Review Article

Jawbone Quality Classification in Dental Implant Planning and Placement Studies. A Scoping Review

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Abstract

Aim: Cone beam computed tomography has become an attractive method for implant planning. However, in most cases, not all the information is taken advantage of and often the radiographic evaluation of bone quality is based on subjective assessment by the individual clinician. Therefore, the aim of this study was to examine classifications of bone tissue characteristics and methods for assessing them in dental implant planning and placement studies. **Materials and Methods:** Three databases (Pubmed, Scopus, Web of Science) were searched using specific index terms: "Bone quality, bone quantity, bone density, cone-beam CT and cone-beam computed tomography". Three reviewers selected titles and analyzed abstracts according to inclusion and exclusion criteria. Some descriptions of bone tissue characteristics (bone quality, density, and quantity) used before or during dental implant placement were selected and categorized. **Results:** The search yielded 442 titles. A total of 32 articles were selected and read in full text. Seventeen articles were considered relevant. Different classification systems were found to evaluate bone tissue characteristics as well as different examination protocols. Thirteen publications included in this review reported on bone quality and quantity using the Lekholm and Zarb classification. However, only four studies implemented and/or proposed modifications of the Lekholm and Zarb system. Four other publications described bone quality according to different classification systems such as Misch, University of California Los Angeles (UCLA), or Trisi and Rao. The assessment methods were often briefly described (or not described at all in one publication). Of the articles analyzed, five presented observer performance, whereas three presented diagnostic accuracy of the assessment method. **Conclusion:** Currently, there are different classification systems applied to dental implant planning and placement, particularly regarding whether bone quality or quantity affects treatment outcomes. However, most authors have not validated the diagnostic accuracy and reproducibility of the classification used. Therefore, it is necessary to develop a classification system consistent with characteristics of bone tissue, taking into consideration an adequate description of bone tissue assessment methods, their diagnostic accuracy, and observer performance.

Keywords: *Bone density, bone quality, bone trabeculation, cone-beam computed tomography, dental implants, Lekholm and Zarb classification, maxillary bones*

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Introduction

Adequate bone quality is often a prerequisite for achieving primary and secondary implant stability.[1] However, the concept of bone quality and how it can be assessed remains a matter of debate for the clinician, as bone density varies between different anatomical regions.[2] Different methods have been described to assess bone density, quality, and quantity, such as clinical analysis of bone mineral density at the time of drilling, imaging analysis of bone density by computed tomography (CT), implant insertion torque, resonance frequency analysis, and Periotest®.[3-5]

Currently, cone beam computed tomography (CBCT) has become an attractive method for implant planning. However, in most cases, the information is not fully exploited and often the radiographic evaluation of bone quality is based on subjective assessment of each clinician. Furthermore, CBCT-derived bone morphometric parameters have been validated to standardize the assessment of trabecular structure using histomorphometry, micro-CT, and multi-slice CT.[6-8]

The terms bone density and bone quality have given different classifications to describe the characteristics of bone tissue. The most widely accepted classification in oral implantology was described by Lekholm and Zarb[9] based on preoperative radiographs and exploratory drilling in the preparation of implant bed. This classification has been modified by other authors.[10,11] Likewise, Misch[12] introduced a bone density classification based on tactile sensation during implant placement. Furthermore, considering that trabecular bone varies in structure and the cortex around the surrounding trabecular bone varies in thickness, Lindh *et al.*[13] proposed to evaluate the trabecular pattern in the mandibular region.

Therefore, the objective of this review was to know the different classifications described in literature, in order to evaluate bone quality in dental implant planning.

Materials and Methods

An electronic search was performed, without time or language restrictions until September 2021, in the following databases: PubMed, Web of Science, and Scopus. Bibliographic search used the following terms (MeSH words): "bone quality, bone quantity, bone density, cone-beam CT and cone-beam computed tomography" [Table 1].

Three reviewers (MEG, JJPZ, and NECL) selected studies by independent selection of titles and abstracts from search results, based on the following inclusion and exclusion criteria.

