The role of ultrasound-guided tissue sampling techniques in the management of extra-ocular orbital lesions

Antonia Timmis¹, Philip Touska¹, Jimmy Uddin² and James Pilcher¹

Abstract

Background: Multiple disease processes may arise within the orbit and imaging plays a vital role in the evaluation of such lesions. The anterior orbital contents are readily amenable to evaluation by ultrasonography. Furthermore, the modality can be used to guide tissue sampling (fine needle aspiration or core biopsy) and may obviate the requirement for invasive surgical biopsy.

Methods: We carried out a retrospective review of ultrasound-guided fine needle aspirations/core biopsies of extra-ocular orbital lesions undertaken at our institution. The anatomical locations, sonographic appearances and sampling techniques were analysed.

Results: There were 7 fine needle aspirations and 1 core biopsy carried out during the period analysed. Multimodality imaging was available in all cases. The majority of lesions were located in the region of the lacrimal gland. All procedures were well-tolerated and there were no post-procedure complications.

Conclusion: Many extra-ocular, orbital neoplasms are amenable to ultrasound-guided tissue sampling and the procedure is well tolerated. However, a clear understanding of orbital anatomy, differential diagnosis and technique is required to enable safe sampling. Furthermore, a collaborative, multimodality approach is imperative for optimal patient management.

Keywords

Head and neck, diagnostic ultrasound

Date received: 30 April 2017; accepted: 7 December 2017

Introduction

Lesions of the orbit are protean in their aetiology, reflecting the anatomic complexity of the region. Such lesions vary from inflammatory processes such as IgG4-related infiltration and thyroid orbitopathy to vascular malformations and a wide range of primary neoplasms, arising from epithelial, mesenchymal or lymphoproliferative elements. The orbit is also a potential site for secondary disease. Metastases represent approximately 2–7% of orbital lesions^{1–3} and may present prior to identification of the primary tumour in up to 60% of cases.⁴ Breast, prostate, melanoma, gastrointestinal, lung and choroid primaries are amongst the most commonly encountered neoplasms that metastasize to the orbit.^{1,4,5}

In some cases, a combination of patient demographics and manner of presentation will significantly narrow the differential; however, in the majority of patients, signs and symptoms are non-specific and the clinical differential will be wide. Imaging is therefore vital in narrowing the differential and planning treatment.

Cross-sectional techniques, namely computed tomography (CT) and magnetic resonance imaging

¹Department of Clinical Radiology, St George's University Hospitals NHS Foundation Trust, UK

²Moorfields Eye Hospital, London, UK

Corresponding author:

Antonia Timmis, Department of Clinical Radiology, St George's University Hospitals NHS Foundation Trust, UK.

Email: antoniaticimtis@gmail.com

(MRI), represent the preferred modalities for evaluating the orbit radiologically. MRI offers superior soft tissue contrast resolution while avoiding the disadvantage of ionising radiation and is therefore favoured, although relatively long scanning times, image motion degradation, cost and availability are limiting factors.

Despite the availability of these diagnostic imaging modalities, obtaining a tissue sample is often the only way to establish an accurate diagnosis and therefore provide appropriate treatment.⁶ Ultrasound is not typically used to evaluate the orbit for diagnosis, except the use of Doppler for vascular lesions, but is an excellent means of guiding tissue sampling techniques such as fine needle aspiration (FNA) and core biopsy. Furthermore, it offers real-time evaluation of tissue characteristics, such as vascularity, and the relationship between a lesion and adjacent mobile structures, including the extra-ocular muscles and globe. Most importantly, ultrasound-guided tissue sampling may preclude the need for an open surgical biopsy with its inherent risks and need for anaesthesia.⁷

Herein, we present our technique and experience with ultrasound-guided FNA and core biopsy. In addition, we present the current literature on ultrasound-guided orbital lesion sampling, including complications.

