficulty of targeting a lesion of such a small size especially if it is located more in-depth, i.e. to a greater distance from the pleural surface. Other parameters such as the complication rate, the effective radiation dose and the presence of diagnostic or non-diagnostic specimens are not dependent in a statistical significant way by the diameter of the lesion.

From a technological point of view, it will be important, in the future, to improve the instrument by creating a system that is able to adapt perfectly to the breathing movements and to the pulsatility of the arteries (problems encountered by radiologists), considering also the opportunity to automate the device. Furthermore, SIRIO could be used to test and enable different solutions to perform lung biopsies especially in patients considered at high risk of complications.

The economic evaluation should not be considered negatively because of SIRIO medium and long-term benefits such as early diagnosis, absence of hospitalisation, use of the system also by non-expert interventional radiologists, reduction of the absorbed dose of X-rays, high quality of the samples taken from the nodule, increasing number of lung cancers in a curable early stage, opportunity to ablate the small cancers in patients with severe contraindications to surgery etc. The main problem is that ICD-9-CM nomenclature does not include the biopsy procedures carried out using SIRIO or other virtual navigators, thus there is no indication on the correct reimbursement on a national level. It is necessary to create a new Diagnosis Related Group (DRG) for biopsy with

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navigation systems, also in relation to medium–long-term benefits. Future studies will be important to assess the overall impact of the SIRIO technology, arising from the higher ability of earlier diagnosis and treatment, made possible by the diagnostic specimen from small nodules and supported by the improvement in quality of histological examinations. Finally, to stimulate the use of such a tool probably the development of a resterilisable kit should be studied. The best solution for the hospital should be to perform biopsies in ordinary hospitalisation (at least two hospitalisation nights), because it represents a good way to meet the costs (positive gross operating margin of at least €300.00 per biopsy), but in Italy the ordinary hospitalisation is appropriate only for patients who have a significant complication after biopsy [18]. In these cases, the reimbursement is associated with specific DRG, i.e. DRG 94 and DRG 95, are for severe PNX with and without complications, respectively. For patients without complications a regime of the outpatient complex procedure is expected, especially for smaller hospitals. It would be thus ideal to perform the ordinary hospitalisation for all those patients considered at high risk of complications, according to the age, comorbidities (cardiac, pulmonary), anamnesis, malignancy suspicion and general clinical picture. Now, the fraction of high-risk patients is unknown in the two groups of patients, but, considering the average age of more than 70 years for both groups and the high incidence of chronic obstructive pulmonary disease at this age, knowing the margins of reimbursement of the different schemes, the trade-off would be about 50%, so one biopsy could be performed under the outpatient complex procedures for each performance in ordinary hospitalisation, at least to have the system in balance in smaller centres.

The results of this Letter are based on data collected by a single centre but there are other similar trials on-going in Ospedale San Paolo (Bari, Italy) and other hospitals abroad. The preliminary results from these centres are in line with the ones described in this Letter, but they are too preliminary to be compared with the present data. In the near future it will be possible to compare data performing a multicentre analysis.

In summary, this is the first study focused on the clinical and economic aspects of an optical CT-guided navigation system that has assessed on a consistent number of patients.

7. Funding and declaration of interests: None declared.

8. References

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