Figures

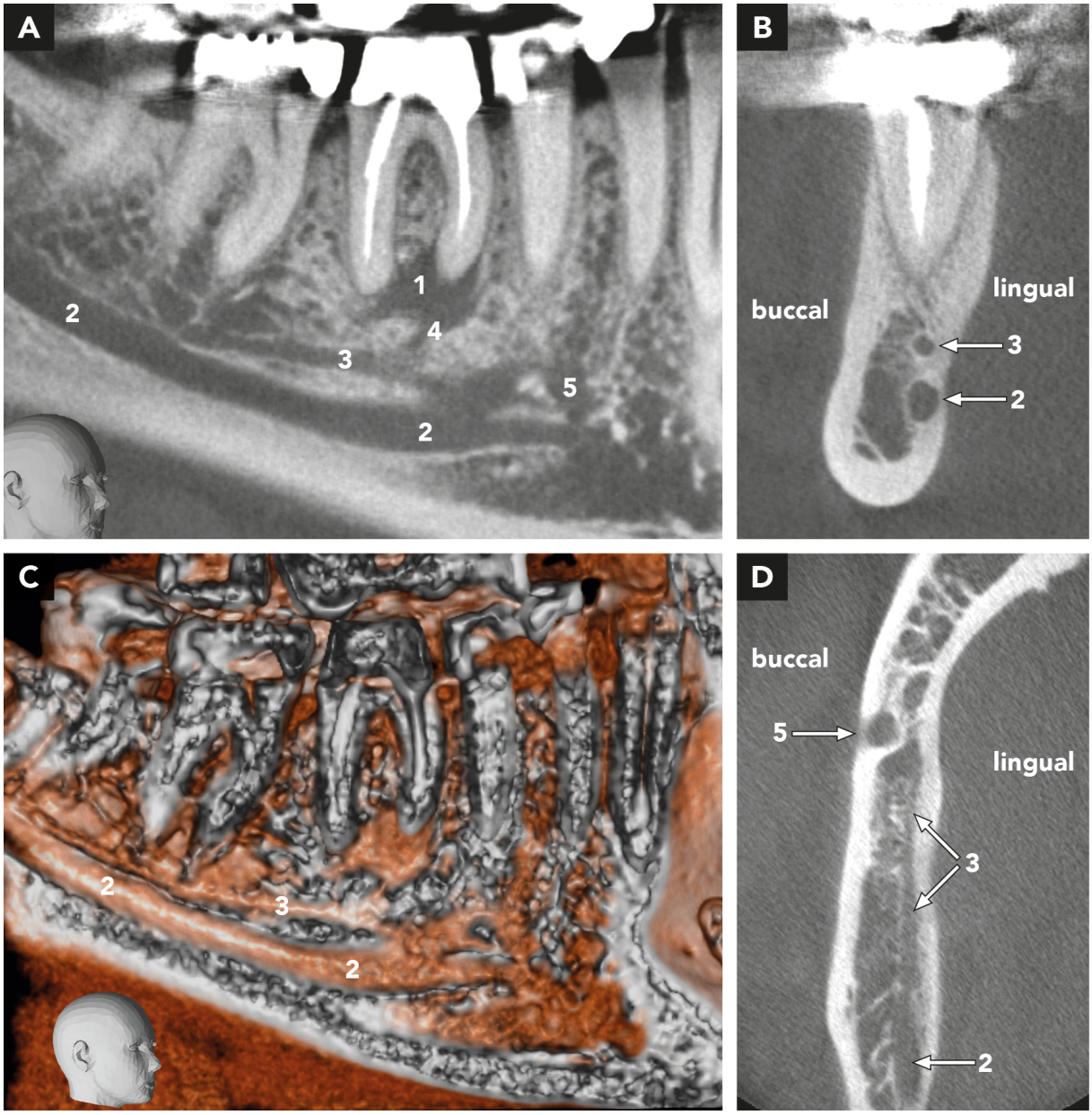
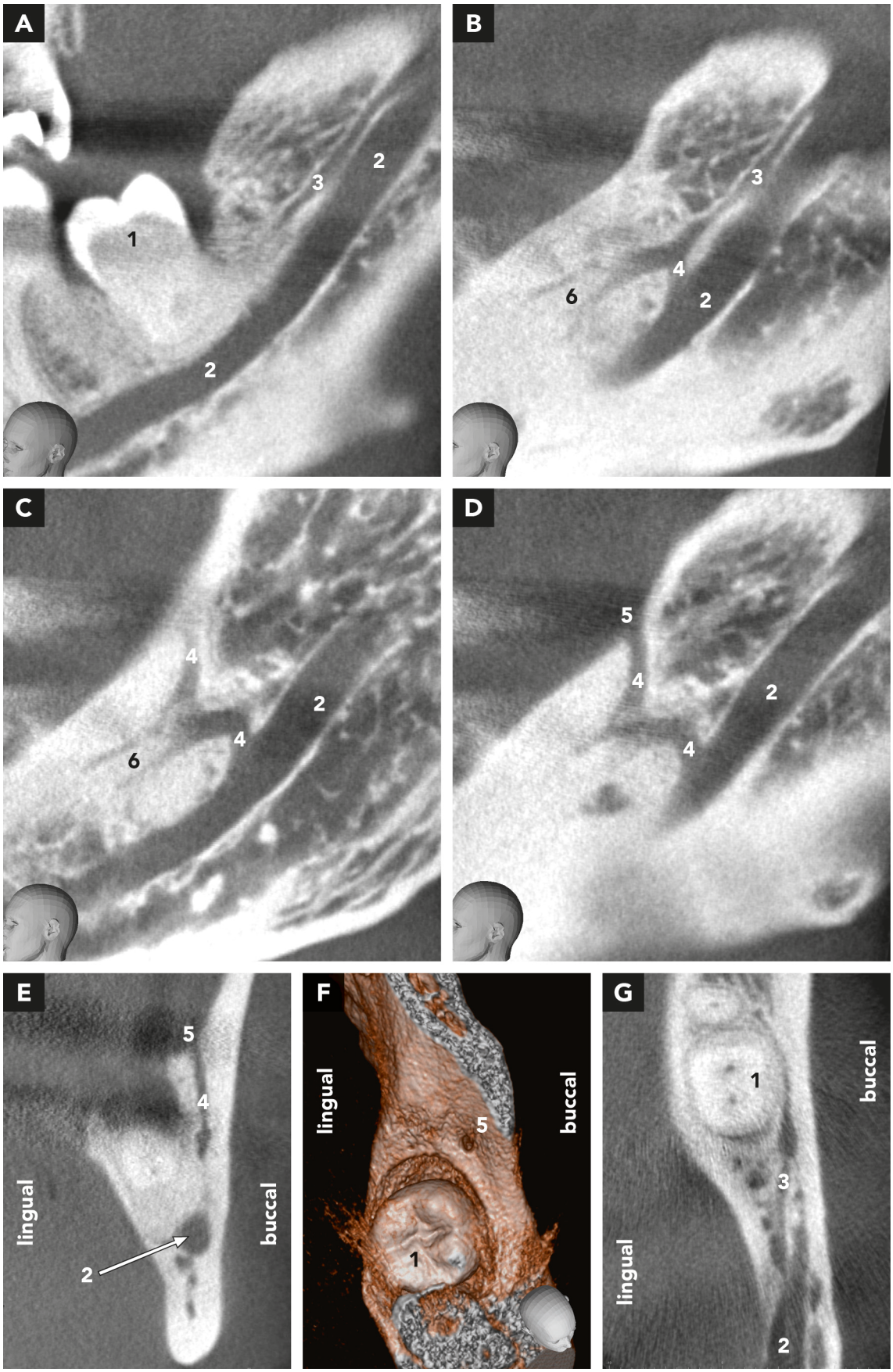


Fig. 1

CBCT-assessment of a 68-year-old male referred for apical surgery of the lower right 1st molar (tooth 46). Sagittal image (A), coronal image at the level of the distal root of 46 (B), 3D-rendered image cut along MC and BMC, and axial image at the level of the mental foramen (D, inferior view).

1 = periapical lesion of mesial root of 46; 2 = MC; 3 = BMC; 4 = branch from BMC to mesial root of 46; 5 = mental foramen.


