BMJ open accessible medical research

Non-steroidal anti-inflammatory drug (NSAID) related inhibition of aldosterone glucuronidation and arterial dysfunction in patients with rheumatoid arthritis: a cross-sectional clinical study

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To cite: Crilly MA, Mangoni AA. Non-steroidal anti-inflammatory drug (NSAID) related inhibition of aldosterone glucuronidation and arterial dysfunction in patients with rheumatoid arthritis: a cross-sectional clinical study. *BMJ Open* 2011;**1**:e000076. doi:10.1136/bmjopen-2011-000076

► Prepublication history for this paper is available online. To view these files please visit the journal online (http://bmjopen.bmj.com).

Received 28 January 2011
Accepted 27 April 2011

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ABSTRACT

Objective: Patients with rheumatoid arthritis (RA) are at increased risk of cardiovascular (CV) disease and are also commonly prescribed non-selective non-steroidal anti-inflammatory drugs (ns-NSAIDs). New in vitro evidence suggests that this increased CV risk may be mediated through aldosterone glucuronidation inhibition (AGI), which differs between NSAIDs (diclofenac>naproxen>indomethacin>ibuprofen). Our aim was to explore the association between ns-NSAID-related AGI and arterial dysfunction.

Methods: The extent (augmentation index, AIX%) and timing (reflected wave transit time, RWT, ms) of aortic wave reflection (measured using radial applanation pulse wave analysis, PWA, SphygmoCor device) were assessed on a single occasion in 114 consecutive RA patients without overt CV disease aged 40–65 years. A higher AIX% and lower RWT indicate arterial dysfunction. Assessment included a fasting blood sample, patient questionnaire and medical record review. Multivariate analysis was used to adjust for age, sex, mean blood pressure, smoking, cumulative erythrocyte sedimentation rate (ESR-years) and Stanford disability score.

Results: We identified 60 patients taking ns-NSAIDs and 25 non-users. Using a ns-NSAID with the highest AGI was associated with a higher AIX% (and lower RWT) versus treatment with a ns-NSAID with the lowest AGI (diclofenac AIX% 32.3, RWT 132.7 ms vs ibuprofen AIX% 23.8, RWT 150.9 ms): adjusted mean differences AIX% 6.5 (95% CI 1.0 to 11.9; p=0.02); RWT −14.2 ms (95% CI −22.2 to −6.3; p=0.001). Indomethacin demonstrated an intermediate level of arterial dysfunction. In relation to arterial dysfunction, both indomethacin and naproxen were more similar to diclofenac than to ibuprofen.

Conclusions: ns-NSAID-related AGI is associated with arterial dysfunction in patients with RA. These findings provide a potentially novel insight into the CV toxicity of commonly used ns-NSAIDs. However, the findings are limited by the small number of patients involved and require further replication in a much larger study.

INTRODUCTION

Non-steroidal anti-inflammatory drugs (NSAIDs) are among the most commonly prescribed drugs in clinical practice. Their relative safety has attracted considerable interest, particularly in relation to their association with adverse cardiovascular (CV) events.[1 2] Most of this interest has focused on the role of selective cyclo-oxygenase-2 (COX-2) inhibitors,[3] but non-selective NSAIDs (ns-NSAIDs) also have the potential to increase the risk of adverse CV events. For example, the use of the ns-NSAID diclofenac has been shown to increase the risk of adverse CV events.[2] ns-NSAID use is associated with adverse CV effects including reduction in renal perfusion, electrolyte disturbances (sodium and water retention) and increase in blood pressure (BP). The detrimental effects regarding renal function are thought to be secondary to reduced synthesis of vasodilatory prostaglandins such as PGE2. However, ns-NSAIDs have been shown to exert adverse renal effects disproportionate to the level of inhibition of prostaglandin synthesis.[4] This suggests that there might be other yet unknown mechanisms responsible for the potential increase in CV risk associated with ns-NSAID use.[5]

Aldosterone metabolism

Very recent in vitro evidence suggests that ns-NSAIDs enhance the action of aldosterone through the inhibition of aldosterone metabolism.[6] Aldosterone is metabolised by 18β-glucuronidation in both the liver and kidneys in a reaction that is catalysed by the enzyme UDP-glucuronosyltransferase-2B7. Several ns-NSAIDs have been shown in vitro (human kidney cortical microsomes) to inhibit aldosterone 18β-glucuronidation and individual NSAIDs vary in their ability to

ARTICLE SUMMARY

Article focus

- Aldosterone glucuronidation inhibition (AGI) potentiates the adverse cardiovascular effects of aldosterone.
- Recently published in vivo research suggests that such inhibition differs between non-selective non-steroidal anti-inflammatory drugs (ns-NSAIDs), with a ranked order of diclofenac>naproxen>indomethacin>ibuprofen, but no previous studies have assessed the relationship between ns-NSAID-related AGI and arterial dysfunction in chronic users.
- This study assessed arterial dysfunction using pulse wave analysis.

