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Original Article

Linear Accelerator Stereotactic Radiosurgery for Vestibular Schwannomas: A UK Series

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Abstract

Aims: To evaluate non-auditory toxicity and local control after linear accelerator stereotactic radiosurgery (SRS) for the treatment of vestibular schwannomas.
Materials and methods: The institutional policy was to use SRS for radiologically progressing vestibular schwannomas. Case notes and plans were retrospectively reviewed for all patients undergoing SRS for vestibular schwannomas between September 2002 and June 2012. All patients were surgically immobilised using a BrainLab stereotactic head frame. The treatment plan was generated using BrainLab software (BrainScan 5.03). The aim was to deliver 12 Gy to the surface of the target with no margin. Patients with a minimum of 12 months of follow-up were included for toxicity and local control assessment. Radiological progression was defined as growth on imaging beyond 2 years of follow-up. Overall local control was defined in line with other series as absence of surgical salvage.
Results: Ninety-nine patients were identified. Two patients were lost to follow-up. After a median follow-up interval of 2.4 years, the actuarial radiological progression-free survival at 3 years was 100% and overall local control was also 100%. However, two patients progressed radiologically at 3.3 and 4.5 years, respectively. Twenty-one of 97 (22%) evaluable patients suffered trigeminal toxicity and this was persistent in 8/97 (8%). Two of 97 (2%) suffered long-term facial nerve toxicity (one with associated radiological progression causing hemi-facial spasm alone). One of 97 (1%) required intervention for obstructive hydrocephalus. No statistically significant dosimetric relationship could be shown to cause trigeminal or facial nerve toxicity. However, 7/8 patients with persistent trigeminal nerve toxicity had tumours in contact with the trigeminal nerve.
Conclusions: SRS delivering 12 Gy using a linear accelerator leads to high local control rates, but only prospective evaluation will fully establish short-term toxicity. In this study, persistent trigeminal toxicity occurred almost exclusively in patients whose tumour was in contact with the trigeminal nerve.

Key words: Acoustic neuroma; radiosurgery; vestibular schwannoma

Introduction

Vestibular schwannoma, also termed acoustic neuroma, is a Schwann cell-derived benign tumour arising from the vestibular component of the eighth cranial nerve. Although unilateral in over 90% of cases, bilateral tumours are found in association with type 2 neurofibromatosis [1]. Vestibular schwannoma is usually diagnosed on magnetic resonance imaging (MRI) carried out routinely for unilateral sensorineural deafness. Although a slow-growing tumour, a progressive increase in size can cause trigeminal and facial neuropathies, as well as brainstem compression with resultant obstructive hydrocephalus.

The management strategies for vestibular schwannoma include observation with serial imaging, surgical resection and radiotherapy (both fractionated and single fraction). The purpose of radiation treatment is two-fold; first to prevent growth in order to avoid surgery (local control) and second to preserve function. However, it remains unclear whether earlier intervention with radiation has any actual clinical benefits compared with observation. The term stereotactic radiosurgery (SRS) is often used to define single-

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fraction high-dose radiotherapy delivered with stereotactic localisation. Widespread reports of high local control rates (predominantly using gamma knife), have established SRS as the favoured approach [2–11]. SRS can also be delivered using a modified linear accelerator and a stereotactic surgical head frame providing necessary quality assurance tests are carried out. For example, tests include checks of mechanical and radiation alignment of the secondary collimator mount (a Winston-Lutz test), checks of rotational dosimetric output and small field dosimetric measurements to enable treatment planning [12].

Although publications support the use of SRS for vestibular schwannoma, prospective trial data are lacking and linear accelerator SRS publications remain limited. The purpose of this study was to evaluate clinical and dosimetric outcomes using linear accelerator-based SRS and to explore factors that may predict non-auditory toxicity.