A
1
2
3
2
B
3
4
6
2
C
4
2
4
6
D
5
4
2
4
E
5
4
lingual
buccal
2
F
lingual
buccal
5
1
G
1
buccal
3
lingual
2

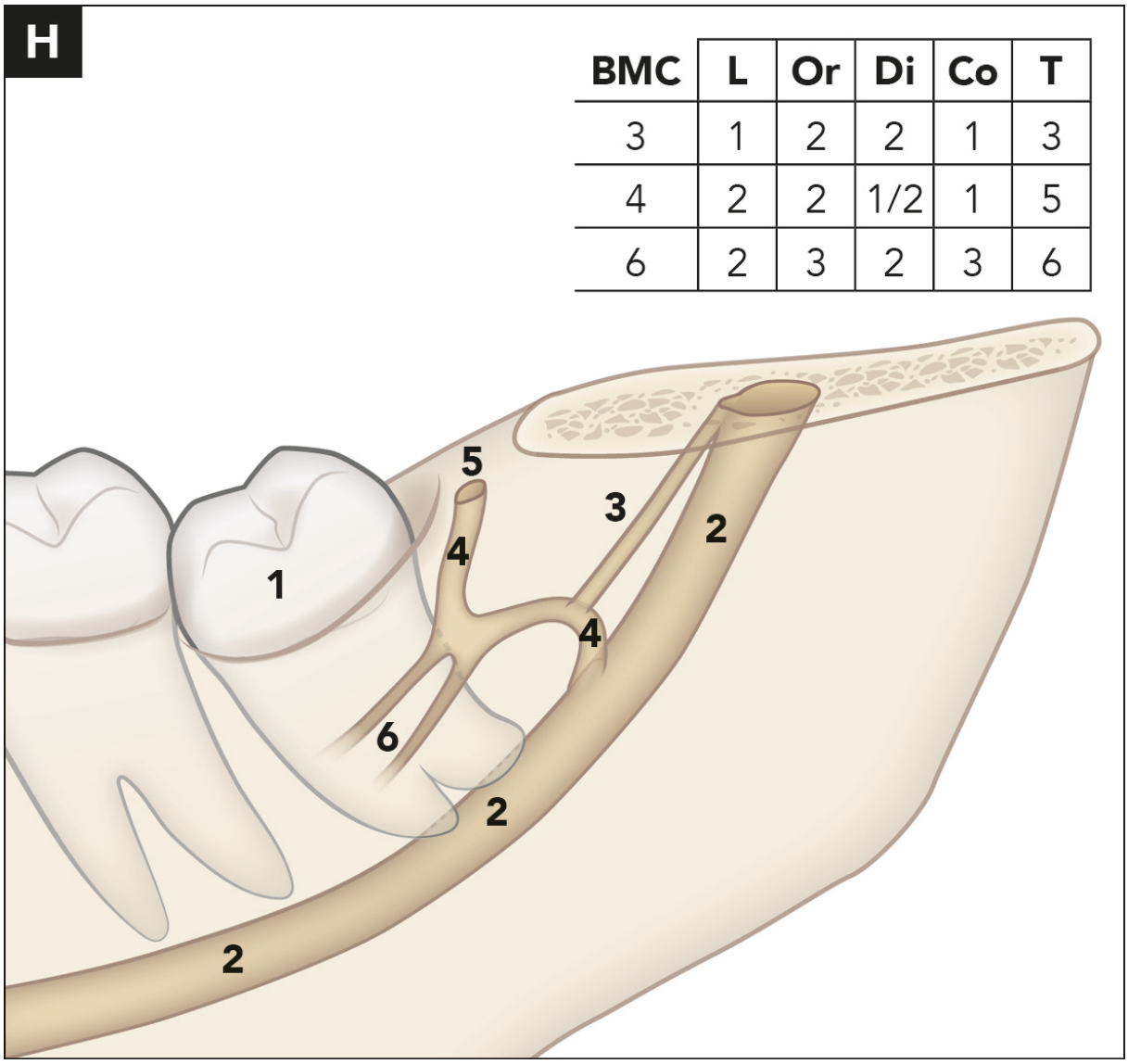
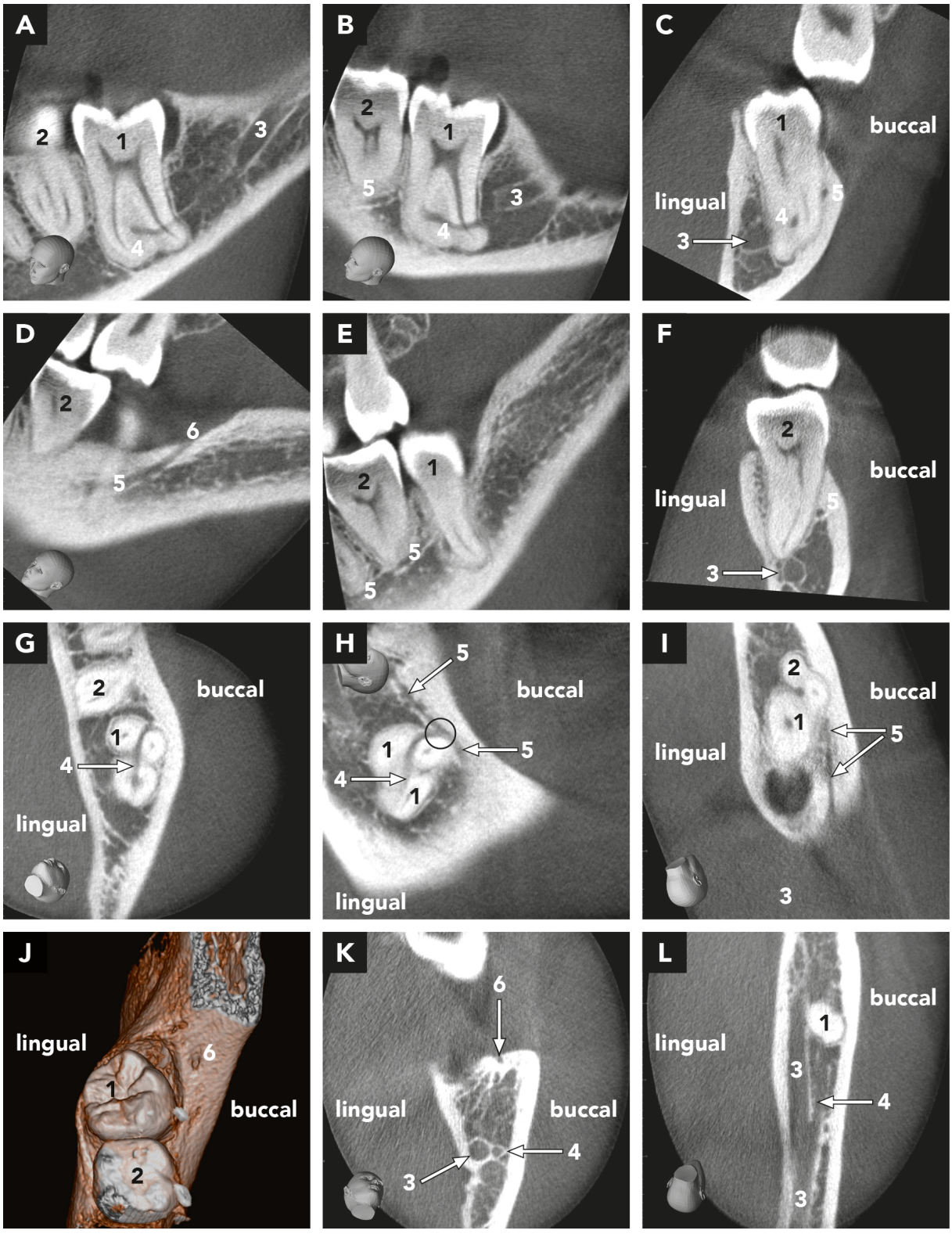


Fig. 2

CBCT-assessment of a 62-year-old female referred for surgical removal of the retained lower left 3rd molar (tooth 38). A complex BMC configuration is present. Sagittal images (A-D), coronal image (E), 3D-rendered image (F, superior view), and axial image (G, inferior view). A 3D-illustration demonstrates the complex BMC courses (H): for **L-Or-Di-Co-T** numbers, refer to Tab. VIII.

1 = tooth 38; 2 = MC; 3 = BMC joining a retromolar canal; 4 = retromolar canal; 5 = retromolar foramen; 6 = two small BMC arising from the retromolar canal and coursing anteriorly.


