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SPECIAL ISSUE REVIEW

Dacryocystography: From theory to current practice☆

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ABSTRACT

Purpose: To provide a review and an update on dacryocystography (DCG) and its relevance in the current era.
Methods: The authors performed a PubMed search of all articles published in English on DCG, digital subtraction-DCG (DS-DCG), computed tomographic DCG (CT-DCG) and magnetic resonance-DCG (MR-DCG). Data analyzed include the indications, techniques, interpretations, complication and limitations.
Results: Dacryocystography has been used for illustrating the morphological and functional aspects of the lacrimal drainage system (LDS). Subtraction DCG provides the precise location of the alterations and acceptably delineates stenosis or an obstruction. Transit time for contrast into the nose varies widely across the studies. Low osmolality iodinated contrast media are tolerated well for DS-DCG and CT-DCG. However, normal saline either mixed with lidocaine or alone provided similar image quality as obtained with gadolinium for MR-DCG. CT-DCG provides useful information in complex orbitofacial trauma and lacrimal tumors. MR-DCG allows better 3D visualization of the LDS and dynamic functional evaluation. Sensitivity of CT-DCG and MR-DCG are mostly similar in identifying an LDS obstruction.
Conclusion: Various forms of DCGs can provide additional information to evaluate patients with maxillo-facial trauma, functional epiphora, suspected lacrimal sac diverticula, partial nasolacrimal duct obstruction, and lacrimal drainage tumors. Canaliculi and the membranous part of the nasolacrimal duct are not yet visualized in detail and further focused studies with advanced techniques are required.

Contents

1. Introduction

First dacryocystography (DCG) was performed by Ewing in 1909 using bismuth subnitrate for visualizing the lacrimal abscess cavity (Ewing, 1909). The techniques, since then have undergone progressive refinements in terms of contrast media, acquisition time, resolution and radiation exposure. The conventional plain

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DCG (CDCG) or digitally subtracted DCG (DS-DCG) does not provide information about the surrounding bony structures and the dynamic tear flow, as obtained by a computed tomographic-DCG (CT-DCG) or a magnetic resonance-DCG (MR-DCG).

The indications for performing a DCG in a patient with epiphora have been variable. The primary purpose is to localize the lacrimal drainage system (LDS) and study the pathologies and their locations. It has also been utilized for evaluating the dynamic changes in canaliculus and the lacrimal sac (LS) with blinking and adrenergic stimuli, and the demonstration of valves in the lacrimal system (Montanara et al., 1979; Lee et al., 2011; Narioka and Ohashi, 2007; Yedavalli et al., 2019). Routine epiphora assessment involves a direct clinical examination of the LDS including irrigation and DCG is mostly advised in atypical cases. The advantages of simple yet informative clinical examinations, advent of microendoscopic techniques and variability in the imaging features seen on DCG across the same subset of patients has only added to confusion and did little to help establishing definitive LDS imaging protocols. The purpose of this review is to present an update on DCG, various subsets and techniques and its relevance in the current era.

2. Methods

A systematic Medline search was performed on PubMed using multiple terms, 'dacryocystography', 'lacrimal', 'digital subtraction dacryocystography', 'DCG', 'DS-DCG', 'computed tomography dacryocystography', 'CT-DCG', 'MR dacryocystography', 'MR-DCG', 'dynamic dacryocystography' 'canaliculi', 'tear-transit', 'functional', and 'lacrimal imaging'. A total of 66 primary papers with focus on DCG or its subtypes were selected. Relevant cross-references from these articles were also considered. Data analyzed include the indications, detailed techniques, interpretations and their pitfalls, complications and limitations.

3. Results

An ASOPRS survey on practice patterns for lacrimal imaging revealed that more than half (55%) of the ophthalmic plastic surgery practitioners did not advise any imaging for confirming the site, type or extent of the obstruction, and CT scans were the preferred choice for cases with trauma or adjacent tissue disease (Nagi and Meyer, 2010). The need of lacrimal imaging in the current era is for complex lacrimal disorders, functional epiphora, suspected lacrimal diverticula, partial nasolacrimal duct obstruction (NLDO), and lacrimal tumors – and rightly so.