Materials and Methods

Sequential patients treated with SRS for unilateral vestibular schwannoma at the Queen Elizabeth Hospital, Birmingham between September 2002 and June 2012 were prospectively recorded on a database. A retrospective review of clinical notes and treatment plans was carried out. Collected data included baseline patient characteristics, indication for radiosurgery, treatment-related toxicity (particularly facial and trigeminal neuropathies) and local control. Patients were followed up by the referring surgical team and MRI was carried out annually for 5 years after SRS as per local protocol.

Facial nerve function was classified using the House-Brackmann scale, and trigeminal toxicity was defined as any new post-SRS facial sensory change or pain, irrespective of the presence of objective physical signs [13]. Cranial neuropathies were subsequently classified as transient or persistent. Neuropathy was defined as persistent if present in two or more separate clinical reviews including the most recent, with a minimum interval of 4 months between reviews.

Tumour control was defined in two ways. Local control was defined in line with other series as the absence of surgical salvage and radiological failure as growth on imaging beyond the second year of follow-up [7,9,14].

Patients were censored at the date of most recent MRI. Absence of surgical salvage and radiological progression-free survival were calculated using the Kaplan–Meier method. For statistical analysis, Fisher's exact test, Student's *t*-test and the Mann–Whitney test were used to evaluate differences between groups.

Radiosurgical Technique and Plan Evaluation

All patients were treated on a 6 MV linear accelerator (Elekta 75-5 from 2002 to 2007 and a Varian 600C from 2007) with an externally mounted SRS collimator. The plan was generated by BrainLab software (BrainScan 5.03). External collimators were BrainLab fixed cones, ranging from 10 to 30 mm in diameter, measured at the machine isocentre of 1000 mm source to target distance. Delivery was via non-coplanar arcs of nominally 100 degree lengths, with typically three to four arcs per isocentre. Multiple isocentres (up to three) were used to achieve maximum conformality of the dose distribution to the surface of the tumour. The dose per arc was between 5 and 10 monitor units per degree, with a dose rate of 600 monitor units/min. Alignment of the radiosurgical beam to the axis defined by the room lasers was confirmed to be within 1.0 mm before each treatment delivery.

Gadolinium-enhanced MRI (T1-weighted, 1.25 mm slice thickness, 1.5T) was obtained before treatment for the purpose of radiosurgery planning. A BrainLab stereotactic head frame was attached to the skull under local anaesthesia to enable immobilisation. Subsequent stereotactic computed tomography was co-registered with the volumetric MR images. Tumour as shown on gadolinium-enhanced MRI was defined as the planning target volume (PTV). A dose of 12 Gy was prescribed to the periphery of the PTV (marginal dose). A maximum dose of up to 24 Gy was accepted within the PTV when using three isocentres. The brainstem objective was set at a maximum point dose of 12.5 Gy. Patients received a 2 or 3 day course of oral dexamethasone 8 mg daily starting on the day before SRS, to reduce the risk of acute swelling of the tumour.

Plans were retrospectively reviewed with the aim of collecting dosimetric data, including the number of isocentres, tumour volume, maximum point dose and maximum dose to brainstem and trigeminal nerve. If necessary, further organs at risk were contoured. The trigeminal nerve was defined from where it becomes visible leaving the brainstem to the petrous ridge. The Radiation Therapy Oncology Group conformity index, gradient index (volume of half the prescription isodose/volume of the prescription isodose) and homogeneity index (maximum dose in treatment volume/prescription dose) were calculated [15,16].

Figure 1 illustrates a typical dose distribution achieved. In this case the Radiation Therapy Oncology Group conformity index, gradient index and homogeneity index were 1.84, 2.55 and 1.46, respectively.

Results

Ninety-nine patients were identified. Two patients were lost to follow-up due to relocation. Ninety-seven patients with over 1 year of radiological and/or clinical follow-up data were analysed for local control and non-auditory toxicity. The median follow-up was 2.4 years (range 1–11.5 years).