A
2
1
3
4
B
2
1
5
3
4
C
1
buccal
lingual
5
4
3
D
2
6
5
E
2
1
5
5
F
2
buccal
lingual
5
3
G
2
buccal
1
4
lingual
H
5
buccal
1
5
4
1
lingual
I
2
buccal
1
5
lingual
3
J
lingual
6
1
buccal
2
K
6
lingual
buccal
4
3
L
buccal
1
lingual
3
4
3

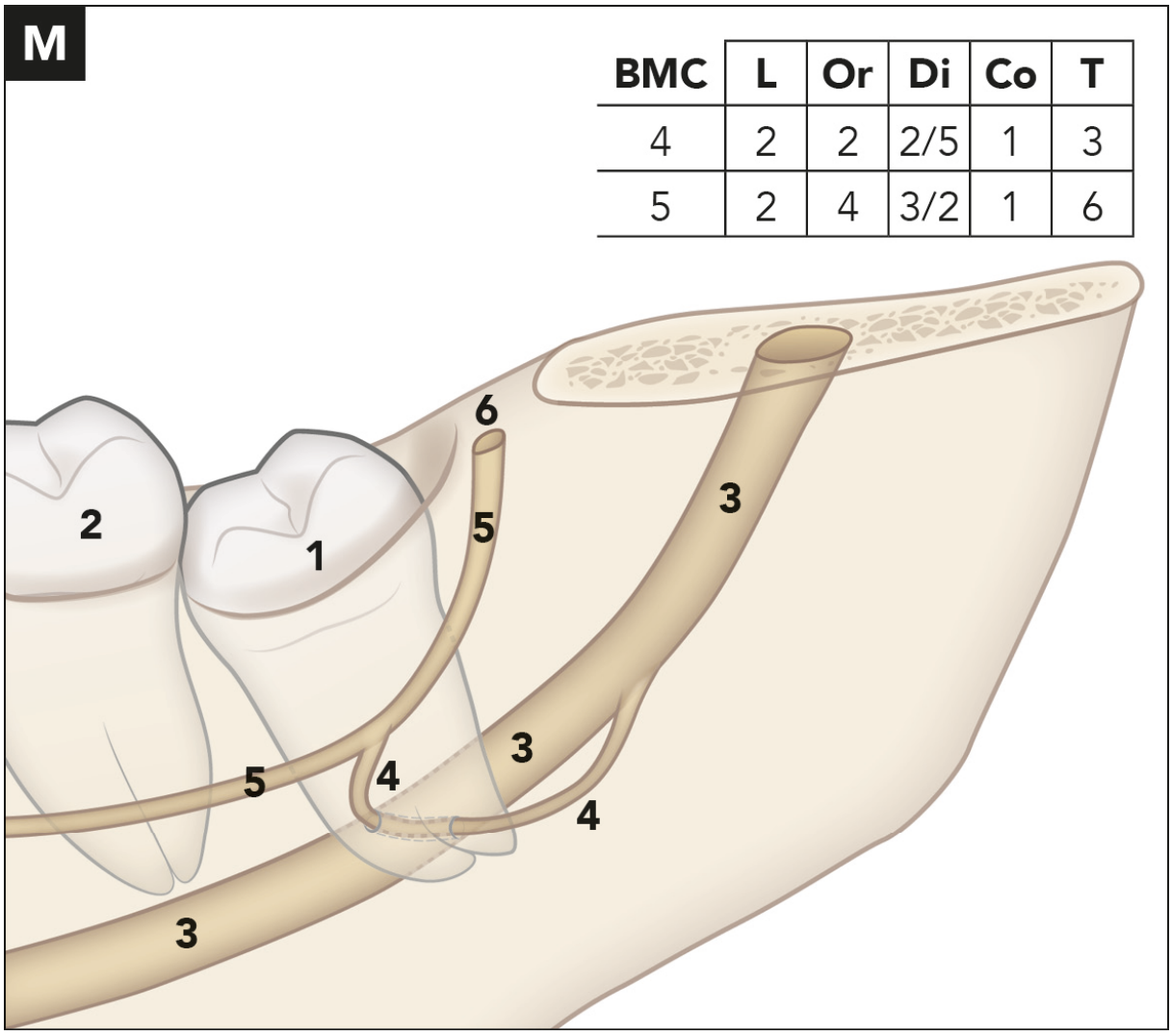


Fig. 3

30-year-old female presenting two BMCs. A lower BMC traverses the apical portion of the roots of the lower left 3rd molar (tooth 38). Then the accessory canal curves buccally to join an upper BMC running along the buccal root surfaces of teeth 38 and 37. The latter canal originates from a retromolar foramen. Sagittal images (A, B, D, E), coronal images (C, F, K), axial images (G, H, I, L, all inferior view), and 3D-rendered image (J, superior view). A 3D-illustration demonstrates the complex BMC courses (M): for **L-Or-Di-Co-T** numbers, refer to Tab. VIII.

1 = tooth 38; 2 = tooth 37; 3 = MC; 4 = BMC traversing apical root portions of tooth 38; 5 = additional BMC running along the buccal aspects of teeth 37 and 38; 6 = retromolar foramen. In Fig. H, the circle ❍ marks the site of BMC confluence.

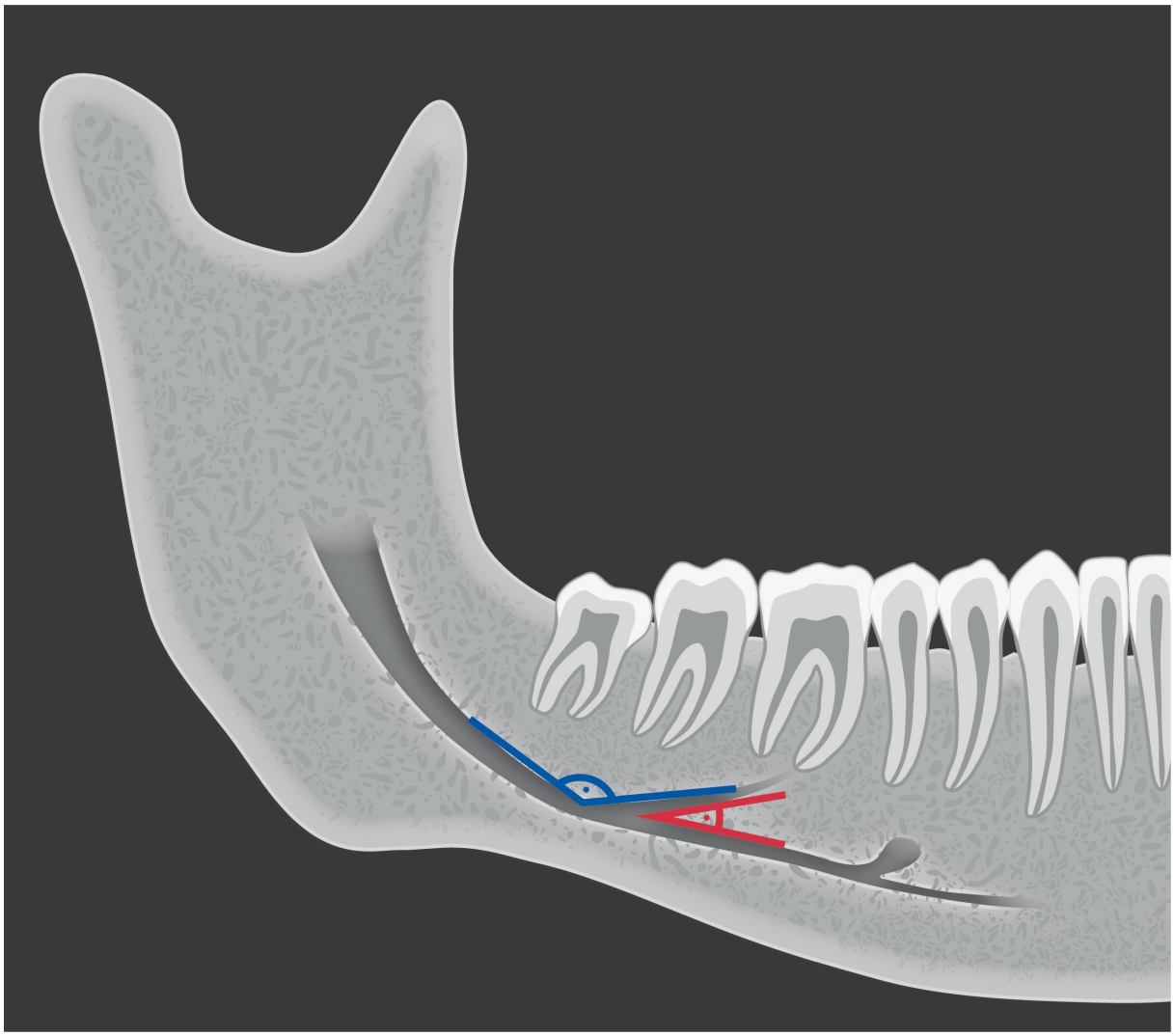


Fig. 4

Schematic illustration demonstrating superior and inferior angles of bifurcation of BMC from MC.