3.1. Dacryocystography: types and contrast media

Conventional DCG (CDCG) involves cannulation of superior or inferior canaliculus and injection of contrast media followed by image acquisition by a plain X-ray in posteroanterior and lateral view. Distension DCG was later introduced for better delineation of the common canaliculus (Iba and Hanaffee, 1968; Rodriguez and Kittleson, 1973; Hurwitz et al., 1975; Mehrotra and Sabharwal, 1984), which was further upgraded to macro DCG to allow a magnified view of the canaliculus (Campbell, 1964). Further modification of the technique involved bilateral simultaneous injection of contrast medium using a needle followed by a seriography (serial radiograms) and image subtraction (Montanara et al., 1979; Lloyd et al., 1972). DS-DCG along with intubation macro DCG (MDCG) produces bone free images of LDS, mainly performed to locate the site of common canaliculus obstruction (CCO) (Fig. 1). Kinetic CDCG (capturing serial images while injecting) could delineate an entire fistulous tract (Trokel and Potter, 1970). Real time DS-DCG using fluoroscopy was attempted to visualize the LDS in real time

Fig. 1. Digitally subtracted DCG demonstrates no flow of dye beyond the common canaliculus with spill over at medial canthus.

and achieve a reduction of the radiation dose (Galloway et al., 1984; Montecalvo et al., 1990; Steinkogler et al., 1993). Real time video recording of DS-DCG using C-arm fluoroscopy has also been performed, however radiation exposure concerns have not been addressed. (Huber et al., 1991; Steinkogler et al., 1993). The radiation dose exposure received during DS-DCG (mean 0.68 mSv) was found to be much less as compared to the CDCG (mean 1.53 mSv) (King and Haigh, 1990). In order to differentiate the stenosis in common canaliculus and area of LS near canaliculus, three-dimensional rotational-DCG (3DR-DCG) was performed (Lüchtenberg et al., 2005). Additional information regarding nasal anatomy and better localization of the stenotic area could be obtained with 3DR-DCG as compared to DSDCG. 3DR-DCG may also have a potential role in obtaining details of CCO and may facilitate surgical decisions, which were earlier based solely on clinical examination (Welham, 1973). Table 1 provides a concise overview of the various types of DCGs.

Ideal radio-opaque contrast media for DCG should be homogenous, non-irritant, non-toxic, with optimal viscosity and free of adverse reactions. Available contrast media for CDCG, DS-DCG and CT-DCG include oil-soluble (like lipoidol) and water-soluble media (like iohexol, iopamidol, sinograffin). The imaging differences among them revealed oil soluble media lipoidal to provide significantly better images than others (Munk et al., 1989). However, media with high iodine content like iohexol, iopamidol 300 faired closely to oil soluble media. Disadvantages of oil-soluble media are its viscous nature, immiscible with tears and the rare chances of a granuloma formation or persistent tissue reaction following accidental extravasation (Mansfield et al., 1994; Delaney and Khooshabeh, 2001). Patient discomfort was more evdident with sinograffin/iopamidol 300 compared to others. A low-iodine water-soluble contrast like omnipaque can also provide useful practical information in a DS-DCG. Elgammal and Brooks (1981) used amipaque contrast media for subtraction DCG (Elgammal and Brooks, 1981). Gadobutrol is considered a good substitute for patients allergic to iodinated contrast media (Priebe et al., 2002).

Contrast media employed for MR-DCG include gadolinium (gadopentetate dimeglumine) solution (diluted 1:100 in sterile liquid tear solution to a 0.5% concentration), normal saline or normal saline mixed with 0.5% lidocaine, and balanced salt solution (BSS) (Goldberg et al., 1993; Amrith et al., 2005; Takehara et al., 2000). No

Table 1
Brief summary of various types of DCGs.