Baseline characteristics are summarised in Table 1. Nine patients (9%) had diabetes mellitus and one (1%) had type 2 neurofibromatosis. This patient had undergone surgical resection of a contralateral vestibular schwannoma and received SRS to a previously untreated tumour. Nine patients (9%) had undergone previous resection. Most patients lacked serviceable hearing at the time of treatment and

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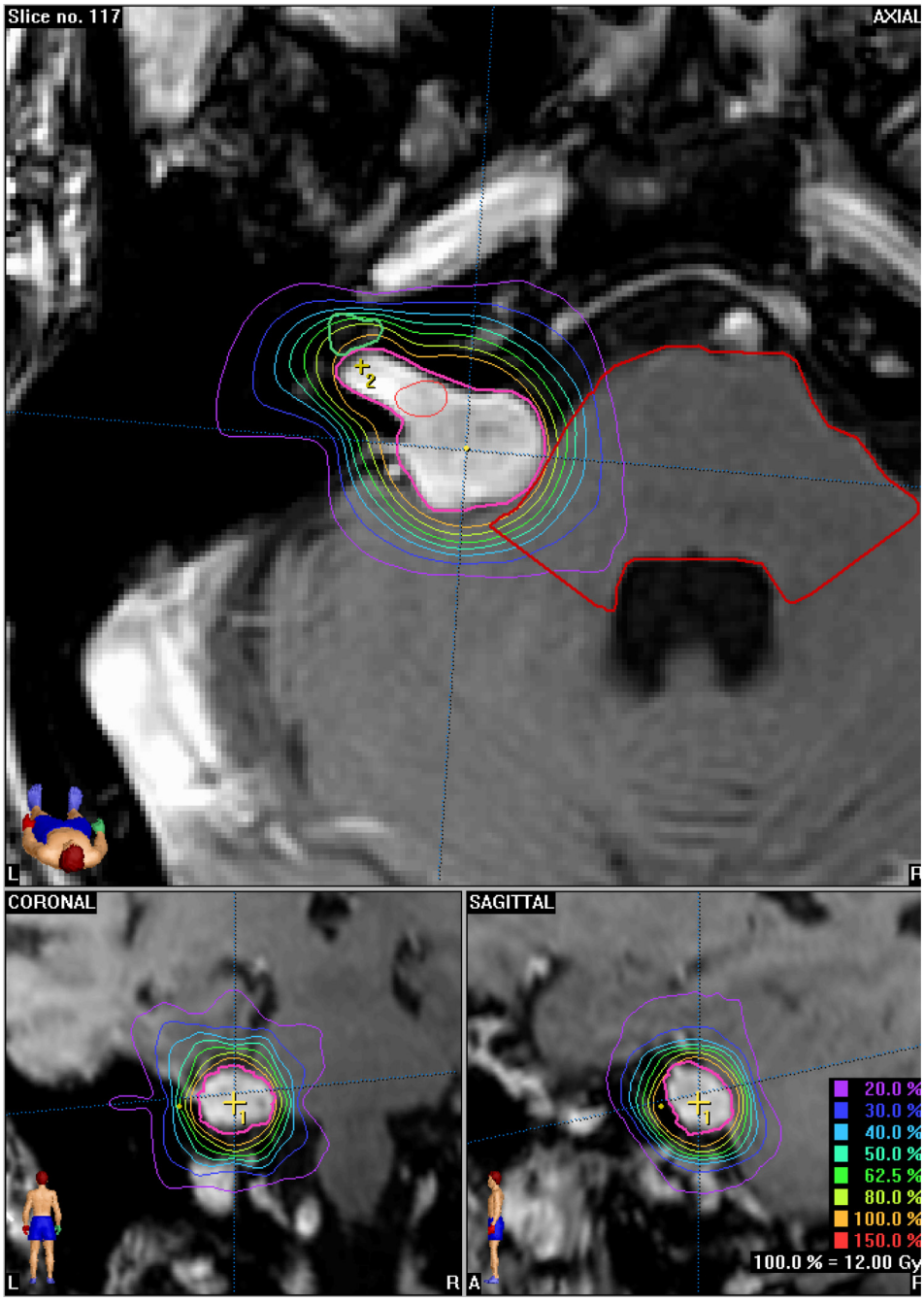

Fig 1. Typical dose distribution achieved using a plan generated by BrainLab.

detailed auditory outcomes were not evaluated. Four of the treated lesions (4%) were cystic in appearance. Most patients (73/99; 74%) had documented growth seen on serial MRIs before SRS, which was our institutional policy.

