The Journal of Laryngology & Otology (2015), ***129***, *923–927*.

doi:10.1017/S0022215115001966

CLINICAL RECORD

Intra-operative skull X-ray for misdirection of the cochlear implant array into the vestibular labyrinth

A M HASSAN[1], R PATEL[2], M REDLEAF[3]

[1]*College of Medicine, University of Illinois at Chicago,* [2]*York ENT Surgical Consultants, Hinsdale, Illinois, and* [3]*Department of Otolaryngology – Head and Neck Surgery, University of Illinois at Chicago, USA*

Abstract

Objectives: This paper reports five cases of aberrant cochlear implant electrode array insertion into the vestibular labyrinth. A review of the literature was conducted in order to clarify reasonable preventive and detection strategies and endorse the routine use of intra-operative plain skull X-ray.

Methods: The study entailed a clinical case series and literature review. The setting was a tertiary academic referral centre. The following data were evaluated: pre-operative temporal bone computed tomography, operative reports, intra-operative imaging, neural response telemetry / imaging and post-operative imaging.

Results: There were no consistent pre-operative risk factors found on computed tomography scans and no reliable intra-operative signs of electrode array misdirection. All misdirections in our case series, and those in the literature, were easily detectable on intra-operative plain film X-ray.

Conclusion: These reported cases demonstrate implant misdirection without the surgeon's awareness. Aberrant insertion cannot be anticipated, and neural response telemetry / imaging is not a reliable indicator of misdirection. Routine intra-operative anteroposterior plain X-ray of the head is a reliable indicator of misdirection, and is fast and relatively inexpensive.

Key words: Cochlear Implantation; Cochlear Implants; Cochlea; Semicircular Canals; Vestibular Labyrinth

Introduction

Cochlear implantation has become the standard of care for hearing rehabilitation in patients with severe to profound sensorineural hearing loss. As of 2010, around 219 000 cochlear implants have been implanted worldwide.[1] Advances in cochlear implant technology and surgical technique have improved the operative procedure and auditory outcomes of patients undergoing implantation. In particular, key advances in the device itself,[2] the surgical procedure and intra-operative monitoring have all improved efficiency and allowed more streamlined management. Examples of such advances include a smaller incision[3,4] and modifications to secure the receiver-stimulator. With regards to the latter, procedures that previously involved drilling wells or suture fixation often now simply entail the creation of a tight temporalis pocket.[5,6]

Most intra-operative or routine post-operative tests, including imaging and audiometric testing, are conducted to alert surgeons to a malfunctioning or misdirected device. Imaging, particularly X-ray, has been traditionally recommended,[7] but the utility of routine post-operative X-ray was recently debated in the literature.[8] Fluoroscopy is used at certain centres and has been found to detect array misdirection in anatomically complex cases,[9,10] but is not used routinely because of the size, expense and operative disruption of the actual device. Intra-operative temporal bone computed tomography (CT) is also employed for particularly difficult cases, such as congenital ear deformities.[11] However, most believe that implant position can be detected easily with X-ray, and does not necessitate the added cost, time and radiation associated with CT scanning.[12]

Electrode impedances and neural response telemetry have also been used to confirm the proper position and functioning of the device. These methods can provide objective data for post-operative mapping, and act as a counselling tool at the conclusion of the surgical procedure.[13] However, the results can be misleading, as abnormal test components do not reflect post-operative function, while normal test results can still occur with misplaced electrodes.[14]

Even with the aforementioned recent advances, improper positioning of the electrode array has been reported in 0.17–2.12 per cent of cases.[15] This study reports on 5 of our patients and 11 patients in the literature with electrode arrays that were misplaced into the vestibular labyrinth. We conclude that the simplest and most reliable precaution against improper positioning is the routine use of intra-operative plain film X-ray.

