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Osteoarthritis at Roonka, Australia: A Local Biology

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ABSTRACT

Objectives: Osteoarthritis (OA) is described as an inevitable part of aging. Palaeopathological studies can challenge such ideas of universal biology. OA from the Australian Aboriginal site of Roonka is analyzed to test whether expectations from contemporary, ethnohistorical, and archeological data are held or whether OA at this place was distinctly different.

Materials and Methods: Human remains from Roonka, South Australia, date to the Holocene and are divisible into early and late periods. A total of 83 adults was analyzed. OA was defined using the criteria of Waldron and Rogers (1995). Analysis used both univariate and quasi-Poisson regression analysis.

Results: Very few joints had evidence of OA except for the TMJ (28.8%). OA was concentrated on the upper body. Lower body OA was observed only in individuals with prior injury or disease. Comparison with human remains from along the Murray River indicates a similar pattern of joints affected but spatial diversity between the upper and lower Murray River.

Discussion: The pattern of OA observed at Roonka corresponds with contemporary records of age development. However, epidemiological patterns were distinctly different. Except for people with prior injury or disease, OA was not prevalent. The comparison of Roonka with archeological samples demonstrates diversity during the Holocene and does not correspond to expectations of increasingly heavier workloads over time. The lack of concordance between the pattern of OA among people at Roonka and expectations based on other data reflects how embodied experiences of the condition are contingent on local entanglements of biology and culture.

1 | Introduction

Osteoarthritis (OA) is a disease causing the breakdown of articular surfaces within synovial joints. It is set apart from other forms of joint degeneration or arthritis by an inflammatory and reparative response within affected joints (Molnar et al. 2011; Berenbaum 2013; Rogers and Waldron (1995); Waldron 2019). The condition is found at varying levels of prevalence in virtually all modern communities and most collections of archeological human remains. Given its contemporary significance as an increasing cause of disability, particularly among older adults, bioarchaeological studies of the patterns of osteoarthritis and degenerative joint changes are important in untangling the relationships between intrinsic and extrinsic factors. These studies help test ideas of osteoarthritis (particularly of the hip and knee) as an inevitable evolutionary trade-off with bipedalism (e.g., Yavuzer 2020) or, alternatively, a contemporary consequence of obesity (e.g., Raud et al. 2020).

In this paper we analyze the presence and severity of OA in the non-vertebral joints among Aboriginal human remains from Roonka, South Australia. Roonka provides a unique opportunity to assess whether osteoarthritis experienced in this locale is consistent with expectations derived from clinical, ethnohistoric, and archeological data or is indicative of a local biology, a condition which is the product of a particular ecological,

Summary

- Osteoarthritis (OA) was rare among Aboriginal people from Roonka, Australia, prior to European contact.
- Conditions like OA are local biologies: they are created and experienced as the result of local interactions between biology and culture.

economic, and cultural setting in which disease has developed and is experienced (Lock 2017).

Our paper tests hypotheses of osteoarthritis distribution and prevalence derived from these sources of data. While the clinical data are largely from Western settings, the archeological and ethnohistoric data are from hunter-gatherer populations, particularly Australian sources. We first review these sources of data before testing hypotheses generated from that review.

1.1 | Osteoarthritis and Joint Degeneration: Contemporary and Past Epidemiology

A variety of intrinsic and extrinsic factors contribute to individual variation in OA. Commonly considered intrinsic factors include age, sex, and genetic predisposition, while extrinsic factors include systemic risk, joint loading, and environment (Bridges 1991; Cheverko and Bartelink 2017; Dommett et al. 2017; Felson et al. 2000; Gilmour et al. 2015; Johnson and Hunter 2014; Nevitt et al. 2001; Schrader 2019; Waldron 2019; Waldron and Willoughby 2016; Weiss and Jurmain 2007).

While all OA is shown to be exacerbated with age, age itself is not a direct mechanism (Calce et al. 2018). Instead, age-related changes to joint tissue and function increase susceptibility, as does prior injury (Calce et al. 2018; Johnson and Hunter 2014). Rossignol et al. (2003) and Seok et al. (2017) examined OA in reference to career categories and found there are differences in distributions of OA between individuals with physically demanding careers and those with more sedentary careers, with oft-cited studies demonstrating the higher prevalence of hip OA in farmers (Croft et al. 1992; Thelin et al. 2004). The observation, based on modern clinical studies, is that osteoarthritis typically begins in the late 40s to mid-50s, with one study estimating that 30.5% of the world's population aged 55 years and over experienced the condition in 2021 (Steinmetz et al. 2023).

The prevalence and distribution of OA is differentiated by sex. Globally, women have a higher prevalence compared to men. A WHO study suggests that women account for 60% of OA cases, with the disparity especially true for the knee and hand. These differences become clearer after 40 years of age, with women tending to have more severe disease (Cui et al. 2021; Segal et al. 2024). The reasons for the disparity are still debated. When comparing OA by sex, estrogen is the most investigated hormonal influence (Peshkova et al. 2022; Roman-Blas et al. 2009; Stevens-Lapsley and Kohrt 2010). Specifically, the decrease of estrogen with menopause and the relationship this has with lowered bone density and muscle loss is thought to directly influence OA development in aging women (Peshkova et al. 2022). However, cellular differences, anatomical and biomechanical factors (such as lower limb alignment), susceptibility to injury (particularly knee injury), lesser muscular strength (particularly of the quadriceps muscle), and obesity have all been implicated in studies of the greater prevalence among women (Segal et al. 2024; Tschon et al. 2021). In modern, largely western clinical settings, the knee, hands, and hip are the most common areas affected by OA (Anderson and Loeser 2010; Long et al. 2022), with a detailed U.K. study of 500 patients showing a roughly equal sex distribution in the knee, a strong female preponderance in the hand, and a male preponderance in the hip. Furthermore, women were more likely to have two or more joint sites affected: 58.8% of women compared to 38% of males (Cushnaghan and Dieppe 1991).

Overall, Aboriginal Australians are 1.2 to 1.5 times more likely to have OA than non-Aboriginal Australians (Australian Institute of Health and Welfare 2018). This serious problem is compounded by comorbidities. More than 50% of Indigenous adults over age 35 years have at least one chronic disease, and in Australia, this increases to 90% of adults aged 55 years and over (O'Brien et al. 2021).

1.2 | Archeological Interpretations of Osteoarthritis

The mid-20th century saw renewed interest in hunting-gathering societies, and along with that came a focus on division of labor and economy, especially compared to sedentary societies (Guenther 2007). A linked assumption is that hunting-gathering and agricultural economies were associated with distinctive patterns of labor and skeletal health. However, as Bridges (1991) discusses, while there are some similarities in where OA is most likely to appear, such as the knee, elbow, and shoulder, there is no distinctive pattern that characterizes either hunter-gatherer or sedentary societies (Bridges 1991; Larsen and Kelly 1995). In fact, synthetic analyses are contradictory, with some authors arguing for higher rates of OA among foragers (Larsen 1982; Jurmain 1990), while others argue for lower rates compared to agriculturalists (Steckel and Kjellström 2018). Recent studies within particular regions have pointed to variability between populations despite cultural continuity (Lieverse et al. 2016), but also the potential for major changes in osteoarthritis in the context of colonialism (Klaus et al. 2009).