A summary of dose metrics is given in Table 2.

Tumour Control

Actuarial 3 year radiological progression-free survival was 100%. Two patients had confirmed radiological progression in line with our definition; one at 3.3 years and the other at 4.5 years after SRS. Neither of these patients has yet required surgical intervention, although they continue to be followed up closely. One of the patients with radiological progression has also developed hemi-facial spasm. Overall local control at 3 years is 100% defined by the absence of surgical salvage.

Treatment-related Toxicity

During the follow-up period, three patients (3%) developed transient facial nerve toxicity and two patients developed persistent facial neuropathy (2%). Of these two patients, one had hemi-facial spasm alone (House-

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Table 1
Patient characteristics

Characteristic		
Age, years	Median (range)	57.5 (19–86)
Gender, *n* (%)	Male	53 (53.5%)
	Female	46 (46.5%)
Location, *n* (%)	Left	49 (49.5%)
	Right	50 (50.5%)
Reason for stereotactic radiosurgery, *n* (%)	Progression on serial scans	73 (73.7%)
	Size/proximity to brainstem	12 (12.1%)
	Preservation of useful hearing	4 (4.0%)
	Other (detailed below)	10 (10.1%)
	Patient choice	2 (2.0%)
	Clinical decision	7 (7.1%)
	Unknown	1 (1.0%)

Brackmann grade 2), which was associated with radiological progression as described above. The other patient had a large vestibular schwannoma (Koos grade 4, volume 7.5 cm^3) and declined surgical intervention. This patient also developed obstructive hydrocephalus after SRS, requiring an external ventricular drain. She remained well at last follow-up and subsequent MRI scans showed significant tumour response to treatment. However, her facial nerve palsy (House-Brackmann grade 4) persisted. There was no statistically significant relationship between the incidence of persistent facial neuropathy and tumour volume (cm^3), maximum dose to 0.1 cm^3 of the PTV or maximum dose received by 0.1 cm^3 of the brainstem ($P = 0.74$, $P = 0.97$ and $P = 0.22$, respectively, Fisher's exact test).

Thirteen patients (13%) developed transient trigeminal nerve symptoms after SRS. Although a higher proportion of diabetic patients as compared with non-diabetics seemed to develop trigeminal toxicity after SRS (44% versus 19%, respectively), this relationship was not statistically significant ($P = 0.099$, Fisher's exact test). Eight patients (8%) developed persistent trigeminal neuropathy after SRS, of whom seven (88%) had tumours that were either in contact with or distorting the trigeminal nerve at the time of treatment. The remaining patient had a small volume tumour (1.1 cm^3), which was not in contact with the trigeminal nerve. The maximum point dose received in this case by the trigeminal nerve (0.01 cm^3) and brainstem (0.1 cm^3) was 5.4 and 7.9 Gy, respectively. Eighteen of the 89 patients (20%) without persistent trigeminal toxicity had tumours that were in contact with or distorting the trigeminal nerve at the time of treatment. A significantly higher proportion of patients with persistent trigeminal toxicity had tumours that were in contact with the trigeminal nerve (80% versus 20%, $P = 0.0002$; Fisher's exact test). A number of variables were examined in relation to the presence of trigeminal toxicity. In particular, the relationship between the maximum dose received by 0.01 cm^3 of the trigeminal nerve and subsequent transient toxicity approached, but did not reach, statistical significance ($P = 0.055$). Using Fisher's exact test, there was no significant relationship shown between tumour volume or the maximum dose received by 0.1 cm^3 of the brainstem and subsequent trigeminal neuropathy.