Case report

We present five patients with cochlear implant arrays that were misdirected into the vestibule or a semicircular canal. This study was approved by the institutional review board of our institution. Four patients who underwent cochlear implantation for profound sensorineural hearing loss were found on post-operative imaging to have misdirected

Accepted for publication 19 March 2015

TABLE I
MISDIRECTED COCHLEAR IMPLANT ARRAY CASE SERIES DATA

Pt no	Year implanted	Device, array type	Appearance of cochlea on CT	Large vestibular aqueduct &/or large endolymphatic sac	Intra-op NRT/NRI	Electrode array pathway (imaging modality)
1	2003	Nucleus Contour, pre-curved	Incomplete partition	+	Not conducted	Ampullated end lateral SCC (post-op CT)
2	2009	Nucleus Freedom CI512, pre-curved	Normal	−	Not conducted	Ampullated end superior SCC (post-op plain film X-ray)
3	2010	Clarion Hi-Res, pre-curved	Normal	+	Not conducted	Non-ampullated end posterior SCC (post-op CT)
4	2012	Nucleus CI422, straight	Partial ossification (explant & re-implant surgery)	+	Responses present in operating theatre	Ampullated end lateral SCC (post-op CT)
5	2014	Nucleus Freedom CI24RE, pre-curved	Normal	−	Impedance testing positive, NRT not conducted	Ampullated end superior SCC (intra-op plain film X-ray, reinsertion)

Misdirection in patients numbered 1–4 was detected post-operatively. Misdirection in patient number 5 was detected intra-operatively on plain film X-ray and corrected. Pt no = patient number; CT = computed tomography; op = operative; NRT = neural response telemetry; NRI = neural response imaging; '+' = present; '−' = absent; SSC = semicircular canal

electrode arrays into a semicircular canal (Table I). The fifth patient underwent intra-operative plain film radiography and was found to have a misdirected electrode array, which was corrected in the same operation (Table I).

Pre-operative CT imaging did not indicate any insertional problems. Possible associated malformations[16] were large vestibular aqueducts and/or large endolymphatic sacs, affecting three of the patients. One of these patients also had incomplete partition, and another had a partially ossified cochlea. The remaining patients had patent cochleae without inner-ear abnormalities.

During the actual operations, there were no difficulties with electrode array insertion. Three of the five patients had an anterior-inferior cochleostomy performed. The patient with the cochlear ossification underwent attempted scala vestibuli insertion, based on the findings seen on pre-operative imaging. For this case, the electrode insertion went smoothly and appeared to be entering into the appropriate place. In the final case, a round window insertion was performed. In four of the five cases, the electrode arrays employed were pre-curved, and in one case the electrode array was straight.

Intra-operative neural response telemetry or impendence testing was performed in two cases, with limited responses for both. Only one of these patients underwent intra-operative plain film radiography, which prompted reinsertion. Misdirection in the other four cases into the semicircular canals was seen post-operatively on plain film X-ray or CT scans (Figures 1–3).

Literature review

A search of the English-language literature published from 1995 to 2013 was conducted using the following search terms: 'cochlear implant position', 'malposition', 'misdirection', 'improper insertion' and 'complications'.

Eleven cases of electrode array misdirection into the vestibules or semicircular canals were identified (Table II).[15,17–23] Four of the 11 patients had documented anatomical abnormalities. In one patient, patent but bulbous middle and apical turns can be seen in the CT images published in the article itself.[17] In the second case, the article reports an ossified cochlea on imaging, but states that intra-operatively only the round window niche was obstructed.[20] One paper reported a case of anatomical abnormality observed at the time of surgery (ossified scala tympani), which led to an attempted scala vestibule insertion, and another case of abnormality only seen on closer inspection of the post-operative CT scan (incomplete spiral lamina at the apical turn), which is of unclear significance.

None of these 11 reports give any information about the size of the vestibular aqueduct or the endolymphatic sac. Of the 11 cases reviewed, only 4 had documented malformations on imaging.

Only one case in the literature reported difficulty with insertion during operation.[19] In the papers that reported the electrode array model employed, four of the arrays were pre-curved and one was a lateral wall array.

Intra-operative audiometric testing did not predict misdirection: seven patients underwent neural response telemetry, and four of these appeared to have responses. In one case, neural response telemetry responses were still absent after repositioning of the electrode array, but the patient went on to have good function of the implant.[18]

Three of the 11 cases of misdirection were found intra-operatively on plain X-ray with anteroposterior views of the head, and were corrected in that same procedure. Two of the 11 misdirections were detected by plain film X-ray post-operatively. In these cases, only the superior and lateral canals were cannulated. All misdirections reported in the English-language literature could be seen on plain film X-ray.