In two Australian studies, bioarchaeological evidence of OA (Webb 1984) and bone geometric properties indicating skeletal robusticity (Hill et al. 2019, 2020) are interpreted to suggest most repetitive strains are linked to subsistence activities using the jaw and upper limbs. Webb's survey of Pleistocene and Holocene human remains across Australia suggested that OA affected elbows more than knees, males more than females, and Murray River people more than anyone else (Webb 1995, 135). OA of the temporo-mandibular joint (TMJ) is also very frequent among people along the Murray. These signs are tied to an argument of higher population density along the Murray and intensification of subsistence activity particularly in the late Holocene. Hill et al. (2019) argue for greater reliance on women's labor in these communities because of the reliability of their gathering and small game hunting compared to men's big game hunting. This is argued to be especially evident in a fluctuating environment after the mid-Holocene, leading to an expectation that women's workloads increased not as a result of increased sedentism and population density but due to increased mobility and environmental stressors.

1.3 | Ethnohistorical Observations and Osteoarthritis

Although archeology creates one set of expectations regarding division of labor for OA, ethnohistoric studies are another source. In the Roonka region, an important source of information is the writing of Edward Eyre (1845), who traveled throughout South Australia in the mid-19th century and was the Protector of the Aborigines in charge of a station at Moorunde (c20 km south of Roonka) in 1844.

As one of many Murray River peoples (Eyre 1845; Broome 2017; Littleton et al. 2021), those at Roonka were primarily involved with subsistence activities like fishing, foraging, and trapping, and associated net and tool creation, along with some large game hunting (Eyre 1845; Broome 2017). While Eyre is descriptive of men's roles and comments that they are more involved in social and political affairs, women were observed at a distance (Eyre 1845). They are portrayed as carrying out gathering activities and associated tool creation, along with most childcare (Eyre 1845). Women often went out of their way to avoid Eyre, often running away at his approach. While there are cultural reasons behind this (Bell 1981), it limited Eyre's observations of women's activities. Eyre acknowledged that men and women often created nets or fished together, though roles sometimes differed.

Within his descriptions of women, Eyre also points out that women were often more abused and emaciated than men. Violence against women seemed common, and women were often overworked while providing for men within their community (Eyre 1845; Spencer and Gillen 1899). We note, however, that these descriptions were made in the context of European colonization, and the widespread illness, displacement, and disruptions to socio-cultural organization that occurred (Ladner 2009; Dowling 1990, 2021). In general, these data suggest that there will be sex differences in OA, with women experiencing more habitually strenuous workloads and potentially earlier onset.

1.4 | Hypotheses

Based on the contemporary, historical, and archeological data, it is possible to derive a set of hypotheses against which the analysis of Roonka may be tested.

Hypothesis 1. *OA will be common increasing with age particularly after mid-40–50 years.*

Hypothesis 2. *Hand, knee and hip will be the most affected joints.*

Hypothesis 3. *Sex-specific patterns of distribution will be visible (females with hands, males with hips).*

Hypothesis 4. *If the current population figures represent potential risk, then OA will have been a significant source of disability for past Aboriginal people.*

Hypothesis 5. *Rates of OA at Roonka will, like the rest of the Murray River, be higher than elsewhere on the continent.*

Hypothesis 6. *These rates of osteoarthritis will have increased in the late Holocene, particularly among women.*

Our goal is to explore the extent to which osteoarthritis is the product of local biological, cultural, and ecological circumstances (i.e., a local biology) as opposed to generalized narratives of osteoarthritis as an evolutionary consequence or solely as a product of economic circumstances (whether patterns of subsistence or contemporary obesity).

2 | Materials and Methods

2.1 | Roonka

Roonka is a large Aboriginal burial ground adjacent to the Murray River in South Australia (Figure 1). The Murray River is Australia's longest river (2500 km) flowing from the Snowy Mountains in the east to the Southern Ocean. Across its course, the river moves from an area of higher rainfall in the Highlands to a drier semi-arid region on the plains. The supply of water (from regular snowmelt) and its associated resources meant that the river sustained high populations relative to other inland areas on the continent even during the climatic fluctuations associated with the mid-Holocene. The contrast between the river and surrounding drier country has defined the Murray River as a distinct region that maintained high levels of linguistic diversity. Archeological and bioarchaeological analyses have tended to emphasize the shared riverine economy and associated population density in contrast to other regions of the continent (Littleton et al. 2021; Pardoe 2006).

In response to extensive erosion and exposure of human remains, Roonka was excavated in the 1960s to 1970s by Graeme Pretty and volunteers from the South Australian Museum. The approximately 216 burials date from c.8500 cal. BP to the early postcontact period, c.1840–1860 CE (Littleton et al. 2024). The extensive records and the remains have been held at the South Australian Museum. In collaboration with the River Murray and Mallee Aboriginal Corporation, we began a research project to fully investigate the bioarcheology of the site in 2014. Our overarching focus is on how to make sense of these sorts of low intensity yet significant sites through interpretation of adaptation to the Holocene riverine environment.

Early use of the site for burial was very intermittent, although demonstrating a consistent patterning of burial styles. However, use of the locale for burials increased from c5000 BP on. There is a discontinuity in site formation between 4290 and 1920 cal. BP, but use of the site persists until European takeover and subsequent decimation of Aboriginal populations. Patterns of osteoarthritis are assessed for the entire sample (except for the postcontact individuals) and then temporal change in the burden of osteoarthritis is tested through the comparison of the early-middle Holocene burials (Phases A and B, c8000-5000 cal. BP, $n = 18$) with the late Holocene burials (c 1920 cal. BP to c1840 CE $n = 45$).

2.2 | Methods

Ethical clearance was obtained from the University of Auckland Human Participants Ethics Committee (2014/01031). Research is also governed by a written research agreement between the Roonka Research Project and the River Murray and Malle Aboriginal Corporation.

Recording of grades of OA in the non-vertebral joints was based on Rogers and Waldron (1995). Detailed criteria for scoring OA are provided in Table 1. Scores were recorded based upon the extent of lipping associated with marginal osteophytosis, evidence of surface bone deposits and porosity on the joint surface, evidence of extensive spicules and/or size of surface osteophytes, and the extent of surface porosity indicating subchondral erosion (Figure 2). While ankylosis was included as a grade of OA, it was not observed in the Roonka remains. Our descriptive analysis focuses on individuals with either evidence of eburnation or evidence of subchondral erosion and marginal osteophytosis (i.e., Scores 2 and above) (Rogers and Waldron 1995; Waldron 2019).

The single exception was the temporo-mandibular joint (TMJ) which, based on the work by Rando and Waldron (2012), was recorded as positive for osteoarthritis if any two of the four indicators were present: osteophytosis, subchondral porosity, eburnation, and/or joint surface flattening (Figure 2d). However, all observations including marginal osteophytosis were included in the multivariate analyses (described below).