Materials and methods

A retrospective review of all ultrasound-guided orbital FNA and core biopsy procedures performed in our institution was carried out spanning a period from November 2012 to March 2017. Cases were identified using the picture archiving and communication system (PACS) and radiology information systems (RIS) databases. Further clinical information was obtained from the institution's pathology database and electronic patient records.

Ultrasound scanning was carried out with a Toshiba Aplio™ XG or 500 machine (Toshiba Medical Systems, Crawley, West Sussex), using a 7.2–14 MHz linear transducer. The procedure was performed in accordance with institutional guidance; written informed consent was obtained for core biopsy sampling and verbal consent was obtained for FNA sampling. Coagulation parameters were checked prior to the procedure.

The orbit was scanned, with patients in a supine position, in axial and sagittal planes with the eye closed. Probe angulation was frequently required in order to accommodate the bony orbital margins and a cushion of coupling gel helped to maintain transducer contact.

FNA was performed by two different radiologists with 5 and more than 15 years' experience in ultrasound-guided procedures (A.S., $n=1$ FNAs; J.P., $n=6$ FNAs respectively). FNA was performed without prior analgesia using a 25-gauge needle or a 27-gauge

needle if the lesion was found to be highly vascular. All procedures were conducted in an aseptic manner, as per institutional policy. A freehand technique was used to obtain the sample, with the needle kept in line with the long axis of the probe, and a view of the needle tip maintained throughout. The typical hand and probe positioning is demonstrated in Figure 1. Once the needle was seen within the lesion, it was agitated within the lesion under real-time ultrasound visualisation. In some cases, the needle was attached to a 10 mL syringe and suction was applied to obtain the sample. The sample was immediately reviewed by an attending cytopathologist to confirm adequacy and repeat sampling performed if an inadequate sample was obtained. A maximum of two passes were performed in all cases.

The biopsy was performed by a third radiologist with 4 years' experience in ultrasound-guided procedures (L.W., $n=1$ core biopsy). Local anaesthesia was used prior to the core biopsy, with 1% lidocaine instilled into the periorbital subcutaneous tissue. The tru-cut biopsy was performed using a 16-gauge semi-automatic needle (Temno™; BD, USA). Again, the needle tip was continuously visualised for the duration of the procedure.

Search strategy

We searched the major databases (PubMed, MEDLINE, EMBASE and Ovid) between January

Figure 1. Typical approach for ultrasound-guided orbital tissue sampling.

1997 and March 2017 using the following search terms: 'Biopsy,' 'Biopsy, Fine Needle,' 'Orbital,' 'Orbital neoplasm,' 'Ultrasound,' and 'Ultrasound guided.' We included only studies that were written in English. The references of studies were also included to assess potential articles that met the criteria. There is extensive literature on the use of non-image-guided orbital sampling.⁸⁻¹¹ Lesions suitable for non-guided sampling are generally palpable and, due to the blind nature of the procedure, are anticipated to result in a different profile of complications compared to ultrasound-guided sampling. Therefore, our review identified studies specifically focusing on ultrasound-guided sampling techniques.

Results

Between November 2012 and March 2017, a total of 8 orbital lesions were sampled under ultrasound-guidance. The mean age was 57 years (range: 27-83 years). The majority (62.5%) of cases were extraconal ($n=5$), 1 case (12.5%) spanned both intra- and extraconal spaces and 2 cases (25%) were intraconal in location. The average size of the lesions was 1.7 cm (range 1-2.5 cm). In all cases, prior cross-sectional imaging was available. Both MRI and CT were obtained in 1 case, and CT alone in 7 cases. In all cases, the cross-sectional imaging was reviewed prior to sampling and a safe window was identified on ultrasound in order to avoid any injury to the globe, vascular structures or optic nerve.

All obtained samples were adequate; however, two patients required surgical biopsy for further histological examination following diagnosis of a malignant lesion. No patients experienced any complications following the procedure.