Inclusion criteria

- Studies involving bone quality, quantity, or density
- Studies with imaging methods of bone quality or bone density
- Studies involving a grading method
- *In vivo* studies

Exclusion criteria

- Animal or dental phantom head studies
- Case report studies, book chapters, literature reviews, and consensus
- Local bone reaction (healing) studies
- Temporomandibular joint studies
- Bone grafting studies
- Studies of dental implants for orthodontic treatment
- Studies of patients with drug treatment or any bone pathology (tumor)

Results

A total of 442 articles found in three databases were analyzed. After elimination of duplicates, 288 articles were left for evaluation of titles and abstracts, where 256 articles were excluded because they did not consider any bone density classification. Full texts of 32 articles were analyzed, excluding 17 articles taking into account inclusion and exclusion criteria. Finally, two articles found by manual search were added to the study, obtaining 17 articles for data extraction and interpretation [Figure 1]. A table with main topics related to problem specifications was used in order to standardize data extraction and interpretation [Table 1].

Table 1: Search strategy

Database	Search strategy
Pubmed	("bone quality" OR "bone quantity" OR "bone density") AND ("cone-beam CT" OR "cone-beam computed tomography").
Scopus	((TITLE ("bone quality") OR TITLE ("bone quantity") OR TITLE ("bone density")) AND ((TITLE-ABS-KEY ("cone-beam CT") OR TITLE-ABS-KEY ("cone-beam computed tomography")).
Web of science	(bone quality OR bone quantity OR bone density) AND (cone-beam CT OR cone-beam computed tomography).