Type of DCG	Technique		Technique of contrast use	Contrast used	Indications	Limitations
Conventional DCG	X-rays		Cannulation method	Lipoidal, iohexol, iopamidol	Complex lacrimal disorders	Lack of functional assessment
DS-DCG	Bone free X rays		Cannulation method	Iohexol, iopamidol, sinograffin	Complex lacrimal disorders	Lack of functional assessment
CT-DCG	CT scan after dye injection into the LDS		Cannulation, topical	Iohexol, iopamidol	Maxillofacial trauma, tumors of LDS	Ionising radiation
MR-DCG	MRI after gadolinium contrast; fast sequencing techniques		Cannulation, topical	Gadolinium solution, normal saline	Functional epiphora, tumors of LDS	Long acquisition time, cost

DCG, dacryocystography; DS-DCG, digitally subtracted dacryocystography; CT-DCG, computed tomographic dacryocystography; MR-DCG, magnetic resonance dacryocystography; LDS, lacrimal drainage system.

adverse effects have been reported with any of these media when used topically. In a dynamic fast sequence MR-DCG, the acquisition time per slice was seven seconds and two seconds for gadolinium and BSS respectively (Amrith et al., 2005).

3.1.1. Conventional and DS-DCG in a normal LDS

There are very few studies depicting the findings observed in normal asymptomatic individuals. A conventional DCG study of 37 normal individuals (without maximal distension) reported the LS to be average 2.4 mm in lateral diameter and 4.0 mm in anteroposterior diameter (Malik et al., 1969). The nasolacrimal duct (NLD) was found to have an average width of 2.3 mm in lateral diameter and 2.8 mm in anteroposterior diameter. Rodriguez et al. however, could not comment upon these parameters in 99 normal individuals due to wide variation observed in their series (Rodriguez and Kittleson, 1973). They preferred morphological reporting LS and NLD on CDCGs; wide and wavy (63%), markedly angulated (17%), small diverticula (14%), thin (4%) or wide straight (2%).

Montanara et al. found that the contrast drainage of the LDS in CDCG begins a few seconds after the introduction of Lipiodol. The emptying into the nasal fossa begins after 6–15 s (mean is 10 s) compared to 2–4 s (mean is 2.2 s) with water-soluble contrast media (Angiografin diluted at 35%) (Montanara et al.,1979). Since cannulation technique is typically employed in CDCG, the timing of contrast clearance cannot be used for assessing functional epiphora for obvious reasons. Another CDCG study in 20 normal individuals reported the average-emptying time of sac to be less than 15 min (range 12–15 min) (Mehrotra and Sabharwal, 1984).

Anatomically, mucosa of the LS and NLD is thrown into multiple folds, which were confused for valves in the past, and might get labeled as areas of stenosis on DS-DCG (Yedavalli et al., 2019). Analysis of frequency of their visualization on dacryocystography revealed the presence of inferior valve of Hasner (plica lacrimalis) in 98.9% of cases, and more superiorly, the valve of Taillefer (93.5%) and the valve of Krause (79.3%); infrequently identified were the superior 'valves'; Rosenmüller or Huschke in 46.4%, Auberat in 40% of cases and Foltz or Bochdalek in 17.1% (Yedavalli et al., 2019). Helical arrangement of the cavernous structure around the NLD can result in varying calibers throughout the system. To add to the list, distension with contrast media (varying volumes or type of contrast used) alters the normal anatomical appearance of lacrimal passages. Hence, interpretation of DCG in general should be performed keeping these factors in mind. To negate the different forces exerted while performing bilateral DCG, a novel syringe holder with a single injecting system was built (Robert, 1983).

Dynamic changes in normal canalicular and sac width were demonstrated using fluoroscopic dacryocystography (Lee et al., 2011). The reduction in the length of canaliculus and increase in superior sac width were significant, providing additional information about the mechanism of tear drainage.

3.1.2. Conventional and DS-DCG in lacrimal pathologies

DCG has been utilized in patients with epiphora for localizing the site of obstruction, differentiate canalicular from proximal sac obstructions, and to visualize the stenotic segments, not negotiated by a canula. However, proximal lacrimal drainage systems (punctum and canaliculus) are better visualized with optical coherence tomography and dacryoendoscopy.