Key messages

- In patients with rheumatoid arthritis we found that chronic use (>3 months) of diclofenac (high AGI) was associated with greater arterial dysfunction compared to ibuprofen (lower AGI); this association was independent of other cardiovascular and rheumatological factors.
- Indomethacin (intermediate AGI) was associated with an intermediate level of arterial dysfunction, although naproxen (intermediate AGI) did not fit the anticipated pattern.
- Our findings support the concept that AGI may play a role in the cardiovascular toxicity of some ns-NSAIDs commonly used in routine clinical practice.

Strengths and limitations of this study

- A single research nurse assessed rheumatoid arthritis patients who were recruited from a consecutive series attending a hospital rheumatology clinic. We adjusted for several important cardiovascular and rheumatological factors known to be independently associated with arterial function and our multivariate analysis explained a high proportion of the variability in arterial dysfunction among chronic ns-NSAID users. The observational cross-sectional design of our study means that we cannot assess causation, nor exclude residual confounding as an explanation for our findings. The small number of patients taking each NSAID meant that the confidence intervals are wide.

inhibit aldosterone glucuronidation.[6] Diclofenac, for example, is a strong inhibitor of glucuronidation, whereas ibuprofen is a weaker inhibitor.[6]

Aldosterone is a mineralocorticoid which plays an important role in the renin–angiotensin–aldosterone system and has generally deleterious effects on the CV system. Higher aldosterone levels are associated with endothelial dysfunction, arterial stiffening, increased arterial wall reflection, myocardial fibrosis and an increase in the risk of CV death.[7–10] Drugs that block the action of aldosterone (such as spironolactone) have been shown to reduce the risk of CV death in patients with heart failure and following myocardial infarction.[11] Aldosterone receptors predominate in the aorta and spironolactone has been shown to improve arterial function assessed using the technique of pulse wave analysis (PWA).[7] Consequently, the increased risk of adverse CV events in patients taking diclofenac may also be related to the enhanced effects of aldosterone as a consequence of ns-NSAID-related aldosterone glucuronidation inhibition (AGI).

RAAIX study

Patients with rheumatoid arthritis (RA) are known to be at a higher risk of CV death.[12] The RAAIX (RA Augmentation Index) study was undertaken to assess the relationship between the cumulative inflammatory burden and arterial dysfunction in patients with RA.[13 14] RAAIX involved a detailed assessment of both CV and rheumatological features, including assessment of the use of NSAIDs. Other researchers have subsequently reported the relative level of aldosterone 18β-glucuronidation inhibition (AGI) for several of the ns-NSAIDs taken by patients in the RAAIX study.[6] In the RAAIX study, arterial dysfunction was assessed non-invasively using radial applanation tonometry and PWA.[13 14] PWA is based on the phenomenon of arterial wave reflection which is influenced by pulse wave velocity, endothelial dysfunction, peripheral arterial resistance and left ventricular ejection.[15 16] In each cardiac cycle, the outgoing systolic pulse wave is also reflected back towards the heart, predominantly at the level of arterial bifurcations,[17] and returns to the heart during systole where it augments the central aortic pressure.[15 16] The speed of travel of both outgoing and reflected waves is greater in patients with stiffer arteries, which increases the extent of augmentation (higher AIX%) and reduces the reflected wave transit time (lower RWT).

Study aim

The aim of this exploratory analysis was to assess the association between ns-NSAID-related AGI and established markers of arterial dysfunction using data from a previous study of patients with RA.