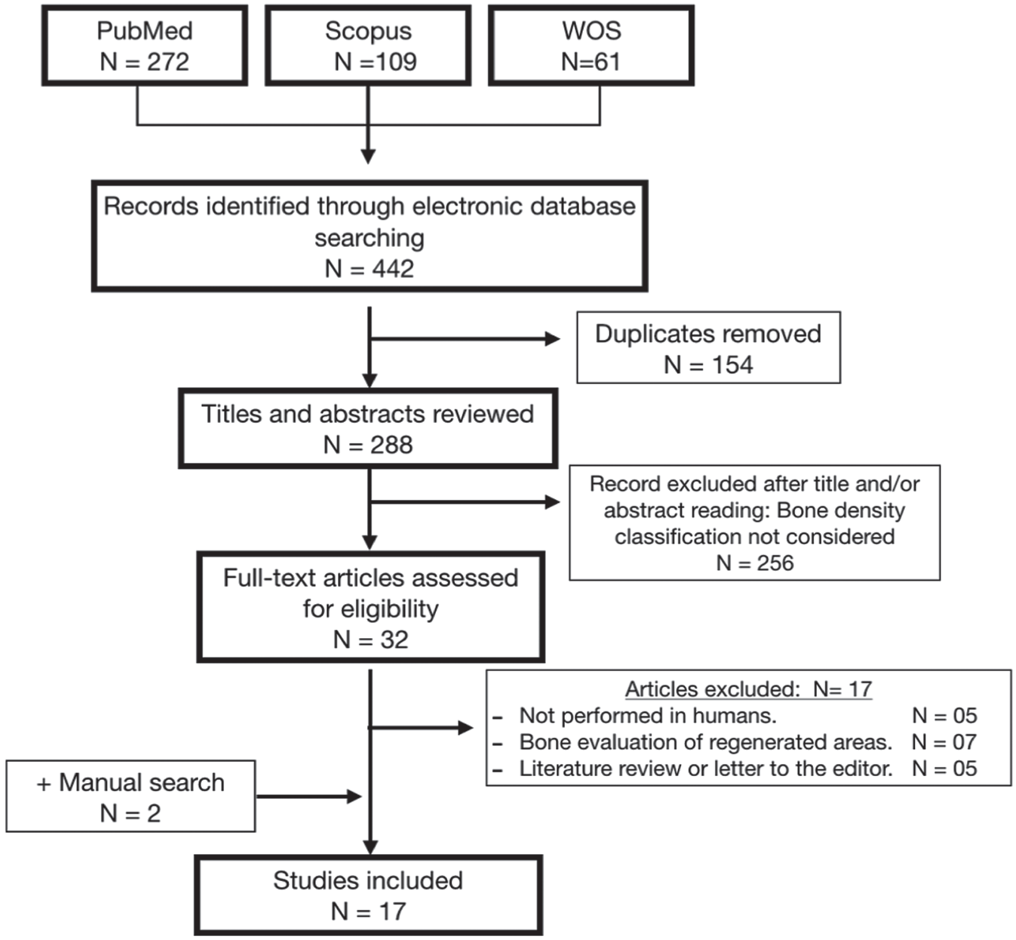

Figure 1: Flowchart of literature search and selection criteria

Different classification systems for bone tissue characteristics and examination protocols were found. Thirteen of included publications reported on bone quality and quantity using the Lekholm and Zarb classification and three studies implemented and/or proposed modifications of this classification. Four publications described bone quality according to different classification systems such as Misch, University of California Los Angeles (UCLA), or Trisi and Rao. The assessment methods were often described only briefly or not at all in one of the reviewed publications. Of articles analyzed, five presented performance of the observers, whereas three presented the diagnostic accuracy of the assessment method [Table 2].

Discussion

In this review, articles focused on determining the diagnostic methods used for evaluation prior to dental implant placement were included. This resulted in the exclusion of studies dealing with case reports, literature reviews, consensus, bone grafts, implants for orthodontic treatment, and patients with drug treatment or with any pathology (tumor), and studies performed in animals. Likewise, studies in human cadavers were included, as they are already used to validate clinical evaluation methods of bone tissue. In addition, in order to ensure retrieval of the largest number of publications, the search strategies included three databases: PubMed, Scopus, and Web of Science.

There are different subjective classification proposals and diagnostic methods to evaluate bone quality prior to dental implant placement. However, these methods do not present a standardized follow-up nor have they been validated as prognostic tests.[30] In this review, it could be appreciated that classification systems for dental implant planning and placement are necessary to provide an orderly, applicable, and scientific scheme for diagnostic purposes.[31-33] In that sense, the included studies presented a diversity of classification systems and units of measurement. It should be noted that the reliability of methods used and the evaluation of maxillary bone tissue were reported in only three publications.[11,21,28] In addition, the classification proposed by Lekholm and Zarb[9] was referred in most

Table 2: Clinical methods to assess bone density, bone quality, and bone quantity prior to dental implant placement

Author (year)	Sample/jaw/site	Reference method: Classification of bone tissue/measure unit	Measure to describe results	Statistical test/results according to the authors
Lee *et al.*[14] (2007)	42 implant sites Human cadaver jaws	• Subjective drilling density rating (Misch classification) • Subjective radiographic bone density assessment (Lekholm and Zarb classification) • Trisi and Rao classification HU (CT and CBCT)	• Subjective drilling resistance correlated to subjective radiographic density evaluation	Spearman´s correlation: • (r = 0.53, P < .001)
Wakimoto *et al.*[15] (2012)	33 patients 33 implant sites	• Lekholm and Zarb classification • UCLA classification HU—ROI (CT)	• Trabecular bone density between males and females • Correlation between morphology and bone quality	Steel– Dwass test • Female patients had lower bone densities than male patients (P < .001) • Not statistically significant differences (P < .05)
Fuster-Torres *et al.*[16] (2011)	22 patients 82 implant sites	• Lekholm and Zarb classification • Lekholm and Zarb classification as reviewed by Norton and Gamble HU (CBCT), ITV, RFA (ISQ)	Correlation between bone density, ITV, and ISQ values	• Bone density and ITV (anterior mandibular; r = 0.562, P < .05) • Bone density and ISQ (men; r = 0.412, P < .05)
Salimov *et al.*[17] (2014)	17 patients 65 implant sites (44 maxillary sites and 21 mandibular sites)	• Subjective radiographic bone density assessment (Lekholm and Zarb classification) HU (CBCT), ITV, RFA (ISQ)	Correlation between • Bone density and ITV • Bone density and ISQ	Spearman's correlation: • (r = 0.935, P < .001) • (r = 0.888, P < .001)
Arisan *et al.*[18] (2013)	11 patients 18 edentulous jaws 108 implant sites (64 maxillary sites and 44 mandibular sites)	• Lekholm and Zarb classification • Lekholm and Zarb classification as reviewed by Norton and Gamble HU (CT), VV (CBCT), ITV, RFA (ISQ)	• Gray density value between CBCT and CT • Gray density value and ITV (CT) • Gray density value and ITV (CBCT) • Gray density value and RFA (CT) • Gray density value and RFA (CBCT)	Kruskal–Wallis test • (P = .00012) Multiple regression model • Adjusted r^2 = 0.6142, P = .001 • Adjusted r^2 = 0.5166, P = .0021 • Adjusted r^2 = 0.5642, P = .0017 • Adjusted r^2 = 0.5423, P = .0031
Hao *et al.*[19] (2014)	128 patients 236 implant sites (14 anterior mandibular sites, 29 anterior maxillary sites, 115 posterior mandibular sites, and 78 posterior maxillary sites)	• Lekholm and Zarb classification • Proposed classification: Group 1: D1, Group 2: D2 and D3, and Group 3: D4 HU (CBCT)	• Bone density in different regions of the jaws • Classified the bone in all sites	• Mann–Whitney U-test (P < .001) • Group 1: 8.9%, Group 2: 74.15%, and Group 3: 16.95%
Tatli *et al.*[20] (2014)	23 patients 77 implant sites (44 maxillary sites and 33 mandibular sites)	• Lekholm and Zarb classification (type 1, type 2, and type 3) (CBCT), ITV, RFA (ISQ)	Correlation between: • Bone density and ISQ • ITV and ISQ	Spearman's correlation: • (r = -0.470, P < .001) • (r = -0.456, P < .001) Negative correlation