Three patients (37%) were found to have an underlying benign pathology: pleomorphic lacrimal adenoma, intra-orbital colloid cyst and chronic inflammation with eosinophils. Five patients (63%) were found to have an underlying malignant pathology: diffuse large B-cell lymphoma, uveal melanoma, lacrimal sac squamous cell carcinoma, lacrimal ductal carcinoma and peripheral T-cell lymphoma. The sonographic appearances of the lesions varied. Anatomy visible on ultrasound of the normal orbit is displayed in Figure 2 and examples of the lesions with corresponding cross sectional imaging are given in Figure 3.

Literature review

There is limited published information on ultrasound-guided FNA and core biopsy and our review found only three articles.

Gupta et al.¹² performed ultrasound-guided FNA using a 5-MHz probe to sample 37 orbital lesions.

Orlandi et al.¹³ performed ultrasound-guided core biopsy on 13 orbital lesions using either linear 12-5 MHz or mini-convex 8-4 MHz probes. Pagni et al.¹⁴ performed ultrasound-guided FNA on 24 patients with orbital lesions.

Discussion

Our results demonstrate that ultrasound-guided FNA and core biopsy is a safe and effective procedure for sampling lesions within the orbit. A range of underlying pathologies accounted for the orbital lesions in our cohort of patients, including benign and malignant aetiologies. Ultrasound-guided sampling prevented the need for invasive surgical biopsy in the majority of our patients.

No complications were observed amongst the patients in our study. Operator experience is an important factor influencing the complication rate of ultrasound-guided procedures. The advantage of ultrasound guidance in providing certainty of needle placement relies on the ability of the operator to manipulate the probe and needle to ensure the needle and target lesion are in constant view. This can be technically challenging, and requires appropriate training and experience to master the skill. The operators in our study had a minimum of 4 years of experience in performing ultrasound-guided procedures, and the majority of procedures in our study (6 of the 7 FNAs) were performed by a senior radiologist with more than 15 years' experience. Although the small sample size makes it difficult to generalise, this level of experience may have contributed to the low complication rate in our study. The importance of adequate experience and training amongst operators performing ultrasound-guided orbital sampling in order to reduce the risk of serious complications cannot be overestimated.

There is extensive literature focusing on non-image-guided fine needle aspiration and core biopsy sampling of orbital lesions, and the complications secondary to non-guided sampling.⁸⁻¹¹ The complications most commonly described include subcutaneous eyelid haematoma, retrobulbar haemorrhage, damage to adjacent structures including the globe, optic nerve and brain (with a subsequent risk of cerebral abscess formation and meningitis), permanent ocular mobility disturbance, ptosis and visual loss.⁸

We present the complications following ultrasound-guided orbital sampling described in the literature found in our review in Table 1.¹²⁻¹⁴ Cutaneous eyelid haematoma was the most commonly encountered complication following ultrasound-guided sampling. This represents a minor complication that is not expected to cause permanent damage and the incidence cannot be reduced with image guidance.^{8,15} All reported cases of cutaneous eyelid haematoma resolved with

Figure 2. Anatomy visible on ultrasound of the normal orbit: (a) medial and lateral recti muscles (transverse view); (b) inferior rectus muscle (longitudinal view); (c) superior rectus muscle (longitudinal view); (d) lacrimal gland (oblique, angled view in the axis of the gland); (e) ophthalmic artery and lacrimal vessels (transverse view); (f) retinal vessels (transverse view); (g) supraorbital nerve (transverse view); (h) infraorbital nerve (longitudinal view).

conservative management.^{12,13} Retrobulbar haemorrhage was the second most common complication following ultrasound-guided sampling; however, in all reported cases, these were small and resolved with conservative management (bed rest with the head of the patient elevated, ice packs and analgesia) and no

visual sequelae were reported on follow up.¹³ The final reported complication was epistaxis in a patient who had a lesion extending into the nasal cavity; this was successfully managed with nasal packing.