Apart from the radial notch on the ulna, each joint surface was recorded if more than 50% of the surface was visible. Joint surfaces were combined into the major joints for this study (Table 1). The proximal fibula was not included in the knee joint. Wrist-hand and ankle-foot joints were combined, given the variable preservation of these smaller bones.

Sex was recorded whenever possible based upon the morphology of the os coxae (Buikstra and Ubelaker 1994). In the absence of the pelvis, sex was assessed from the cranium using Brown's modification of the Larnach and Freedman scoring system for Southeastern Australian remains (Brown 1981). Age was assigned where possible to one of three categories: young adults (c20–35 years), middle adults (35–50 years) and older adults (50+years). This was done using multiple methods: pubic symphyseal aging (Brooks and Suchey 1990), epiphyseal closure (Scheuer and Black 2004), sacroauricular aging

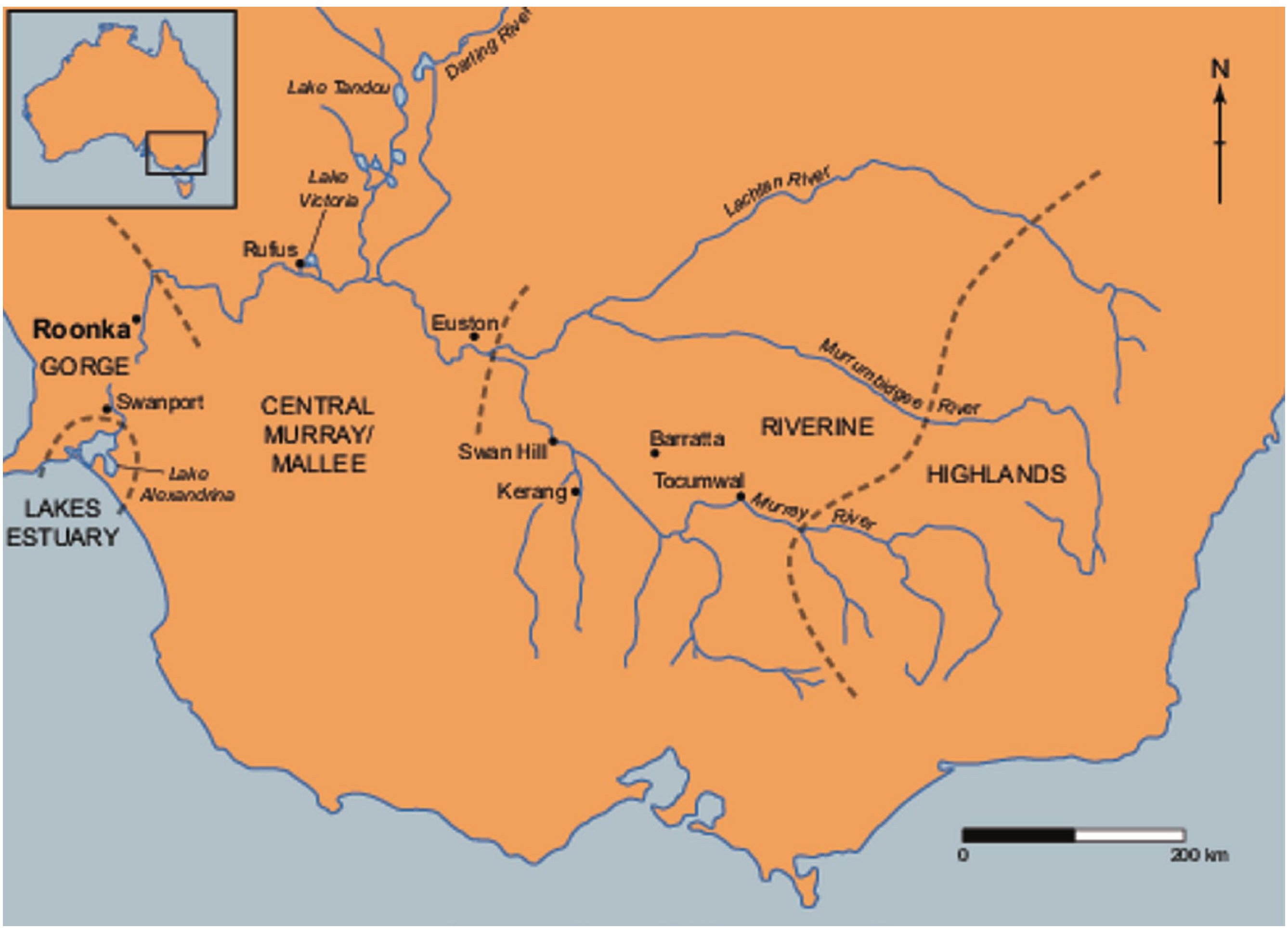

FIGURE 1 | Map of the Murray River in Southeastern Australia showing locations referred to in this paper. Dashed lines indicate the regional distinctions used by Webb (1995).

TABLE 1 | Criteria for non-vertebral osteoarthritis severity indicator score at Roonka and definitions of compound joints used in the current study.

	Criteria
Indicator score	
0	No evidence of joint change
1	Osteophytic lipping (> 2 mm) or slight surface bone deposits and/or porosity* on less than 10% of the joint surface
2	Two of the following: new bone formation and lipping (> 2 mm) with sharp ridge, extensive spicules, and/or very large surface osteophytes; surface porosity* pinpointed or coalesced; 50% or less of the joint surface affected.
3	Eburnation OR two of the following: lipping (> 2 mm) with sharp ridge, extensive spicules, and/or very large surface osteophytes; surface porosity* pinpointed or coalesced; more than 50% of the surface affected.
4	Ankylosis
	*Distinguished from postmortem damage due to evidence of sclerosis at the margins, undercut edges, scooped floor.
Compound joint	
Temporomandibular joint	Articular tubercle and mandibular fossa of temporal bone, mandibular condyle.
Sternoclavicular	Sternum and Medial Clavicle
Shoulder	Acromioclavicular Joint and Glenohumeral Joint
Elbow flexion & extension	Humeroulnar Joint and Humeroradial Joint
Elbow pronation & supination	Proximal Radioulnar Joint
Wrist-hand	Distal radius, Distal Ulna, Carpals, Metacarpals and Phalanges
Hip	Acetabulum and Femoral Head
Knee	Tibiofemoral Joint and Patellofemoral Joint
Ankle-foot	Distal Tibia, Distal Fibula, Talus, Calcaneus, Tarsals, Metatarsals, and Phalanges

(Lovejoy et al. 1985), and cranial suture closure (Meindl and Lovejoy 1985). Priority was given to the os coxae observations, but partial preservation meant that at times only the cranium remained.