Table 2: Continued

Author (year)	Sample/jaw/site	Reference method: Classification of bone tissue/measure unit	Measure to describe results	Statistical test/results according to the authors
Cortes *et al.*[21] (2015)	25 patients 31 implant sites	ROI (CBCT) DXA, micro-CT, histology	• Insertion torque • Thickness of the alveolar osseous ridge • Histomorphometry of the implant area: (bone volume [BV]/total volume [TV]) × 100%	Conditional logistic regression Odds ratio/BV/TV ($r = 0.817$, $P = .001$ and $r = 0.795$, $P = .001$, respectively) Alveolar bone crest was significantly associated with maximum insertion torque ($P < .05$). MCW and radiographic bone density from CBCT were not significantly associated with peak insertion torque ($P > .05$)
Kamigaki *et al.*[22] (2017)	Maxillary first molar region of 91 cadavers 46 males and 45 females	• Lekholm and Zarb classification • Proposed classification: S1, S2, and S3 ROI (CBCT–CT)	Correlation between: • Right and left bone structure and density • Bone density between males and females	Student´s test • Not statistically significant difference • Male patients had higher bone densities than female patients ($P < .01$)
Alkhader *et al.*[23] (2017)	210 patients 436 posterior mandibular implant sites	• Subjective radiographic bone density assessment (Lekholm and Zarb classification) HU (CBCT)	• Overall percentage between two observers • CBCT as a predictor of high-density sites • CBCT as a predictor of intermediate density sites • The best cutoff value for intensity to predict intermediate density • The best cutoff value for intensity to predict high density	• Kappa statistics = 0.50, $P < .005$ ROC curve analysis • AUC = 0.94, $P < .005$ • AUC = 0.81, $P < .005$ • 218 (sensitivity = 0.77 and specificity = 0.76) • 403 (sensitivity = 0.93 and specificity = 0.77)
Al-Ekrish *et al.*[11] (2018)	47 images	• Lekholm and Zarb classification • Proposed classification: added three new classes (types 2b, 2c, and 3b) ROI (CBCT–CT)	Three examiners: A prosthodontic and two oral and maxillofacial radiologists • Intraobserver agreement	Kappa statistics: Intraobserver agreement: Prosthodontic (0.749) and radiologist (0.738, 0.747) After calibration: Prosthodontic (0.835) and radiologist (0.898, 0.919)
Dahiya *et al.*[24] (2018)	200 patients 352 posterior mandibular implant sites	• Lekholm and Zarb classification HU (CBCT)	Reliability of preoperative bone density of mandibular posterior region for implant placement using CT-derived bone densities in HUs	ROC analysis CBCT intensity values had a high predictive power for predicting both high-density and intermediate-density sites ($P < .005$)
Nicolielo *et al.*[25] (2018)	25 human cadaver mandibles	• Lekholm and Zarb classification Morphometric 3D (CBCT)	• Four examiners: dentomaxillofacial radiologists • Evaluation of three-dimensional classes of trabecular pattern: sparse, intermediate, and dense	Kappa statistics: • Interobserver agreement 0.25. Test–retest agreement 0.46 • Statistically significant differences ($P < .05$)
Rajaraman *et al.*[26] (2018)	35 images	• Bone density classification by Misch HU (CBCT), GSV (CBCT)	• Correlation of HU and GSV • Clinician's interpretation about bone quality • GSVs at coronal sites • GSVs at apical sites	Kruskal–Wallis test between three groups • Statistically significant differences ($P < .05$)