Malik et al. performed CDCG on 37 normal and 169 patients with epiphora; 11% of symptomatic individuals had normal looking lacrimal passages and another 11% had shrunken LS, 8.2% had diverticula (Malik et al., 1969). They used a high concentration of dionosil in an aqueous base to overcome difficulties of using a sole oily medium. A correlation of pre-operative CDCGs in 18 patients who underwent endoscopic DCR with the outcomes of surgery (ten resurgery; eight primary DCR) demonstrated that the surgery

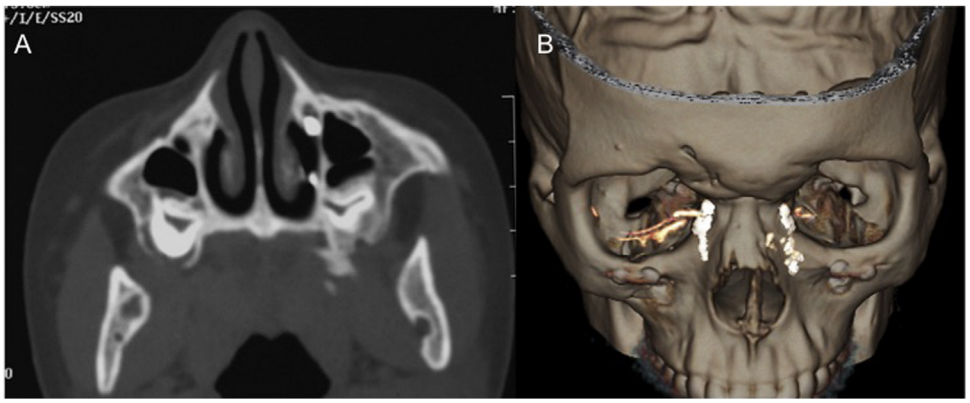

Fig. 2. A & B, CT-DCG with 3D reconstruction shows a normal right lacrimal system and discontinuity beyond the lacrimal sac on the left side.

was more successful with normal or large sized sacs (Mannor and Millman, 1992). Castren and Korhonen (1964) evaluated CDCG in 80 patients of epiphora, and found enlarged LS in 61%, normal sized in 14%, small sized in 10%, and no contrast in the sac in 15%. However, no clinical relevance was discussed.

Iba et al. in the CDCG of 15 patients found diverticula in three, obstructed NLD in nine, and obstructed sinus of Maier in two (Iba and Hanaffee, 1968). Pre-operative knowledge of diverticula helps in DCR surgery while making flaps. A CDCG study in 35 cases of dacryocystitis found that the junction of the LS and NLD was the most common site of obstruction (in 89%) (Nahata, 1964). The largest series of 1000 CDCGs in 500 patients reported that the obstruction of the lacrimal ducts is normally total, unilateral, and located at the valve of Krause (Francisco et al., 2007). There was a predominance of the valve of Krause obstruction in women in their study ($p = 0.013$).

The delineation of sac and the superior half of the duct is seen clearly on DCG but the proximal lacrimal system, especially common canaliculus anatomy, is not clearly seen. Nixon and colleagues evaluated the role of DCG in epiphora and found normal LDS in 54% (85/158) of symptomatic patients (Nixon et al., 1990). Among the abnormal DCGs (73/158), NLD stenosis or obstruction was the most common (56%, 41/73), followed by CCO (37%, 27/73) and LS stenosis (7%, 5/73). Interestingly, there was a discrepancy between lacrimal irrigation and DCG findings in 36% patients (Obstructed LDS on irrigation but patent on DCG). However, this was not true for others. Irrigation and DS-DCG not only concorded in 24 out of 25 DCGs, but also provided additional findings of congenital malpositioning of LS ($n = 2$), multiple areas of stenosis ($n = 3$) and dacryolith ($n = 1$) (Saleh et al., 2007). Putterman et al. performed a CDCG using an interesting technique – to assess NLD patency in two cases with CCO. Using blind maneuver, 0.5 ml of water-soluble contrast medium was injected directly into the sac using a 25G needle, and the dye was demonstrated to flow into the nasopharynx in both the cases (Putterman, 1973). A review of 100 CDCGs of patients with epiphora suggested the diagnosis of functional dacryostenosis if the drainage time into the nasal passages is delayed beyond 30 s in the absence of LS dilatation. Ultrafluid lipiodol was used in their study, which takes a mean of 10 s to pass through the nasolacrimal system (Montanara et al., 1979). Stenoses of the canaliculi are frequently associated with other distal constrictions in the lacrimal passages and may be more clinically significant if any microendoscopy-guided surgical procedure is planned. DCG has also been utilized in congenitally obstructed lacrimal system where mucoceles were suspected as mass lesion (Cibis et al., 1986).