There were no cases of damage to adjacent structures described in the literature on sampling using

Figure 3. Ultrasound and cross-sectional imaging of the orbital tumours in our case series. (a) Diffuse Large B-Cell Lymphoma. The left-hand image is a transverse (TS) view through the superolateral left orbit which demonstrates a predominantly hypoechoic mass with areas of increased echogenicity and vascularity (arrow), with infiltration of intra- and extra-conal fat. The right-hand image, from an accompanying postcontrast axial CT, demonstrates an enhancing mass within the lateral orbit, which extends into the intraconal space, abuts the optic nerve, deforms (but does not invade) the globe and results in proptosis. (b) Uveal melanoma. The left-hand image is a TS US view through left orbit demonstrating a predominantly intraconal mass (arrow), which is hypoechoic with lobulated margins. The right-hand image is from an accompanying axial T2 weighted MR image, which demonstrates an ovoid lesion of homogeneously low signal, consistent with presence of melanin containing tissue. (c) Benign pleomorphic lacrimal adenoma. The left-hand image is a TS US view of left orbit, which demonstrates an intermediate echogenicity, lobular mass (arrow), which replaces the normal left lacrimal gland. The left-hand image from an accompanying coronal CT confirms the presence of an extraconal mass situated within the superolateral left orbit, replacing the normal lacrimal gland (for comparison, the normal right lacrimal gland is of considerably lower volume (arrowhead)). The lesion causes mass effect on the intraconal tissues, local bony remodelling and thinning of the orbital roof. (d) Intraorbital colloid cyst. The left-hand image is a TS US of the right orbit, which demonstrates an ovoid, hypoechoic lesion (arrow), with fine internal echoes and posterior acoustic enhancement. The right-hand image from the accompanying coronal CT confirms the presence of an extraconal, cystic mass within the superolateral right orbit, which causes inferomedial displacement of the extraocular muscles (arrowhead) and optic nerve. Ultrasound-guided aspiration of the lesion resulted in almost complete collapse of the cyst. (e) Lacrimal sac squamous cell carcinoma. The left-hand image is a targeted longitudinal (LS) US view of the region of the lacrimal sac, showing a low-reflectivity mass with disorganised vascularity on power Doppler. The right-hand image from an accompanying coronal T1 weighted, fat-suppressed, MR following gadolinium injection shows moderate, diffuse enhancement (arrow) within the lesion, centred on the left lacrimal sac. (f) Chronic inflammation with eosinophils. The left-hand image is a targeted TS US view of the left superolateral orbit demonstrating a mixed reflectivity, soft tissue mass. The biopsy needle can be seen as a linear echogenic structure entering the mass in a medial to lateral approach to avoid injury to the globe. The right-hand image is from an accompanying post-contrast CT of the orbits and demonstrates an enhancing soft tissue mass that is inseparable from the lacrimal gland (arrow). (g) Peripheral T-cell lymphoma. The left-hand image is an oblique US image at the level of the inferior orbital margin, showing poorly-marginated, heterogeneous soft tissue extending into the periorbital subcutaneous tissues. The tip of a 25G needle can be seen as an echogenic structure with the bevel in the centre of the lesion. The right-hand image is from an accompanying sagittal CT reconstruction of left orbit showing the soft tissue mass centred on the inferior orbital margin, extending anteriorly into the periorbital tissues (arrow). (h) Lacrimal Gland Ductal Carcinoma. The left-hand image is an oblique US view demonstrating diffuse, abnormal enlargement of the right lacrimal gland. The right-hand image is from an accompanying coronally-reconstructed CT, which demonstrates an ill-defined lesion in the upper outer quadrant of the right orbit with central low attenuation, consistent with internal necrosis.