METHODS

In the original study we recruited patients with a consultant rheumatologist diagnosis of RA by reviewing the medical records of a consecutive series of patients attending hospital-based rheumatology clinics in the city of Aberdeen. We identified patients 40–65 years of age with RA of more than 6 months' duration. While all of our study participants had a clinical diagnosis of RA made by a rheumatologist, only 56% (64/114) met American College of Rheumatology criteria (ACR 4/7) for RA. We excluded patients with overt arterial disease (angina, prior myocardial infarction, transient ischaemic attack, stroke, arterial revascularisation, intermittent claudication, peripheral arterial disease), atrial fibrillation, heart failure and valvular heart disease. The exclusion of patients with arterial disease was based upon an initial screening patient questionnaire, resting 12-lead ECG (independently reported by a cardiologist to identify pathological Q-waves, conduction defects, minor Q-waves associated with ST-segment/T-wave anomalies) and a detailed medical record review by a rheumatologist. No participants had a history of recent

infection, antibiotic treatment or immunisation within the previous 2 weeks.

Clinical assessment

Patients attended the Clinical Pharmacology Department at Aberdeen Royal Infirmary on a single occasion and underwent assessment by a single clinical research nurse (April–December 2006). Assessment took place in the morning after participants had fasted overnight and abstained from smoking, alcohol and caffeine. Standardised assessment included BP measurement, PWA and fasting venous blood sample (including erythrocyte sedimentation rate (ESR), rheumatoid factor (RF) and lipid profile). A self-completed patient questionnaire included smoking habit and the Stanford Health Assessment Questionnaire (HAQ).[18] Current medication use was comprehensively reviewed by the research nurse and included use of over-the-counter (without the need for a prescription) NSAIDs. A detailed retrospective review of the medical records using a previously piloted study form, was undertaken by a single rheumatologist blinded to all PWA results and included date of arthritis onset, previous blood test results (ESR, RF), joint surgery and co-morbidity (including treated hypertension). Our methods have been described in detail elsewhere.[13 14] The nurse remained blind to the patient's previous medical records (which were not made available at assessment) and only reviewed current medication and questionnaire responses (to ensure that all questionnaires items were fully completed) after PWA assessment had been completed.

Pulse wave analysis (PWA)

Patients rested supine in a quiet side-room for at least 10 min before undergoing three BP/PWA measurements according to current guidelines.[19] BP was measured at the right brachial artery using a validated automatic oscillometric BP machine (Omron HEM757 IntelliSense BP monitor; Omron Healthcare, Bannockburn, Illinois, USA).[20] PWA was undertaken using the SphygmoCor device (AtCor Medical, Sydney, Australia) with a hand-held tonometer (Millar, Houston, Texas, USA) applanated at the right radial artery. The SphygmoCor PWA device employs a validated generalised transfer function to derive the central aortic pulse waveform from the peripheral waveform.[21] All three PWA recordings were required to have a in-built SphygmoCor quality index score at least 95% (based on average pulse height, pulse height variation and diastolic variation). We have previously demonstrated the research nurse's high levels of within-observer and between-observer repeatability.[22] The research nurse remained blind to the patient's previous medical history until PWA was completed.

Aldosterone glucuronidation inhibition (AGI)

Aldosterone 18β-glucuronidation inhibition constants, Ki, derived from in vitro studies of human kidney cortical microsomes (HKCM), have been published for four of the ns-NSAIDs taken by patients in the RAAIX study (diclofenac: 8 μM; naproxen: 49 μM; indomethacin: 113 μM; ibuprofen: 441 μM; a lower Ki indicates greater inhibition).[6] Nabumetone is a close structural analogue of naproxen and the two were combined together in the analysis.

Statistical analysis

Analysis is based on the mean of the three PWA measurements. The principle measures of arterial dysfunction are augmentation index (AIX%) and reflected wave transit time (RWT, ms). Since AIX% varies with heart rate in an individual, it was standardised to 75 beats per minute.[23] The UK version of the Stanford HAQ was scored using standard methods without any imputation required for missing data.[18] Cumulative ESR-years were derived from the highest single annual ESR recorded in the medical record during each year of follow-up and calculated using the trapezium rule with linear interpolation when data for a given year were missing.[24] ESR-years reflects both the duration and level of inflammatory burden (eg, 5 years of arthritis and annual ESRs of 30, 20, 10, 10 and 20 mm/h would equate to approximately 90 ESR-years). ESR is routinely measured for almost all RA patients attending the rheumatology outpatient clinic in Aberdeen, where the policy is to review all RA patients at least annually. Complete medical records were available for 112 patients who contributed a total of 1040 person-years of rheumatoid disease. An annual ESR was available for 77% (797/1040) of these person-years and the availability of an annual ESR for each year since the onset of arthritis for individual patients was a median of 93% (IQR 67–100%). The availability of an annual ESR did not differ by age, gender, RF positivity, RA criteria (ACR 4/7) or Stanford HAQ disability index (data not shown).