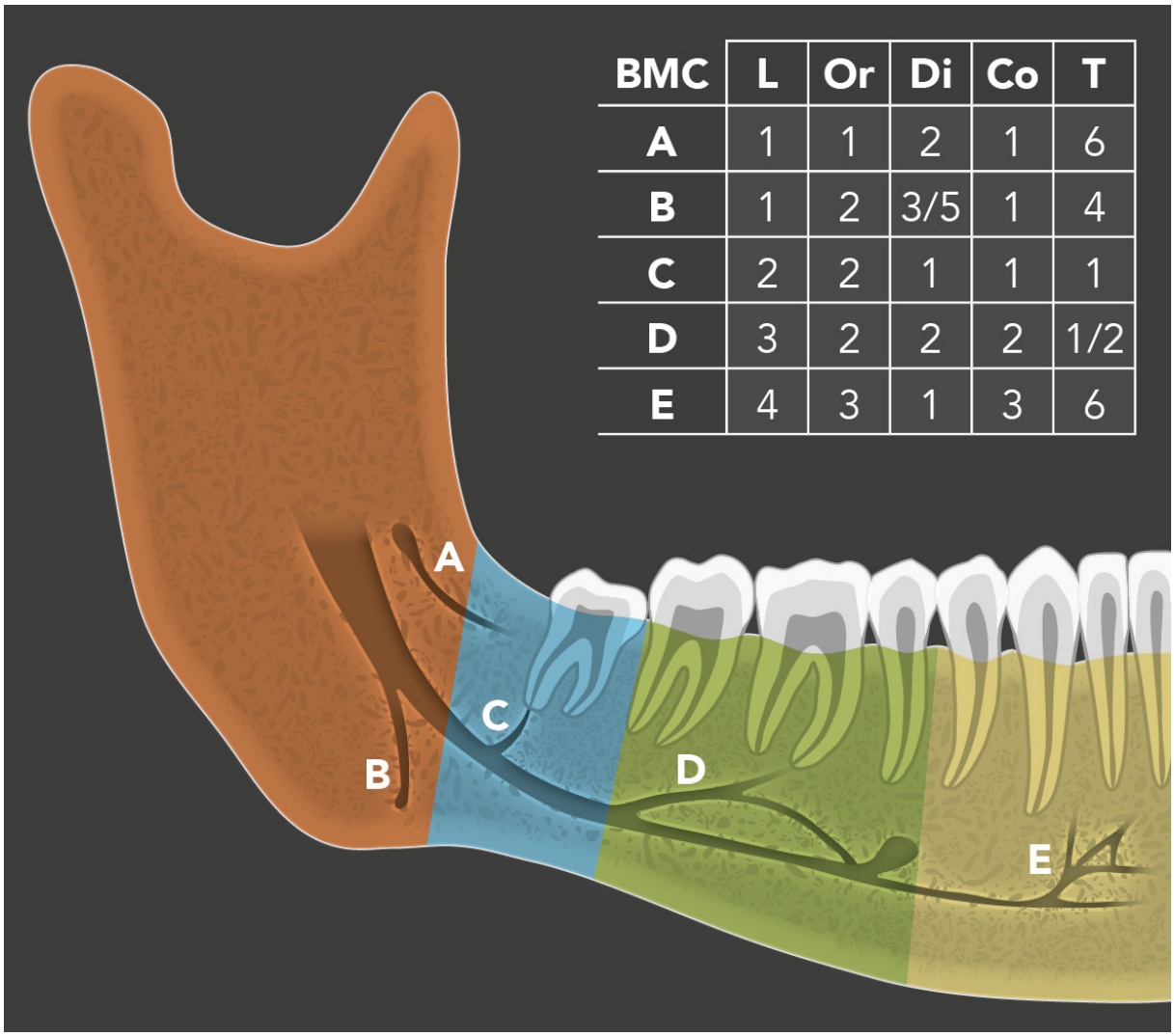
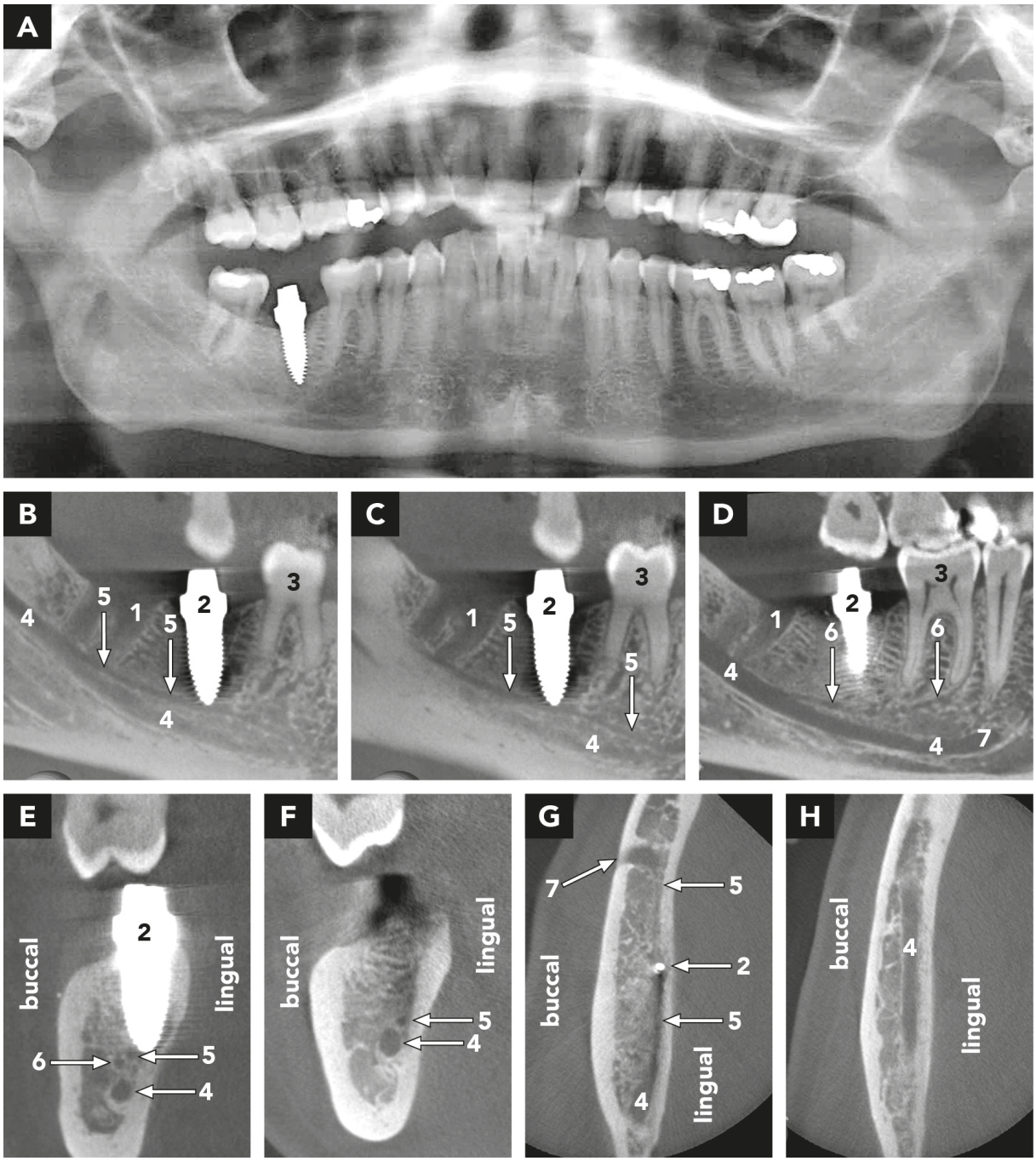


Fig. 5

Schematic illustration of new BMC classification based on L-Or-Di-Co-T (see also Tab. VIII).