Descriptive statistics were calculated in R (4.2.0) with non-parametric comparisons undertaken when necessary. Except when comparing with Webb's data (see below), the denominator of any joint frequencies was the minimum number of observable joints (i.e., a joint was included if at least one surface was observable). The OA score was the maximum score of the observable surfaces of a joint. While this method is transparent and common in analyses of OA, it is also a minimum estimate since it effectively assumes that the missing joint surfaces were not osteoarthritic (Waldron 2017). It does make within-sample comparisons clear since there is no evidence of systematic biases in preservation among the adult individuals at the site. However, the more observable joint surfaces preserved, the more likely it is that OA will be recorded. Therefore, in conjunction with descriptive analyses, we used quasi-Poisson regression, part of the general linear model function in R (4.2.0), to assess individual variation in the number of joint surfaces with evidence of OA, adjusted for the total number of observable surfaces. This included separate analyses for individuals with each available surface scored as 1 or more (includes possible indications of OA) and 2 or more (only clear signs of OA) for a given anatomical grouping. Analyses using scores of 1 and above were undertaken because those with clear evidence of OA were also more likely to have additional surfaces affected by minor indications, and the patterning among lesions was identical regardless of severity. Analyses of joint surface groupings were hierarchical, beginning with all non-vertebral joint surfaces, then total upper limb surfaces, total lower limb surfaces including hip, and then just shoulder, elbow, wrist-hand, hip, knee, or ankle-foot.

Quasi-Poisson regression was selected because counts of affected joints cannot be assumed to be completely independent. The approach adopted adjusts estimates of dispersion to avoid underestimation of covariate or predictor standard errors. The number of observable surfaces for a given anatomical category per individual was used as a covariate in all models. We also included sex and age categories as predictors. Multiple regression analyses reported here exclude four post-contact individuals because of potential changes in lifestyle (though analyses with and without these individuals were similar). Period (early, late and unknown) is not reported as a predictor in regression analyses below as it consistently was not statistically significantly associated with counts of joint surfaces when the covariate and predictors described above were included in various models.

Comparison with other data sets is complicated by inter-observer variation in scoring as well as the nature of those data. Nevertheless, such comparisons are necessary for any regional analyses. Webb (1984, 1995) relied upon collected museum samples. Most were undated but assumed, based on condition, to be Holocene in date. Remains from the Pleistocene were dealt with separately, and obvious postcontact remains were also removed. Based on Webb's (1984) method, it appears that his recording of chronic OA (as opposed to osteophytosis) is equivalent to the recording used here (i.e., a score of 2+). Webb analyzed OA of the TMJ, elbow, and knee. Because the human remains his work

FIGURE 2 | Recording of osteoarthritic changes on Roonka remains. (A) Marginal lipping; (B) marginal lipping and subchrondral erosion; (C) eburnation (in addition to the signs of 2); (D) subchrondral pitting of the TMJ.

was based upon were disarticulated and had been sorted by element, each element that comprised part of a joint was summed to provide the denominator for the frequency of OA (e.g., the frequency of OA of the elbow is the sum of the affected joint surfaces divided by the sum of the left distal humerus, proximal ulna, and proximal radius). In order to undertake comparison, we have followed the same procedure.

3 | Results

3.1 | Sample Composition

The number of individuals and the mean and median number of surfaces with a score of one or more (on left) or a score of 2 or more (on right) by sex, age, and time period are shown in Table 2. There are 18 individuals for whom there is no known period. No scores of 4 (ankylosis) were observed.

Overall, there are near equal numbers of males and females for whom osteoarthritis could be recorded. Although not shown in Table 2, there are proportionately fewer females ($n=6$) than males ($n=12$) in the early period, which is argued to reflect the less inclusive nature of burials at this time (Littleton et al. 2024).

3.2 | Laterality

Laterality of osteoarthritic change for each joint was evaluated by comparing the left and right sides where both are visible in the same individual using a paired t-test. There are no statistically significant differences in occurrence by side ($t=0.72$, $df=27$, $p=0.48$). The single joint where the difference is notable is the TMJ, where the right side has a higher frequency of osteoarthritis than the left side for both surfaces, i.e., on the temporal bone and the mandibular condyle (see Table 3). Given the lack of obvious laterality, further analyses of the distribution of arthritis were on the basis of joint surfaces being visible on at least one side of an individual rather than by left or right.

3.3 | Distribution by Joint

The distribution of affected composite joints by sex is shown in Table 4. The TMJ is the most affected joint, but there are sex-specific patterns apparent. Among females, the TMJ is disproportionately affected, with all other affected joints (sternoclavicular, the shoulder, elbow and wrist) having a frequency of less than 10%. The order of joints affected among men is

TABLE 2 | Unadjusted median, mean and SD of non-vertebral joint surfaces with at least minimal evidence of OA (scored 1+, on the left) or only clear evidence (scored 2+, on the right) per individual by sex, age category, or period of pre-contact indigenous human remains from Roonka.

Sex category	No. of individuals	1+ Median	1+ Mean	1+ SD	2+ Median	2+ Mean	2+ SD
Female	36	0.50	0.81	1.21	0.00	0.53	0.97
Indeterminate sex	8	0.00	0.13	0.35	0.00	0.13	0.35
Male	39	1.00	2.41	4.22	0.00	1.18	2.45
Age category							
Young adult	24	0.00	0.33	0.70	0.00	0.17	0.48
Middle-aged adult	33	1.00	1.82	2.84	0.00	0.94	1.52
Old Adult	17	1.00	2.59	4.86	0.00	1.41	2.90
Adult, age unknown	9	0.00	1.33	3.32	0.00	0.78	2.33
Period							
Unknown	18	0.50	1.06	2.31	0.00	0.33	0.97
Early	20	1.00	1.35	1.63	0.00	0.70	1.26
Late	45	0.00	1.73	3.83	0.00	1.02	2.24

proximal fibula, sterno-clavicular, TMJ, wrist/hand, ankle/ft, with shoulder, hip, knee, and elbow all less than 10%. While the proximal fibula is most frequently affected, the sample size for this joint (which has limited movement) is very small.

OA does increase with age (Table 4). Among young adults, degeneration was only noticed in the TMJ (20%) and the elbow (5.6%). In middle adults, a wider range of joints is affected, including the sterno-clavicular and proximal fibular joints, which are not affected in the older adult group, although that is probably a consequence of small sample size. Old adults have a similar pattern but a higher frequency of OA. In all groups, OA is primarily centered on the upper body: TMJ, sternoclavicular, wrist/hand, and only middle-old adult males show any lower body involvement.

3.4 | Overall Prevalence

While individual joints are both countable and comparable, examining OA at the individual level is problematic since not all individuals have every joint complex visible. Nevertheless, it is important to note that among all individuals with visible non-vertebral joint surfaces at Roonka, OA is not typical. This is true even if we include joint surfaces with only minor evidence of OA (score of 1+) where 44 of 87 (50.5%) individuals have no evidence of OA. As shown in Table 5, most individuals have no clear arthritic changes. Among those that do, most have only one joint affected. This holds even when the sample is subdivided by age: more than 50% of middle and old adults do not have any clear evidence of OA, although there are several cases of polyarthritis within the sample. This relative absence of OA is even more stark if we look for evidence of eburnation, which is only observed in two individuals: one shoulder in a male of unknown age and one metatarsal of an old adult male.