Multiple linear regression was used to adjust mean differences in AIX% (and RWT) for variables known to be associated with AIX%, namely: age, sex, mean arterial BP, ever smoked, Stanford HAQ disability score and cumulative ESR-years. Analysis was undertaken using SPSS v 17. We confirmed that the assumptions of linearity, normal distribution and equal variance for multiple linear regression were met. Goodness of fit was assessed using the adjusted R^2. The inclusion of additional variables (study ESR, duration of arthritis, RA criteria, fasting cholesterol, smoking pack-years, treated hypertension and current disease-modifying anti-rheumatic drug (DMARD) use) did not alter the adjusted values for AIX and RWT reported, nor improve the goodness of fit of the final regression model.

The study adhered to the principles of the Declaration of Helsinki and was approved by Grampian Research Ethics Committee (study reference: 04/S0801/67). All participants provided informed written consent. The study was funded from a charitable source (NHS Grampian Rheumatology Endowments).

RESULTS

The original study recruited 114 patients. We excluded nine patients from the analysis who were not currently taking NSAIDs but had done so within the previous 3 months, and excluded two users of infrequently prescribed NSAIDs (ketoprofen and tiaprofenic acid). The characteristics of the remaining 103 patients (82% female) are shown in table 1.

No patients were taking aspirin or more than one NSAID concurrently. All NSAID users had been taking their current NSAID for more than 3 months. Diclofenac was the most commonly used NSAID and was taken by almost a third of patients. One quarter of patients had not taken an NSAID within the previous 3 months (although 88% of these patients had been prescribed an NSAID in the past). All patients, both NSAID users and non-users, had previously received DMARD therapy.

Patient characteristics

NSAID users and non-users were similar regarding age, sex, waist–hip ratio, fasting lipids, glucose, arthritis duration, age at arthritis onset and previous joint surgery

Table 1 Characteristics of patients with rheumatoid arthritis

	Current NSAID use			
	Yes (n=78)		No (n=25)	
Cardiovascular features				
Female	64	82%	20	80%
Mean age, years (SD)	53.4	6.9	53.9	5.7
Mean heart rate, beats per minute (SD)	69.7	10.6	64.5	8.6
Mean systolic BP, mm Hg (SD)	126.2	16.9	124.7	12.1
Mean diastolic BP, mm Hg (SD)	82.9	10.0	81.3	7.6
Mean pulse pressure, mm Hg (SD)	35.6	9.1	36.9	7.4
Mean arterial BP, mm Hg (SD)	99.5	12.2	97.8	8.8
Mean fasting cholesterol, mmol/l (SD)	5.3	1.2	5.6	1.1
Mean fasting glucose, mmol/l (SD)	5	0.8	5	0.5
Mean waist–hip ratio (SD)	0.85	0.08	0.85	0.08
Ever smoked for 12 months or more	44	56%	17	68%
Treated hypertension	12	15%	7	28%
Bendroflumethiazide	10	13%	5	20%
Atenolol	6	8%	5	20%
Calcium channel blocker	3	4%	1	4%
ACE inhibitor	2	3%	3	12%
Rheumatological features				
Mean age at onset of arthritis, years (SD)	41.8	10.4	41.4	12.1
Median duration of arthritis, years (IQR)	9	4–15	8	4–16
Median Stanford HAQ disability (IQR)	1.4	0.6–1.9	0.6	0.3–1.3
Median study ESR, mm/h (IQR)	19	8–30	10	6–18
Median cumulative ESR-years (IQR)	206	99–468	93	58–297
Rheumatoid factor positive (≥30 IU/ml)	66	85%	18	72%
Rheumatoid arthritis criteria (ACR 4/7)	47	60%	10	40%
Previous joint surgery	17	22%	4	16%
Current DMARD therapy	70	90%	24	96%
Current prednisolone therapy	8	10%	3	12%
Current NSAID therapy (>3 months)	78	100%	0	0%
Diclofenac	31	40%	–	–
Naproxen/nabumetone	16	21%	–	–
Celecoxib/etoricoxib	11	14%	–	–
Ibuprofen	7	9%	–	–
Meloxicam	7	9%	–	–
Indomethacin	6	8%	–	–
Other (ketoprofen, tiaprofenic acid)	2	3%		
Current cytokine therapy	4	5%	1	4%
Proton pump inhibitor	27	35%	4	16%
Misoprostol	6	8%	0	0%
Central arterial function				
Mean augmentation index, AIX% (SD)	31.9	7.9	30.9	8.3
Mean reflected wave transit time, ms (SD)	135.7	11.4	133.1	12.4