A
B
5
1
5
2
3
4
4
C
3
1
5
2
5
4
D
3
2
1
6
6
4
4
7
E
buccal
lingual
2
6
5
4
F
buccal
lingual
5
4
G
7
5
buccal
2
5
4
lingual
H
buccal
4
lingual

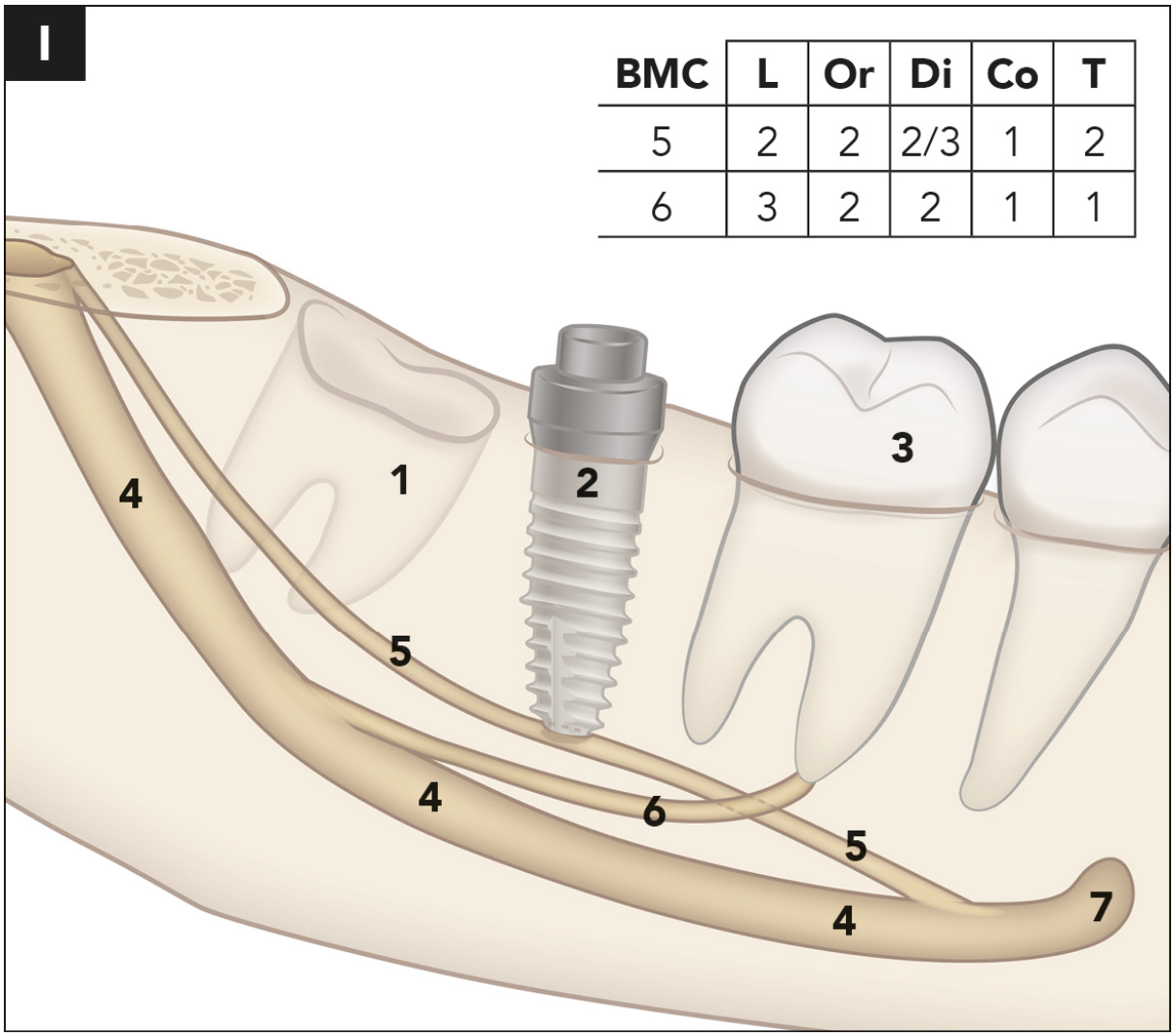
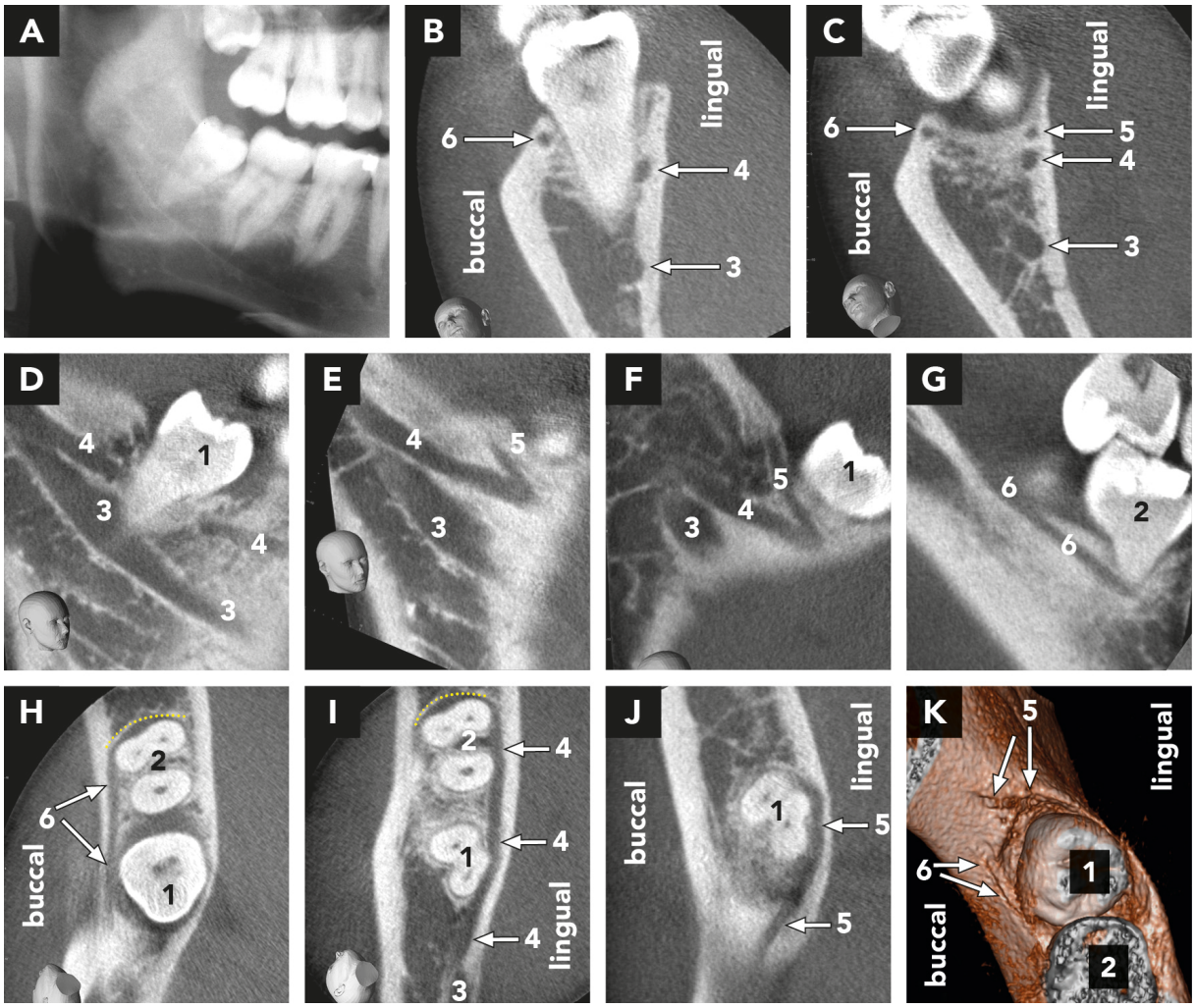


Fig. 6

Referral of a 47-year-old female with severe pain and sensitivity loss in the right lower lip and chin areas following implant insertion in the position of the lower right second molar (47). Panoramic radiograph by private dentist shows good distance from implant tip to mandibular canal (A); tooth 48 was subsequently removed by the referring dentist hoping that the sensitivity would improve but it didn't. CBCT images show that the implant is impinging on a BMC that rejoins the MC. An additional BMC to the mesial root of tooth 46 is visible. Sagittal images (B, C, D), coronal image (E, F), and axial images (G, H, all inferior view). A 3D-illustration demonstrates the BMC courses (I): for **L-Or-Di-Co-T** numbers, refer to Tab. VIII.