A direct comparison between FDDT, Jones test, dacryoscintigraphy (DSG) and DS-DCG revealed imaging to have no decisive role in the diagnosis of partial NLDO or functional epiphora, however, the sample size was small (Guzek et al., 1997). Wearne et al. (1999) compared CDCG with DSG in functional epiphora, and an agreement regarding the location of delay occurred in only 59% of the cases. However, comparison with the normal population or contralateral eye was not performed. On similar lines, a comparative study of 100 patients showed that clinical tests combined with either DS-DCG or DSG, provide no additional information in cases with functional epiphora (Sousa et al., 1993). However, if any surgical intervention was planned then DS-DCG was preferable over DSG. DS-DCG is still considered as a useful lacrimal imaging modality, but in the past, it was explored mainly for locating the site of obstruction, but has the potential to be explored for many more indications.

3.1.3. *Computed tomographic-dacryocystography (CT-DCG)*

CT-DCG allows for documentation of adjacent bony and soft tissues structures apart from the LDS (Fig. 2). First CT-DCG was performed in 1990 almost 81 years after the first DCG (Zinreich et al., 1990). Clinical application of CT-DCG lies in the assessment of complex NLD obstructions (NLDO) following craniofacial trauma, congenital craniofacial deformities and LS neoplasms (Ashenhurst et al., 1991; Ali et al., 2016; Ali and Paulsen, 2017). CT-DCG involves use of contrast media (lipiodal, iohexol, omnipaque) either in topical form or injection via inferior (or superior) canaliculus followed by axial and coronal images of 1–2 mm varying slice thickness. Topical method involves instillation of iodinated contrast medium every minute for five minutes or three times at 0, 5 and 10 min.

Glatt evaluated 13 patients with NLDO and facial fractures – presence of dye was useful in locating the LS in only five patients (Glatt, 1996). They also evaluated the CT-DCG in five failed DCRs and demonstrated improper ostium location, suboptimal size, and bone regrowth at the ostium, anteriorly placed ethmoidal cells responsible for failure (Glatt et al., 1991). Although a nasal endoscopic examination could have also picked up these causes, CT-DCG will supply additional anatomical information. No added advantage with regards to common canalicular visualization was noted either with DCG or CT-DCG. Modification in the form of 3D helical CT-DCG was introduced in 2002, and was evaluated in 30 patients with epiphora (Freitag et al., 2002). The agreement between 3D helical CT-DCG and LDS irrigation was better (14 of 18 systems) in the clinically partial obstructions group, fair (10 of 15 systems) in complete obstructions and poor (16 of 26) in freely patent systems. The mean cross-sectional area of LS between unobstructed and partially obstructed systems was not statistically significant, hence the need for a better technique for the subset of patients with partial obstructions or functional NLDO (Freitag et al., 2002). While operating with navigation assistance in complex facial trauma, 3D CTDCG guidance helps in dacryolocalisation in secondary acquired lacrimal duct