Figures are numbers (%) unless otherwise indicated.
ACR, American College of Rheumatology; BP, blood pressure, DMARD, disease modifying anti-rheumatic drug; ESR, erythrocyte sedimentation rate; HAQ, Health Assessment Questionnaire; IQR, inter-quartile range; NSAID, non-steroidal anti-inflammatory drug.

(table 1). Based on the Scottish ASSIGN score, NSAID users had a slightly lower 10-year predicted risk of a CV event compared to non-users (median 6% vs 8%; Mann–Whitney U test, p=0.38).[25] NSAID users had a higher brachial BP at assessment, lower prevalence of treated hypertension and lower exposure to tobacco. The level of current inflammation (study ESR), cumulative inflammation (ESR-years) and arthritis related disability (Stanford HAQ) were higher in current NSAID users. The use of proton pump inhibitors and misoprostol was also higher among current NSAID users. The current use of prednisolone and DMARD was similar for both groups; the overall use of cytokines was relatively low. The rheumatological and CV features of ns-NSAID users (with NSAIDs ordered by their level of AGI) are shown in table 2.

Differences in arterial function

Increasing levels of ns-NSAID-related AGI were associated with a higher AIX% and a lower RWT (figure 1). Mean differences in arterial function between patients taking diclofenac and the other three ns-NSAIDs (naproxen, indomethacin, ibuprofen) are shown in table 3. Diclofenac was selected as the reference group as it has the highest level of in vitro AGI and was also the most commonly used ns-NSAID. Compared to the

Table 2 Patient characteristics and use of non-selective non-steroidal anti-inflammatory drugs

Aldosterone 18β-glucuronidation inhibition constant (Ki), μM	Diclofenac (n=31) Ki=8		Naproxen (n=16) Ki=49		Indomethacin (n=6) Ki=113		Ibuprofen (n=7) Ki=441	
Cardiovascular features								
Female	28	90%	12	75%	5	83%	5	71%
Mean age, years (SD)	54	6.5	55	5.6	57	5.9	50	9.5
Mean heart rate, beats per minute (SD)	70.7	11.9	73.0	10.5	68.9	4.6	70.0	10.9
Mean systolic BP, mm Hg (SD)	126	17.6	125	20.3	118	14.0	123	13.4
Mean diastolic BP, mm Hg (SD)	83	9.9	82	12.1	75	7.4	84	7.9
Mean pulse pressure, mm Hg (SD)	35.3	10.5	35.3	9.0	34.4	6.1	31.1	8.1
Mean arterial BP, mm Hg (SD)	99	12.2	99	15.3	92	9.8	100	10.3
Mean fasting cholesterol, mmol/l (SD)	5.4	1.3	5.4	1.5	5.8	0.9	5.1	1.0
Mean fasting glucose, mmol/l (SD)	4.9	1.0	5.1	0.6	5.0	0.4	4.9	0.5
Mean waist–hip ratio (SD)	0.85	0.08	0.86	0.09	0.89	0.08	0.88	0.09
Ever smoked for 12 months or more	17	55%	9	60%	4	67%	3	43%
Treated hypertension	7	23%	3	19%	2	33%	0	0%
Rheumatological features								
Mean age at onset of arthritis, years (SD)	43	11.2	42	8.4	39	7.1	37	11.9
Median duration of arthritis, years (IQR)	9	3–15	10	2–17	19	11–22	11	7–20
Median Stanford HAQ (IQR)	1.4	0.8–2.0	1.6	1.2–1.9	1.5	0.9–1.9	0.6	0.0–1.9
Median ESR-years (IQR)	221	99–526	186	77–435	706	140–825	315	81–829
Rheumatoid factor positive (≥30 IU/ml)	26	84%	13	81%	6	100%	7	100%
Rheumatoid arthritis criteria (ACR 4/7)	14	45%	11	69%	4	67%	5	71%
Previous joint surgery	9	29%	4	25%	1	20%	2	29%
Current DMARD therapy	28	90%	15	94%	5	83%	6	86%
Central arterial function								
Mean augmentation index, AIX% (SD)	32.3	7.1	34.0	7.3	30.7	3.6	23.8	14.1
Mean reflected wave transit time, ms (SD)	132.7	7.3	134.5	12.6	136.4	8.7	150.9	18.0

Figures are numbers (%) unless otherwise indicated.
ACR, American College of Rheumatology; BP, blood pressure; DMARD, disease modifying anti-rheumatic drug; ESR, erythrocyte sedimentation rate; HAQ, Health Assessment Questionnaire; IQR, inter-quartile range.