3.5 | Prevalence Over Time

Examining individuals affected over time, patterns of OA do not change in any clear direction (Table 6). Contrary to any expectation that rates of OA increase in the late period, females and middle adults in the early period have slightly higher frequencies of OA, but sample sizes are small. Given that the upper body joints bore the brunt of degenerative change, we analyzed whether these joints changed by time period. The TMJ showed no significant change. Sterno-clavicular osteoarthritis seemed to be more frequent in the early phase, but the sample size is small. Curiously, though, despite the sample sizes being sufficient, there was no osteoarthritis in the early phase elbow or wrist/hand joints. This is not accounted for by age composition differences for these joints. The affected individuals are middle-aged and old adult males from the late period; nevertheless, the frequencies are low.

3.6 | Quasi-Poisson Analyses

The patterns outlined above are supported and clarified further by results of quasi-Poisson regression analyses. As shown in Table 7, when all indications of OA are considered, men have significantly greater numbers of affected non-vertebral joint surfaces than women ($p = 0.0012$). There are also clear increases in affected surfaces with age among individuals ($p < 0.0104$). When we repeat this analysis including only surfaces with scores of 2+, results are similar but weaker (Table 7). Men tend to have more affected joint surfaces ($p = 0.098$). The age categories retain the same pattern relative to young adults (middle-aged, $p = 0.068$), (old-aged, $p = 0.0007$). Period did not contribute to either model ($p > 0.35$). We note, too, that the covariate, total number of observable non-vertebral surfaces per individual, was highly statistically significant in both models ($p < 0.0005$).

TABLE 3 | The number and percentage of surface, joint, or joint complex affected with OA (scores 2+) by side among individuals for whom both sides were observable.

	Observable (*N*)	Left (%)	Right (%)	Only Left (*N*)	Only Right (*N*)	Symmetrical (*N*)
Mandibular fossa	28	17.9	28.6	2	5	3
Mandibular condyle	21	9.5	14.3	1	2	1
Sternoclavicular joint	17	17.6	17.6	2	2	1
Acromioclavicular joint	6	33.3	33.3	0	0	2
Glenoid fossa	21	0.0	4.8	0	1	0
Humeral head	16	0.0	12.5	0	2	0
Capitulum	21	9.5	9.5	0	0	2
Trochlea	23	13.0	8.7	1	0	2
Radial head	20	10.0	10.0	1	1	1
Distal radius	20	10.0	15.0	1	2	1
Proximal ulna	37	18.9	16.2	4	3	3
Distal ulna	16	18.8	25.0	1	2	2
Carpals	17	0.0	0.0	0	0	0
Metacarpals	21	0.0	0.0	0	0	0
Phalanges (Hand)	20	0.0	0.0	0	0	0
Acetabulum	36	2.8	5.6	0	1	1
Femoral head	21	0.0	4.8	0	1	0
Distal femoral condyles	25	16.0	8.0	2	0	2
Patella	30	10.0	6.7	1	0	2
Proximal tibia	22	4.5	0.0	1	0	0
Proximal fibula	7	14.3	28.6	0	1	1
Distal tibia	23	0.0	0.0	0	0	0
Distal fibula	13	7.7	0.0	1	0	0
Calcaneus	31	0.0	0.0	0	0	0
Talus	32	0.0	0.0	0	0	0
Tarsals	17	0.0	0.0	0	0	0
Metatarsals	21	9.5	4.8	1	0	1
Phalanges (foot)	12	8.3	8.3	0	0	1

The same analysis was undertaken for the upper limbs and the lower limbs (Table S1). When we examine all signs of OA on the upper limbs, we also find that males have more affected joint surfaces than females, and middle and old aged individuals have more affected surfaces than young adults. When the comparison is limited to only those with clear signs of OA (scores of 2+), males no longer have significantly more affected surfaces ($p = 0.36$), but old adults do as compared to young adults ($p = 0.027$). In contrast, a regression model accounting for variation in the number of affected lower limb surfaces indicates that, while the model eventually converged, only the covariate and male sex were well modeled judging from estimated standard errors. Males are again seen to have a higher number of affected joint surfaces ($p = 0.013$). When only individuals with clear evidence of OA (i.e., scores of 2+) are included, only the covariate is well modeled (estimate: 0.629, standard error: 0.068, $t = 9.283$, $p < 0.0005$). All other predictors, including sex, have very inflated standard errors.

When analyses focus on evidence of OA within smaller joint surface clusters, most models either did not converge or produced non-significant results. There were, however, a few exceptions. In both the elbow (Table S2) and hand–wrist clusters (Table S3), males tended to have more affected surfaces than females ($p \leq 0.026$). Old age, however, was only significantly associated with the number of affected surfaces in the wrist–hand

TABLE 4 | The total number of composite joint surfaces observed (*N*), affected (*n*), and percent with clear evidence of OA (score 2+) overall, and by sex and age category.

Joint(s)	Total (*N*)	Total OA (*n*)	Total (%)	Female (*N*)	Female OA (*n*)	Female OA (%)	Male (*N*)	Male OA (*n*)	Male OA (%)
Jaw	52	15	28.8	24	10	41.7	26	5	19.2
Sternoclavicular	27	5	18.5	12	1	8.3	14	4	28.6
Shoulder (wo SC)	58	2	3.4	24	1	4.2	32	1	3.1
Elbow (total)	66	5	6.1	32	2	6.3	30	3	10.0
Elbow (flex. & ext.)	63	4	6.3	29	1	3.4	30	3	10.0
Elbow (pro. & sup.)	54	4	7.4	25	1	4.0	25	3	12.0
Wrist-hand	65	8	12.3	29	2	6.9	31	5	16.1
Hip	61	2	3.3	29	0	0.0	29	2	6.9
Knee	60	2	3.3	26	0	0.0	29	2	6.9
Fibula (proximal)	16	2	12.5	8	0	0.0	6	2	33.3
Ankle-foot	61	3	4.9	30	0	0.0	24	3	12.5
Joint(s)	**Young adult (*N*)**	**Young adult OA (*n*)**	**Young adult OA (%)**	**Middle adult (*N*)**	**Middle adult OA (*n*)**	**Middle adult OA (%)**	**Old adult (*N*)**	**Old adult OA (*n*)**	**Old adult OA (%)**
Jaw	15	3	20.0	24	7	29.2	12	5	41.7
Sternoclavicular	7	0	0.0	15	5	33.3	3	0	0.0
Shoulder (wo SC)	15	0	0.0	26	1	3.8	12	1	8.3
Elbow (total)	18	1	5.6	28	2	7.1	13	1	7.7
Elbow (flex. & ext.)	18	1	5.6	27	1	3.7	11	1	9.1
Elbow (pro. & sup.)	15	0	0.0	24	2	8.3	8	1	12.5
Wrist-hand	20	0	0.0	28	4	14.3	11	3	27.3
Hip	21	0	0.0	26	2	7.7	10	0	0.0
Knee	17	0	0.0	28	0	0.0	9	1	11.1
Fibula (proximal)	5	0	0.0	8	2	25.0	2	0	0.0
Ankle-foot	17	0	0.0	27	1	3.7	10	2	20.0

TABLE 5 | Numbers of individuals with from zero through six or more joint surfaces affected with OA (score of 2+) by sex and adult age group.