Table 1. Complications following ultrasound-guided tissue sampling – a review of the literature

Study	<i>n</i>	Sampling technique	Adequate tissue	Complications	Complication management
Orlandi	13	Core biopsy	13 (100%)	Retrobulbar haematoma (1, 7%)	Conservative management, no longstanding complications
				Cutaneous eyelid haematoma (3, 23%)	Conservative management, no longstanding complications
Gupta	37	FNA	29 (78%)	Retrobulbar haematoma (2, 5.4%)	Conservative management, no longstanding complications
				Cutaneous eyelid haematoma (1, 2.7%)	Conservative management, no longstanding complications
				Epistaxis (1, 2.7%)	Nasal packing
Pagni	24	FNA	17 (70%)	Retrobulbar haematoma (2, 8%)	Conservative management, no longstanding complications

FNA: fine needle aspiration.

ultrasound guidance, which is most likely the consequence of continuous real time visualisation of the needle tip during the procedure. Orlandi et al.¹² also described the technique of injecting saline into the extraocular tissues adjacent to the globe in order to form a 'salinoma' to displace the globe in patients found to have a very narrow space between the globe and bony orbit. The absence of any cases of globe perforation in this study may be secondary to the use of this technique.

Whilst the cases of retrobulbar haematoma in the reviewed literature are described as small and not leading to permanent visual sequelae, retrobulbar haematoma does represent a potentially serious complication that can result in irreversible visual loss. Therefore, post-procedural ultrasound to exclude haematoma formation and routine post-procedural monitoring is considered prudent following FNA and core biopsy procedures, regardless of the use of image guidance.

CT guided orbital FNA is also a recognised procedure for sampling retrobulbar lesions. As with ultrasound-guided sampling, there are limited publications regarding this procedure; however, the studies available demonstrate that this also represents a safe and effective procedure. Dubois et al.¹⁶ performed fine needle aspiration using 23 gauge needles on two patients with pathological optic nerves under CT guidance.¹⁶ They achieved 100% adequacy of their samples

and their patients experienced no complications. Czerniak et al.¹⁷ performed CT guided fine needle aspiration using 23 gauge needles on 13 patients with retrobulbar lesions, achieving 100% adequacy and encountered no complications.

The advantages of obtaining histological samples via core biopsy over cytological samples via FNA stem from the larger tissue volume obtained and the ability to appreciate tissue architecture, potentially increasing the likelihood of a definitive diagnosis.^{6,14} Moreover, core biopsy has traditionally been required for immunohistochemical analysis, which is of particular importance for tumours of a lymphoproliferative nature where precise subtyping and classification is critical for guiding treatment.¹³ However, immunohistochemical techniques can be applied to cell block preparations made from material obtained via FNA.¹⁸ Furthermore, cytological specimens can be subjected to flow cytometry, which enables immunophenotyping of lymphoproliferative lesions.¹⁸ Therefore, it is vital to collaborate with pathology departments to determine what facilities and expertise are available locally. Two patients in our study (one with peripheral T-cell lymphoma and one with a lacrimal squamous cell carcinoma) required open biopsy to obtain tissue for immunohistochemical analysis following an initial FNA.

Despite the benefits, an anticipated disadvantage of core biopsy is the increased potential for complications

secondary to the use of significantly higher gauge needles.⁶ Moreover, there is a purported increased risk of tumour seeding secondary to core biopsy procedures again due to the larger calibre of the needle.^{6,14} For these reasons, FNA is often used as the initial sampling procedure and, for many tumours, cytology is adequate to produce a diagnosis.

A number of non-ophthalmological studies have shown that increased diagnostic accuracy can be achieved with core biopsy over FNA without increasing the number of complications.^{19–22} However, no studies have compared the complication rate of FNA and core biopsy for sampling orbital tumours. Although our case series did include both core biopsy and FNA sampling techniques, the extremely small sample size (a single core biopsy) precludes accurate comparison of the complication rates. Comparison with existing published studies is also difficult due to small sample sizes, and procedural differences e.g. size of the lesion, operator experience and equipment.^{12–14} More research in this area would be useful to establish accurate complication rates of core biopsy versus FNA in orbital sampling to help determine which is the optimal first line sampling technique.