Discussion

Eleven cases of aberrant electrode array insertion into the vestibular labyrinth reported in the English-language literature were reviewed (Table II). No pre-operative anatomical variable that makes misdirection more likely was identified. These cases do not describe the vestibular aqueducts;

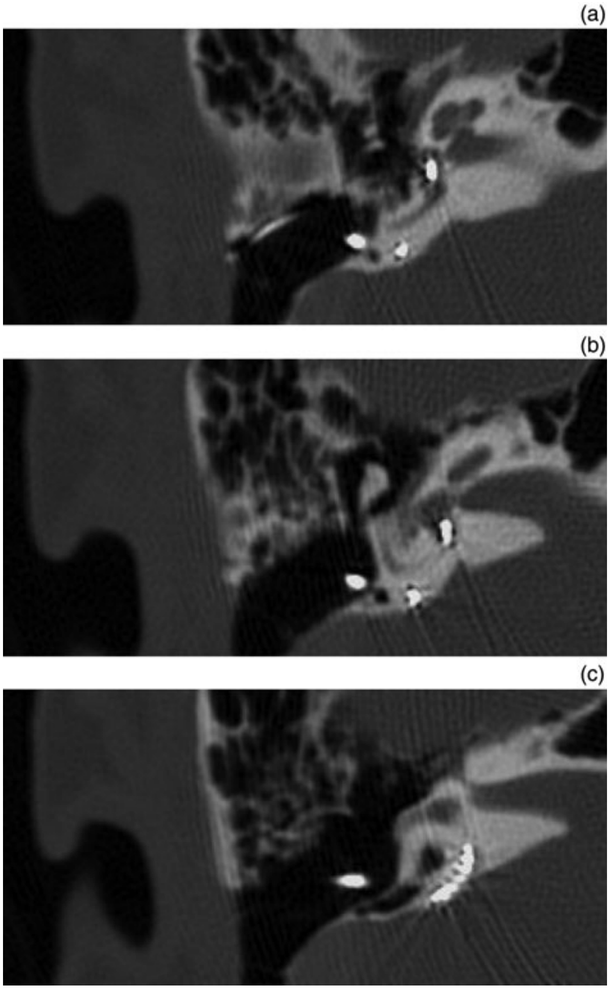

FIG. 1

(a) – (c) Serial axial temporal bone computed tomography images showing the electrode array pathway (patient number 3). The entrance is into the basal turn of the cochlea, next turning 180°, then entering the vestibule and non-ampullated end of the posterior semicircular canal. Note the enlarged vestibular aqueduct and normal anatomy of the cochlea.

however, the cochlea is described as being patent in most of these 11 cases. In our series, three of the five patients had enlarged vestibular aqueducts, and one patient had a patent cochlea with incomplete partition. Another patient had partial ossification of the basal turn, which made explantation and re-implantation surgery problematic; therefore, scala vestibuli insertion was attempted, which appeared to proceed smoothly.

It is interesting that three of the five patients in our series had enlarged vestibular aqueducts. When our case series and the cases reported in the literature were considered together, pre-operative imaging did not predict misdirection. Ten of the 16 patients had a normal cochlea pre-operatively, and only 6 patients had malformations. Intra-operatively, there were no clear warning signs of misdirection either. Only one of the insertions in the literature was reported to be difficult. Also, impedance testing was positive or neural response telemetry responses were present for six of the nine cases in which the technique was employed. It is believed that a response may still be elicited if the electrode array is in the vestibule.[23] Therefore, misdirection occurred even with normal pre-operative imaging findings, when