Table 2
Dose metrics

Tumour volume, median (range) cm^3	1.6 (0.1–9.5)
Isocentres, *n*, median (range)	2 (1–3)
Conformity index, median (range)	2.1 (1.4–4.0)
Homogeneity index, median (range)	1.4 (1.1–2.0)
Gradient index, median (range)	2.8 (2.3–3.5)
Maximum dose (Gy), median (range)	16.2 (12.6–24)
Brainstem maximum dose to 0.1 cm^3 (Gy), median (range)	10.0 (1.7–15.0)
Trigeminal maximum dose to 0.01 cm^3 (Gy), median (range)	11.0 (1.4–17.4)

Discussion

To our knowledge this is the first UK linear accelerator-based SRS series for vestibular schwannoma. Local control rates are high and compare favourably with other large published series. The rate of facial nerve preservation was comparable with other series delivering a marginal dose of 12–13 Gy. Table 3 contains a summary of pertinent results from other large SRS series using a comparable marginal dose.

The trigeminal preservation rate reported in published studies varies from 78.7 to 100% with marginal doses of 12–13 Gy [18,20]. A potential explanation for this variation includes the retrospective nature of most published series. This series has a relatively short follow-up period, with four

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Table 3
Selected published outcomes using stereotactic radiosurgery for vestibular schwannoma

Reference	Median follow-up (years)	Patients (*n*)	Modality	Median marginal dose (Gy)	Mean tumour \volume (cm^3)/median tumour volume (cm^3)	Local control	Definition local control	Cranial nerve V preservation (%)	Cranial nerve VII preservation (%)
[7]	2.9	232	Gamma knife	15 Gy	3.7/NA	97%	Freedom from surgical intervention	98.5%	99%
[5]	3.3	296	Linac	12.5 Gy	NA/2.2	98% (2 years)	Last imaging shows no enlargement	99.3%	99.3%
[17]	9	26	Linac	13 Gy	NA	91.1% (5 years)	No additional surgical intervention	92%	95%
[9]	5.6	216	Gamma knife	13 Gy	NA	98.3% (10 years)	No additional surgical intervention	94.9%	100%
[18]	3.5	96	Gamma knife	13 Gy	0.001/NA	99% (2.3 years)	No additional surgical intervention	100%	100%
[19]	8.1	75	Linac	14 Gy	NA/1.5	92%	No change in tumour volume	100%	92%
[11]	5	103	Gamma knife	13 Gy	1.95/NA	91.1% (5 years)	No additional surgical intervention	99%	95%
[20]	2.4	73	Gamma knife	12 Gy	NA/1.69	96% (2 years)	No additional surgical intervention	78.7%*	96.3%
Present study	2.4	97	Linac	12 Gy	1.99/1.65	100% (3 years)	No additional surgical intervention	91.7%	97.9%

* Study did not separate trigeminal events into transient versus persistent.

of the eight patients with persistent trigeminal neuropathy having had less than 18 months of follow-up. Some of these events may resolve as surveillance continues due to transient swelling that is known to occur during the first 2 years after SRS [21]. The definition of a trigeminal event in this study included any sensory change or pain that may represent a lower threshold than other series. In a recent series by Hayhurst *et al.* [20] the threshold dose to the fifth nerve associated with an increased risk of trigeminal dysfunction was 9 Gy. As described, 7/8 patients with persistent neuropathy in our study had tumours in contact with or distorting the trigeminal nerve, and all received a maximum dose to 0.01 cm^3 of 9.6 Gy or higher (median 12.96 Gy, range 9.6–14.4 Gy). However, there was no statistically significant difference in maximum point dose received by the trigeminal nerve and brainstem in patients who developed persistent trigeminal toxicity compared with those who did not. There was also no significant relationship between tumour volume and the incidence of neuropathy in this series. In this study, patients who developed persistent trigeminal toxicity were significantly more likely to have a tumour in contact with or distorting the nerve at the time of treatment versus those who did not.