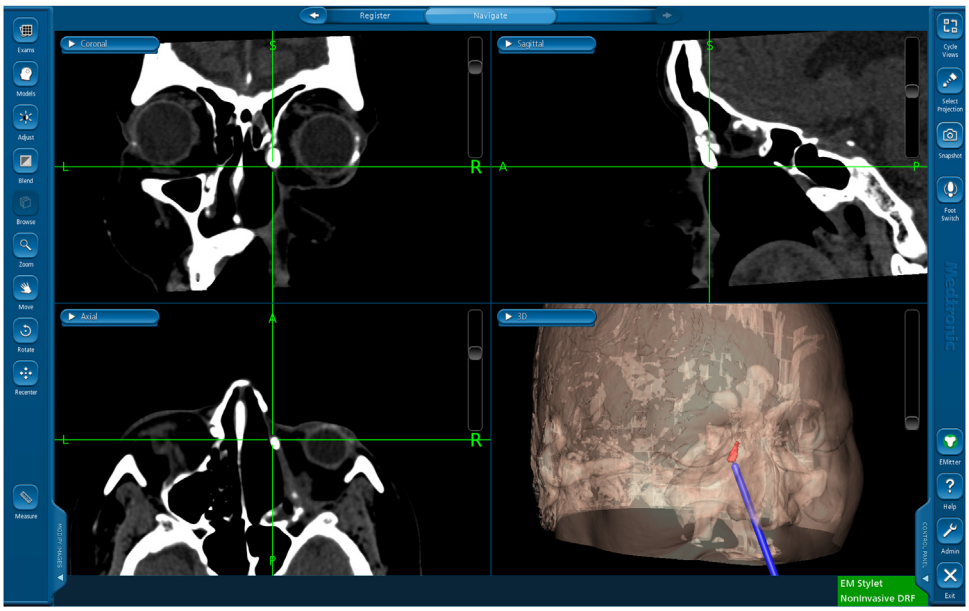

Fig. 3. Dye filled lacrimal sac helps in dacryolocalisation with navigation assistance following extended maxillectomy.

obstructions (Ali et al., 2016). Two patients with extensive maxillofacial trauma and one following maxillectomy were managed successfully with endoscopic DCR using 3D CT-DCG and navigation (Ali et al., 2016) (Fig. 3).

Evaluation of feasibility of using topical contrast during helical CT-DCG and normal saline in MR-DCG in 14 healthy volunteers (unobstructed system) showed that all parts of LDS could be visualized with CT-DCG whereas canaliculus and membranous NLD could not be seen with MR-DCG in 45% and 59%, respectively (Caldemeyer et al., 1998). Adjacent mucosal disease in paranasal sinuses was quoted as one of the reasons for difficult visualization on MR-DCG. Presence of mucosal disease in the paranasal sinuses does make the visualization of the lacrimal system difficult (Udhay et al., 2008).

Physiological assessment was also attempted with a CT-DCG using topical contrast drops. Twenty-one patients with epiphora were evaluated using CT-DCG (topical method) and CDCG. CT-DCG delineated obstruction in five systems, which were patent on DCG (Saraç et al., 1995). However, their clinical correlation and application in epiphora management would define the real significance of CT-DCG in such scenarios. Massoud et al. highlighted the role of CT-DCG in two patients undergoing endoscopic DCR after extensive sinus surgery and reported the advantages of concurrent information regarding sinus disease recurrence or persistence in the adjacent paranasal sinuses (Massoud et al., 1993).

Cone beam CT-DCG (CBCT-DCG) can be performed in sitting position and uses a limited field of view with 0.5 mm slices at 0.5 mm intervals. Evaluation of CBCT-DCG in 10 obstructive epiphora (confirmed with irrigation) with cannulation and topical method revealed 73% overall correlation with clinical findings (Tschopp et al., 2014). They found better correlation with topical (80%) rather than cannulation technique (67%). One reported benefit of CT-DCG was the possibility of simultaneous correction of nasal disease if present while perfroming endoscopic DCR (Waite et al., 1993).

The role of CT-DCG in the pediatric population has been assessed for congenitally obstructed ducts undergoing a balloon dacryoplasty (Limongi et al., 2012). Decrease in LS volume after dacryoplasty was a significant predictor of success and larger circumference of dilated portion of LS was associated with procedure failure. Exposing children to radiation might not be justifiable for the procedure, however complicated cases such as lacrimal outflow dysgenesis or reoperations may be the potential indications (Hermina et al., 1999). The dose exposure is 2.7–6 mGy with CDCG and 10–12 mGy with CT-DCG (Galloway et al., 1984). The reduction in radiation exposure was achieved with cone-beam CT-DCG that gives equally good images of the LDS (Wilhelm et al., 2009; Tschopp et al., 2014). Currently, CT-DCG is being mainly used for scenarios where adjacent bony anatomy is relevant for pre-operative planning.