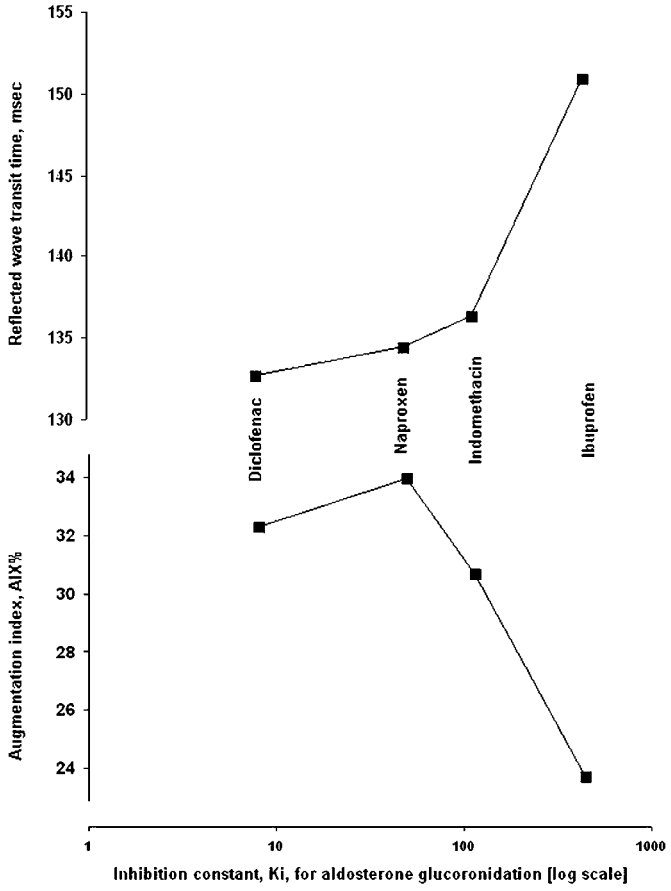

Figure 1 Use of non-steroidal anti-inflammatory drug (NSAIDs) and central arterial function in patients with rheumatoid arthritis.

unadjusted comparisons, the adjustment for other CV and rheumatological factors reduced the differences between ns-NSAIDs, but the observed trend of a higher degree of arterial dysfunction (higher AIX% and lower RWT) being associated with increasing levels of ns-NSAID-related AGI persisted. The exception to this pattern was the slightly higher AIX% for naproxen compared to diclofenac. The differences between ibuprofen and diclofenac reached statistical significance (AIX% 6.5, 95% CI 1.0 to 11.9, p=0.02; and RWT −14.2 ms, 95% CI −22.2 to −6.3, p=0.001), although only seven patients were chronic users of ibuprofen. The differences between diclofenac and the two other ns-NSAIDs (indomethacin and naproxen) were not statistically significant.

Patients with no NSAID use over the previous 3 months (n=25) had a mean AIX% of 30.9 (SD 8.3) and a mean RWT of 133.1 (SD 12.5) ms. On adjusted comparison with current NSAID users (all NSAIDs listed in table 1 combined), AIX% was −1.0 (95% CI −3.9 to 1.9; p=0.49) lower and RTW 4.3 ms (95% CI −0.6 to 9.2; p=0.09) higher among non-current users. The use indomethacin was associated with a similar level of dysfunction (AIX%) compared to patients not currently taking an NSAID. Interestingly, the use of ibuprofen was associated with a lower level of AIX% compared to non-current users (unadjusted mean difference in AIX% 7.1, 95% CI −1.4 to 25.6).