1 = socket of extracted 48; 2 = implant for replacement of tooth 47; 3 = tooth 46; 4 = MC; 5 = BMC rejoining MC; 6 = BMC extending to mesial root of 46; 7 = mental foramen.


A
B
lingual
6
4
buccal
3
C
lingual
6
5
4
buccal
3
D
4
1
3
4
3
E
4
5
3
F
5
1
4
3
G
6
2
6
H
2
6
buccal
1
I
2
4
1
4
4
lingual
3
J
lingual
buccal
1
5
5
K
5
lingual
6
1
buccal
2

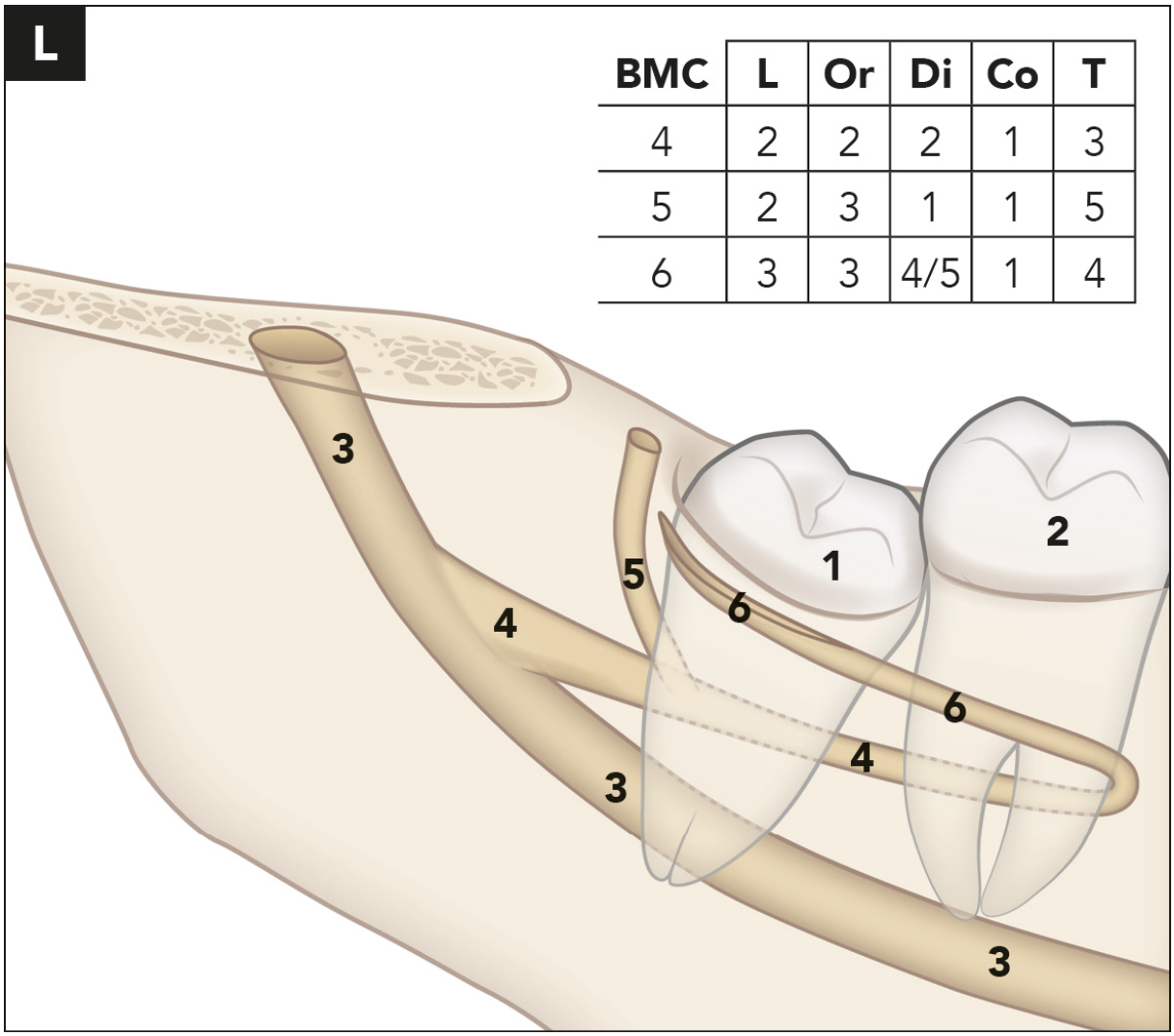


Fig. 7

Radiographic assessment of a lower right 3rd molar (48) in a 32-year-old male. A BMC is assumed on the cropped panoramic radiograph (A), but in fact, 3 BMCs are visible on the CBCT images. Sagittal images (D, E, F, G), coronal images (B, C), axial images (H, I, J, all inferior view), and 3D-rendered image (K, superior view). A 3D-illustration demonstrates the complex BMC courses (L): for **L-Or-Di-Co-T** numbers, refer to Tab. VIII.

1 = tooth 48; 2 = tooth 47; 3 = MC; 4 = large lingual BMC; 5 = branching upper lingual BMC; 6 = small buccal BMC. Dotted yellow line (in H and I) represents fusion of large lingual and small buccal BMCs.

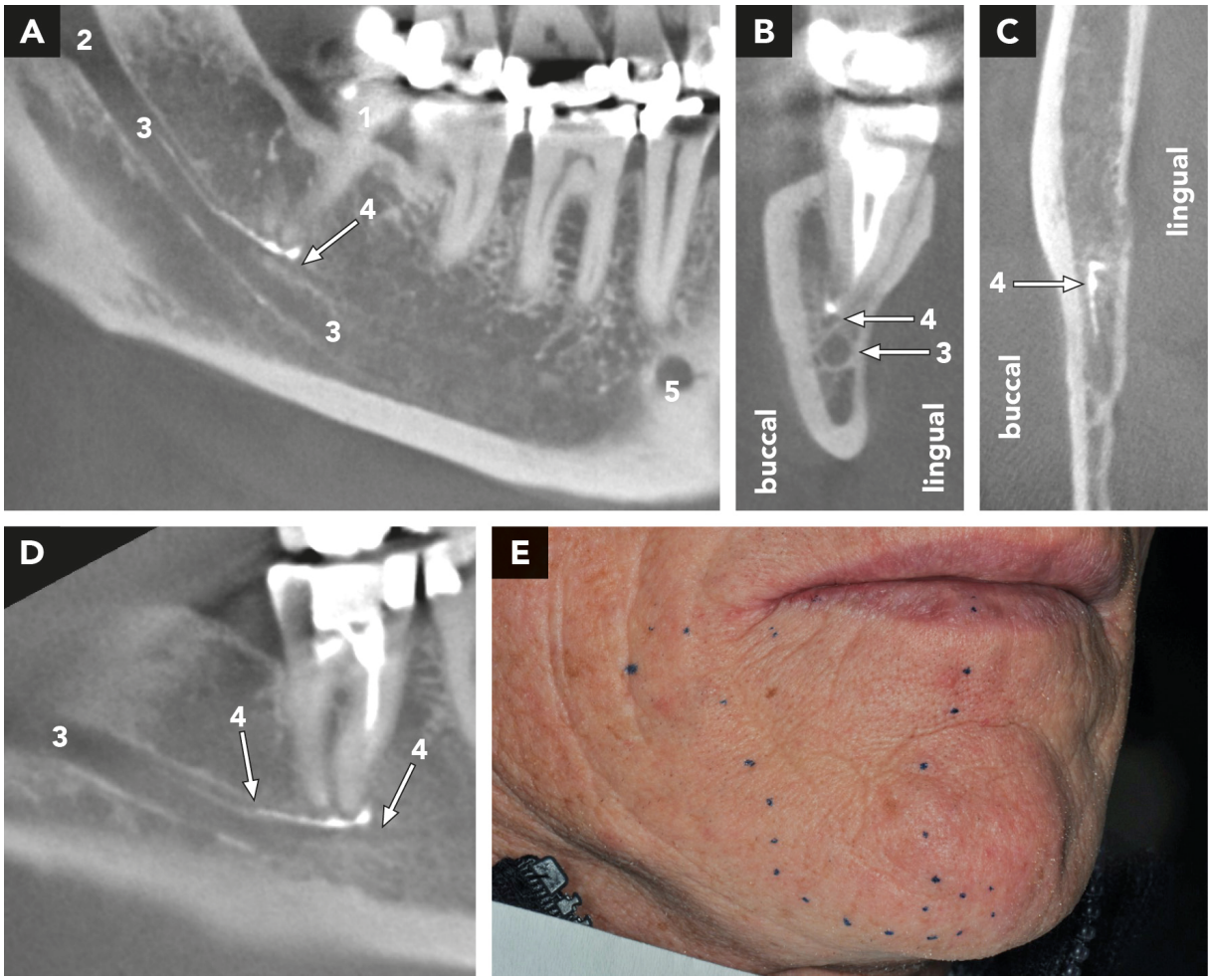


Fig. 8

CBCT-assessment of a 62-year-old male presenting severe pain and sensitivity loss following root-canal medication with calcium hydroxide ($CaOH_2$) of the lower right 3rd molar (tooth 48). The CBCT images clearly exhibit overfilling and migration of $CaOH_2$ in a BMC running below 48. Sagittal images (A, D), coronal image (B), axial image (C, inferior view), and clinical picture showing the extent of the sensitivity loss (E).