Sex or age group	Number of joint surfaces affected with OA							Total
	0	1	2	3	4	5	6+	
Females	24	10	3	0	0	1	0	38
Males	29	3	3	1	1	0	4	41
Young adults	21	2	2	0	0	0	0	25
Middle adults	19	9	2	1	1	1	1	34
Old adults	10	3	2	0	0	0	2	17
Age unknown	10	0	0	0	0	0	1	11
All	60	14	6	1	1	1	4	87

cluster ($p = 0.0057$). Another partial exception is with the model considering surfaces of the knee. Male sex, the only predictor with a small standard error, was positively associated with the number of affected surfaces ($p = 0.0202$).

3.7 | Polyarthritis

Five individuals have polyarthritic change, i.e., OA of score 2+ affecting more than five post-cranial joints (Arden and Nevitt 2006; Doherty et al. 1998) (Table S4). Four individuals have healed injuries and infections which appear to account for the distributed nature of OA. In the case of Individual 576 (a middle-aged adult female, early period), a clavicular injury potentially accounts for the degenerative change to the sterno-clavicular and shoulder joints, but not the TMJ. In Individual 281 (a middle-aged male, no date) trauma appears to be contributing to OA of the wrist and hip. Trauma to the feet seems to be the primary cause of OA of

TABLE 6 | Number and percent of individuals by age and sex and upper body composite joints affected with OA (score of 2+) during various time periods.

Sex or age	Early (*n*)	%	Late (*n*)	%	Postcontact (*n*)	%	Total (*n*)	%
Females	3	50.0	8	40.0	1	50.0	14	20.0
Males	4	33.3	7	36.8	0	0.0	12	12.5
Young adults	1	5.0	2	16.7	1	100.0	4	0.0
Middle adults	5	62.5	7	53.8	0	0.0	15	37.5
Old adults	1	25.0	6	54.5	0		7	0.0
Age unknown	0	0.0	1	16.7	0	0.0	1	0.0
All	7	25.9	16	59.3	1	3.7	27	11.1
TMJ	15	33.3	24	20.8	2	50.0	52	30.8
Sternoclavicular	5	60.0	14	14.3	3	0.0	27	18.5
Elbow	14	0.0	36	13.9	2	0.0	66	7.6
Wrist-hand	16	0.0	36	19.4	2	0.0	65	12.3

the lower limb in the case of Individual 506 (old adult male, late period). Trauma possibly also contributed to the wrist and elbow changes in Individual 584 (an old adult male, late period).

The one exception to traumatic arthritis is Individual 634 (a middle-aged adult male, late period) who has crush fractures of the vertebrae, extensive periostitis, and nodular destruction of the long bones indicative of some form of systemic infection. The subsequent osteoarthritic change (visible on the elbow, wrist and hip) therefore seems to be related to this widespread pathology, possibly directly through traumatic injury in the case of the hip, but also potentially as a secondary complication of joint destruction due to infection. Overall, individuals with polyarthritis account for the small number of cases of lower body OA that are observed among the male adults from Roonka ($n=5$). In contrast, the pattern of upper body dominance in OA is not accounted for by cases of polyarthritis.

3.8 | Regional Comparison

In undertaking regional comparison with Webb's data, Roonka was compared to location-specific samples rather than the collected regional groupings since these include remains with nonspecific provenance. Furthermore, Roonka fills a gap in the spatial distribution between Webb's Rufus River and Swanport samples (Figure 1).

In all of the samples (Table 8) it is clear that OA of the joint surfaces of the knee was uncommon along the Murray River during the Holocene (except for the Kerang males). The pattern for the elbow is rather different. Rates of arthritis of the elbow at Roonka are strongly comparable to the Rufus River and Swanport groups, but groups from Swan Hill and above have higher rates of elbow degeneration in both sexes. While Roonka fits with the neighboring groups, there is a regional difference on the Murray, with upriver groups having more significant OA of the elbow.

While Webb (1995) recorded OA in both the temporal bone (articular tubercle and mandibular fossa) and mandibular condyle, he found, like the current study, that the temporal surface was most frequently affected. His sample was divided into young and old adults based on cranial indicators which we assess as comparable to the division between our young adults and our middle and old adults. Minor differences in percentages may not be significant given the potential differences between scoring and aging in the two analyses. However, it is distinctive that while the females at Roonka have comparable rates of TMJ OA as women elsewhere on the river, particularly older females, the males from Roonka experienced less TMJ OA (Table 9). This suggests a different pattern of joint stressors than elsewhere.

4 | Discussion

This analysis began with the question, are the patterns of OA that we observe today a reflection of a universal biology (i.e., the hip and knee are most affected) and does increased age make the accumulation of wear and the breakdown of joint integrity inevitable? As Waldron (2017) points out, there is no easy way by which studies of prevalence in contemporary humans can be compared to past skeletal populations; the diagnostic criteria and methods are not identical, the sample composition is distinctly different (i.e., non-survivors versus survivors). There are instances where a skeletal sample might more nearly resemble a cross-section of a living population, but a burial ground in Australia that has accumulated over thousands of years is not one of them. Indeed, the five individuals with polyarthritis at Roonka demonstrate how mortality bias can operate. While there is no indication that osteoarthritis is a direct cause of death, it may reflect other stressors they encountered during their lives that may indeed predispose them to an earlier death.

Nevertheless, it is striking that Roonka is characterized by infrequent OA with the exception of the TMJ. Supporting

TABLE 7 | Results of quasi-Poisson regression of counts of affected non-vertebral bone surfaces (score of 1+) per individuals among 83 pre-contact indigenous human remains from Roonka.

	Estimate	Standard error	*t*-value	*p*
(A) All non-vertebral (1+)				
Intercept	−3.018	0.519	−5.816	< 0.0005
Observable NV surfaces	0.058	0.008	7.439	< 0.0005
Indeterminate sex	−2.004	1.267	−1.581	0.1179
Male	0.894	0.266	3.365	0.0012
Middle-aged adult	1.234	0.470	2.627	0.0104
Old-aged adult	2.143	0.475	4.513	< 0.0005
Adult, age unknown	2.401	0.582	4.124	< 0.0005
Deviance residuals				
Minimum	1Q	Median	3Q	Maximum
−2.725	−0.941	−0.430	0.530	3.197
Dispersion parameter estimated for quasi-Poisson model	1.519			
		Null deviance	303.08	82 df
		Residual deviance	116.42	76 df
Number of fisher scoring iterations	6			
B. All non-vertebral (2+)				
Intercept	−3.779	0.691	−5.470	< 0.0005
Observable NV surfaces	0.068	0.010	6.341	< 0.0005
Indeterminate sex	−1.655	1.225	−1.350	0.1809
Male	0.547	0.327	1.674	0.0982
Middle-aged adult	1.165	0.634	1.846	0.0688
Old-aged adult	2.237	0.634	3.527	0.0007
Adult, age unknown	2.752	0.766	3.593	0.0006
Deviance residuals				
Minimum	1Q	Median	3Q	Maximum
−2.404	−0.894	−0.470	0.061	3.135
Dispersion parameter estimated for quasi-Poisson model			1.368	
		Null deviance	200.89	82 df
		Residual deviance	93.69	76 df
Number of fisher scoring iterations			6	

Note: Model includes covariate of the total number of observable non-vertebral surfaces per individual, and predictors of sex[a] and age[b] category. Model with score 2+ for affected non-vertebral bone surfaces below.
[a] Male and indeterminate sex values relative to those in "Female" category.
[b] Values associated with age categories relative to those of "Young Adult" individuals.