Eleven patients were currently taking a selective COX-2 inhibitor (eight celecoxib, three etoricoxib) and had a mean AIX% of 33.6 (SD 6.4) and a mean RWT of 132.8 (SD 8.8) ms. On adjusted comparison with diclofenac, AIX% was non-significantly higher for patients taking a selective COX-2 inhibitor (2.9, 95% CI −1.4 to 6.8; p=0.19), whereas mean RWT was similar (adjusted difference −0.7 ms, 95% CI −6.7 to 5.4; p=0.80). Brachial BP (135/86 vs 125/82 mm Hg) and pulse pressure (47 vs 33 mm Hg) were higher for patients taking a selective COX-2 inhibitor compared to diclofenac.

DISCUSSION

In summary, we found that the current use of an ns-NSAID with a higher level of AGI (in vitro AGI) in patients with RA, appears to be associated with a higher level of arterial dysfunction. Arterial dysfunction was highest in patients taking diclofenac (high AGI) and lowest in those taking ibuprofen (low AGI); differences

Table 3 Differences in central arterial function associated with the use of non-selective non-steroidal anti-inflammatory drugs

	Unadjusted mean difference (95% CI)	p Value	Adjusted mean difference (95% CI)	p Value	Summary of model R	Adj R^2	p Value (ANOVA)
Augmentation index (AIX%)							
Diclofenac	Reference group						
Naproxen/nabumetone	1.7 (−2.8 to 6.1)	0.46	1.7 (−2.0 to 5.4)	0.35	0.70	0.40	0.0003
Indomethacin	−1.6 (−7.7 to 4.5)	0.59	−1.0 (−7.8 to 5.8)	0.77	0.65	0.28	0.02
Ibuprofen	−8.6 (−15.9 to −1.2)	0.02	−6.5 (−11.9 to −1.0)	0.02	0.86	0.67	0.000001
Reflected wave transit (RWT), ms							
Diclofenac	Reference group						
Naproxen/nabumetone	1.9 (−3.9 to 7.7)	0.52	1.3 (−4.5 to 7.0)	0.66	0.54	0.16	0.05
Indomethacin	3.8 (−3.0 to 10.6)	0.26	3.5 (−4.8 to 11.7)	0.40	0.56	0.14	0.13
Ibuprofen	18.2 (9.8 to 26.6)	0.0001	14.2 (6.3 to 22.2)	0.001	0.82	0.59	0.00001

Adjusted using multiple linear regression (MLR) for age, sex, mean arterial blood pressure, ever smoked, Stanford HAQ score and cumulative erythrocyte sedimentation rate (ESR)-years.

in arterial function were not attributable to other important CV and rheumatological features known to influence arterial function. Patients using indomethacin (intermediate AGI) had an intermediate level of arterial dysfunction, but we were not able to demonstrate an entirely consistent relationship since naproxen had a higher AIX% than would be anticipated from its relative level of in vitro AGI.

Comparison with existing literature

A small number of previous studies have assessed arterial dysfunction in patients with RA using PWA.[13 26–29] The difference observed in AIX% in this analysis (of 6.5) between diclofenac and ibuprofen is of a statistically and clinically relevant magnitude. It compares, for example, with a 4.2 point reduction in AIX% associated with 3 months of atorvastatin therapy in patients with RA.[28] At coronary angiography, a 10-point higher AIX% at baseline is associated with a 27% increased risk of CV events over 4 years of follow-up; a 10 ms higher RWT is associated with a 15% reduction in CV events.[30] Published research concerning NSAID-related arterial dysfunction is currently limited. Only one previous study has directly assessed the influence of NSAID use on AIX%. In 12 patients with RA, 14 days of therapy with indomethacin (75 mg twice daily) was associated with a 1.2 (95% CI −2.1 to 4.5) point increase in AIX%.[29] In a study of men aged >50 years undergoing community-based screening for abdominal aortic aneurysm in the UK, the use of an NSAID (75% took either ibuprofen, diclofenac or indomethacin) was significantly associated with reduced aortic wall distensibility assessed using M-mode ultrasound.[31]

Study strengths and limitations

The strengths of our study are that a single research nurse undertook high quality PWA in a controlled environment among individuals with RA recruited from a consecutive series of patients attending a rheumatology clinic. Our measurement of the cumulative inflammatory burden is a particular strength of our study. The ESR area under the curve (cumulative ESR-years) reflects both the level and duration of inflammatory burden. Only one previous study investigating the relationship between arterial dysfunction and inflammation has attempted to assess inflammatory burden, but this was restricted to only the most recent 5 years of rheumatology clinic follow-up.[13] We measured and adjusted for several important CV and rheumatological factors in our analysis, including factors known to be independently associated with arterial function. PWA has previously been shown to be predictive of CV events in patients after coronary angiography.[30] Our multivariate model explained a high proportion of the variability (60–70%) in arterial dysfunction between patients taking diclofenac and ibuprofen. The characteristics of our participants are similar to those of RA patients receiving outpatient care elsewhere in the UK.[32] The study prevalence of treated hypertension is lower than that reported elsewhere and probably relates to the exclusion of patients with overt arterial disease.[33]