3.1.4. *Magnetic resonance dacryocystography*

The first MRDCG was performed in 1993 using 0.5% gadolinium (1:100 dilution) contrast media (Goldberg et al., 1993). Information regarding the functional and morphological aspects of lacrimal pathways without any radiation exposure, and the ability to acquire series of images are the main advantages of MR-DCG. However, the high cost, longer acquisition time and motion artifacts are the limitations of this technique.

MR-DCG is performed using 1, 1.5 or 3-T MR scanners and images are typically enhanced by fat suppression and dedicated surface coils (Fig. 4). Both cannulation and topical instillation of contrast have been tried. Topical drops are instilled every minute for five minutes or one drop every three minutes for 15 to 20 min. Various sequencing techniques have been employed – fast spin echo (FSE), single shot turbo spin echo, fast spoiled gradient-recalled, three dimensional (3D) fast-recovery fast spin-echo (FRSE), and 3D fast spin echo-Cube sequences. With the fast sequences, the duration of MR-DCG reduces considerably from 20–30 min to 7–12 min (Coskun et al., 2012). Three-dimensional FSE-Cube sequence provides a better visualization of structures, especially canaliculi, compared to combined 3D-FRFSE MR-DCG and 2D T2-weighted images. However, there was no difference in sensitivity or accurate prediction of the level of obstruction (Zhang et al., 2015a,b; Jing et al., 2013; Liu et al., 2019). Increased focal artifacts in the ductal segments due to adjacent paranasal sinuses may result in degraded image quality in Cube FSE MR-DCG. Dynamic MR-DCG allows for the capture of passage of contrast media across the LDS; oblique coronal and sagittal plane represent the whole LDS in one image. Tear flow was assessed using MR-DCG in normal individuals, and notable findings were the passage of contrast only after multiple blinks, the LS never empties completely and saline solu-

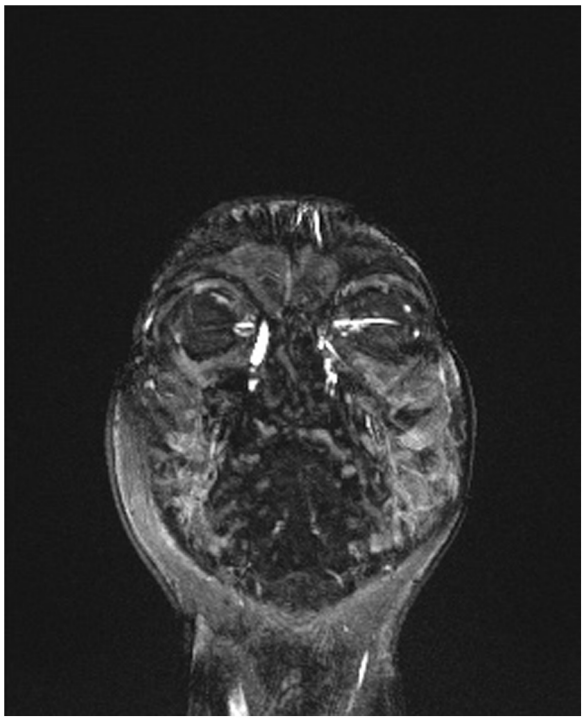

Fig. 4. Coronal MR-DCG MIP image shows dye delineating the canaliculi, lacrimal sac and nasolacrimal duct.

tion traverses as multiple bolus units from the LS to NLD (Amrith et al., 2005).

High resolution MR-DCG was able to distinguish stenosis from obstruction in conjunction with clinical findings and DCG (Hoffmann et al., 1999). Stenosis was assumed if either irrigation or DCG showed patent system but MR-DCG holds up the contrast medium. The lack of corroborative evidence of intraoperative findings or the treatment modality precluded attempts to assess the complete utility of MR-DCG. Takehara and colleagues performed MR-DCG and DS-DCG using saline with 2% lidocaine in eight patients with epiphora (Takehara et al., 2000). MR-DCG and DS-DCG showed similar findings for ductal obstructions (n = 6). No significant difference in sensitivity was found among CT-DCG, DCG, clinical irrigation, and MR-DCG (topical and cannulation) in 22 LDS (Manfre et al., 2000). Stenosis proximal to the LS was present in 32% and distal to LS in 68% of patients on CT-DCG and MR-DCG (cannulation method). Only one patient showed pre-saccal obstruction on MR-DCG with the topical method. Authors believed it as a false positive from a diffuse exudate filling a dilated LS (Manfre et al., 2000).