Table 2: Continued

Author (year)	Sample/jaw/site	Reference method: Classification of bone tissue/measure unit	Measure to describe results	Statistical test/results according to the authors
Eskandarloo *et al.*[27] (2019)	22 patients 100 implant sites (48 maxillary and 52 mandibular sites)	• Lekholm and Zarb classification ROI (CBCT)	• Correlation between bone loss and bone quality • Interobserver agreement for bone quality between two observers • Intraexaminer correlation for bone density	• Not statistically significant differences ($P < .05$) • Kappa statistics: Interobserver agreement 52% • 0.99 = high reproducibility
Sorkhabi *et al.*[28] (2019)	83 patients 207 areas	Misch alveolar bone density classification GSV (CBCT), CNN	• Evaluation of alveolar bone density was performed by CNN at the CBCT images: Hexagonal prism, and cylindrical, cubical, and rectangular voxels	High precision: Hexagonal prism voxel: 84.6 %. Cylindrical voxel: 95.2%. Low precision: Cube and rectangular voxel
Al-Jamal *et al.*[29] (2021)	16 patients 40 implant sites	• Lekholm and Zarb classification • Misch classification ROI (CBCT), ITV, IST	• Correlation between bone density, primary stability, and ITV Pearson correlation coefficient (r)	• Bone density—Primary stability IST ($r = 0.746$, $P < .001$) • Bone density—ITV ($r = 0.610$, $P < .001$) • Primary stability IST—ITV ($r = 0.610$, $P < .001$)

CT = computed tomography, CBCT = cone beam computed tomography, DXA = dual-energy x-ray absorptiometry, HU = Hounsfield unit, ITV = insertion torque value, VV = voxel value, RFA = resonance frequency analysis, ROI = region of interest, ISQ = implant stability quantized, IST = implant stability meter device, CNN = Convolutional Neural Network, ROC = receiver operating characteristic, AUC = area under the curve, GSV = grayscale value, MCW = mandibular cortical width, UCLA = University of California Los Angeles

of reviewed studies, although it has not been previously validated.[11,14-20,22-25,27,29] This classification takes into account bone quality, according to the amount of cortical (compact) and trabecular (cancellous) bone, and determines Type I: completely homogeneous compact bone, Type II: thick layer of compact bone surrounding dense trabecular bone, Type III: thin layer of compact bone surrounding dense trabecular bone, and Type IV: thin layer of compact bone surrounding sparse trabecular bone. This classification is advantageous because it provides preoperative information that can be used in treatment planning. However, it is subjective and unspecific, with many overlaps between its various types.[11,25,27,29] Another classification used in the evaluated researches was that proposed by Misch,[12] based on tactile sensation during implant bed preparation and divided into four classes (D1 bone type: hardness similar to maple or oak wood, D2 bone type: hardness similar to white pine or spruce wood, D3 bone type: hardness similar to balsa wood, and D4 bone type: hardness similar to polystyrene foam), being also a subjective classification.[14,26,28,29] In order to improve the predictability and reproducibility of different classifications, some researches have proposed modifications adding or proposing new classes in relation to density level, use of artificial intelligence, or equivalence between Hounsfield units (HUs) and gray scale.[11,19,23,28] In spite of these efforts, some characteristics have not yet been considered and are important to analyze, such as quantity, visibility of trabeculae, and size of the medullary spaces. On the other hand, considering that the combination of bone density and trabecular architecture parameters can predict implant stability with greater certainty,[33,34] it would be important to include them for future proposals. The only research that tried to include in its proposal the density, quantity of trabeculae, and width of medullary spaces was that of Kamigaki *et al.*[22] However, they only used images at the maxillary first molar level and did not include other areas of the maxilla or mandible.