The aetiology of trigeminal dysfunction after SRS is complex and multifactorial. The factors associated with trigeminal neuropathy in published studies include tumour volume, the dose to trigeminal nerve, brainstem and length of fifth nerve irradiated [5,20,22–25]. An additional potential factor as identified by this series is the presence of diabetes mellitus. The likelihood of trigeminal symptoms is no doubt higher for patients with a tumour in close proximity to the nerve due to swelling and patients should be counselled accordingly.

Within this series, most patients (74%) received SRS at progression on serial imaging. The percentage of tumours remaining stable for several years without intervention varies considerably and is as high as 75% [26]. Some institutions advocate treating all suitable tumours at presentation, arguing preservation of function and minimal toxicity [27]. However, prospective evaluation with scheduled clinical assessments, including toxicity and quality of life, is required to establish the true benefits of earlier treatment. In the series by Beegle *et al.* [28], a significant association was found between prior tumour growth and the incidence of both facial weakness and numbness. This may have relevance to this study as most patients received SRS after documented growth on serial imaging.

Systems delivering SRS aim to achieve rapid dose fall off to minimise the intermediate dose spread outside the PTV. The gradient index is a measure of such dose spread. The median gradient index of 2.82 achieved here compares favourably with the other modern planning systems [29]. However, the conformity index was inferior to gamma knife and more modern linear accelerator SRS solutions capable of shaping the high dose around the PTV using multileaf collimation or non-isocentric planning. The planning technique presented here prioritised dose fall off to organs at risk permitting a higher dose to bone. The current local SRS solution has moved to Cyberknife with Multiplan software resulting in an improved conformity index and a greater ability to reduce the dose to the cochlea and trigeminal nerve. Clinical benefits from these dosimetric improvements remain to be proven; however, an ability to conform to more irregular shapes does extend the application of SRS. Although the median homogeneity index using this linear accelerator platform was favourable, some irregularly shaped tumours required treatment using three isocentres. This improved the conformity index but resulted in a higher dose in the overlap region within the PTV. However, experience using gamma knife to treat vestibular schwannoma is extensive and retrospective data support acceptable toxicity, despite similar high intrinsic doses, providing the marginal dose is 12–13 Gy [7,11].

It has been suggested that fractionated stereotactic radiotherapy schedules reduce the risk of cranial neuropathy and improve rates of hearing preservation [30,31]. A recent UK series also reported equivalent local control rates [32]. There may be radiobiological advantages to delivering fractionated homogenous radiotherapy, but no direct prospective comparison has been carried out with SRS. The relatively low toxicity and high efficacy of using single fraction 12–13 Gy SRS has made prospective evaluation challenging. The introduction of frameless SRS has also led to increased use of hypofractionation with similar high levels of local control and low toxicity [33,34]. However, again direct comparison studies are lacking.

This retrospective study shares limitations with all the other retrospective series informing practice. With high local control rates the importance of reducing toxicity and maintaining quality of life is paramount. Retrospective evaluation is limited due to an inability to control for confounding factors and more importantly the lack of uniformly applied, scheduled and validated toxicity tests capable of detecting subtle events. Vestibular and hearing functions are also important outcomes that should be included. Such data are not reported here due to the lack of uniform prospectively scheduled assessments using a validating scoring system.

Conclusions

A marginal dose of 12 Gy delivered in a single fraction using linear accelerator radiosurgery leads to high levels of local control for vestibular schwannoma. A prospective evaluation with control for confounding variables, including pretreatment growth rate, comorbidities and disability, with uniform application of validated toxicity tools and quality of life assessment will help to refine treatment and establish the benefits of earlier intervention. In this study, persistent trigeminal toxicity occurred almost exclusively in patients whose tumour was in contact with the trigeminal nerve.