Hypothesis 1, osteoarthritic change does increase with age, and at around the same age as in modern populations, i.e., in middle age (after mid-40s according to the clinical literature, between 35 and 50 years. based on skeletal age estimates). However, OA is not as prevalent as today (contra Hypothesis 1). Even in the joint complexes of old adults, less than 10% are affected, if at all, except for the TMJ and the wrist/hand. In the Steinmetz et al. (2023), approximately 40% of the 50–59 year age group have OA, though this has doubled since 1990. The comparison demonstrates that the temporal contrast is not solely a matter of longer life expectancy in today's population (Steinmetz et al. 2023). This image of the lack of severity of OA at Roonka is supported by the absence of eburnation.

Contemporary data suggests that hand, knee, and hip would be the most affected joints (Hypothesis 2) but this was not

TABLE 8 | Elbow and knee joints with observable indications of OA (*n*) as a percentage of observable surfaces (*N*) by age and sex category for locations along the Murray River.

	Elbow							Knee					
	Left			Right				Left			Right		
Males	*n*	*N*	%	*n*	*N*	%	**Males**	*n*	*N*	%	*n*	*N*	%
Tocumwal	7	44	15.91	10	45	22.22	Tocumwal						
Kerang							Kerang	7	38	18.42	5	27	18.52
Baratta	11	90	12.22	18	107	16.82	Baratta	6	87	6.90	3	71	4.23
Swan Hill	10	83	12.05	23	96	23.96	Swan Hill	2	59	3.39	3	64	4.69
Euston	0	9	0.00	3	13	23.08	Euston	0	10	0.00	1	11	9.09
Rufus	7	140	5.00	15	149	10.07	Rufus	3	99	3.03	10	108	9.26
Roonka	4	56	7.14	6	50	12.00	Roonka	2	33	6.06	1	28	3.57
Swanport	0	17	0.00	4	29	13.79	Swanport	5	41	12.20	3	56	5.36

	Elbow							Knee					
	Left			Right				Left			Right		
Females	*n*	*N*	%	*n*	*N*	%	**Females**	*n*	*N*	%	*n*	*N*	%
Tocumwal	3	43	6.98	6	45	13.33	Tocumwal						
Kerang							Kerang	0	19	0.00	0	24	0.00
Baratta	6	40	15.00	4	39	10.26	Baratta	1	32	3.13	2	28	7.14
Swan Hill	3	65	4.62	4	63	6.35	Swan Hill	0	43	0.00	1	48	2.08
Euston	0	5	0.00	0	4	0.00	Euston	0	6	0.00	0	6	0.00
Rufus	2	70	2.86	0	76	0.00	Rufus	2	55	3.64	0	49	0.00
Roonka	2	50	4.00	0	56	0.00	Roonka	0	28	0.00	0	25	0.00
Swanport	0	15	0.00	0	48	0.00	Swanport	0	60	0.00	0	56	0.00

	Elbow							Knee					
	Left			Right				Left			Right		
All	*n*	*N*	%	*n*	*N*	%	**All**	*n*	*N*	%	*n*	*N*	%
Tocumwal	22	227	9.69	34	194	17.53	Tocumwal						
Kerang							Kerang	10	155	6.45	7	148	4.73
Baratta	19	174	10.92	28	198	14.14	Baratta	9	157	5.73	8	146	5.48
Swan Hill	14	152	9.21	28	165	16.97	Swan Hill	2	102	1.96	4	112	3.57
Euston	2	47	4.26	13	49	26.53	Euston	0	37	0.00	2	39	5.13
Rufus	13	307	4.23	21	330	6.36	Rufus	7	183	3.83	13	187	6.95
Roonka	6	114	5.35	6	112	5.36	Roonka	2	66	3.03	1	56	1.79
Swanport	6	250	2.40	8	235	3.40	Swanport	10	177	5.65	7	187	3.74

supported. The other striking contrast is that expectations of sex-specific patterns (which are the entangled result of biological sex, gendered patterns of work, and behavior) are not mirrored at Roonka, contra Hypothesis 3. Females do not have osteoarthritis of the wrist and hands; men do. Women do not have arthritis of multiple joints; men are more likely sufferers. This latter difference, because it is tied to some instances of trauma, also demonstrates the entanglement of gender and biology. Furthermore, the expected pattern of accumulated stress on weight-bearing joints such as the hip and knee (Long et al. 2022) is not borne out: the two cases of hip arthritis are explicitly secondary to previous trauma. Instead, OA is centered on the upper body and particularly the TMJ.

Hypothesis 4 was also unsupported. The low frequency of OA and its lack of severity among the people from Roonka contrast

TABLE 9 | Temporo-mandibular joints with observable indications of OA (*n*) as a percentage of observable surfaces (*N*) by age and sex category for location-specific samples along the Murray River.

	Young males			Old males			All males		
Location	***n***	***N***	**%**	***n***	***N***	**%**	***n***	***N***	**%**
Tocumwal	11	17	64.71	13	25	52.00	24	42	57.14
Kerang	6	8	75.00	18	22	81.82	24	30	80.00
Baratta	4	12	33.33	17	28	60.71	21	40	52.50
Swan Hill	15	24	62.50	24	30	80.00	39	54	72.22
Euston	19	47	40.43	44	71	61.97	63	118	53.39
Rufus	23	47	48.94	49	74	66.22	72	121	59.50
Roonka	2	7	28.60	5	18	27.80	7	25	28.00
Swanport	7	16	43.75	25	41	60.98	32	57	56.14
	Young females			**Old females**			**All females**		
Location	***n***	***N***	**%**	***n***	***N***	**%**	***n***	***N***	**%**
Tocumwal	1	13	7.693	9	13	69.23	10	26	38.46
Kerang	6	9	66.67	6	7	85.71	12	16	75.00
Baratta	6	17	35.29	10	11	90.91	16	28	57.14
Swan Hill	17	32	53.10	5	8	62.50	22	40	55.00
Euston	21	40	52.50	17	25	68.00	38	65	58.46
Rufus	23	53	43.40	15	30	50.00	38	83	45.78
Roonka	2	7	28.60	8	17	47.10	10	24	41.70
Swanport	8	21	38.10	17	30	56.67	25	51	49.00

strongly with the contemporary pattern of widely prevalent and severe OA among Aboriginal people, particularly of the hips, hands, and knees (O'Brien et al. 2021). The contrast points to the accumulated effects of post-contact changes to health and aging, and their contribution to current patterns of disability (Finlay and Broe 2024).