1 = tooth 48; 2 = mandibular foramen; 3 = MC; 4 = BMC with overfilled $CaOH_2$; 5 = mental foramen.

Table I

Classification of BMCs

Author(s) year ***(Imaging method)***	**Classification**	**Definition**
NORTJE ET AL. 1977 *(panoramic radiography)*	Type I	Two canals originating from one mandibular foramen
	Type II	Short supplemental upper canal extending to 2nd or 3rd molar
	Type III	Two canals originating from two mandibular foramina, but joining together in the molar region to form one canal
	Type IV	Supplemental canal arising from the main canal and reaching the retromolar pad region
LANGLAIS ET AL. 1985 *(panoramic radiography)*	Type 1	Uni- or bilateral BMC extending to 3rd molar or immediate surrounding area
	Type 2	Uni- or bilateral BMC extending along the course of the MC and rejoining it within the ramus or the body of the mandible
	Type 3	Combination of Type 1 on one side and of Type 2 on other side
	Type 4	Consists of two canals originating from separate mandibular foramina and then joining to form one larger MC
NAITOH ET AL. 2009 *(cone beam computed tomography)*	Type I	Retromolar canal: terminates at a foramen on the bone surface of the retromolar region
	Type II	Dental canal: extends to the root apex of 2nd or 3rd molar
	Type III	Forward canal: arising from superior MC wall other than Types I or II (with/without confluence to MC)
	Type IV	Buccolingual canal: originating from buccal or lingual wall of MC
LUANGCHANA ET AL. 2019 *(cone beam computed tomography)*	Type A	Superior type: single or multiple canals branching superiorly from the main MC
	Type B	Forward type: BMC coursing forward and running lower than apices of teeth (B1 no merging, B2 merging with MC)
	Type C	Plexus type: branching plexus from MC
	Type D	Anterior extension type: branching from mandibular incisive canal (D1 single or series of canals; D2 plexus of canals)

BMC = Bifid Mandibular Canal
MC = Mandibular Canal

Table II

CT- or CBCT-studies evaluating the presence and morphology of BMCs

Author(s) year	Country	N patients N sides (age)	Imaging technique	BMC classification	Mean frequency of BMCs	BMC subtypes	Comments
NAITOH ET AL. 2009	Japan	122 patients 244 sides (mean 50.8 years, 17-78 years)	CBCT	Naitoh	Patients: 64.8% Sides: 43.0%	Forward: 59.6% Retromolar: 29.8% Dental: 8.8% Buccolingual: 1.8%	-
KURIBAYASHI ET AL. 2010	Japan	252 patients 301 sides (mean 33 years, 18-74 years)	CBCT	Nortje	Sides: 15.6%	Type I: 4.3% Type II: 85.1% Type III: 0% Type IV: 10.6%	-
NAITOH ET AL. 2010	Japan	28 patients 56 sides (mean 54.5 years, 21-74 years)	CBCT	Naitoh	Sides: 32.1%	Forward: 84.2% Retromolar: 15.8% Dental: 0% Buccolingual: 0%	4 forward canals observed in CBCTs were not seen on CTs; 2 forward canals in CTs were longer than in CBCTs
	CTs were taken on average 30 months before CBCTs	Multislice CT		Sides: 25.0%	Forward: 80% Retromolar: 20% Dental: 0% Buccolingual: 0%	
ORHAN ET AL. 2011	Turkey	242 patients 484 sides (mean 36.7 years, 17-83 years)	CBCT	Naitoh	Patients: 66.5% Sides: 46.5%	Forward: 38.2% Retromolar: 34.7% Buccolingual: 17.8% Dental: 9.3%	-
YAMADA ET AL. 2011	Japan	96 patients 112 sides (mean NA, 16-77 years)	CBCT	Bifurcation from MC related to 3rd molar (M3)	(Sides: 94.6%)*	55.5% below M3 32.9% buccal to M3 11.6% lingual to M3	*Evaluation was limited to region of impacted lower third molars (M3)
DE OLIVEIRA-SANTOS 2012	Belgium	100 patients 200 sides (age NA)	CBCT	-	Patients: 19%	Retromolar: 15.8% Forward: 10.5% Associated with double mental foramen: 31.6% Associated with accessory mental foramen: 42.1%	Only BMC with a diameter of > 1mm included
CORRER ET AL. 2013	Brazil	75 patients (unilateral exams) (mean 48.2 years, 17-83 years)	CBCT	Langlais	(Patients/sides: 100%)*	Type 1: 72.6% Type 2: 19.3% Type 3: 8% Type 4: 0%	*Selected cases with previously diagnosed BMC
CHOI & HAN 2014	South Korea	446 patients 892 sides	CBCT	-	(Patients: 1.35% Sides: 0.9%)*	Retromolar canal: 75% Forward canal: 25%	*Evaluation was limited to canals originating from

							double mandibular foramina
FU ET AL. 2014	Taiwan	173 patients 346 sides (mean 54 years, 14-85 years)	Multislice CT	-	Patients: 30.6% Sides: 18.5%	-	-
KANG ET AL. 2014	South Korea	1933 patients (unilateral exams) (mean 33 years, 13-93 years)	CBCT	Naitoh	Patients: 10.2%	Retromolar: 52.5% Forward: 40.9% Dental: 4.5% Buccolingual: 2%	-
NEVES ET AL. 2014	Brazil	127 patients 254 sides (mean 41.9 years, 18-61 years)	CBCT	-	Patients: 9.8%	Canals located posterior to 3rd molar: 80% Canals located in mandibular body: 20%	Study also evaluated panoramic radiographs of same patients
RASHSUREN ET AL. 2014	South Korea	500 patients 755 sides (age NA)	CBCT	Naitoh (modified)	Patients: 22.6% Sides: 16.2%	Retromolar: 71.3% Dental: 18.8% Forward: 4.1% Buccolingual: 0% Trifid: 5.8%	-
SHEN ET AL. 2014	Taiwan	308 patients 616 sides (mean 51 years, 12-85 years)	135 CBCT 173 Multislice CT	-	Patients: 41.2% Sides: 27.6%	-	-
LIMA VILLACA-CARVALHO ET AL. 2016	Brazil	300 patients (mean NA, 25-87 years)	CBCT	-	Patients: 26.7%	-	-
SHEN ET AL. 2016	Taiwan	327 patients 654 sides (mean 51 years, 23-85 years)	154 CBCT	-	Patients: 58.4% Sides: 42.2%	-	-
			173 Multislice CT	-	Patients: 30.6% Sides: 18.7%	-	-
AFSA & RAHMATI 2017	Iran	116 sides (age NA)	CBCT	-	Sides: 40.5%	-	-
YANG ET AL. 2017	China	280 patients 560 sides (mean 42 years, 18-78 years)	CBCT	Naitoh	Patients: 31.1%	Forward: 70.1% Retromolar: 15.9 Buccolingual: 12.1% Dental: 0% V-type: 1.9%	V-type = 2 branches arising from the MC, running forward and upward forming a V-shape
DE CASTRO ET AL. 2018	Canada	700 patients (mean 21.0 years, median 16 years)	CBCT	-	Patients: 41.1%	-	-