References

[1] Lanser MJ, Sussman SA, Frazer K. Epidemiology, pathogenesis and genetics of acoustic tumors. *Otolaryngol Clin North Am* 1992;25:499–520.

Please cite this article in press as: Benghiat H, et al., Linear Accelerator Stereotactic Radiosurgery for Vestibular Schwannomas: A UK Series, Clinical Oncology (2014), http://dx.doi.org/10.1016/j.clon.2014.02.008

[2] Hasegawa T, Kida Y, Kobayashi T, *et al*. Long-term outcomes in patients with vestibular schwannomas treated using gamma knife surgery: 10-year follow up. *J Neurosurg* 2005;102(1): 10–16.
[3] Lunsford LD, Niranjan A, Flickinger JC, *et al*. Radiosurgery of vestibular schwannomas: summary of experience in 829 cases. *J Neurosurg* 2005;102(Suppl.):195–199.
[4] Hasegawa T, Fujitani S, Katsumata S, *et al*. Stereotactic radiosurgery for vestibular schwannomas: analysis of 317 patients followed more than 5 years. *Neurosurgery* 2005;57(2): 257–265.
[5] Friedman WA, Bradshaw P, Myers A, *et al*. Linear accelerator radiosurgery for vestibular schwannomas. *J Neurosurg* 2006;105(5):657–661.
[6] Chung QY, Liu KD, Shiau CY, *et al*. Gamma knife surgery for vestibular schwannoma: 10-year experience of 195 cases. *J Neurosurg* 2005;102(Suppl.):87–96.
[7] Rowe JG, Radatz MW, Walton L, *et al*. Gamma knife stereotactic radiosurgery for unilateral acoustic neuromas. *J Neurol Neurosurg Psychiatr* 2003;74(11):1536–1542.
[8] Wowra B, Muacevic A, Jess-Hempen A, *et al*. Outpatient gamma knife surgery for vestibular schwannoma: definition of the therapeutic profile based on a 10-year experience. *J Neurosurg* 2005;102(Suppl.):114–118.
[9] Chopra R, Konziolka D, Niranjan A, *et al*. Long-term follow-up of acoustic schwannoma radiosurgery with marginal tumor doses of 12 to 13Gy. *Int J Radiat Oncol Biol Phys* 2007;68(3):845–851.
[10] Kondziolka D, Lunsford LD, McLaughlin MR, *et al*. Long-term outcomes after radiosurgery for acoustic neuromas. *N Engl J Med* 1998;229(20):1426–1433.
[11] Murphy ES, Barnett GH, Vogelbaum MA, *et al*. Long term outcomes of Gamma Knife radiosurgery in patients with vesticular schwannomas. *J Neurosurg* 2011;114(2):432–440.
[12] Tsai JS, Buck BA, Svensson GK, *et al*. Quality assurance in stereotactic radiosurgery using a standard linear accelerator. *Int J Radiat Oncol Biol Phys* 1991;21(3):737–748.
[13] House JW, Brackmann DE. Facial nerve grading system. *Otolaryngol Head Neck Surg* 1985;93(2):146–147.
[14] van de Langenberg R, Dohmen AJ, de Bondt BJ, *et al*. Volume changes after stereotactic LINAC radiotherapy in vestibular schwannoma: control rate and growth patterns. *Int J Radiat Oncol Biol Phys* 2012;84(2):343–349.
[15] Feuvret L, Noel G, Mazeron JJ, *et al*. Conformity index: a review. *Int J Radiat Oncol Biol Phys* 2006;64(2):333–342.
[16] Paddick I, Lippitz B. A simple dose gradient measurement tool to complement the conformity index. *J Neurosurg* 2006;105(Suppl.):194–201.
[17] Combs SE, Thilmann C, Debus J, *et al*. Long-term outcome of stereotactic radiosurgery (SRS) in patients with acoustic neuromas. *Int J Radiat Oncol Biol Phys* 2006;64(5):1341–1347.
[18] Niranjan A, Mathieu D, Flickinger JC, *et al*. Hearing preservation after intracanalicular vestibular schwannoma radiosurgery. *Neurosurgery* 2008;63(6):1054–1062.