A further potential limitation of FNA is the risk of obtaining a suboptimal aspirate.¹³ In our study, we achieved 100% adequacy for diagnosis in the seven fine needle aspiration samples that were performed. By comparison, Gupta et al.¹² reported that the FNA was adequate in 78%, with the remainder of aspirates yielding either no tissue, blood or fibrous tissue, which rendered cytological diagnosis impossible. Pagni et al.¹⁴ reported that the FNA was adequate in 70% of studies.

A cytopathologist was present for all the FNA procedures performed in our study, which allowed either confirmation of adequacy or request for a repeat aspirate at the time of sampling. This most likely contributes to the high adequacy rate from our study. Other authors have reported up to 94% accuracy for FNA samples in orbital tumors, when working in collaboration with an experienced cytopathologist; even without image guidance.^{9,23}

Needle size may also be a factor in achieving sample adequacy. In our study, 25-gauge needles were routinely used, unless there was significant vascularity within the lesion or blood in the initial aspirate, where 27-gauge needles were utilised. Gupta et al.¹² used slightly larger gauge needles for sampling, initially using 22 gauge or 23–25 gauge if there was significant vascularity within the lesion. This may represent a further contributing factor to the comparatively high adequacy rate in our study, particularly as a number orbital lesions can have significant internal vascularity.⁷

Finally, the underlying nature of the tumour may be a significant factor in the success of obtaining adequate cells by FNA. Three of the 37 patients (8%) in the study by Gupta et al. and 2 of the 7 patients in the study by Pagni et al. who had non-diagnostic aspirates were subsequently found to have pseudo-tumours, which are notoriously difficult to obtain an adequate diagnostic aspirate from.^{11,24} Non-diagnostic smears from a further 3 of the 7 patients in the study by Pagni et al.¹⁴ were from patients who had underlying vascular tumours: two patients were subsequently found to have cavernous haemangiomas and one had an epithelioid haemangioendothelioma. The aspirates obtained from these lesions consisted entirely of haemorrhagic material, making the distinction between benign and malignant entities on cytology extremely challenging.¹⁴

Conclusion

Ultrasound-guided FNA and core biopsy are potentially safe and effective procedures for sampling lesions within the orbit, with the ability to obviate the need for surgical intervention in a considerable number of patients. Further studies comparing the complication rates of FNA with core biopsy would be useful to determine the optimal initial sampling technique for patients presenting with orbital tumours.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Ethics approval

The project was reviewed by the local Joint Research and Enterprise Office and no ethical or Health Research Authority review was deemed to be required.

Guarantor

JP

Contributors

JMU and JP conceived the study. AT and PT researched literature and drafted the manuscript. JP and JMU revised the final version of the manuscript. All authors approved the final version of the manuscript.

Permission of subject to publish photograph

Written consent was obtained from the individual pictured in Figure 1 giving permission to publish his photograph.