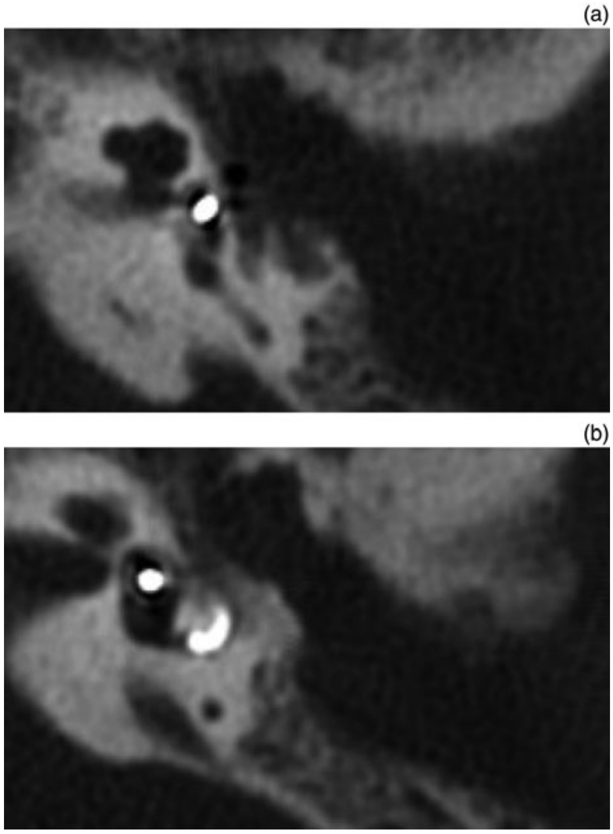

FIG. 2

(a) & (b) Serial axial temporal bone computed tomography images from patient number 1. Again, the electrode array enters the basal turn of the cochlea, turns 180°, and enters the vestibule and lateral semicircular canal via the ampullated end. Note the enlarged vestibular aqueduct and patent cochlea with an incomplete partition.

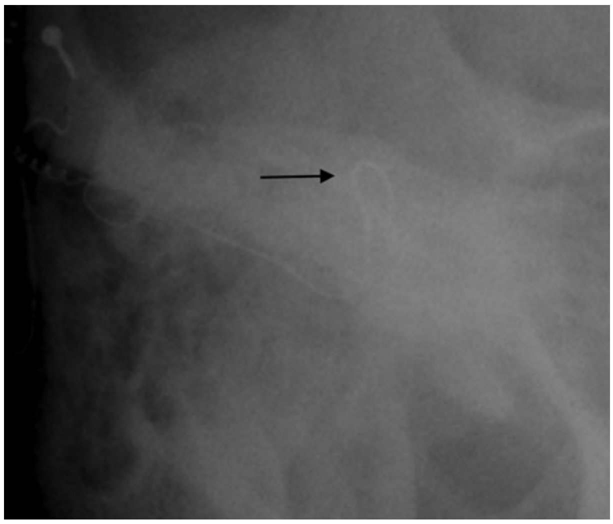

FIG. 3

Intra-operative X-ray demonstrating S-shaped configuration of the electrode array inserted into the superior semicircular canal (arrow), as opposed to the normal helix of cochlear placement (patient number 5). This array was withdrawn and correctly redirected intra-operatively.

https://doi.org/10.1017/S0022215115001966 Published online by Cambridge University Press

TABLE II
PREVIOUS REPORTS OF MISDIRECTED COCHLEAR IMPLANT ARRAYS

Study (year)	Device, type	CT findings	Intra-op NRT/NRI	Electrode array pathway	Misdirection detection modality
Mecca *et al.*[17] (2003)	Unknown	Bulbous middle & apical turns of cochlea (image)	Unknown	Ampullated end superior SCC (image)	Post-op CT
Muzzi *et al.*[18] (2012)	Nucleus, pre-curved	Normal cochlea (image)	Non-detectable	Coiled in vestibule (image)	Post-op CT
Ramalingam *et al.*[19] (2009)	Unknown	Normal cochlea (description)	Non-detectable	Superior SCC (report)	Intra-op X-ray
Rotteveel *et al.*[20] (2004)	Med-El Combi 40, lateral wall	Ossification (description); no obstruction of basal turn (report)	Unknown	Lateral SCC (report)	Post-op X-ray
Rotteveel *et al.*[20] (2004)	Nucleus 22, pre-curved	Normal cochlea (description)	Unknown	Superior SCC (report)	Post-op X-ray
Sorrentino *et al.*[22] (2009)	Unknown	Absence of spiral lamina at apex (description)	Non-detectable	Vestibule (image)	Post-op CT
Sorrentino *et al.*[22] (2009)	Unknown	Scala tympani ossification (description)	Unknown	Vestibule & superior SCC (image)	Post-op CT
Tange *et al.*[15] (2006)	Unknown	Normal cochlea (description)	Present	Lateral SCC (image)	Post-op CT
Viccaro *et al.*[21] (2009)	Clarion 90k, pre-curved	Normal cochlea (description)	Present in apical frequencies	Superior SCC (report)	Intra-op X-ray
Viccaro *et al.*[21] (2009)	Clarion 90k, pre-curved	Normal cochlea (description)	Present	Superior SCC (report)	Intra-op X-ray
Ying *et al.*[23] (2013)	Unknown	Normal cochlea (description)	Present in basal electrodes, absent in apical electrodes	Vestibule, anteromedial to lateral SCC (image)	Post-op CT

Eleven patients are reported. Five misdirections were detected on plain film X-rays. The remaining misdirections were detected by computed tomography post-operatively. CT = computed tomography; op = operative; NRT = neural response telemetry; NRI = neural response imaging; SSC = semicircular canal

insertion was smooth, and when impedance testing was positive and neural response telemetry responses were present.