[19] Hsu PW, Chang CN, Lee ST, *et al*. Outcomes of 75 patients over 12 years treated for acoustic neuromas with linear accelerator-based radiosurgery. *J Clin Neurosci* 2010;17(5): 556–560.
[20] Hayhurst C, Monsalves E, Bernstein M, *et al*. Predicting nonauditory adverse radiation effects following radiosurgery for vestibular schwannoma: a volume and dosimetric analysis. *Int J Radiat Oncol Biol Phys* 2012;82(5):2041–2046.
[21] Hayhurst C, Zadeh G. Tumor pseudoprogression following radiosurgery for vestibular schwannoma. *Neuro Oncol* 2012;14(1):87–92.
[22] Foote KD, Friedman WA, Buatti JM, *et al*. Analysis of risk factors associated with radiosurgery for vestibular schwannoma. *J Neurosurg* 2001;95:440–449.
[23] Regis J, Metellus P, Hayashi M, *et al*. Prospective controlled trial of gamma knife surgery for essential trigeminal neuralgia. *J Neurosurg* 2006;104:913–924.
[24] Linksey ME, Flickinger JC, Lunsford LD. Cranial nerve length predicts the risk of delayed facial and trigeminal neuropathies after acoustic tumor stereotactic radiosurgery. *Int J Radiat Oncol Biol Phys* 1993;25:227–233.
[25] Flickinger JC, Kondziolka D, Lunsford LD. Dose and diameter relationships for facial, trigeminal and acoustic neuropathies following acoustic neuroma radiosurgery. *Radiother Oncol* 1996;41:215–219.
[26] Nikolopoulos TP, Fortnum H, O'Donoghue G, *et al*. Acoustic neuroma growth: a systematic review of the evidence. *Otol Neurotol* 2010;3:478–485.
[27] Kondziolka D, Mousavi SH, Kano H, *et al*. The newly diagnosed vestibular schwannoma: radiosurgery, resection, or observation? *Neurosurg Focus* 2012;33(3):E8.
[28] Beegle RD, Friedman WA, Bova FJ. Effect of treatment plan quality on outcomes after radiosurgery for vestibular schwannoma. *J Neurosurg* 2007;1075:913–916.
[29] Gevaert T, Levivier M, Lacornerie T, *et al*. Dosimetric comparison of different treatment modalities for stereotactic radiosurgery of arteriovenous malformations and acoustic neuromas. *Radiother Oncol* 2013;106(2):192–197.
[30] Combs SE, Welzel T, Schulz-Ertner D, *et al*. Differences in clinical results after LINAC-based single-dose radiosurgery versus fractionated stereotactic radiotherapy for patients with vestibular schwannomas. *Int J Radiat Oncol Biol Phys* 2010;76(1):193–200.
[31] Murphy ES, Suh JH. Radiotherapy for vestibular schwannomas: a critical review. *Int J Radiat Oncol Biol Phys* 2011;79(4):985–997.
[32] Woolf DK, Williams M, Goh CL, *et al*. Fractionated stereotactic radiotherapy for acoustic neuromas: long-term outcomes. *Clin Oncol* 2013;25:734–738.
[33] Karam SD, Tai A, Strohl A, *et al*. Frameless fractionated stereotactic radiosurgery for vestibular schwannomas: a single-institution experience. *Front Oncol* 2013;17(3):121.
[34] Hansasuta A, Choi CY, Gibbs IC, *et al*. Multisession stereotactic radiosurgery for vestibular schwannomas: single-institution experience with 383 cases. *Neurosurgery* 2011;69(6): 1200–1209.

Please cite this article in press as: Benghiat H, et al., Linear Accelerator Stereotactic Radiosurgery for Vestibular Schwannomas: A UK Series, Clinical Oncology (2014), http://dx.doi.org/10.1016/j.clon.2014.02.008