4.1 | Osteoarthritis Along the Murray River

While there is a marked contrast with contemporary experiences of OA, the comparison of the Roonka data with that from Webb (1984, 1995) highlights regional continuities and differences during the Holocene. The rates of osteoarthritis of the knee at Roonka, while low, are comparable to other Murray River locales as anticipated in Hypothesis 5. In contrast, elbow OA at Roonka is comparable to the neighboring groups, but there is a marked difference with the samples from Tocumwal, Kerang, Barratta, and possibly Swan Hill. At these locations, the rate of osteoarthritis is markedly higher. While there is no strong evidence at any location on the Murray for unimanual patterns, it does seem there is heavier joint loading of the elbows in that region described by Webb (1984) as Central Murray (and by us as Riverine; Figure 1). Webb notes it is the surfaces of the elbow involved in the hinge joint, as opposed to rotation, that are affected.

At Roonka there is no indication that either motion is more causal. It does suggest, as argued elsewhere (Littleton 2017; Littleton et al. 2021), that seeing the Murray as a single unit obscures spatial variation. It is not clear what the cause of the difference is. One major difference between Roonka and upriver locations is the extent of flood plains upstream compared to the cliffs at Roonka. This may mean that, while people at Roonka were using bulrush (*Typha orientalis*) and other sources of fiber for net-making as observed by Eyre (1845), they were not relying upon typha as a major source of dietary starch. Preparing typha for starch requires pounding down the bulb then stripping it through the teeth (Eyre 1845; Gott 1999). It has been hypothesized that the difference in the degree of reliance on such starch accounts for differences in dental wear that roughly (but not perfectly) correspond to these two areas (Littleton 2017).

It is not clear, however, that this activity or even patterns of dental wear relate directly to TMJ arthritis. Just over a quarter of young adult males and females at Roonka had arthritis of the TMJ—these rates are lower than other places on the Murray River. Rates among females increased with age; rates among males did not. Of course, this is not indicative of severity. While the female rates for older individuals are comparable to other places on the Murray, the male rates remain relatively low. This does not reflect patterns of dental attrition. At Roonka, dental wear shows age grading, with middle-aged and older men and women sharing the same pattern of heavy molar wear (Littleton 2017). The relatively early onset and then the lack of an increase in males suggests that the full range of causes for TMJ arthritis should be considered, including the morphology of the glenoid fossa, habitual clenching of the jaw (either during work or at night), bruxism, and dental wear (Kaidonis et al. 2014; Richards 1988, 1990). Clenching of the jaw is often required when using the teeth as tools and can place significant biomechanical stress upon the TMJ. Relatively free movement of the mandible within the mandibular fossa (Richards 1987) might also result in joint flattening and destruction. There is little doubt that dental wear would be associated with both mechanisms, but it would not necessarily be the only prime mover. The contrast upriver does suggest a different set of oral stressors at Roonka, but tying that down to any specific cause is not feasible.

It is not possible with the data from Webb (1984) to examine change over time. At Roonka, contrary to Hypothesis 6, there is no evidence of changed or increased workloads over time except for more elbow and wrist related pathology in the late Holocene males. Clearly, change occurred over time, but the pattern is not sufficiently systemic to argue for a definite pattern of labor change in the way postulated in various scenarios of intensification (Lourandos 1983; Webb 1995). Instead, what is more evident is the nature of local adaptations to the environment which create different constellations of osteoarthritic changes.

Patterns of OA do vary between men and women, but they do not reflect the expected pattern of greater workloads on women hypothesized from ethnohistoric accounts (e.g., Eyre 1845). That does not necessarily mean those accounts are wrong, but it emphasizes that such accounts cannot be read either as an unbiased version of the past or as indicative of precolonial population conditions. The sex-specific pattern of arthritis at Roonka potentially reflects cultural patterns. For example, upper body loading and how that is differentially experienced is potentially a result of gendered patterns of labor and secondary causes such as trauma. However, there are also indications that biological differences such as the size and robustness of the TMJ also affect OA.

4.2 | Local Biologies

The lack of concordance between the pattern of OA among people buried at Roonka and our expectations based on clinical and historical data reflects local biologies. Local biologies refer to the way in which the embodied experience of physical sensations, including those of well-being, health, illness, and so on, is in part informed by the material body, itself contingent on evolutionary, environmental, and individual variables (Lock and Kaufert 2001, 483). While biological processes (such as those underlying the degeneration of joints) are generally shared, how they develop, are experienced, and embodied is contingent upon local entanglements of biology and culture. This stands in contrast, we argue, to ideas of a universal and inevitable pattern of OA, whether as a consequence of evolutionary processes (i.e., the trade off with bipedalism) or economic circumstances (e.g., hunter-gatherer economies).

At Roonka, rather than OA being an inevitable outcome of encroaching age or a potential cause of widespread disability, it was a relatively uncommon experience even among the elderly, except for OA of the TMJ. The distinct age and sex-related trajectory of TMJ arthritis at Roonka suggests that it would not have been recognized as a condition of age, but rather a ubiquitous experience shared by men and women from early adulthood. The greater rates of TMJ among older women potentially reflect the complex relationship between sex (smaller joint surfaces) and gendered patterns of work and stress (using teeth as tools and bruxism).

OA at Roonka was just one part of lived human experience (see also Dommett et al. 2017; O'Brien et al. 2021). It certainly contributed to the problems experienced by people who were already suffering from injury or severe infection, but for most people at Roonka, their experience of old age did not encompass the bony signs of joint degeneration. One might argue that, on average, people died at a younger age than contemporary populations, but that fails to account for the low rates of OA among middle adults. It also ignores that, while we cannot be precise about the age of death past 50, it is more probable than not that deaths were spread across the decades after 50. Except for TMJ, the rates of OA are still lower than the 30% of individuals aged 55 or older, as estimated by the WHO.

An alternative argument mounted in relation to OA is that the weight-bearing joints of the knee and hip are most affected due to a combination of the evolutionary trade-offs associated with bipedalism and obesity. At Roonka, the joints of the lower limbs are affected by the distribution of injury, and that pattern of injury seems to be related to the distribution of trauma by gender and other factors, rather than an evolutionarily inevitable relationship. Obesity was probably uncommon, but the high rates of OA in contemporary Aboriginal society cannot be assigned to a single cause (AIHW 2018). As at Roonka, OA reflects a culmination of lived experiences; hence the importance of thinking about local biologies.

A strength of palaeopathological analyses, even with relatively small sample sizes, is their capacity to challenge assumptions of universal biology and to demonstrate "how biological and physiological aspects of health and disease are created out of their constant interaction with physical and social surroundings" (Kontos 1999, 686). Furthermore, such studies emphasize the lack of constancy in such patterns. In this case the changes to Aboriginal life post contact were experienced in the development of a new pattern of aging not just in the evanescent events of infectious disease and violence.

Author Contributions

Matilda McVicar: investigation, conceptualization, writing – original draft. **Judith Littleton:** supervision, formal analysis, writing – original draft, writing – review and editing. **Bruce Floyd:** supervision, formal analysis, writing – review and editing.

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Ethics Statement

Ethical clearance is from the University of Auckland Human Participants Ethics Committee (01031).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that supports the findings of this study are available in the Supporting Information of this article.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** Supporting Information. **Data S2:** Supporting Information.