In reviewing the images in our case series, the electrode arrays are entering the cochleostomy site and turning 180° from the basal turn insertion, and proceeding posterior-superior into the vestibule rather than anterior-inferior towards the middle turn (Figures 1 and 2). The array then enters the ampullated or non-ampullated end of any of the semicircular canals. There is no clear aetiology or anatomical obstruction seen on these images that indicates why the electrode array takes this course.

One probable explanation for the misdirection of the electrode array is a suboptimal angle of insertion. For example, when our fifth patient's implant was directed more anterior-inferiorly, the subsequent implant path was appropriate. Another potential cause for misdirection is the type of electrode array inserted. Considering all cases where implant type was known, 8 of 10 involved a pre-curved array. However, most of the literature cases reviewed did not report the model or type of implant used. Other possible explanations that have been cited in the literature include: an inadequate facial recess or inability to visualise the round window, improper placement of the cochleostomy, ossification of the cochlea, inner-ear malformations, and patient positioning.[23]

All of the misdirected electrode arrays were detected using imaging, either intra-operatively or post-operatively. The majority of cases in our series and in the literature were detected after the patient had recovered from the surgery, and required a second operation. This delay in detecting the problem adds to morbidity and cost. In 1 of our 5 cases, and in 3 of the 11 cases reported in the literature, an intra-operative X-ray was performed and the implant was adjusted during the same procedure.

- **Cochlear implant electrode arrays can be misplaced in an anatomically normal ear without the surgeon's awareness**
- **X-ray has been traditionally recommended to detect misplacement, but routine post-operative X-ray use was recently debated**
- **Intra-operative fluoroscopy and computed tomography scans can also detect array misdirection, but are less favourable because of time, cost and radiation**
- **Pre-operative imaging did not predict misdirection into vestibular labyrinth, and intra-operative imaging showed no clear misdirection warning signs**
- **Positive impedance tests and neural response telemetry responses were common, even when implant was misplaced**
- **Misdirection was detected and corrected in same procedure using intra-operative X-ray; hence, routine intra-operative X-ray is recommended for proper placement**

Although some advocate restricting the use of X-rays to anatomically difficult cases,[8] it is clear from these cases that the electrode can often be misplaced in an anatomically normal ear, without the surgeon being aware. Intra-operative CT or fluoroscopy have been suggested to ensure good insertion, but these are too cumbersome, time consuming and expensive to employ for every implantation. A recent retrospective review analysed the use of intra-operative

https://doi.org/10.1017/S0022215115001966 Published online by Cambridge University Press

electrophysiological monitoring and intra-operative Stenver's view plain film radiography, and found that only the radiological findings altered surgical management.[24] We posit that plain X-ray anteroposterior views of the head are inexpensive and fast to carry out, and can be used routinely for every implantation.

Conclusion

Sixteen cochlear implant electrode arrays that were misdirected into the vestibular labyrinth are reported and reviewed here. There appears to be no consistent pre-operative risk factors or anatomical variables present on CT scans that indicate predisposition to this complication. Intra-operative audiometric testing is inconsistent in its ability to detect an electrode array within the vestibule or a semicircular canal, and there is often no reported difficulty in electrode insertion. We therefore recommend employing intra-operative X-ray as a routine method of ensuring proper placement.