SHAH ET AL. 2018	England	281 patients (unilateral exams) (mean 31.5 years, 14-79 years)	CBCT	Bifurcation from MC related to 3rd molar	Sides: 38%	Type 1 (ramus area): 57% Type 2 (area of 3rd molar): 38% Type 3 (area mesial to 3rd molar): 5%	For patients with bilateral images, one side was randomly selected for examination. Types refer to location of bifurcation.
YOON ET AL. 2018	USA	194 patients 388 sides (mean 55 years, 13-103 years)	CBCT	Nortje	Patients: 13.4% Sides: 7.7%	Type I: 46.7% Type II: 53.3% Type III: 0% Type IV: 0%	-
ZHANG ET AL. 2018	China	1000 patients 2000 sides (age NA)	CBCT	Naitoh	Patients: 13.2% Sides: 8.4%	Retromolar: 68.4% Dental: 14.9% Forward: 13.7% Buccolingual: 0% Trifid: 2.4% Bicanal: 0.6%*	*bifurcates from inferior wall of MC
LUANGCHANA ET AL. 2019	Thailand	176 patients 243 sides (mean 54.2 years, 20-86 years)	CBCT	Luangchana	Sides: 43.6%	Premolar/Molar areas: Type A: 29%/32%/ Type B1: 0%/16% Type B2: 9%/13% Type C: 29%/39% Type D1: 19%/0% Type D2: 14%/0%	-
OKUMUS & DUMLU 2019	Turkey	500 patients 1000 sides (mean 38.2 years, 14-79 years)	CBCT	Naitoh	Patients: 40% Sides: 24.8%	Forward: 48.8% Retromolar: 26.2% Dental: 12.9% Buccolingual: 9.7% Trifid: 2.4%	-
ZHOU ET AL. 2020 (ahead of print)	China	321 patients 642 sides (mean NA, range 8-80 years)	CBCT	Naitoh	Patients: 26.2% Sides: 16.4%	Forward: 40.0% Retromolar: 46.7% Dental: 10.5% Buccolingual: 2.9%	-

BMC = Bifid Mandibular Canal
CBCT = Cone Beam Computed Tomography
CT = Computed Tomography
MC = Mandibular Canal
NA = Not Available

Table III

Mean frequencies of BMCs per geo regions

Geo region	N studies*	Frequency per patients	Frequency per sides
Far East Asia (Japan, South Korea, China, Taiwan, Thailand)	12	10.2 - 64.8%	8.4 - 43.6%
Middle East Asia (Iran, Turkey)	3	40 – 66.5%	24.8 - 46.5%
Europe (Belgium, England)	2	19%§	38%§
Americas (USA, Canada, Brazil)	4	9.8 - 41.1%	7.7%▵

BMC = Bifid Mandibular Canal

*3 studies excluded for this analysis (Yamada et al. 2011, Correr et al. 2013, Choi & Han 2014) since study samples comprised only selected patients

§patient rate is lower than side rate, since the two reported values in this table are from two different studies

▵data only from one study

Table IV

Extension of BMCs (dental canals) to molars as reported using 3D radiography

Authors	N dental canals	Dental canal reaches 1st molar	Dental canal reaches 2nd molar	Dental canal reaches 3rd molar
NAITOH ET AL. 2011	10	-	20%	80%
ORHAN ET AL. 2011	21	38%	5%	57%
KANG ET AL. 2014	9	-	-	100%
ZHANG ET AL. 2018	25	-	16%	84%
OKUMUS & DUMLU 2019	32	47%	19%	34%

BMC = Bifid Mandibular Canal

Table V

Confluence of BMCs (forward canals) as reported using 3D radiography

Authors	N forward canals	Confluence of forward canal with MC
NAITOH ET AL. 2011	68	7.4%
ORHAN ET AL. 2011	86	31.4%
KANG ET AL. 2014	81	11.1%
ZHANG ET AL. 2018	23	43.5%
OKUMUS & DUMLU 2019	121	15.7%

BMC = Bifid Mandibular Canal

Table VI

Mean length (mm) of BMCs as reported using 3D radiography

Authors	N BMCs	All BMCs	Retromolar canals	Dental canals	Forward canals	Buccolingual canals	Comments
NAITOH ET AL. 2009	114	-	14.8[1,2,3] (7.2 – 24.5)	8.9[1] (1.6 – 23)	9.6[2,4] (1.4 – 25)	1.6[3,4] (1.5 – 1.7)	Same superscripts denote statistically significant differences
ORHAN ET AL. 2011	225	13.6 (right sides) 14.1 (left sides)	13.5	8.3	20.1	3.8	-
FU ET AL. 2014	64	10.2 ±4.8 (3.5 – 24.3)	-	-	-	-	Males: 11.5 ±5.7 Females: 8.2 ±2.4 (statistically significant difference)
KANG ET AL. 2014	198	15.0 (2.2 – 38.8)	16.2[1] (2.2 – 33.2)	8.7[1,2,3] (3.1 – 20.9)	14.0[2] (2.6 – 38.8)	16.0[3] (9.4 – 22.3)	Same superscripts denote statistically significant differences
RASHSUREN ET AL. 2014	122	16.9 ±6.8	17.9 ±6.7	10.7 ±3.0[1]	18.9 ±9.3	-	Trifid canals (n=7): 20.1 ±5.8[1] Same superscripts denote statistically significant difference
AFSA & RAHMATI 2017	63	13.6 (3.9 – 48.5)	10.5 (4.1 – 20)	13.6 (4.9 – 26.2)	-	-	Ramus canals: 16.9 (3.9 – 48.5)
ZHANG ET AL. 2018	168	12.6 ±4.9	13.3 ±4.4[1]	10.3 ±5.3[1,2]	12.2 ±5.9[2]	-	Same superscripts denote statistically significant differences
ZHOU ET AL. 2020	105	13.7* (2.6 – 28.8)	-	-	-	-	*Median value Gender did not influence BMC length

BMC = Bifid Mandibular Canal

Table VII

Mean diameter (mm) of BMCs as reported using 3D radiography

Authors	N BMCs	All BMCs	Retromolar canals	Dental canals	Forward canals	Buccolingual canals	Comments
KURIBAYASHI ET AL. 2010	47	1.68 (0.88 – 3.4)	-	-	-	-	Diameter ≥50% of main canal: 49% Diameter <50% of main canal: 51%
DE OLIVEIRA ET AL. 2012	NA	1.5 ±0.2 (1.03 – 3.3)	-	-	-	-	Diameter measured at widest portion of BMC
FU ET AL. 2014	64	0.9 ±0.4 (0.4 – 2.1)	-	-	-	-	Gender or side did not influence BMC diameter
KANG ET AL. 2014	198	1.27 (0.27 – 3.29)	1.36 (0.27 – 3.29)	0.91 (0.64 – 1.29)	1.21 (0.59 – 3.0)	1.14 (0.95 – 1.33)	No statistically significant differences among canal types
RASHSUREN ET AL. 2014	122	2.2 ±0.5	2.2 ±0.5	2.1 ±0.4	1.9 ±0.3	-	Trifid canals (n=7): 2.0 ±0.4 Diameter measured at widest portion of BMC.
AFSA & RAHMATI 2017	63	1.12 (0.4 – 3.6)	1.02 (0.4 – 1.8)	1.0[1] (0.4 – 1.8)	-	-	Ramus canals: 1.42[1] (0.7 -3.6) Same superscripts denote statistically significant difference
SHAH ET AL. 2018	113	-	-	-	-	-	Diameter ≥50% of main canal: 23% Diameter <50% of main canal: 77%
ZHANG ET AL. 2018	168	2.1 ±1.4	2.28[1,2] ±1.29	1.75[1] ±0.53	1.74[2] ±0.68	-	Same superscripts denote statistically significant differences
ZHOU ET AL. 2020	105	*2.26 (1.24 – 5.55)	-	-	-	-	*Median value Gender did not influence BMC diameter

BMC = Bifid Mandibular Canal

NA = Not Available

Table VIII

New classification of BMC (L-Or-Di-Co-T) based on 3D radiography

	Location **Site where BMC arises**	**Or**igin **Structure from which BMC arises**	**Di**rection **Course of BMC**	**Co**nfiguration **Morphology of BMC**	**T**ermination **End of BMC**
1	Ramus	Duplicate mandibular foramen	Superior	Single canal	Joins root apex
2	Retromolar / 3rd molar area	Mandibular canal	Anterior	Branching canal	Rejoins mandibular canal
3	Region of 2nd molar to mental foramen	Other BMC	Inferior	Multiple canals or plexus	Rejoins other BMC
4	Zone anterior to mental foramen	Other structure	Posterior		Buccal or lingual cortical foramen
5			Lateral		Retromolar foramen
6			Medial		Vanishes in bone

BMC = Bifid Mandibular Canal