The sensitivity of 3D FSPGR MR-DCG (using topical method) for the detection of nasolacrimal obstruction was calculated using the DS-DCG findings as the standard of reference and 88% correlation was noted amongst the two (Karagulle et al., 2002). On similar lines, 22 LDS of 21 patients were evaluated with 3D FSPGR (topical method) and DS-DCG, and showed good agreement in terms of morphology of the LS, junctional areas, NLD and passage of contrast into the nasal cavity (Coskun et al., 2012). Interestingly, differences were noted between the two techniques in terms of normal versus stenotic appearance of sac-NLD junction or the NLD. Another study reported the sensitivity and specificity of MR-DCG in comparison to standard DCG to be 90.5% and 89.3% respectively (Cubuk et al., 2010). Efficacy of MR-DCG in accurate positional diagnosis of lacrimal obstruction was evaluated with respect to dacryoendoscopy and intraoperative findings. The overall accuracy of MR-DCG in depicting the stenosis/obstruction in nasolacrimal system was 84% (26 out of 31 systems), and least for canalicular obstructions (Higashi et al., 2016). A good correlation was also noted between a dacryoscintigraphy and MR-DCG in eight patients with NLD obstruction (Karaali et al., 2014). Comparison between MR-DCG and DS-DCG in 11 patients reported them to be equivocal in detecting obstructed lacrimal systems, however, the exact site of obstruction could be located better with MR-DCG (Kirchhof et al., 2000). However, it cannot be rightly said that MR-DCG can entirely replace DS-DCG in the assessment of the nasolacrimal duct system, but seems promising in evaluating functional epiphora.

Tear transport time using the drop method of CT-DCG or MR-DCG is highly variable. But its documentation among normal individuals in real time will give us a base for assessing lacrimal pump failure. MR-DCG has also been used to evaluate post DCR ostium with patent irrigation (Detorakis et al., 2010). Significant reduction in signal intensity was noted at the ostium in patients with watery eye following a patent DCR.

Gadolinium, being a paramagnetic substance, has yielded satisfactory images and no adverse effects have been reported so far. Normal saline alone or in combination with 0.5% lidocaine have also reproduced comparable imaging features (Goldberg et al., 1993; Amrith et al., 2005; Takehara et al., 2000). One study used normal saline mixed with hydroxyl propyl cellulose since normal saline passed very quickly to allow dynamic capture (Zhang et al., 2015a,b). Yoshikawa et al. compared the topical applications of saline solution and Gd-DTPA solution, more accurate information was obtained with gadolinium than the saline solution (Yoshikawa et al., 2000). On the contrary, tear flow dynamics was clearly seen with BSS than with gadolinium in dynamic MR-DCG (Amrith et al., 2005).

4. Conclusion

There is no single ideal imaging technique for LDS evaluation, and most of the existing imaging modalities are complementary to each other. In spite of advances with dacryoendoscopy, the imaging modalities retain their utility for specific indications like partial obstructions and functional NLDO. However, the limitation of C-DCG or DS-DCG lies in their non-physiological nature since injection of dye does not mimic the real tear flow dynamics. Currently DS-DCG remains the standard examination technique for the assessment of obstructions of the LDS. The role of CT-DCG comes into play in complex orbito-facial trauma and lacrimal drainage tumors. Imaging interpretations of functional aspects of LDS are not yet completely known. Future studies should comprehensively evaluate and simultaneously correlate lacrimal irrigation, dynamic imaging and microendoscopic findings followed by their impact on the outcomes.

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Originality and plagiarism

The authors ensure that they have written entirely original works, and if the authors have used the work and/or words of others, that this has been appropriately cited or quoted.

Multiple, redundant or concurrent publication

This article has not been submitted for publication nor has it been published in whole elsewhere.

CRediT authorship contribution statement

Swati Singh: Conceptualization, Data curation, Writing - original draft. **Mohammad Javed Ali:** Supervision, Visualization, Writing - review & editing. **Friedrich Paulsen:** Writing - review & editing.

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