References

- Holland D, Maune S, Kovács G, et al. Metastatic tumors of the orbit: A retrospective study. *Orbit* 2003; 22: 15–24.
- Bonavolontà G, Strianese D, Grassi P, et al. An analysis of 2,480 space-occupying lesions of the orbit from 1976 to 2011. *Ophthalm Plast Reconstr Surg* 2013; 29: 79–86.
- Shields JA, Shields CL and Scartozzi R. Survey of 1264 patients with orbital tumors and simulating lesions: The 2002 Montgomery Lecture, part 1. *Ophthalmology* 2004; 111: 997–1008.
- Dutton JJ. Orbital diseases. In: Yanoff M and Duker JS (eds) *Ophthalmology*. 4th ed. London: Elsevier, pp. 1318–1332.
- Valenzuela AA, Archibald CW, Fleming B, et al. Orbital metastasis: Clinical features, management and outcome. *Orbit* 2009; 28: 153–159.
- Yarovoy AA, Bulgakova ES, Shatskikh AV, et al. CORE needle biopsy of orbital tumors. *Graefes Arch Clin Exp Ophthalmol* 2013; 251: 2057–2061.
- Bourne TD and Karcioğlu ZA. Orbital biopsy. In: Karcioğlu ZA (ed.) *Orbital tumors: Diagnosis and treatment*. New York: Springer, 2015, pp. 121–128.
- Liu D. Complications of fine needle aspiration biopsy. *Ophthalmology* 1985; 92: 1768–1771.
- Dey P, Radhika S, Rajwanshi A, et al. Fine needle aspiration biopsy of orbital and eyelid lesions. *Acta Cytol* 1993; 37: 903–907.
- Tijl JW and Koornneef L. Fine needle aspiration biopsy in orbital tumours. *Br J Ophthalmol* 1991; 75: 491–492.
- Kennerdell JS, Dekker A, Johnson BL, et al. Fine needle aspiration biopsy use in orbital tumour. *Arch Ophthalmol* 1979; 97: 1315–1317.
- Gupta S, Sood B, Gulati M, et al. Orbital mass lesions: US-guided fine-needle aspiration biopsy-experience in 37 patients. *Radiology* 1999; 213: 568–572.
- Orlandi D, Sconfienza LM, Lacelli F, et al. Ultrasound-guided core-needle biopsy of extra-ocular orbital lesions. *Eur Radiol* 2013; 23: 1919–1924.
- Pagni F, Jaconi M, Smith AJ, et al. The role of fine needle aspiration of orbital lesions: A case series. *Acta Cytol* 2016; 60: 31–38.
- Lagrèze WA, Rössler J, Illerhaus G, et al. Therapy of tumors of the anterior orbit. *Ophthalmologe* 2011; 108: 519–530.
- Dubois PJ. Computed tomographic localisation for fine needle aspiration biopsy of orbital tumours. *Radiology* 1979; 13: 149–152.
- Czerniak B, Woyke S, Daniel B, et al. Diagnosis of orbital tumours by aspiration biopsy guided by computerised tomography. *Cancer* 1984; 54: 2385–2389.
- Ramzy I and Herbert A. Cytopathology: The history, the present and the future direction. In: Gray W and Kocjan G (eds) *Diagnostic cytopathology*. 3rd ed. London: Churchill Livingstone, 2010, pp. 3–13.
- Kraft M, Laeng H, Schmuziger N, et al. Comparison of ultrasound-guided core-needle biopsy and fine needle aspiration in the assessment of head and neck lesions. *Head Neck* 2008; 30: 1457–1463.
- Huang YC, Wu CT, Lin G, et al. Comparison of ultrasonographically guided fine-needle aspiration and core needle biopsy in the diagnosis of parotid masses. *J Clin Ultrasound* 2012; 40: 189–194.
- Gong Y, Sneige N, Guo M, et al. Transthoracic fine-needle aspiration vs concurrent core needle biopsy in diagnosis of intrathoracic lesions: A retrospective comparison of diagnostic accuracy. *Am J Clin Pathol* 2006; 125: 438–444.
- Leifland K, Lundquist H, Lagerstedt U, et al. Comparison of preoperative simultaneous stereotactic fine needle aspiration biopsy and stereotactic core needle biopsy in ductal carcinoma in situ of the breast. *Acta Radiol* 2003; 44: 213–217.
- Tani E, Seregard S, Rupp G, et al. Fine needle aspiration cytology and immunocytochemistry of orbital masses. *Diagn Cytopathol* 2006; 34: 1–5.
- Kennerdell JS, Dubois PJ, Dekker A, et al. CT guided fine needle aspiration biopsy of orbital optic nerve tumours. *Ophthalmology* 1980; 87: 491–496.