In this review, CBCT was the most commonly used auxiliary examination for diagnostic evaluation of planned dental implant sites. In addition, different authors have sought to compare the HUs of CT with the gray scale of CBCT in order to examine bone density[14,18,26] and to establish quantitative parameters of bone quality based on the HU value[18] using these values to measure bone density.[13,14,16,24] It is important to note that subjective assessment through CBCT is routinely performed for bone quality diagnosis.[20,22,23,27,29,35] On the other hand, Nicolielo *et al.*[25] used an automatic computer-assisted method to aid in the classification of trabecular bone pattern based on three-dimensional morphometric parameters derived from CBCT images of alveolar regions. This computer-based process showed twice the accuracy in trabecular bone pattern prediction compared to a visual classification performed by specialized oral radiologists. Computer-assisted structural pattern recognition applications are already often used in clinical radiology applications, breast tumor diagnosis, and cardiovascular diseases.[36,37] Comparing machine learning expertise with a radiologist, either through an imaging platform, could help predict bone quality, increasing the expected outcomes of implant treatment and reducing the cost of multiple expert diagnostic opinions. As a result, some studies have proposed the use of new classifications to determine bone quality.[11,19,22,23] In addition, a new approach has been sought to classify them morphologically, proposing the use of convolutional neural networks from volumetric CBCT data.[28] In this sense, it has been observed that artificial intelligence techniques are being widely explored in the field of dental radiology and maxillofacial surgery, with favorable findings.[38]

Despite the clear advantage of computer-assisted classifications, there are also some limitations. The latter require a gold standard of predictor variables to accurately classify groups. Currently, there is no objective gold standard for bone quality type. Most authors opt for a classification generated by combined expert responses, which can serve as a reasonable reference standard.[39,40] In this review, only five publications took into account the observer performance,[11,23-25,27] and in two of them, even intra- and interobserver concordance was assessed.[11,27]

Bone mineral density is also an important parameter in determining bone strength and bone quality. Some of the reviewed studies correlated insertion torque with bone density, obtaining different results. For example, one study reported that correlation was moderate,[14] whereas others reported a significantly good correlation.[16-18,20,29] Only one study used dual X-ray absorptiometry, micro-CT, and histology in order to predict insertion torque.[21] On the other hand, assessing the relationship between resonance frequency analysis and bone density obtained a significant relationship.[16-18,20,29] Finally, since there are several variables related to bone structure and quantity, future work is needed to establish their direct clinical impact on the implant treatment outcome.

The main limitation of this scoping review is that most of the studies reviewed did not perform an analysis of internal and external consistencies of the classifications they used for assessment of bone quality. Therefore, validity and reliability of the most commonly used classifications could not be discussed in depth. In addition, the sample size of analyzed groups was unequal in reference to the distribution of bone zones, finding predisposition for posterior zones. Therefore, most studies were based on the group size instead of analyzing similar groups. Studies with larger sample sizes are recommended and may help to overcome this problem.

In light of what has been explored in the available literature, it is advisable to implement standardized and validated methods of bone tissue quality evaluation and classification, analyzing their precision and reproducibility, to determine a reference method in which the quantity, visibility of the trabeculae, and size of the medullary spaces can be accurately assessed. Having a more precise knowledge of bone quality at the site planned for implant placement will allow us to perform more predictable treatments with fewer complications, in addition to allowing validations in future classification proposals.

Conclusion

Within the scope of this review, it can be concluded that there are different classification systems applied to dental implant planning and placement, in order to determine whether bone quality or quantity affects treatment results. It is necessary to propose a coherent classification system capable of eliminating subjectivity in trabecular pattern evaluation using computer-assisted image processing and categorization by bone morphometric parameters.

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Conflicts of interest

None to declare.

Authors contributions

JJPZ conceived the research idea; JJPZ, NECL, CFCR, LACG, and MEG elaborated the manuscript; NECL and JJPZ collected and tabulated the information; JCRD and MEG carried out the bibliographic search; CFCR, JJPZ, and NECL interpreted the results and helped in the development from the discussion; and JJPZ, NECL, JCRD, CFCR, LACG, and MEG performed the critical revision of the manuscript. All authors approved the final version of the manuscript.

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Patient declaration of consent

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Data availability statement

Not applicable.

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