References

1 National Institute on Deafness and Other Communication Disorders (NIDCD). Cochlear Implants. In: http://www.nidcd.nih.gov/health/hearing/coch.asp [3 December 2012]

2 Carlson ML, Driscoll CL, Gifford RH, McMenomey SO. Cochlear implantation: current and future device options. *Otolaryngol Clin North Am* 2012;**45**:221–48

3 Magnus B, Rivas A, Tsai BS, Haynes DS, Roland JT. Surgical techniques in cochlear implants. *Otolaryngol Clin North Am* 2012;**45**:69–80

4 Flint PW, Haughey BH, Niparko JK, Richardson MA, Lund VJ, Robbins KT *et al*., eds. *Cummings Otolaryngology – Head and Neck Surgery*, 5th edn. Philadelphia: Mosby/Elsevier, 2010; 2237

5 Cohen NL, Roland JT, Fishman A. Surgical technique for the nucleus contour cochlear implant. *Ear Hear* 2002;**23**(1 suppl): 59–66S

6 Balkany TJ, Whitley M, Shapira Y, Angeli S, Brown K, Eter E *et al*. The temporalis pocket technique for cochlear implantation: an anatomic and clinical study. *Otol Neurotol* 2009;**30**:903–7

7 *MED-EL Surgical Manual, version 1*. Durham, NC: US Med-El, 1998;15

8 Copeland BJ, Pillsbury HC, Buchman CA. Prospective evaluation of intraoperative cochlear implant radiographs. *Otol Neurotol* 2004;**25**:295–7

9 Coelho DH, Waltzman SB, Roland JT Jr. Implanting common cavity malformations using intraoperative fluoroscopy. *Otol Neurotol* 2008;**29**:914–19

10 Fishman AJ, Roland JT Jr, Alexiades G, Mierzwinski J, Cohen NL. Fluoroscopically assisted cochlear implantation. *Otol Neurotol* 2003;**24**:882–6

11 Yuan YY, Song YS, Chai CM, Shen WD, Han WJ, Liu J *et al*. Intraoperative CT-guided cochlear implantation in congenital ear deformity. *Acta Otolaryngol* 2012;**132**:951–8

12 Shpizner BA, Holliday RA, Roland JT, Cohen NL, Waltzman SB, Shapiro WH. Postoperative imaging of the multichannel cochlear implant. *AJNR Am J Neuroradiol* 1995;**16**:1517–24

13 Shapiro WH, Bradham TS. Cochlear implant programming. *Otolaryngol Clin North Am* 2012;**45**:111–27

14 Mason S. Electrophysiologic and objective monitoring of the cochlear implant during surgery: implementation, audit, and outcomes. *Int J Audiol* 2004;**43**:S33–8

15 Tange RA, Grolman W, Maat A. Intracochlear misdirected implantation of a cochlear implant. *Acta Otolaryngol* 2006; **126**:650–2

16 Fishman A. Imaging and anatomy for cochlear implants. *Otolaryngol Clin North Am* 2012;**45**:1–24

17 Mecca MA, Wagle W, Lupinetti A, Parnew S. Complication of cochlear implant surgery. *AJNR Am J Neuroradiol* 2003;**24**: 2089–91

18 Muzzi E, Boscolo-Rizzo P, Santarelli R. Cochlear implant electrode array misplacement: a cautionary case report. *J Laryngol Otol* 2012;**126**:414–17

19 Ramalingam R, Ramalingam KK, Padmaja HS. An unusual occurrence in cochlear implant surgery: misplaced electrode. *J Laryngol Otol* 2009;**123**:e4

20 Rotteveel LJ, Proops DW, Ramsden RT. Cochlear implantation in 53 patients with otosclerosis: demographics, computed tomographic scanning, surgery, and complications. *Otol Neurotol* 2004;**25**:943–52

21 Viccaro M, Covelli E, De Seta E, Balsamo G, Filipo R. The importance of intra-operative imaging during cochlear implant surgery. *Cochlear Implants Int* 2009;**10**:198–202

22 Sorrentino T, Cote M, Eter E, Laborde ML, Cochard N, Deguine O *et al*. Cochlear reimplantations: technical and surgical failures. *Acta Otolaryngol* 2009;**129**:380–4

23 Ying YM, Lin JW, Oghalai JS, Williamson RA. Cochlear implant electrode misplacement: incidence, evaluation and management. *Laryngoscope* 2013;**123**:757–66

24 Cosetti MK, Troob SH, Latzman JM, Shapiro WH, Roland JT Jr, Waltzman SB. An evidence-based algorithm for intraoperative monitoring during cochlear implantation. *Otol Neurotol* 2012; **33**:169–76

Address for correspondence:
Mr Ahmad M Hassan,
College of Medicine,
University of Illinois at Chicago,
808 S Wood St,
Chicago,
IL 60612, USA

E-mail: ahassa8@uic.edu

Mr A M Hassan takes responsibility for the integrity of the content of the paper
Competing interests: None declared