The main limitation of our study is its cross-sectional nature which means that we can only assess association rather than direct causation. Since we did not measure serum aldosterone and ns-NSAID levels in these patients with RA, we are unable to directly confirm the previous in vitro findings. While in vitro research is particularly useful for the investigation of biological mechanisms, such laboratory based findings may not translate exactly to the less controlled situation of patients with RA. The analysis reported is based on data from an existing study, rather than from a study specifically designed to assess the influence of different NSAIDs on arterial dysfunction. Our assessment of RA patients included a relatively small number of patients taking each NSAID and only seven patients were chronic users of ibuprofen. The numbers of patients taking individual NSAIDs were too small to permit a comparison of the association of low/high-dose NSAIDs with arterial dysfunction. The relatively small size of our study restricted the number of potential confounding factors (rheumatological and CV) that could be included in the multivariate analysis without running the risk of over-fitting the data, although the inclusion of additional variables in the multivariate model, such as treated hypertension, did not improve the goodness of fit or substantially alter the adjusted values reported for AIX and RWT. As with all observational studies, we cannot excluded the possibility of residual confounding as an explanation for our findings.

Study implications

The finding that ns-NSAID-related AGI appears to be associated with arterial dysfunction in patients with RA provides a potentially novel insight into the CV toxicity of commonly used ns-NSAIDs. Our results are preliminary and require confirmation in larger studies investigating different ns-NSAIDs, serum aldosterone concentrations and surrogate markers of arterial dysfunction. Several important questions remain to be addressed, including whether high/low ns-NSAID dosage is related to arterial dysfunction and if switching ns-NSAIDs (from high-AGI to low-AGI) improves arterial function. If the adverse CV events associated with ns-NSAID use are due to AGI, then switching to an alternative lower-AGI ns-NSAID may be an appropriate option for patients heavily dependant on NSAIDs for symptomatic relief.

Selective COX-2 inhibitors lack a carboxylic acid functional group and would not be anticipated to inhibit aldosterone glucuronidation to the same extent as diclofenac. It is therefore interesting that chronic users of selective COX-2 inhibitors and diclofenac had similarly high AIX% values. If AGI is not the explanation for the relatively high level of arterial dysfunction associated with selective COX-2 inhibitor use, then alternative mechanisms must be involved. A recent meta-analysis suggests that selective COX-2 inhibitors may induce a greater rise in brachial BP compared with ns-NSAIDs.[34]

This might account for the relatively high AIX% values associated with selective COX-2 inhibitor use in our study, since higher brachial pressures (diastolic, systolic, mean and pulse) also correlate with a higher AIX%.[35]

Acknowledgements We are grateful to Kathleen Knights for scientific advice concerning NSAID-related inhibition of aldosterone glucuronidation and to all the previous collaborators involved with the original RAAIX study—David J Williams, Alan G Macdonald, Vinod Kumar, Hazel Clark, Neil Scott, John Meecham and David Crosbie.

Funding The original study was supported by charitable funding from NHS Grampian Rheumatology Endowments. The funders played no role in the analysis or reporting of this study.

Competing interests None.

Ethics approval This study was approved by the Grampian Research Ethics Committee (ref: 04/S0801/67).

Contributors MAC conceived and designed the study, analysed and interpreted the data, drafted and re-drafted the article and gave final approval of the version to be published. AAM proposed the original hypothesis, interpreted the data, revised the article critically for important intellectual content, re-drafted the article and gave final approval of the version to be published.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement Consent for data-sharing was not obtained from study participants at the time of recruitment, but the presented data are held in an anonymised dataset. Access to the dataset is available from the corresponding author (mike.crilly@abdn.ac.uk) in SPSS format for clinical academic researchers interested in undertaking a formally agreed collaborative research project(s). Although the risk of individual patient identification is low, any research involving the release of the dataset to other clinical academics would require approval by Grampian Research Ethics Committee.

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